iGrow Soybeans: Best Management Practices for Soybean Production

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iGrow Soybeans: Best Management Practices for Soybean Production

Edited by
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SOUTH DAKOTA SOYBEAN RESEARCH & PROMOTION COUNCIL

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iGrow publishes books, electronic publications and multimedia materials in the fields of agriculture, farming and rural living.

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1500 copies printed at no cost to the State of South Dakota.
You can eat soybeans, use them to run engines, and even use them to shampoo your hair. Soybeans are an incredibly versatile crop. Every year, South Dakota farmers plant more than 4 million acres of soybeans. It's an important crop because of its domestic uses and international markets.

At South Dakota State University, we believe yields of 100 bushels of soybeans per acre is not only possible, but must be achieved to assure the food security of a growing global population.

The global population has passed seven billion and is projected to reach 10 billion by 2050. To feed the world, we must grow more food, but with the same amount of land and less water than has ever been done before. Global demand for food is projected to grow to the point that farmers must produce the same amount of food in the next 40 years that was produced in the last 1,500 years.

It's a daunting challenge, but one that can be achieved when scientists and soybean producers work together. Today's global challenges and opportunities place great demand on modern agriculture to address worldwide food security, while at the same time advancing U.S. interests in renewable energy, food safety, human health, natural resource sustainability, and global economic competitiveness.

Agricultural research and SDSU Extension programs have responded to the emerging opportunities with new technologies to increase crop yields, reduce input costs, and protect crops against pests and diseases. We are reaching new boundaries of knowledge that ultimately will make American agriculture more profitable and productive.

South Dakota State University has worked to create a singular handbook on how to profitably produce soybeans. My congratulations to the authors, scientists, and producers who worked hard to make this book a reality.

Barry H. Dunn, Ph.D.
South Dakota Corn Utilization Council Endowed Dean
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Soybeans rank as the second largest crop in South Dakota. Beyond the economic impact of this crop, the uses of the tiny soybean make a large difference in our world.

Soybeans consist of two components—soybean oil and protein-rich soybean meal. Soybean meal makes up approximately 80 percent of the soybean and is mostly used to feed livestock that provide the world’s poultry, pork, beef, dairy and fish. The majority of the soybean oil, however, is used for human consumption while biodiesel production and other uses are on the rise for industrial products.

About half the soybeans grown in the United States are sold internationally. China is the number one export market for U.S. soybeans. One of every four rows of American soybeans is shipped to China. Domestically, poultry and livestock are the top customers for soybean farmers, together using about 98 percent of the soybean meal in the United States.

Soybeans are an important crop in South Dakota. This book, iGrow Soybeans: Best Management Practices for Soybean Production, contains the principles that growers need to increase profitability and production. The partnership of farmers, scientists, SDSU Extension specialists make it possible for America to feed the world.

This book contains much of the research that has helped create the agronomic success of the American farmer. It is intended to be a valuable resource for study, analysis and technical assistance. Combined with current information at iGrow.org, producers have the full range of knowledge needed to continue to change the world.

The South Dakota Soybean Research and Promotion Council extends great appreciation and commendation to all who participated and contributed to the content and development of iGrow Soybeans: Best Management Practices for Soybean Production.
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The information in this book is provided for educational purposes only. Product trade names have been used for clarity, but reference to trade names does not imply endorsement by South Dakota State University; discrimination is not intended against any product. The reader is urged to exercise caution in making purchases or evaluating product information. Label registrations can change at any time. Thus the recommendations in this book may become invalid. The user must read carefully the entire, most recent label and follow all directions and restrictions.
No magic bullet exists that will result in 100 bushels of soybeans per acre (Table 1.1). Reaching this goal will require the development of new, high yielding cultivars, as well as adopting site-specific management practices that optimize production efficiency. One approach for testing your soybean production program is to enter the South Dakota Soybean Yield Contest sponsored by the South Dakota Soybean Research and Promotion Council and managed by the South Dakota Soybean Association. Although 100-bu/acre yields may seem out of reach, increasing your yield several bu/acre per year will put you there sooner than you think.

This chapter draws on production surveys completed by producers entering the South Dakota Soybean Yield Contest (Table 1.2). These surveys provide a starting point in the creation of a roadmap leading to 100 bu/acre. Topics discussed in this chapter include the importance of selecting the right variety, optimizing sunlight collection, controlling pests, eliminating nutrient deficiencies, minimizing harvest losses, paying attention to details, and using a proactive management style.
South Dakota Soybean Yield Contest

The South Dakota Soybean Yield Contest was created to encourage the development and testing of new innovative management practices. Producers enrolled in the contest are requested to complete a production survey which is summarized and distributed to producers at various events. Entering this program provides an opportunity for you to compare your practices with other growers. For details about the contest see, http://www.sdsoybean.org/Producer_Resources/Yield_Contest. Results from 2010 and 2011 are provided in Table 1.2.

Capturing sunlight

The efficient capture of sunlight is a key component of striving to produce 100 bu/acre (Fig. 1.1). Soybean plants convert sunlight, nutrients from the soil, and carbon dioxide from the air to complex forms of chemical energy, which is eventually harvested as soybean grain. Different plants convert sunlight to chemical energy

---

Table 1.2. Factors common to 2010 and 2011 South Dakota soybean contest winners.

1. Planted prior to May 15.
2. Used a narrow row spacing (15-22").
3. Used a relatively high plant population (160,000 seeds/acre seeded).
4. Treated the seed with seed inoculants, fungicides, and insecticides.
5. Applied foliar fungicides and insecticides when needed.
6. Selected soybean varieties carefully.
7. Managed soil moisture and fertility.
with different efficiencies. Not all soybean plants fix the same amount of CO₂. Leaves growing in full sunlight generally fix more CO₂ than those under reduced sunlight. Adopting management practices that increase the efficiency of CO₂ capture will increase the likelihood of achieving 100-bu/acre soybean yields.

In South Dakota the maximum amount of solar radiation occurs during the months of June and July (Fig. 1.3). To maximize light energy capture, it is critical that soybeans be seeded as early as possible, but late enough to avoid spring frost injury. Winners of the South Dakota Soybean contest generally seeded before May 15 (Table 1.2). Bigger plants with more leaf area in the critical months of June and July have higher sunlight capture potential.

However, seeding too early in cool, wet soil can result in the reduced emergence of live seedlings. Practices that reduce this risk involve selecting varieties proven to emerge under these conditions and avoiding mechanically damaging these seeds prior to or during planting. Seed treatments also help to improve emergence. Early planting risks increase as you travel from south to north across South Dakota. If soil and weather conditions are favorable, planting early offers a great opportunity to capture increased sunlight. To enable uniform, quick emergence of healthy seedlings, planting should be no earlier than when the soil temperature at the 2-inch depth averages at least 50°F (optimum has been reported to be 77°F) (Table 1.3). Data from across the Corn Belt indicates that high yielding soybeans will lose 0.25 to 1 bu/(acre day) after the optimum planting date.

![Huron Average Solar radiation](image)

**Figure 1.1. Average solar radiation at Huron, South Dakota.**

Table 1.3. Measuring soil temperature.

1. Determine the desired planting depth.
2. Place your thermometer at that depth.
3. Measure the temperature in the morning and early evening.
4. Average those temperatures.
5. Measure temperatures at multiple locations and different landscape positions.

**Selecting a variety (Chapter 6)**

One of the most important decisions to reach 100 bu/acre is the selection of the variety to plant. We recommend that yield, pest resistance, yield stability, maturity rating, lodging resistance, and findings from multiple years and multiple locations be considered when selecting a variety. Varieties should be selected with the appropriate pest package and maturity group rating. South Dakota State University conducts annual testing of many cultivars. A summary of these tests are available at [http://www.sdstate.edu/ps/extension/crop-mgmt/cpt/soybean-variet...](http://www.sdstate.edu/ps/extension/crop-mgmt/cpt/soybean-variet...).
To evaluate the ability of a variety to optimize yields within your production system, we recommend that you:

2. Carefully study all soybean performance testing reports and choose varieties with the greatest probability of success in your growing environment.
3. Select an appropriate pest package.
4. Use seed with a high germination percentage.
5. Discuss your decision with knowledgeable people in the region.

Row spacing and seeding rate (Chapter 10)

Producers have a number of options of row spacing. The three dominant options are 15-, 22-, and 30-inch row spacing. Generally, planters do a much better job at controlling seed spacing and depth than cantilever linked drills. Precision seed placement is important because plant stand variability reduces yield. The number of seeds/acre and the actual plant population may be different. We recommend that the actual plant population be measured. A comparison between actual populations and seeding rate may help identify planter or emergence problems.

Planting soybeans into corn residue can be very challenging. It is important to avoid hair pinning seed into residue. This causes unevenness in emergence. When soybeans follow corn, this could be a large problem. Possible solutions are using tillage and disking to reduce surface residue, attention to coulter operation on planting equipment, ridge tillage, and corn residue harvesting.

Research across the Midwest suggests that narrowing row spacing increases yield. These results were confirmed by the winners of the South Dakota yield contests. Benefits from narrow rows may be increased if delays in the planting date are unavoidable. However, narrow rows may reduce yields in fields with a high risk of white mold or if water is limited at the end of the season (Chapters 58, 59).

Seeding rate can also impact yield. Typically the optimum seeding rate has been reported to be between 140,000 and 150,000 seeds/acre. However, the top yielding entries in the 2011 South Dakota Soybean Yield Contest were planted at rates greater than 160,000 seeds/acre.

Rotation impact (Chapter 4)

Rotating crops can help reduce pests and increase yields. Research in Iowa showed that both corn and soybean yields were increased by crop rotation. For example, soybean yields were 5 to 6% higher in a Corn-Corn-Soybean rotation compared with a corn-soybean rotation. The major factor increasing yield was due to reduced pest pressure. [http://www.extension.iastate.edu/CropNews/2011/0225alkaisi.htm](http://www.extension.iastate.edu/CropNews/2011/0225alkaisi.htm)

Controlling pests: Seed and field treatment at R3 with fungicides (Chapter 8)

With the cost associated with soybean production, many producers consider insecticide and a fungicide seed treatment as insurance. When seed is planted into cool, wet environments, research suggests that seed treatment can increase yields. Table 1.2 indicates that top yielding entries in the recent South Dakota Soybean Yield Contests utilized seed inoculants, seed fungicide, and seed insecticide treatments.

Analysis of kitchen sink experiments (experiments where everything including the kitchen sink is added) suggests foliar-applied fungicides applied at R3, containing strobilurin, produce significant yield increases. Yield increases are often observed when the disease scores are below threshold levels. Research conducted in Iowa suggests that there is a 60-70% chance of breaking even when fungicides containing strobilurin such as Headline® or Stratego YLD® are applied at R3. When disease is present, the chances of breaking even is increased (Bestor et al., 2011). This research suggests that the economic threshold levels and diagnosis tools for diagnosing diseases need additional research. It should be noted that the wide scale strobilurin applications can lead to pest resistance.
CHAPTER 1: Growing 100-Bushel Soybeans

Weed control (Chapters 32 -34)

It is important to start the growing season with a weed-free field. Research suggests that soybean yield losses occur when a pre-emergent herbicide is not applied and the first post emergent herbicide treatment is first applied 2-3 weeks after planting. Weeds that are resistant to herbicides are likely to increase future problems. In South Dakota, weeds with resistance to glyphosate herbicides include kochia, horseweed, common ragweed, common water hemp, and volunteer corn (Chapter 33).

Eliminating nitrogen (N) deficiencies: Rhizobium seed inoculation (Chapter 23)

If a field is rotated out of soybean for an extended period of time (greater than three or more years), you should consider inoculating the soybean seed with rhizobia (Fig. 1.2). Rhizobia are soil bacteria that fix atmospheric nitrogen (N2). Nitrogen fixation has been found to be inhibited by the availability of a significant amount of soil inorganic N. Rhizobia bacteria are plant species specific. If soybeans are not seeded on a frequent basis, rhizobia bacteria populations will gradually decline. Sandy soils may require more frequent inoculations than fine-textured soils. In fields where soybeans have never been seeded or where soils have been flooded for extended periods of time, inoculation is a must.

It is important to note that for the first 20 days after emergence, soybean seedlings may appear nitrogen deficient. Yellowing can occur due to a time lag between when nitrogen stored in the seed is exhausted and active nitrogen fixation begins. This deficiency will have a minimal impact on yield. One hundred bushels of soybeans contains approximately 380 lb of nitrogen in the grain. This N must be provided either by the soil or through N fixation in the nodules.

Starter fertilizer (Chapter 21)

Starter fertilizers refer to a small amount of fertilizer applied near the seed. Starter fertilizer has mixed impacts on soybean production. Most data from across the lower Midwest indicates that if soil test phosphorous levels are medium or above, there is no benefit from applying starter fertilizer. An exception occurs when soybeans are planted in cool, wet soil. Many producers in the South Dakota yield contest used starter fertilizers to promote early season growth. Starter fertilizer can stimulate early growth, reduce the period of time to canopy closure, and increase yields.

Fertilizer placed in contact with the seed should be used with caution since soybeans are quite susceptible (as much as twice as susceptible as is corn) to fertilizer salt injury. Producers that plan on using an in-furrow fertilizer application should study the information in the below website to identify the maximum amount that can be placed in contact with the seed. http://www.sdstate.edu/ps/soil-lab/upload/FertSeedDecisionAid.xls

Late season N (Chapter 24)

There is some evidence that rhizobia bacteria may not produce adequate N for yields higher than ~70 bu/acre. Late season applied N may increase yield in these high yield environments. Additional research is needed to evaluate the possibility of yield response to late season N application for South Dakota producers. http://www.fluidfertilizer.com/pastart/pdf/25P16-19.pdf

Figure 1.2. Nodules containing rhizobia on a soybean root. Active nodules when cut in half are red. (Photo courtesy of Becker Uderwood, Iowa State University and Top Crop. Available at http://www.agannex.com/field-crops/match-the-soybean-inoculant-formulation-to-the-planting-setup)
Uniform seeding at the correct depth

To obtain an ideal plant stand the seed must be uniformly spaced within the row and planted at a uniform depth of ¾ to 1½ inches. Soybean should not be seeded deeper than two inches. Cooler temperature with increasing depth slows germination and growth. Planters that use the parallel linkage generally have more accurate seed depth placement than drills using cantilever placement. Fluted feed-metering mechanisms on grain drills generally do not space soybean seed uniformly in the row and may split or damage large seeds.

http://ohioline.osu.edu/agf-fact/0114.html

Minimize field compaction

Yield losses due to compaction can be reduced by many techniques including controlling traffic and minimizing driving across the field. The weight of tractors has increased from less than 1-3 tons in the 1930s to tractors weighing more than 20 tons. Driving heavy equipment across fields can reduce yields. The most damage is done when the soil is moist. However, this damage may not be visible. To obtain the highest yields possible, limit grain cart and grain loads to the ends of the field.

Prepare the combine for harvest

A significant amount of the soybean yield can be left in the field. These losses can be minimized by planning and tracking performance. Harvesting as soon as possible after grain moistures allow is recommended. In the area behind the combine, 5 small beans/ft² represents 1 bu/acre of yield loss. Setting the cutting bar too high can also reduce yields. For example, 50 beans found post harvest on the stems of 4 feet of row (in 30-inch rows) represents a yield loss of 1 bu/acre.

Use proactive management for pests

Scout frequently for nutrient deficiencies, insects, and disease and treat appropriately to assure that pests are controlled as effectively as is warranted. Table 1.2 indicates that top yielding entries in the recent South Dakota Soybean Yield Contest scouted their fields frequently and applied foliar insecticide and fungicide as needed.

References and additional information


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Using Field Records for Current Recommendations

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Optimizing soybean profitability requires an investment in time that leads to a clear understanding of the factors limiting production. This process starts by understanding what happened last year, followed by making changes to address those deficiencies. Knowledge-based management strategies can minimize risk and maximize efficient production by linking soil condition, fertility management, pest management, tillage, and residue management into your system. This chapter discusses what should be included in your field records and how to integrate this information into your management program.

Figure 2.1. Plant population and crop condition data collection. (Photos courtesy of USDA-NRCS Photo Gallery)
**Field records**

Field records are the gathering of what was done and what happened in a specific field into a single folder (Figs. 2.1 and 2.2). Recordkeeping becomes the primary source of information. Whether you keep notes written in a notebook or use computerized software, field information can be your greatest management tool. Miscalculated or incorrect applications of crop inputs can lead to expensive mistakes. Field records could prevent mistakes, or indicate why a problem occurred (Denke et al., 2012; Chapter 29).

Electronic recordkeeping is swiftly becoming the norm in modern agriculture. Yields are measured and located in the field via yield monitors and global positioning systems (GPS). Fertilizer and pesticide applications are mapped using similar technologies. Scouting records are invaluable for determining pest problems. Field records can be used for determining land value and planning a management strategy once land is acquired.

![Figure 2.2. Scouting a field.](Photo courtesy of USDA-NRCS)

**Table 2.1. List of recommended items to include for field records.**

1. Prior field history:
   a. crop yields and field productivity,
   b. location of old farmsteads,
   c. tillage practices,
   d. fertilizer applications and locations of fertilizer bands,
   e. pest maps from the field,
   f. varieties, pesticide, and fertilizers applied for the prior three years,
   g. prior weather conditions,
   h. soil test results (Chapters 25 and 26),
   i. seed emergence (Chapter 9), and
   j. summary of previous pests and yield-limiting factors.

2. Soybean variety and trait package.
3. Soybean seed treatments.
4. Seeding date, rate, row spacing, and tillage.
5. Rate and date of fertilizers and pesticides applications.
6. Specific crop scouting:
   a. GPS location,
   b. extent and magnitude of problem,
   c. beneficial insects present, and
   d. date of scouting.
7. Pest information in adjacent fields.
**Field productivity**

Field productivity is impacted by long-term management of the capabilities and limitations of the soils. There are a few simple techniques to evaluate the soils production potentials.

Using a soil survey can be a good first approach. Information attained from the survey can be used to assess your relative yield potential.

The land capability class provides a rating for crop production and the subclass provides the main limitation for crop production. Drainage class, productivity index value, soluble salts, exchangeable sodium percentage, and other properties can identify limitations and opportunities.

Although the soil survey does not provide detailed data, it can be useful for gaining general knowledge of the site. [http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm](http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm)

A second approach is to determine how prior management impacted long-term productivity. If long-term productivity information is not available, it may be possible to assess yield improvements using archived landsat images. Currently this information is archived at the EROS Data Center located near Sioux Falls.

Archived data can be used as liberal benchmarks. If the data suggests that yields have not increased, then the land may not have been managed properly or natural processes have impacted production. Diagnosing problems may be difficult and solutions may require capital investments or long-term investment recovery. This step involves organizing your field records.

**Yield data**

Yield data is a valuable tool for evaluating management strategies. Differences between the observed and expected yields can be used to identify problem areas.

Fields can be divided into at least four categories (Fig. 2.3):

- Low Yield-Low Variability
- Low Yield-High Variability
- High Yield-High Variability
- High Yield-Low Variability

Techniques for identifying these zones are available in Pierce and Clay (2007). Ideally, you want a field that produces a high yield year after year. Reviewing historical management and yield data can help explain why these areas vary in yield from year to year and if a remedy is suitable (Fig. 2.4).

**Farmsteads**

A history of land use also provides valuable information. When South Dakota was homesteaded, most quarter sections had a farmstead where livestock were maintained. Even though many of these homesteads were removed 50 years ago, their location can be easily located, based on grid soil sampling (Fig. 2.5). These hotspots may be small or large depending on the homestead. A technique for managing this variability is available in Chapter 20. These areas can be identified in old aerial photographs available at local USDA-NRCS offices.
Pest management history

Field records and record keeping are critical components of an integrated pest management program (IPM). Field pressure from weeds, plant diseases, soybean cyst nematodes (SCN) and insects is affected by crop management practices (Fig. 2.6). Access to this information is critical in selecting the appropriate cultivar.

Weeds

A history of tillage methods may have contributed to the weed species dominating a field. Weed control management history provides a picture of what weeds may have existed in the field. Documents of herbicide applications may also indicate possible carryover problems. Past records of weed control success may reveal the weed seed bank that exists in the soil.

Soybean diseases and nematodes

Fields that have a history of a soil-borne disease very rarely are free from a reoccurrence of the pathogen. When weather conditions promote the growth of the disease spores, there will be an infection in the field. It might occur after being absent for a number of years. Soil-borne soybean diseases that are common to the upper Midwest are root rot, white mold, and seedling blight. Although not as common, sudden death syndrome is also suspect. (Ruden et al. 2011; Chapters 57-60)
Preventative management of susceptible fields by planting resistant varieties and delayed planting dates could avoid considerable yield loss. Disease history records should be included in a field profile (Hall et al., 2011).

Soybean cyst nematode (SCN) can reduce yields (Smolik et al., 2007; Chapter 57). If a field previously had SCN, it is likely that it still has SCN. If you suspect that a field has SCN, it should be confirmed by soil sampling (Fig. 2.7).

**Insects**

A complete history of each field should include any insect infestations, which management methods worked, and which did not. It is very important to find records that contain information including: crop rotation, tillage, planting dates, insect identifications, insect scouting reports, and economic losses. All of these factors could be useful in predicting future insect infestations. When assessing insects, scout the borders of your field (Chapter 29). Many insects over-winter in these plants (Chapters 35, 36, and 67).

**Conclusion**

Access to detailed field records can provide very useful and valuable information. Field records can paint a picture of a field as it exists, and what its capabilities can be in the future. The use of yield monitors and maps will enable producers to build a profile for every field. The gathering of field information and data from the past, present, and future is the basis of productivity and economic efficiency.

This chapter has touched on some of the primary principles of evaluating fields on their past management. Accurate, concise field records and data will provide the knowledge to creatively minimize risks and maximize profits.

**References and additional information**


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Soybean Growth Stages

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Introduction

To optimize soybean yields, growers must provide the best management possible. Management practices that influence soybean growth and yield include variety selection, seedbed preparation, seeding rate, seeding date, planting depth, and pest management. Many of these practices are dependent on plant growth stage. Growers who understand how the soybean plant grows and develops are in better positions to use management practices for growing the crop more effectively. Highlights of this chapter are shown in Table 3.1.

<table>
<thead>
<tr>
<th>Table 3.1. Selected highlights of soybean development.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. At VE to VC, yields can be reduced 8-9% if cotyledons are lost.</td>
</tr>
<tr>
<td>2. Between VC and V5, a new trifoliate is added about every 5 days.</td>
</tr>
<tr>
<td>3. At R2, 50% defoliation reduces yield 6%.</td>
</tr>
<tr>
<td>4. At R4, plant is very sensitive to stress.</td>
</tr>
<tr>
<td>5. At R5, 100% defoliation can reduce yields 75%.</td>
</tr>
<tr>
<td>6. At R7, stress has a minimal impact on yield.</td>
</tr>
</tbody>
</table>

General characteristics of the development of a soybean plant

Soybean varieties are classified into maturity groups based on the length of growing season in which they are most adapted. The maturity groups range from 00 to IX with group 00 being for shortest growing season and IX being designed for the longest growing season. In the United States, maturity group 00 is grown in the most northern areas including Minnesota and North Dakota, while maturity group IX is grown in southern states. In South Dakota, maturity groups 0, 1, and 2 are commonly grown.
In general, soybeans have two growth habits: determinate and indeterminate. Determinate cultivars finish vegetative growth when the plant enters reproductive stages, whereas indeterminate growth habit cultivars have simultaneous vegetative growth and flowering during the reproductive phase. Most soybean varieties in the 00 to IV groups have an indeterminate growth habit, whereas varieties in the V to IX groups exhibit a determinate growth habit.

The biological cycle of the soybean plant is divided into the vegetative and reproductive phases. The vegetative phase starts when the seed absorbs water to induce germination process. The vegetative phase ends and the reproductive stage begins with the appearance of first floral buds in soybean varieties of determinate growth habit, or the appearance of the first raceme in varieties of indeterminate growth habit. The reproductive phase ends at harvest.

Stages of Development

Factors that influence duration of growth stages

A multitude of factors influence the duration of each growth stage but the most important factors are the characteristics of the soybean variety and climate (temperature and daylength [photoperiod]). Other factors that can contribute to developmental variation include: soil conditions, location, planting date, and planting pattern.

Maturity class

Maturity class influences the duration of the stages of development. Late maturing soybean varieties may develop more leaves and progress more slowly from one developmental stage to the next, while early maturing soybean varieties may develop fewer leaves and progress through the developmental stages faster. Additional information on selecting a maturity class to match the planting date and growing length is available in Chapter 6.
Table 3.2. Plant growth stages and time from one stage to the next. (Modified from Naeve, 2011; Pedersen, 2007; and Kansas State University, 1997)

<table>
<thead>
<tr>
<th>Stage Number</th>
<th>Average Time Between Stages</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetative Stages</td>
<td># days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VE</td>
<td>Plt to VE 10d</td>
<td>Emergence</td>
<td>Cotyledons above soil surface.</td>
</tr>
<tr>
<td>VC</td>
<td>VE to VC 5d</td>
<td>Cotyledon</td>
<td>Unifoliate leaves unfold so leaf edges are not touching.</td>
</tr>
<tr>
<td>V1</td>
<td>VC to V1 5d</td>
<td>1st trifoliate</td>
<td>First trifoliate fully emerged and opened.</td>
</tr>
<tr>
<td>V2</td>
<td>V1 to V2 5d</td>
<td>2nd trifoliate</td>
<td>Plants have three nodes with two trifoliates unfolded.</td>
</tr>
<tr>
<td>V3</td>
<td>V2 to V3 5d</td>
<td>3rd trifoliate</td>
<td>Plants have four nodes with three trifoliates fully unfolded.</td>
</tr>
<tr>
<td>V4</td>
<td>V3 to V4 5d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V5</td>
<td>V4 to V5 5d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V6</td>
<td>V5 to V6 5d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V(n)</td>
<td>V6 to Vn 3d</td>
<td>nth trifoliate</td>
<td>N= the number for the last fully developed trifoliate leaf.</td>
</tr>
<tr>
<td>Reproductive Stages</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>R1 to R2 3d</td>
<td>Beginning flowering</td>
<td>One open flower at any node on the main stem.</td>
</tr>
<tr>
<td>R2</td>
<td>R2 to R3 10d</td>
<td>Full bloom</td>
<td>Open flower at one of the two top nodes on the main stem with a fully developed leaf.</td>
</tr>
<tr>
<td>R3</td>
<td>R3 to R4 9d</td>
<td>Beginning pod</td>
<td>A pod on one of the four upper nodes in 3/16 inch (0.5 cm) long.</td>
</tr>
<tr>
<td>R4</td>
<td>R4 to R5 9d</td>
<td>Full pod</td>
<td>A pod ¾ inch (2 cm) long at one of the four uppermost nodes on the main stem.</td>
</tr>
<tr>
<td>R5</td>
<td>R5 to R6 15d</td>
<td>Beginning seed</td>
<td>Seed is 1/8 inch (3 mm) long in one of the four uppermost nodes on the main stem.</td>
</tr>
<tr>
<td>R6</td>
<td>R6 to R7 18d</td>
<td>Full seed</td>
<td>A pod containing a green seed that fills the pod cavity at one of the four uppermost nodes on the main stem.</td>
</tr>
<tr>
<td>R7</td>
<td>R7 to R8 9d</td>
<td>Beginning maturity</td>
<td>One normal pod on the main stem has reached the mature pod color (tan or brown).</td>
</tr>
<tr>
<td>R8</td>
<td></td>
<td>Full maturity</td>
<td>95% of pods have reached mature pod color. Five to 10 days of dry weather are required to dry the seed to &lt; 15% moisture.</td>
</tr>
</tbody>
</table>

**Temperature**

The rate of plant development for any soybean variety, early or late maturing, is directly related to temperature. This means that the length of time between developmental stages will vary with temperature within and between growing seasons.

**Photoperiod (daylength)**

Soybean plants are sensitive to photoperiod or daylength, and the plant response to photoperiod regulates the timing of flowering. Soybean varieties differ in their response to photoperiod. Some varieties will flower under relatively shorter days while other require longer days to initiate flowering. Soybean varieties adapted to the northern region of the U.S. initiate flowering under longer days (e.g., daylength is nearly 14 hours during the summer in South Dakota) when compared to varieties adapted to the southern part of the country. Because of the change in photoperiod, if a southern variety is planted north of its adaptation zone, flowering will be delayed, whereas a northern variety planted south of its adaptation zone will have accelerated flowering.
Other factors

The environment in which a soybean plant grows strongly influences its development. Seed viability and environmental stress may influence the length of time between plant growth stages. A soybean plant grown at low densities will branch profusely and develop into a large plant. Increasing plant density increases plant height, while reducing branching and pod number per plant.

Identifying Soybean Stages of Development

The stages of development are identified following Iowa State University and Kansas State University staging system that divides plant development into vegetative (V) and reproductive (R) stages (Table 3.2). The V stage has subdivisions that are designated numerically as V1, V2, V3 through V(n), with the exception of the first two stages that are designated VE (emergence stage) and VC (cotyledon stage). The reproductive stage begins with flowering (R1) and ends with full maturity (R8).

Figure 3.1 An overview of the vegetative growth stages. (Modified from Naeve, 2011; University of Minnesota Extension)

Emergence (VE) (Figure 3.2)

The soybean seed begins the process of germination by absorbing water equal to about 50% of its weight. The radical or primary root is the first to emerge from the swollen seed, elongating downward to anchor in the soil. Shortly afterwards, the hypocotyl (stem) begins to elongate toward the soil surface pulling the cotyledons (seed leaves) upwards with it. Depending on temperature, moisture, variety and planting depth, emergence typically occurs one to two weeks after planting.

Cotyledon stage (VC) (Figure 3.3)

Shortly after emergence, the hypocotyl straightens out and discontinues growth as the cotyledons unfold. The epicotyl (young leaves, stem, and growing point located just above the cotyledonary node) is exposed at this stage. The expansion and the unfolding of the unifoliate leaves (Fig. 3.3) marks the initiation of the VC stage.
The cotyledons supply the nutrient needs of the young plant during emergence and for about seven to 10 days after emergence. The cotyledons lose about 70% of their weight during this time. If one cotyledon is lost during this time, the effect on plant growth rate is minimal, but if both cotyledons are lost either at VE or VC, seedlings are stunted and, ultimately, yields can be reduced by 8-9%.

Figure 3.2. The VE growth stage. At this stage, cotyledons are pushing through the soil surface. (Photo courtesy of Pedersen, 2007; Lenssen and Wright, 2013; Iowa State University Extension)

Figure 3.3. The VC growth stage. At this growth stage the unifoliate leaves unroll sufficiently so the leaf edges do not touch. (Photo courtesy of Pedersen, 2007; Lenssen and Wright, 2013; Iowa State University Extension)

First trifoliate (V1) (Figure 3.4)

The V1 stage is achieved when the 1st trifoliate is fully emerged and unfolded. The vegetative growth stages after VC are defined and numbered by the upper, fully developed trifoliate leaves on the main stem. Trifoliate leaves on branches are not counted when determining vegetative growth stages. New V stages appear about every five days from VC through V5 and then every three days from V5 to shortly after R5 for indeterminate cultivars, when the maximum number of nodes are developed.

Second node (V2) (Figure 3.5)

At the V2 growth stage, soybean plants are 6 to 8 inches (15 to 20 cm) tall and have two fully developed trifoliate leaf nodes. Most of nitrogen required by the soybean plant can be supplied through a process called N-fixation (Chapter 23). Through N-fixation, nitrogen fixing bacteria in the roots convert atmospheric N₂ to
usable forms of nitrogen for the plant. The bacteria enter the plant through the root hairs. Nodules become visible shortly after the VE stage, but active N\textsubscript{2} fixation does not begin until V2 to V3 stages. Thereafter, the number of nodules formed and the amount of N\textsubscript{2} fixed increases with time until about R5.5. Nodules that are pink or red inside are healthy and actively fixing nitrogen whereas brown, white, or green nodules are not efficiently fixing nitrogen. Bacteria in the nodule are able to supply most of the plant’s N requirements. Inherent nitrate in the soil, whether from N fertilizer or carryover from the previous crop, reduces nodule formation.

![Figure 3.4. The V1 growth stage. At this stage, there is a fully developed trifoliate. (Photo courtesy of Pedersen, 2007; Lenssen and Wright, 2013; Iowa State University Extension)](image)

Third to fifth nodes (V3 through V5) (Figure 3.6)

At the V3 growth stage, soybean plants are 7 to 9 inches tall (18 to 23 cm) and have three fully developed trifoliate leaf nodes. At the V4 growth stage, plants are 8 to 11 inches (20 to 27 cm) tall with four fully developed trifoliate leaf nodes whereas at V5, plants are 10 to 12 inches (25 to 30 cm) tall with five fully developed trifoliate leaf nodes. For most varieties, the number of branches increases at wider row widths and lower plant densities. Typically, up to six branches develop under field conditions. At the V5 stage, the soybean plant normally has axillary buds in the top stem that will develop into flower clusters called racemes. At V5, the total number of nodes that the plant will potentially produce is set.
Sixth node (V6) (Figure 3.6)

At this stage, soybean plants are 12 to 14 inches (30 to 36 cm) tall with six fully developed trifoliate leaf nodes. The cotyledons and the unifoliate may have senesced and fallen from the plant. New vegetative growth stages are appearing every two to five days. At this stage, lateral roots have grown completely across inter-row spaces of 30 inches or less.

Reproductive Stages of Development

Beginning bloom (R1) (Figure 3.7)

At this stage, there is at least one open flower at any node on the main stem. Soybean plants at this stage are 15 to 18 inches (38 to 46 cm) tall. Flowering initiates on the third to sixth nodes of the main stem, depending on the vegetative stage at the time of flowering, and progresses up and down the plant. Flowers at branch nodes appear a few days later. Within each raceme, flowering occurs from the base to the tip, meaning that basal pods are always more mature. At this stage, vertical roots grow at a fast rate and continue this rate through R4 to R5 stage. Secondary roots and root hairs proliferate near the soil surface.

Full Bloom (R2) (Figure 3.8)

At this stage, the soybean plant has one open flower at the two top nodes on the main stem (Fig. 3.8) and a least one of the two upper nodes shows a fully developed leaf. Plants are 17 to 22 inches (43 to 56 cm) tall. The soybean plant has accumulated 25% of its total dry weight, about 50% of its mature height, and has about 50% of its total mature node number. The R2 stage also marks the beginning of the very rapid nutrient and dry matter accumulation that continues until the R6 growth stage. The rate of N₂ fixation by root nodules is
also increasing rapidly at this stage. At R2, roots can reach across a 40-inch inter-row space. The major lateral roots have turned downward in the soil and these, along with the taproot, continue to elongate deeply into the soil profile until late into the R6 stage. Fifty percent defoliation at this stage reduces yield by about six percent.

\[\text{Figure 3.8. The R2 (Full Bloom) growth stage.} \text{ At this stage, the plant has at least one flower on the two uppermost nodes. (Photo courtesy of Pedersen, 2007; Lenssen and Wright, 2013; Iowa State University Extension)}\]

**Beginning pod (R3) (Figure 3.9)**

Soybean plants are about 23 to 32 inches (58 to 81 cm) tall. One of the uppermost nodes has a pod \(\frac{3}{16}\) inch (0.5 cm) long. At this stage, a plant has developing pods, open flowers, withering flowers, and flower buds. Developing pods are located on lower nodes where flowering began. Temperature and soil moisture stress at R3 can affect yield through reduction of one or more yield components. A reduction in one component may be compensated by increases in others such that yields may not be significantly changed. As the soybean plant matures from R1 to R5, the plant’s ability to compensate after stressfull conditions decreases.

\[\text{Figure 3.9. Soybean at the R3 (Beginning Pod) growth stage.} \text{ At this stage, the plant is beginning pod development and the pods in one of the uppermost nodes is \(\frac{3}{16}\)“ (0.5 cm). (Photo courtesy of Pedersen, 2007; Lenssen and Wright, 2013; Iowa State University Extension)}\]

**Full pod (R4) (Figure 3.10)**

At this stage the soybean plant has a pod \(\frac{3}{4}\) inch long (2 cm) at one of the four top nodes on the main stem. Plants are 28 to 39 inches (71 to 100 cm) tall. This stage is characterized by rapid pod growth and the beginning of seed development. Pods show rapid growth and dry weight accumulation between R4 and R5. Pods on the lower nodes of the main stem are full size or close to full size, but most pods will be full size by R5 stage.
At the R4 growth stage, the soybean plant is very susceptible to stress (moisture, light, temperature, nutrient deficiencies, etc). Any major stress occurring anytime from R4 to R6 will reduce yield more than the same stress at any other period of development. This is because flowering is complete and no new flowers can be produced to compensate for aborted young pods and seeds under stressful conditions.

**Beginning seed (R5) (Figure 3.11)**

At this stage plants are 30 to 43 inches (76 to 109 cm) tall. The plant has seeds at least $\frac{1}{8}$ inch (3 mm) long in a pod at one of the four top nodes on the main stem. The R5 stage is characterized by rapid seed growth and and redistribution of dry weight and nutrients within the plant. Root growth slows down when seed development begins. At about halfway through this stage, the soybean plant:

- Attains its maximum height, node number, and leaf area.
- Nitrogen fixation rates peak and begin to drop rapidly.
- Seeds gain weight rapidly.

Midway between R5 and R6, dry weight and nutrient accumulation in the leaves, stems, and petiole peaks and the process to redistributing to the seed begins. The process of seed dry weight accumulation continues until the middle of R6. Stress may influence both the rate and length of time that dry weight accumulates in seeds. During this rapid seed filling period, demand for water and nutrients is high. Soil moisture stress may reduce nutrient availability by inhibiting root growth in dry soil. One hundred percent leaf loss at this stage can reduce yields by 75%.
**Full seed (R6) (Figure 3.12)**

At R6 the soybean plant is 31 to 47 inches (79 to 120 cm) tall. This stage is initiated when plants have a pod containing a green seed that fills the pod cavity on at least one of the four top nodes on the main stem. Total pod weight maximizes at this stage. Growth rates of the seeds and the whole plant are still very rapid, but will begin to slow down in the whole plant shortly after R6. Leaf yellowing begins shortly after R6 and continues rapidly to about R8. Root growth is complete midway between R6 and R7.

![Figure 3-12. The R6 (Full Seed) growth stage.](image)

At this stage, the seed fills the pod capacity in one of the four uppermost nodes. (Photo courtesy of Pedersen, 2007; Lenssen and Wright, 2013; Iowa State University Extension)

**Beginning maturity (R7) (Figure 3.13)**

At this stage, the soybean plant has one normal pod on the main stem that has reached mature color (tan or brown). Dry matter accumulation for individual seeds peaks at this stage. The soybean plant is visually yellow as all green color is lost from seeds and pods. Soybean seeds contain about 60% moisture at maturity. At this stage and later, the possibility of yield reduction due to stress is much lower.

![Figure 3.13. The R7 (Beginning Maturity) growth stage.](image)

At this growth stage, one normal pod on the stem has reached its mature pod color. (Photo courtesy of Pedersen, 2007; Lenssen and Wright, 2013; Iowa State University Extension)

**Full maturity (R8) (Figure 3.14)**

At this stage, 95% of pods have reached their mature color (tan or brown). Five to 10 days of dry weather are required after R8 before soybean seeds have less than 15% moisture. Timeliness of harvest is very important for soybean. Ideally, seed moisture content at harvest and for storage should be 13% (see Chapter 46 for additional information). Harvesting at higher moisture will increase drying costs. Delaying harvest to moisture contents of less than 13% may reduce yield due to pre-harvest shatter, sickle-bar shatter loss during harvest, and split seeds.
Figure 3.14. The R8 (Full Maturity) growth stage. At this growth stage, 95% of pods on the plant have reached their mature color. (Photo courtesy of Pedersen, 2007; Lenssen and Wright, 2013; Iowa State University Extension)

References and additional information

Acknowledgements
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A Look at Crop Rotation and Soybean Production

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This chapter provides a brief overview on how rotations that include soybeans can increase long-term sustainability and resilience against climate variability. Crop rotation is a complex subject where biological factors, farm management resources, and market forces all interact in shaping its effectiveness (Fig. 4.1).

Figure 4.1. This image shows crops in a corn-soybean-wheat/red clover rotation. Crop rotation is an approach that diversifies income, spreads labor, breaks disease and weed cycles, and spreads climate risk across several crops. (Source: http://soilquality.org/practices/row_crop_rotations.html)
**Introduction**

A crop rotation is a long-term plan for whole farm planning. In a broad sense, sustainable and productive crop rotations should:

- Be profitable.
- Provide an acceptable level of risk in the face of climate and market variability.
- Provide adequate residue to protect the soil from erosion and to provide for soil quality.
- Provide sufficient diversity to prevent buildup of weeds, pests, and diseases.
- Match timing and amount of crop production requirements to resource availability (moisture, length of growing season, equipment, etc.).

We may not realize it, but the practice of good crop rotation is a foundational element in our nation and society. For example, the introduction of the "Norfolk Rotation" (Barley-Clover/ryegrass-Wheat-Turnips) by Sir Charles Townshend in England played a large role in nearly tripling England’s agriculture output in the 1700s in a sustainable manner. This led the way into England’s Industrial Revolution, which changed the world.

There are also negative examples of extractive agricultural systems that over-exploited their resource base which led to ecological and societal collapse (e.g., ancient inhabitants of Easter Island over time apparently deforested their island leading to soil erosion and loss of productivity). The latter is an example we do not want to follow.

One way to consider sustainable production systems is to look at natural systems as a model to mimic. Natural systems tend to maximize resource capture and biomass production while minimizing nutrient loss; they keep the soil covered and protected from erosion; their diversity provides for resilience against pests and diseases as well as environmental stresses. As natural systems develop, they follow a “succession” process where one set of species modifies the environment to the benefit of the next set of species—each step, so to speak, prepares the way for the next. In a similar manner, a good rotation program should be productive, minimize nutrient loss, cover the soil, provide resilience against pests and stress, and each crop should prepare the way to the benefit of the next.

**Designing a rotation**

Rotations should be adaptable to local conditions and problems. There are many factors that must be considered when designing a rotation. Some of these are:

- Crop water use patterns (critical periods, rooting depths, and peak use periods) and total water use.
- Soil properties.
- Climate conditions.
- Pests.
- Costs, returns, and markets.
- Equipment availability.
- Labor availability.

Producers need to consider rotations as one tool for optimizing long-term profitability and reducing risk.
Table 4.1. Some soybean diseases of interest with their alternate hosts and reported lifetime in the soil.

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Alternate Hosts</th>
<th>Lifetime in the Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean Cyst Nematode (SCN)</td>
<td>hairy vetch, cowpea, dry bean, sweet clover</td>
<td>15 or more years</td>
</tr>
<tr>
<td>Phytophthora Root Rot</td>
<td>none of economic importance</td>
<td>5+ years</td>
</tr>
<tr>
<td>White Mold</td>
<td>almost all broadleaves are susceptible, plants with more flower petals seem to be more susceptible (infection often starts on dropped flower petals)</td>
<td>3 to 5 years</td>
</tr>
<tr>
<td>Brown Stem Rot (Note: this disease is exacerbated by the presence of SCN)</td>
<td>none of economic importance</td>
<td>survives on residue only</td>
</tr>
<tr>
<td>Charcoal Rot</td>
<td>wide host range, including corn</td>
<td>2+ years in dry soil; appears to be less persistent in wet soil</td>
</tr>
</tbody>
</table>

**Rotation and diseases**

Rotation is a very valuable tool for breaking disease cycles. For diseases that persist in the soil, rotating away from hosts is critical for decreasing the disease potential. Even if it doesn't provide complete control, rotation to non-host crops keeps the disease from increasing and it gives time for soil organisms an opportunity to decrease pest populations.

Diseases with a wide host range such as seedling damping off caused by *Pythium* spp. fungi and root rots caused by *Rhizoctonia solani* are more difficult to manage with rotation. These fungi attack so many different crops and persist long enough in the soil, that they usually have to be managed by other means (e.g., using appropriate seed treatments, waiting until the soil is warmed up before planting, promoting good soil structure to increase drainage).

**Rotation and weeds**

Rotation can have large impacts on weed pressure. Rotation allows for the use of different herbicides which can help prevent buildup of resistant weed populations. This is particularly true in “stacked” rotations where the same or very similar crops are grown two years in a row and then skipped for four or more years (e.g., corn-corn-soybean-soybean-wheat-wheat), allowing for the use of herbicides with long residuals in the first year of each crop while maintaining a long period (four years) where the land is rotated to other crops (Beck, 2003).

Similarly, an advantage can be gained by rotation between warm- and cool-season crops where each cycle is held for two seasons (two warm-season crops followed by two cool-season crops) (Anderson, 2008). Holding the given pattern for two years disrupts weed lifecycles such that the weed seeds have to survive for three years before they get the opportunity to grow and multiply, leading to decreased weed populations (Fig. 4.2).
Rotation, residue, and nutrient availability

Soybeans return much less residue to the soil than corn or small grains. A 45 bu/acre soybean crop will generate about 2500 lbs/acre of residue, much of this being leaves which quickly decompose; whereas a 150 bu/acre corn crop will produce about 8400 lb/acre of residue and a 60 bu/acre wheat crop will produce about 3600 lb/acre of residue. Therefore, soybeans will provide less residue cover to protect the soil from erosion. This problem can be partially solved by following the soybean crop with a cover crop (Chapter 5).

Consistent with their relatively rapid decomposition and low residue levels, soybeans tend to release more N for the following crop than do grass crops. The SDSU soils lab allows a 40 lb/acre N credit for soybeans. This is a broad estimate and may vary based on growth and yield of the soybeans; for example, work in Nebraska has shown a N credit equivalent to 58 lb/acre of fertilizer N applied as either ammonium nitrate or urea-ammonium-nitrate (Varvel and Wilhelm, 2003).

Soybeans tend to tolerate high residue situations better than many other crops, perhaps because they are generally seeded following corn (Chapter 10) and their growing point is above ground during seedling growth. Hence they are not as affected by low soil temperatures. In any case, while soybean seedling growth tolerates high residue fairly well, they don't leave much residue behind them.

This is an area that needs some thought and work in terms of using cover crops, especially in erosion-prone areas, to help minimize soil loss and maintain soil structure. If current climate projections hold true, then more of our rain will come in intense storms (Seeley, 2012) and the value of using cover crops to maintain soil cover and limit erosion will become increasingly important.

Soybeans tend to remove more K than corn or small grains (Table 4.2). A typical 45 bu/acre soybean crop will remove 62 lbs/acre of K₂O; a 150 bu/acre corn crop will remove about 40 lb K₂O/acre; and an 80 bu/acre wheat crop will remove about 24 lb/acre of K₂O. This is not a critical difference in the short run, but over the years it means that soybean cultivation will tend to draw down soil K a little faster than other grain crops would.
Table 4.2. Pounds of nutrient removed in the harvested crop. (Modified from Clay et al., 2012)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Unit of Yield</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>Mg</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>ton</td>
<td>51</td>
<td>12</td>
<td>49</td>
<td>5.4</td>
<td>5.4</td>
</tr>
<tr>
<td>Canola</td>
<td>bu</td>
<td>1.9</td>
<td>1.2</td>
<td>2</td>
<td>–</td>
<td>0.34</td>
</tr>
<tr>
<td>Corn grain</td>
<td>bu</td>
<td>0.9</td>
<td>0.38</td>
<td>0.27</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>Fescue</td>
<td>ton</td>
<td>37</td>
<td>12</td>
<td>54</td>
<td>3.7</td>
<td>5.7</td>
</tr>
<tr>
<td>Red clover</td>
<td>ton</td>
<td>45</td>
<td>12</td>
<td>42</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Rye grain</td>
<td>bu</td>
<td>1.4</td>
<td>0.46</td>
<td>0.31</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Soybean grain</td>
<td>bu</td>
<td>3.8</td>
<td>0.84</td>
<td>1.3</td>
<td>0.21</td>
<td>0.18</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>ton</td>
<td>22</td>
<td>12</td>
<td>58</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Wheat grain</td>
<td>bu</td>
<td>1.5</td>
<td>0.6</td>
<td>0.34</td>
<td>0.15</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The other point regarding rotations and nutrient availability has to do with cover crops and green manures. This is an area that needs further research, but it appears that sometimes cover crops or green manures may increase P availability (Sexton et al., 2009), perhaps by bringing P up from deeper in the soil profile and concentrating it near the surface or by contributing to improved soil structure and root exploration of the profile. Managing the rotation to maintain sufficient residue to protect the soil will build soil quality over time and in the long term help improve nutrient availability.

**Impacts on yield in a corn-soybean system**

It is well-known that continuous corn production tends to result in a yield drag. Studies in South Dakota, Minnesota, Wisconsin, and Nebraska show a 10 to 22% yield benefit for corn grown in rotation with soybeans versus continuous corn systems (Porter et al., 1997; Reidell et al., 2009; Stanger and Lauer, 2008; Wilhelm and Wortmann, 2004) (Fig. 4.3). In turn, soybeans also yield on the order of 8 to 10% greater yield when grown in rotation with corn than continuous soybean (Porter, 1997; Pederson and Lauer, 2004; Wilhelm and Wortmann, 2004). So both corn and soybeans benefit from the presence of the other crop.

The two crops show a trend for better root growth lower in the profile when they are grown in rotation (Nickel et al., 1995). A 15-year study done in Wisconsin comparing corn-soybean rotation to continuous corn, amongst other rotations including oats and alfalfa, found that the corn-soybean rotation was the more profitable and less risky over time than was the continuous corn system. In their study, it was also more profitable than rotations including oats and alfalfa; however, that would, of course, be influenced by whether or not the farm was engaged in livestock production.

While a corn-soybean rotation has been shown to be superior to continuous corn over time, it is still not a very diverse system. Crookston et al. (1991) conducted a nine-year study looking at corn and soybean yields in southwestern Minnesota and concluded, even in this relatively humid area, that “a superior cropping sequence . . . would include at least three crops and possibly more.”

As we look to the future and contemplate increasing development of pest resistance to chemical controls, and the likelihood of more variable weather conditions, it seems prudent over time to develop or maintain a diverse crop rotation.
Rotations and water use

Rotations can be used to manage water excesses and shortages. The relationship between water and rotations is especially important given the wide range of climate conditions observed over the past several years. Rotations provide protection from summer droughts by distributing the critical water use periods across the growing season. Research shows that corn, wheat, and soybeans use different amounts of water and have different critical periods. Wheat partially avoids this problem by flowering and completing its lifecycle earlier in the growing season than either corn or soybeans (Fig. 4.4).

Soybean flowering is spread over several weeks so that it can better avoid the effect of drought stress on seed set. A worksheet for calculating agricultural intensity for different rotations is available at http://www.dakotalakes.com/Publications/Div_Int_FS_pg6.pdf. This calculator can be used to determine water harvesting from different regions and from crops in a rotation. Along with timing of water use, another factor to consider in looking at rotations is rooting depth of the crop in question. Crops with deep extensive root systems that grow late into the season (e.g., sunflower and alfalfa) are less likely to leave behind reserve moisture than are crops with shallower root systems that mature relatively early in the season (e.g., peas, flax, and lentils).

Figure 4.3. Average corn yields, at the end of six years, in three rotational sequences. (Katsvairo and Cox, 2000). Even after just two cycles, yield differences were apparent. Data shown are averages across three tillage regimes from the final year of the study. These plots received 163 kg/ha of N.

Figure 4.4. Estimated crop water use spring wheat, corn, and soybeans grown over a season at Huron, S.D. Based on data from http://www.extension.umn.edu/distribution/cropsystems/components/DC1322a.pdf and http://climate.sdstate.edu/archives/data/tempnormals.shtml. Note how wheat water use is shifted earlier in the season so that it avoids drought stress.
References and additional information

Websites
http://soilquality.org/practices/row_crop_rotations.html
http://www.dakotalakes.com/crop_rotations.htm

Acknowledgements
Support was provided by SDSU and the South Dakota Soybean Research and Promotion Council.

Cover crops, grown during or after cash crops, are used to improve soil health, increase organic matter, increase water infiltration, reduce erosion, reduce nutrient deficiencies, increase fertilizer efficiency, and increase available forage for livestock. Cover crops include a wide array plants including but not limited to: brassicas (sugar beet, turnips, radish) (Fig. 5.1); grasses (barley, winter wheat, rye); and legumes (chickling vetch, lentils, peas). The ability to benefit from cover crops depends on your ability to fit the cover crop into your rotation. This chapter provides background material using cover crops in rotations containing soybeans.

Figure 5.1. Brassicas (radishes and turnips) planted into spring wheat stubble after early August harvest. Photo taken in November, about 10 weeks after planting (11/10/2010). These radishes provide forage for livestock and help reduce soil compaction. (Photo courtesy of Cheryl L. Reese, SDSU)
Economic benefits from cover crops

Cover crops have been advertised as a one-step solution to many problems associated with row crop production. For example, they have been linked to increased fertilizer efficiency, improved soil quality, increased carbon sequestration, and reduced erosion. Cover crops can reduce nutrient losses. If using legumes, these crops may increase soil nitrogen, if N levels are low, by fixing atmospheric N. Brassica crops with large tap roots can help break compaction zones and increase water infiltration.

Cover crops also add organic matter, which improves soil quality, reduces erosion, and reduces runoff. Some cover crops also provide glucosides, which act as a biofumigant, and may reduce disease organisms.

While some of these benefits are more obscure than others, in a practical sense cover crops must have economic value within your rotation. Economic benefits from cover crops may include increased yields in row crops, increased fall and winter forage, reduced fertilizer requirements, improved soil yield potential, and under some conditions reduced iron deficiency chlorosis (IDC) in soybean (Chapter 26).

The definitive impact of cover crops on crop yields is often indirect. For example, research suggests that under some conditions cover crops can increase soybean yields by reducing iron deficiency chlorosis (IDC) (Chapter 26, Kaiser et al., 2011). This hypothesis is based on the plant releasing the negatively charged bicarbonate ion (HCO$_3^-$) when it takes up the negatively charged nitrate ion (NO$_3^-$). The bicarbonate ion then reacts with iron to form a relatively insoluble complex that cannot be taken up by the plant. Kaiser et al. (2011) suggests that cover crops can reduce the risk of IDC by decreasing the soil nitrate concentration and forcing the soybean to fix N.

Steps for introducing cover crops into a rotation

In the northern Great Plains, cover crops can be used to fill specific and general needs within rotations. For example, a specific need might be to improve nutrient recycling while a general need is to increase the long-term yield potential by increasing soil organic matter content. The requirements for both systems are similar, yet slightly different. Implementing an effective cover crop program requires following several key steps (Table 5.1).

Table 5.1. Steps for integrating cover crops into your rotation.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Develop a cover crop plan.</td>
</tr>
<tr>
<td>2.</td>
<td>Identify specific objectives.</td>
</tr>
<tr>
<td>3.</td>
<td>Identify crop rotational requirements.</td>
</tr>
<tr>
<td>4.</td>
<td>Determine agronomic requirements:</td>
</tr>
<tr>
<td></td>
<td>a. desired species (single or mix), seeding rates, and landscape positioning (if any) for specific cocktails (i.e., seed mix);</td>
</tr>
<tr>
<td></td>
<td>b. examine herbicide labels to determine if herbicide residuals will limit selected species growth.</td>
</tr>
<tr>
<td>5.</td>
<td>Determine costs (seed, planting, future control, if needed) and expected returns.</td>
</tr>
</tbody>
</table>

Developing a cover crop plan and objectives

Developing a cover crop plan is critical for justifying your use of limited farm resources. Cover crop management objectives may include extending fall grazing, scavenging nutrients, reducing pests, wildlife habitat, and/or decreasing soil compaction. Each field is likely to have a different set of objectives. One producer might target increasing the soil organic matter content while a different farmer might target providing forage for fall grazing.

Selecting the appropriate seeding data and plant species to use for a cover crop is critical for achieving your goals. Often a mix of species, i.e., a cover crop “cocktail,” is used. Mixing many species allows for many goals to be addressed by a single planting, and often enhances the opportunity for successful establishment...
of at least one species. In South Dakota, considerable success has been achieved by seeding a cover crop after
winter or spring wheat harvest in August. Other opportunities for seeding cover crops include following a
failed crop (e.g., late frost or hail damage) or after the critical weed-free period in a row crop (about V4 to V5
in corn). Questions that should be considered when selecting a cover crop cocktail include:

1. Did prior herbicide use (or environmental conditions) result in carryover or residuals that will
prevent successful cover crop establishment?

2. Will the soil chemical characteristics influence plant establishment? For example, in salty soils
cocktails should include salt tolerant plants (Chapter 48).
   a. Salt tolerant plants include barley, sugarbeets, tall wheat grass, canola, and wheat grass.
   b. Soybeans is moderate tolerant, while corn is moderately sensitive.

3. Will the cover crop cocktail increase or decrease pests in the cash crop (insects, weeds, and
diseases) the following spring? For example, grass species like barley, rye, oats, or corn can
act as a secondary host for the wheat curl mite which vectors wheat streak mosaic virus.
Planting these grasses may provide a ‘green bridge’ for this pest to over winter and cause
significant disease problems in wheat planted the following spring.

4. Does the cocktail influence future management? For example, will the cover crop need to be
killed? If a cover species is planted that can potentially over winter, make sure to apply needed
treatments in the spring to cease the cover crop growth so that it does not interfere with the
season's intended cash crop.

5. How will the cover crop cocktail influence fertilizer requirements? For example, legumes like
clover may increase soil N or deep rooted brassicas will alleviate soil compaction.

**Crop rotations and cover crops**

There are many crop rotations that could be enhanced by including cover crops (Chapter 4). This chapter
concentrates on three rotations: (1) corn grain followed by soybean; (2) corn for silage followed by soybean,
and (3) soybean, wheat, and corn for grain (Table 5.2). Fall cover crops in South Dakota are difficult and
risky to establish after harvest of both soybean and corn due to the cold, short, and often dry growing season
remaining in September and October.

***Table 5.2. Three crop rotations with cover crops and possible risk for successful cover crop
emergence.*** (Cheryl L. Reese, SDSU)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn (Grain)/Soybeans/Corn (Grain)</td>
<td>Corn (Grain)</td>
<td>High</td>
<td>Soybeans</td>
</tr>
<tr>
<td>Corn (Silage)/Soybeans/Corn (Grain)</td>
<td>Corn (Silage)</td>
<td>Moderate to Low</td>
<td>Soybeans</td>
</tr>
<tr>
<td>Soybeans/Wheat/Corn (Grain)</td>
<td>Soybeans</td>
<td>Moderate to High</td>
<td>Wheat</td>
</tr>
</tbody>
</table>
Planting a cover crop into growing corn or soybeans in July and August (Figure 5.2) has produced mixed results (Mutch and Martin 1998, http://www.covercrops.msu.edu/pdf_files/covercrop.pdf; authors unpublished data). These crops are often seeded aerially with an airplane and moisture is crucial for germination.

In South Dakota, research where a cover crop was seeded at the corn V5-V6 growth period showed that the cover crop has a minimal impact on the corn crop yield. For this application, cover crop cocktails should include plants that germinate and grow well under shade, such as red clover. If corn has been treated with atrazine, there may be few cover crops that will establish during the season, especially if conditions that minimize breakdown (dry or abnormally cool conditions) have occurred.

Drilling the cover crop between rows has produced a more consistent stand (Fig. 5.3) than broadcast applications (Figs. 5.2 and 5.4); however, either technique can be successful if growth characteristics, seeding requirements, and water are available. When cover crops are seeded in-season, the cover crop usually remains quite small until the main crop starts to senesce and approaches maturity, at which time growth accelerates. Following corn harvest, the cover crop can be fall and winter grazed.

In soybean, the canopy may be too dense to allow for good establishment of in-season cover crops and planting may need to be delayed until leaf senescence.
Opportunities for planting fall cover crops exist in rotations where a short-season crop like wheat is harvested in July or if corn is harvested as silage in August (Fig. 5.5). In this application, the cover crop should be seeded as soon as possible after harvest. Seeding before September 1 improves the ability of the cover crop to be established before a killing frost. Cover crops can provide fall and winter grazing, reduce compaction, and increase nutrient cycling. A cocktail that includes cereals such as rye or oats, broadleaves like radishes or turnips, and legumes are desirable and can provide excellent livestock forage (Fig. 5.6).
In the soybean, wheat, and corn rotation, a cover crop after the wheat harvest has been used to increase the yield in the following corn crop. In South Dakota wheat is typically harvested in July or early August which provides the best opportunity to establish fall cover crops. Generally there is an ample opportunity to seed the cover crop cocktail and have a longer time for establishment and growth. Care must be taken to choose herbicides with short residuals or to provide ample time between application and seeding to optimize growth and development (see Table 5.8).

![Cover Crop Planting Date vs. Biomass](image)

**Figure 5.7.** Cover crop dry biomass by planting date.
(Adapted from South Dakota NRCS Cover Crop Survey 2008-2010)

**Cover crop planting dates**

To optimize fall growth of cover crops, the earlier the crop is seeded, the more biomass will be produced. In Figure 5.7, regardless of the cover crop mixtures, either brassicas or broadleaf mixture, dry biomass averaged approximately 3,800 lbs/acre when planted on August 1 and decreased to about 200 lbs/acre when cover crops were planted on August 31. Similar results have been observed in South Dakota demonstration studies where dry biomass production was 1091 and 237 lbs biomass/acre when seeded on 8/17/2010 and 9/19/2009, respectively.

**Cover crops composition: Warm-season vs. cool-season**

Selecting an appropriate seeding mixture is critical. Cover crop composition could be warm- or cool-season plants or a mixture depending on when the cover crop is seeded. Cool-season plants grow best in cool temperatures. Cool-season species start growth when air and soil temperatures are cool and will continue to grow during the spring and fall but go dormant or quickly die off when temperatures are warm (>80°F). Cool-season broadleaves can be typically divided into (1) brassicas like canola, radishes, or turnips or (2) legumes including clovers, peas, and vetch. Cool-season grasses include barley, oats, winter wheat, and rye. In a South Dakota fall, cool-season cover crops often blend broadleaf and grass species to provide the most biomass and potentially survive light frosts.
Warm-season plants grow best with warm temperatures. Warm-season species typically start growth in late spring when soil and temperatures are warm. These plants thrive during the warm summer weather. Examples of warm-season plants are big blue stem, corn, and sorghum. Warm-season species typically do not tolerate frost and will die out quickly as fall temperatures fall at or below freezing. In South Dakota, cool-season species are used for cover crops in most cases.

**Cover crop categories and uses**

In compacted soils, cover crop cocktails that include brassicas (grazing radish) can be used to reduce soil compaction (bulk density). These plants produce a tap root that penetrates soils up to two feet (Fig. 5.8). These plants can rapidly decompose leaving large pores in the soil. In Figure 5.9, a knife is inserted in a root channel of a decomposing tillage radish.

![Figure 5.8. Diakon radishes and purple top turnips root size. (Photo, C. Reese, SDSU)](image)

![Figure 5.9. Knife inserted into macro channel created by decomposing radish root, May, 2012. (Photo, C. Reese, SDSU)](image)
**Cover crop impacts on soil health**

Cover crops mixtures can help increase the diversity of the soil biota which can help increase aggregate stability (Fig. 5.10, Ketterings et al., 1996) and N mineralization (Fig. 5.11). Plants with high C to N ratios, such as wheat straw or corn stover, generally mineralize slowly, whereas plants with low C to N ratios, brassicas or turnips, peas or soybean residue, generally mineralize fast. The mineralization rate influences how much of the N contained in residue will be available to the following crop early in the growing season (Fig. 5.11).

![Earthworms associated with a decomposing radish root. May, 2011.](http://www.iGrow.org)

**Figure 5.10.** Earthworms associated with a decomposing radish root. May, 2011. (Photo, C. Reese, SDSU)

![Crop residue decomposition based cover crop C:N ratios.](http://www.weblife.org/humanure/chapter3_7.html)

**Figure 5.11.** Crop residue decomposition based cover crop C:N ratios. (Source: http://www.weblife.org/humanure/chapter3_7.html)

When determining a cover crop blend, consideration should be made for the current soil residue cover. If the desired outcome is crop residue retention, cover crops with high C:N ratios should be considered. However, if the goal is to improve soil nutrient recycling from one crop to the next, then crops with a low C to N ratio should be seeded. http://soils.usda.gov/sqi/management/files/C_N_ratios_cropping_systems.pdf

Cover crops can be used to help manage high salt soils. Cover crops can be useful in salt management by increasing water loss through transpiration vs. evaporation, and reducing capillary movement of water and salts into surface soil. For cover crops to be effective they must germinate and reduce evaporative water loss. In South Dakota, barley, sugarbeets, rape, rye, canola, and western wheat grass can be seeded into salty soil zones (Chapter 53). Challenges using this cover crop seeding include (1) a good method to plant the cover crop into the growing corn and (2) seed germination.
**Developing a cover crop cocktail**

Determining the blend is accomplished by establishing the cover crop goals, evaluating seeding season characteristics of the plants (warm- vs. cool-season), and considering soil variability. Tables 5.3 to 5.7 summarize cover crop blends that provide options for various cover crop management objectives. An important note here is that after producers have some experience with cover crops, they often will modify seed mixtures to fit their needs. Cool-season grazing blends will often consist of turnips, radishes, and grasses whereas cowpeas, millet, and sudangrass can be used for warm-season grazing.

**Table 5.3. Cover crop blends for grazing.** (Revised from Jason Miller, NRCS, Pierre, SD).

<table>
<thead>
<tr>
<th>Grazing Blends</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Warm-season grazing</th>
<th>Grazing / Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>Type</td>
<td>Full Seeding Rate Pounds</td>
<td>Percent</td>
<td>Rate in Mixture</td>
</tr>
<tr>
<td>Lentils</td>
<td>Cool Broad</td>
<td>30</td>
<td>30</td>
<td>9</td>
</tr>
<tr>
<td>Turnip</td>
<td>Cool Broad</td>
<td>4</td>
<td>30</td>
<td>1.2</td>
</tr>
<tr>
<td>Radish</td>
<td>Cool Broad</td>
<td>8</td>
<td>10</td>
<td>0.8</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>Cool Broad</td>
<td>5</td>
<td>10</td>
<td>0.8</td>
</tr>
<tr>
<td>Oat</td>
<td>Cool Grass</td>
<td>70</td>
<td>30</td>
<td>21</td>
</tr>
<tr>
<td>Cowpea</td>
<td>Warm Broad</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Millet</td>
<td>Warm Grass</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sudangrass</td>
<td>Warm Grass</td>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 5.4. Cover crops that may aid in reducing compaction.** (Revised from NRCS, Pierre, SD)

<table>
<thead>
<tr>
<th>Compaction Blends</th>
<th>Compaction</th>
<th>Grazing / Compaction</th>
<th>Residue Cycling / Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>Type</td>
<td>Full Seeding Rate Pounds</td>
<td>Percent</td>
</tr>
<tr>
<td>Lentils</td>
<td>Cool Broad</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Radish</td>
<td>Cool Broad</td>
<td>8</td>
<td>60</td>
</tr>
<tr>
<td>Canola</td>
<td>Cool Broad</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Cowpea</td>
<td>Warm Broad</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Millet</td>
<td>Warm Grass</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Sudangrass</td>
<td>Warm Grass</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Turnip</td>
<td>Cool Broad</td>
<td>4</td>
<td>30</td>
</tr>
</tbody>
</table>
Table 5.5. Cover crops that may enhance residue cycling compaction. (Revised from NRCS, Pierre, SD)

<table>
<thead>
<tr>
<th>Residue Cycling Blends</th>
<th>Residue Cycling</th>
<th>Residue Cycling / Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full Seeding Rate</td>
<td>Percent</td>
</tr>
<tr>
<td></td>
<td>Pounds</td>
<td>%</td>
</tr>
<tr>
<td>Species</td>
<td>Type</td>
<td>lbs A⁻¹</td>
</tr>
<tr>
<td>Lentils</td>
<td>Cool Broad</td>
<td>30</td>
</tr>
<tr>
<td>Canola</td>
<td>Cool Broad</td>
<td>5</td>
</tr>
<tr>
<td>Radish</td>
<td>Cool Broad</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 5.6. Cover crops that may potentially germinate under saline conditions. (Revised from NRCS, Pierre, SD)

<table>
<thead>
<tr>
<th>Salinity Blends</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full Seeding Rate</td>
<td>Percent</td>
<td>Rate in Mixture</td>
</tr>
<tr>
<td>Species</td>
<td>Type</td>
<td>lbs A⁻¹</td>
<td>%</td>
</tr>
<tr>
<td>Sugarbeets</td>
<td>Cool Broad</td>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td>Barley</td>
<td>Cool Broad</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Canola</td>
<td>Cool Broad</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 5.7. Cover crops that may reduce soil moisture and enhance nitrogen cycling. (Revised from NRCS, Pierre, SD)

<table>
<thead>
<tr>
<th>Spring Moisture or N Cycling Blends</th>
<th>Spring Moisture / N Cycling 1</th>
<th>Spring Moisture / N Cycling 2</th>
<th>Spring Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full Seeding Rate</td>
<td>Percent</td>
<td>Rate in Mixture</td>
</tr>
<tr>
<td>Species</td>
<td>Type</td>
<td>lbs A⁻¹</td>
<td>%</td>
</tr>
<tr>
<td>Hairy Vetch</td>
<td>Cool Broad</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>Canola</td>
<td>Cool Broad</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>Rye</td>
<td>Cool Grass</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Triticale</td>
<td>Cool Grass</td>
<td>60</td>
<td>50</td>
</tr>
</tbody>
</table>
Other considerations

The cover crop should be matched to the drainage characteristics of the soil. For example, annual rye is a cool-season grass and has a weight of 26 lbs per bushel. Annual rye will grow under wet soil conditions and tends to grow better on both poor, rocky soils and heavy clay soils than cereal rye, although cereal rye can grow under dry to excessive moisture conditions if the soils are more loamy.

Both cereal and annual rye will overwinter like winter wheat. The major problem with cereal rye is excessive spring growth that is not controlled. Under these circumstances, soil moisture is depleted and the producer is left with residue that can be up to six feet tall. The mat of residue can be difficult to manage in the spring and cause soils to dry out and warm up slowly.

Annual rye is typically burned down with an herbicide in the spring when its growth is between 8 to 16 inches. Annual rye has been reported to be difficult to control by many producers during cool weather when glyphosate does not translocate well in the plant. Annual ryegrass can go to seed in the spring and become a weed in future crops if not closely monitored.

Cover crops may reduce available moisture for the row crop; however, they also increase water infiltration and snow catch. Our research suggests that they can reduce as well as increase available moisture for the row crop.

Cover crops increase plant diversity which can increase soil biological diversity. It has been hypothesized that cover crops increase soil mycorrhizae. These organisms can help the row crop utilize nutrients and water (Fig. 5.12).

Many herbicides have activity for a relative long period of time. For example, Roundup® (glyphosate) has no residual soil activity and there are no restrictions to planting any crop after application. In comparison, Maverick® (sulfosulfuron) has a long residual activity (22 months) and planting to any cover crop species except small grain crops may result in reduced populations or less growth (Table 5.8). Matching the herbicide rotation to the desired cover crop is critical for the cover crop success (Table 5.8). Table 5.8 lists estimated rotation restrictions for wheat herbicides based on label information or limited field research. It is important to carefully follow labeled rotation guidelines and contact the appropriate herbicide industry representative if there are any questions regarding rotational restrictions.

Many soybean herbicides may not cause injury to fall-planted cover crops since soybeans are a broadleaf species. Some soybean herbicides that are a moderate to high risk of injuring fall-planted cover crops include products containing fomesafen (Flexstar®, Reflex®, Prefix®, etc.), sulfentrazone (Authority® products, Sonic, etc.), chlorimuron (Enlite® and others), and perhaps other products.

Cost share programs may be available for cover crop seeding from county USDA-NRCS offices. EQIP and CSP are programs that typically allow some cost share benefits for cover crops. The best way to take advantage of the programs is to check early with your county NRCS office for applications and deadlines.
<table>
<thead>
<tr>
<th>Approximate months required between wheat herbicide applications and cover crop seeding</th>
<th>Application Timing</th>
<th>Forage Legumes (alfalfa, clover, vetch)</th>
<th>Pulse Crops (peas, dry beans, lentils)</th>
<th>Seed Mustards (canola, rape)</th>
<th>Root Mustards (turnips, radish)</th>
<th>Small Grains (rye, wheat, triticale, millet)</th>
<th>Other Grasses (sorghum, sudan)</th>
<th>Oilseeds (sunflower, safflower)</th>
<th>Other Broadleaf (flax, buckwheat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maverick (sulfosulfuron)</td>
<td>Fall</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>3</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Olympus (propoxycarbazone)</td>
<td>Fall</td>
<td>24</td>
<td>12-24</td>
<td>12</td>
<td>12-24</td>
<td>4</td>
<td>12</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>Rimfire (propoxycarbazone + mesosulfuron)</td>
<td>Spring</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>0-4</td>
<td>12</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Power (pyroxsulam)</td>
<td>Fall</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>GoldSky (pyroxsulam + florasulam + fluroxypyr)</td>
<td>Spring</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Beyond (imazamox)</td>
<td>Spring</td>
<td>3</td>
<td>3</td>
<td>18-26</td>
<td>9-18</td>
<td>4-9</td>
<td>9</td>
<td>9</td>
<td>9-18</td>
</tr>
<tr>
<td>Ally (metsulfuron)</td>
<td>Spring</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>1-10</td>
<td>12</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Harmony (thifensulfuron)</td>
<td>Spring</td>
<td>1-2</td>
<td>1-2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1-2</td>
<td>1-2</td>
<td>1-2</td>
</tr>
<tr>
<td>Express (tribenuron)</td>
<td>Spring</td>
<td>1-2</td>
<td>1-2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1-2</td>
<td>1-2</td>
</tr>
<tr>
<td>Buctril (bromoxynil)</td>
<td>Spring</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Huskie (pyrasulfotole + bromoxynil)</td>
<td>Spring</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>0-4</td>
<td>4</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>WideMatch (clopyralid + fluroxypyr)</td>
<td>Spring</td>
<td>10.5</td>
<td>18</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>10.5</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>Starane (fluroxypyr)</td>
<td>Spring</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
Potential Cover Crop Seed Suppliers in South Dakota

Spink County Fertilizer & Chemical
Dylan Troske
10 Main St
Northville, SD 57465
Phone: 605-887-3422
Email: dylan.troske@uap.com

Prairie States Seed
Brad Young
Wausa, NE
Phone: 866-373-2514
Email: prairie@gpcom.net

Millborn Seeds Inc.
Matt Fenske
1335 Western Avenue
Brookings, SD 57006
Phone: 888-498-7333
Email: mattf@millbornseeds.com
Web: www.millbornseeds.com

Hansmeier Seed Inc.
Floyd & Keith Hansmeier
Bristol, SD
Phone: 605-492-3611
Email: hansson1@midconetwork.com

Howe Seeds, Inc.
Charles Howe
Box 496
McLaughlin, SD 57642
Phone: 605-823-4892
Cell: 605-845-5892
Email: charleshowe@westriv.com

Cronin Farms
Dan Forgey
30431 167th St
Gettysburg, SD 57442
Phone: 605-765-9287
Email: dcforgey@venturecomm.net

Henry Roghair
PO Box 16
Okaton, SD 57562
Phone: 605-669-2819
Email: hgrseeds@gwtc.net
Pulse USA

Brad Meckle
1900 Commerce Drive
Bismarck, ND 58501
Phone: 1-888-530-0734
Email: brad@pulseusa.com

Mark Stiegelmeier
13402 306th Avenue
Selby, SD 57472
Phone: 605-649-7009
Email: mstiegel@sbtc.net

Sunbird Inc.
Lee Klocke
PO Box 942
702 3rd St SW
Huron, SD 57350
Phone: 605-353-1321 Ext 212
Email: lklocke@sunbird-inc.com
Web: http://www.sunbird-inc.com

Jerome Webb
32050 201st ST
Harrold, SD 57536
Phone: 605-875-3558
Sioux Nation of Fort Pierre
Steve Magdanz
504 Deadwood Ave
Fort Pierre, SD 57532
Phone: 605-223-2427 (seed house)
Email: Sioux.nation2@plantpioneer.com

Winner Seed,
Gene Brondsema
E. HWY 44,
27763 317th Ave
Winner, SD 57580
Phone: 605-842-0481
Cell: 605-680-9886
References and additional information


Managing Cover Crops Profitably. 3rd Edition. SARE Learning Center. Available at http://www.sare.org/Learning-Center/Books

Millborn Seeds, Cover Crop
www.Millbornseeds.com

Moechnig, M. 2013. Personnel communication. South Dakota State University


USDA Cover Crop Chart. Available at http://www.ars.usda.gov/Services/docs.htm?docid=20323


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Selecting Soybean Varieties

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C. Gregg Carlson (Gregg.Carlson@sdstate.edu)
Robert Hall (Robert.Hall@sdstate.edu)

Many agronomists believe that variety selection influences profitability more than any other routine management decision. Therefore, take some time in making your decision. When selecting your next year’s varieties, it is important to consider the factors listed in Table 6.1. Discussion of these factors is provided in this chapter.

Table 6.1. Factors to consider when selecting a variety.
- Availability and seed cost.
- Yield potential and maturity groups.
- Traits and management practices to address common pests and soil conditions.
- Third-party (university) variety performance trial results.

Availability and seed cost
The first step, though simple, is to ask seed companies for price sheets or quotes of available soybean varieties in your region. The additional seed cost of one variety over another can be covered by a relatively small increase in yield, assuming a real yield benefit exists. For example, the difference in the price per bag may only be $9.00 from the cheapest to the most expensive variety within a company. Results from the South Dakota State University soybean variety performance trials (available at http://igrow.org/) demonstrates a significant yield difference exists between soybean varieties within and between companies that could easily cover the added cost of some varieties over another.
Early pay discounts provided by companies often allow for some flexibility where bags or units can be paid for without specifying the variety until later. Please check with your seed company on this policy. The advantage of this option is that it allows for results from variety performance trials to be made available, which is important information in the variety selection process. However, if certain varieties have a relatively tight seed supply, a first-come-first-serve rule usually applies. Please discuss availability of particular varieties with your seed company representative.

Increasingly, soybeans are being sold based on seed count (140,000 seeds per bag), not weight, therefore selection for seed size is less of a cost consideration than it once was. Under most conditions, seed size does not affect germination and emergence. However, planting equipment should be adjusted to account for the seed size being used to ensure that the desired seeding rate and uniformity of spacing is obtained.

Planting more than one or two soybean varieties with diverse genetic backgrounds on your farm will help increase the genetic pool and minimize your risk for a particular environmental condition or pest to preferentially impact a particular variety. It is important and helpful to document where varieties are planted on the farm and within particular fields. It is generally recommended not to mix varieties with different herbicide-resistance traits or vastly different maturity groups within the same field to avoid potential management complications.

Yield potential and maturity groups

The yield potential for a soybean plant is genetically determined and is only achieved when environmental conditions are optimized. The yield potential of soybeans has been estimated to be about 250 to 300 bu/acre, with the highest realized field-level yield of 160.6 bushels per acre by Mr. Kip Cullers of Stark City, MO. However, numerous yield-limiting factors exist that cannot be controlled by even the most savvy soybean producer. Climate and soil factors are largely uncontrollable, whereas variety selection and other management factors that minimize yield loss from the potential are under producer control.

Producers across South Dakota and other states are attempting to minimize yield-limiting factors in high yield trials (Chapter 1). Winners of the South Dakota soybean contest are optimizing yield and learning how to minimize yield loss. More information about the South Dakota contest is available at http://www.sdsoybean.org/. Production records from these trials are being compiled and shared with producers attending winter meetings in an effort to inform others how yield was optimized.

The maturity rating (or group) of a variety is a general indication of when that soybean cultivar is able to start flowering based on the night length, since soybeans are photoperiod sensitive. However, some other factors such as high temperatures can affect flowering date. For example, moving a Group II soybean too far north (where nights are shorter in midsummer) causes delayed flowering and an increased risk of frost damage during seed fill. Likewise, moving a Group 0 too far south (where nights are longer in the midsummer) will lead to earlier flowering and limit yield potential. Selecting an appropriate maturity that utilizes the full growing season provides the best chance to achieve the highest yield. Yield data from variety performance trials and from your own experience often provide a good approach to determine the most appropriate range of maturity groups to plant in your region. The maturity group zones common to eastern South Dakota are shown in Figure 6.1.

It is recommended to reduce the maturity rating, from what is normally planted as a full-season soybean in your area, when planting is delayed past mid-June. The final planting date for full insurance coverage is June 10 in South Dakota with delayed planting coverage until July 5 (Chapter 46). Consider reducing the maturity rating by 0.5 from normal if planting is delayed into mid-June and by 1.0 if planting into early July to minimize the risk of frost damage during seed fill (Chapter 51). Increasing the seeding rate with late-planted soybeans can help improve yield in some years.
Traits and management practices

Pinpointing yield-limiting factors, identified in your scouting records (Chapter 2), is critical for matching those problems with management and genetic solutions. This step is based on the availability of “good” field records (Chapter 2). Scouting your fields or hiring someone to scout on a regular basis provides data needed for problem solving. Your first time out in the field after planting should not be with the combine. Different fields and locations within a field are likely to have different yield-limiting factors and that these deficiencies can be reduced by matching the varietal traits to specific problems.

Most seed companies provide ratings for several common yield-limiting factors since resistance or tolerance differences exist between varieties. Variety ratings on phytophthora root rot (PRR), brown stem rot (BSR), white mold, soybean cyst nematodes (SCN), iron deficiency chlorosis (IDC), and sudden death syndrome (SDS) are important to consider along with other traits like herbicide-resistant technology. Use this information and work with your seed company representative or agronomist to utilize variety selection to minimize these yield-limiting factors.

Links for variety disease ratings

Monsanto: Channel Bio
http://www.channel.com/Products/Pages/seed_finder.aspx

Dow: Prairie Brand
http://prairiebrand.com/soybeans/product-finder/

DuPont: Pioneer
https://www.pioneer.com/home/site/us/products/soybean/

Syngenta: NK

AgReliant: Wensman

Note: These lists are provided for the convenience of the reader and do not imply endorsement.
For example, SCN-resistant soybean varieties can yield 23-63% more than susceptible varieties when SCN pressure is high (Smolik and Draper, 2007). Management practices to minimize yield loss from SDS include delaying planting, improving drainage, reducing compaction, and variety selection (Chapters 27 and 59). In fields with a history of SDS, later planting and selection of varieties with higher tolerance to SDS highlights how management practices are combined with variety selection to minimize yield loss. More information on diseases is available in Chapters 57 through 60.

In the near future, one of the best approaches is to match varieties with problems (SCN, IDC, etc.) that have high spatial variability is to adopt a site-specific management program. In site-specific variety management, different varieties can be seeded in different management zones. Today many growers have the capacity to: 1) track their field locations using onboard GPS technology; 2) use air seeders (planters in the near future) to plant seed from two or more hoppers; and 3) vary the population level. These innovations are moving agronomic management into a new era where varieties will be selected to maximize yield based upon site-specific soil physical, chemical, and other conditions (Chapter 20). To prepare for site-specific variety management, consider collecting:

- Precision scouting reports.
- Field monitor data.
- Site specific soil samples and soil survey maps.

Over the past several years, management trends suggest that site-specific management is becoming conventional management. This change is attributed to high crop values, high input costs, and precision management practices that are becoming easier to seamlessly implement. Research documenting the economic benefits from adopting site-specific variety management is needed.

**Third-party (university) variety performance trial results**

A producer is influenced by marketing campaigns, farm partners, neighbors, seed dealers, university and independent variety performance trials, and more when selecting varieties each year. The high turnover rate of recently released varieties and the phase out of older varieties compound the difficulty in making a sound decision. South Dakota State University and other universities in the north central region of the U.S. are part of the University Crop Testing Alliance (http://www.ucta.org/) that conducts annual variety performance trials (Fig. 6.2).

The South Dakota State University Crop Performance Testing uses replicated and statistically sound analyses to present the data on days-to-maturity, yield, and lodging between submissions from soybean seed companies. Six locations each year are spread out across South Dakota’s dominant soybean production regions (example shown in Figure 6.1). Information on weather, site conditions, and management are collected. The top performance group of varieties for the current crop year and a two-year average, if available, are clearly identified in the reports at http://igrow.org/. A least significant difference (LSD\textsubscript{0.05}) value is reported for each site by maturity group. Those LSD values are used to determine if two varieties are significantly different. For example, if the LSD value is 5 bu/acre and Variety A has a yield of 50 bu/acre and Variety B has a yield of 40 bu/acre, then the difference between the two varieties is 10 bu/acre. Because the difference, 10 bu/acre, is greater than the LSD\textsubscript{0.05} (5 bu/acre), they are significantly different.

Assessing variety performance under different environmental conditions is possible by looking at the supplemental data provided for a given site and year. If a variety is frequently in the top performance group across sites and years, it has good yield stability. Selecting a variety with a stable yield potential is a good approach for reducing risk.
Summary

Variety selection is a very important step towards increasing profitability. Due to the importance of this decision, an appropriate amount of time should be allocated for variety selection. When making this decision, consider seed availability and cost, yield potential, yield stability, maturity groups, available traits and management practices to address common pests and soil conditions, and third-party variety performance trial results.

South Dakota's variety testing information is posted as quickly as possible (http://igrow.org/agronomy/soybeans/soybean-variety-trial-results/). However, the earliest pay discounts that seed companies offer often expire prior to completion of harvest, thus before results from variety trials are available. As stated before, please check with your seed representative as you may be able to pay for a particular number of bags or units and select the variety later. This will hopefully allow you to utilize variety performance trial results during your variety selection.

References and additional information


Acknowledgements

Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

There are many companies selling soybean seed in South Dakota. In this chapter, Monsanto, Pioneer, and the SDSU soybean breeding program completed a survey related to products that are currently offered or are planned for release in the near future. The survey requested information on drought tolerance, flooding tolerance, aphid resistance, soybean cyst nematode resistance, iron deficiency chlorosis resistance, phytophthora rot root tolerance, and dicamba resistance in soybeans. If information from your company of choice is not provided, we recommend that you contact them for information. This information is provided for readers convenience and does not imply endorsement.
The purpose of this chapter is to provide reference information that can be used for: 1) comparison with the trait packages on your current varieties; and 2) improving the long-term sustainability of your production system.

Drought tolerance is also an ongoing concern, as evidenced by the 2012 growing season with many areas of the U.S. experiencing extreme heat coupled with abnormally low precipitation. Drought stress reduces a plant’s ability to defend itself against opportunistic diseases. To mitigate the opportunistic diseases that often occur during droughts, Monsanto, Pioneer, and Syngenta offer competitive lines of stress-tolerant and disease-resistant soybeans.

http://www.agseedselect.com
https://www.pioneer.com/home/site/us/products/soybean/
http://cornandsoybeandigest.com/seed/syngenta-pipeline-new-technologies-future-traits

In addition, South Dakota State University (SDSU) breeders are working in conjunction with the University of Minnesota breeding program, and have released “Davison,” which has exhibited some degree of drought tolerance.

In the next decade, farmers may see biotechnology offerings for drought tolerance, similar to new corn varieties, as well as more seed treatments and varieties that specifically address these issues. At SDSU, researchers are using genomics, proteomics, and metabolomics to identify key compounds and genes associated with drought effects and tolerance in soybeans.

http://www.monsanto.com/products/Pages/corn-pipeline.aspx#firstgendroughttolerantcorn

Managing too much water (flooding)

Cultivation and drainage systems are used to manage wet soils. Fall tillage can be used to expose the soil to optimize drying in the spring; however, this also leads to soil erosion and a gradual decrease in the soils yield potential. Most current soybean varieties grow poorly in wet soils (Figure 7.1). In the future it may be possible to manage for problems associated with wet soils when you select your variety. Currently, Monsanto, Pioneer, and Syngenta offer seed treatment options to protect soybeans from early seedling diseases that are associated with wet soils.

https://www.acceleronsts.com/Soybeans/Pages/Soybean-Products.aspx
https://www.pioneer.com/home/site/us/products/soybean/seed-treatments/

In addition, ARS has identified flood-tolerant soybean germplasm with root systems that can better cope with flooding than currently available soybean varieties. SDSU researchers are screening sources for waterlogging tolerance to add to their established breeding program.

http://www.ars.usda.gov/is/AR/archive/jul12/soybeans0712.htm

Aphid Resistance/Rag (resistance to Aphis glycines) genes (Chapter 35)

The traditional approaches to manage aphid problems include diligent field scouting, application of fungicides, use of biological controls, and selecting appropriate traits. Aphid tolerance/resistance is found in several “Rag” genes. Alone, a single “Rag” gene in a plant slows aphid population growth; used in combination, they almost halt population growth. However, aphid biotypes resistant to both of the currently used genes (Rag1 and Rag2) exist.

Pioneer and Monsanto offer product lines that incorporate genetic resistance to aphids. This resistance is available in the varieties found in their online catalogs.

https://www.pioneer.com/home/site/us/products/soybean/
http://www.agseedselect.com

SDSU researchers are investigating genes relating to plant architecture dealing with pest resistance, in addition to evaluating resistant varieties to develop new cultivars and germplasm lines, particularly a newly-identified source of resistance gene Rag3 and other genes that are still effective against soybean aphids. In private sector research, aphids may be a future target as a Biodirect application.

http://www.monsanto.com/products/Pages/biodirect-ag-biologicals.aspx

Pioneer’s team of researchers continue to look for novel genes and other forms of aphid control.


Resistance genes rag1c, Rag3, rag4, and Rag5 have been pinpointed in source lines (Bonin, 2012) and are being developed for future use. These new resistance genes will provide resistance to the biotypes that can overcome Rag1 and Rag2 genes. Monsanto and Pioneer will launch the 2nd generation of aphid resistant products incorporating novel genes for aphid resistance in the near future.

http://www.monsanto.com/products/Pages/soybean-pipeline.aspx#secondgensoybeanaphidresistance

Soybean Cyst Nematode (SCN) resistance (Chapter 57)

SCN is a pest that many producers do not know about and would not recognize its effects. This pest reduces yields even if foliar symptoms are not observed. There are currently no known methods effective in eradicating SCN from infested soils. The traditional control mechanisms include using soil sampling to confirm the presence of SCN in the soil, planting resistant varieties, practicing crop rotation, using appropriate seed treatments, and minimizing spread through contaminated equipment.


Monsanto currently has different seed treatment options to specifically address SCN and other nematodes.

http://www.monsanto.com/products/Pages/agronomics-pipeline.aspx#nematicide
https://www.acceleronsts.com/Soybeans/Pages/Soybean-Products.aspx

Varieties going back to PI 88788 or Peking typically demonstrate SCN resistance. Private companies offer varieties that convey varying levels of SCN resistance.


Over 95% of Monsanto's pipeline has genetic resistance to SCN through the PI88788-source. An additional 3% have resistance from an alternative source of resistance, from the public variety Peking. Future Monsanto options will possibly include Biodirect applications, as well as varieties incorporating novel and diverse sources of genetic resistance to SCN.

http://www.monsanto.com/products/Pages/soybean-pipeline.aspx#cystnematoderesistantsoybeans
Pioneer continues to improve cyst nematode resistance in their soybeans through native variation and non-transgenic, which are resistant to multiple races of SCN which includes both PI88788-source and Peking. These were developed through Accelerated Yield Technology (AYT). Pioneer offers several SCN-resistant varieties.


SDSU researchers are screening varieties for SCN resistance and have developed segregating populations demonstrating SCN resistance. Most populations used in the SDSU breeding program incorporate the resistance genes rhg1 and Rhg4.

Iron deficiency chlorosis (Chapter 26)

Iron Deficiency Chlorosis (IDC) is indicated by yellowing of the leaves with green veins. The traditional approaches to managing IDC includes using EDDHA chelated seed treatment, planting resistant varieties and/or a companion crops, and reducing weed and other stresses.


The SDSU cultivar Sodak is a soybean variety with IDC tolerance.

Additional varieties with IDC tolerance are available from Asgrow.
http://www.agseedselect.com

Varieties with IDC tolerance are also available from Pioneer.

Syngenta/NK Brands also offer varieties with IDC tolerance.

Ongoing research at SDSU involves screening varieties for IDC resistance and identifying new sources for tolerance. This work involves identifying genetic resistance in wild soybean lines. Breeders are using different sources of tolerance in their variety development, and future offerings will combine those different sources to deliver a higher IDC tolerance. Monsanto research and development is working to understand and dissect the components of IDC, in order to better deliver solutions to farmers in the next decade.

Figures 7.2 and 7.3. (Left) Typical discoloration of the stem associated with root and stem rot. (Right) Leaf wilting and plant death due to Phytophthora root and stem rot. (Photos courtesy of Daren Mueller, Iowa State University, Bugwood.org)
**Phytophthora root/stem rot**

The current management practices for phytophthora root rot are field drainage, seed treatments, and seeding tolerant varieties (SDSU Soybean Disease Guide).
http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC932.pdf


Seed treatments are available from Monsanto and Pioneer.
https://www.acceleronsts.com/Soybeans/Pages/Soybean-Products.aspx
https://www.pioneer.com/home/site/us/products/soybean/seed-treatments/

The current genetic defense is available from the Rps genes (e.g., 1a, 1c, 1k). However, this resistance may be overcome by aggressive races of the pathogen.

The SDSU soybean breeding program has developed Phytophthora-resistant varieties/lines, such as recently-released “Brookings” and “Deuel” with Rps1k, “SD06-525” with Rps1c, and potential line “SD03-2154” with Rps1k. Monsanto offers varieties with single-gene and stacks of single genes in their product lineup.
http://www.agseedselect.com

Future offerings from Monsanto will include stacks of novel genes to further protect the soybean from this quickly changing pathogen.
http://www.monsanto.com/products/Pages/soybean-pipeline.aspx#phytophthorarootrotresistance

Pioneer also offers several varieties with multiple approaches for resistance and tolerance.

Pioneer is working towards stacking genes and providing producers with more varieties to choose from in the fight against rot diseases.

SDSU will predominantly use their released lines and introduce new lines carrying different Rps genes found in soybean lines from other breeding programs, such as ND07-2019 and ND07-3761 that contain Rps6, which is resistant to three or four races.

**Dicamba resistant varieties**

Monsanto is developing the Roundup Ready® Xtend Crop System*, which is designed to provide farmers with more consistent, flexible control of weeds—especially tough-to-manage and glyphosate-resistant weeds—to maximize crop yield potential. Pending regulatory approvals, the Roundup Ready Xtend Crop System will consist of two components: innovative trait solutions and advanced herbicide formulations. Roundup Ready® 2 Xtend soybeans include tolerance to both glyphosate and dicamba herbicides.

Monsanto is also developing an enhanced, low volatility dicamba and glyphosate herbicide premix, to be branded as Roundup® Xtend that will enable farmers to manage weeds before planting and as an over-the-top-option during the season. XtendiMax™ will be the brand name for a low-volatility dicamba herbicide. Monsanto is seeking regulatory approval to use both the premix and single herbicide products pre-, at, and post-planting with Roundup Ready 2 Xtend soybeans.

There are multiple ways to achieve sustainable weed management programs in the field and a significant number of farmers have found that using combinations of herbicides and herbicide-tolerant crops is a way to
achieve this in both conservation and conventional tillage systems. Dicamba is one of the most economical herbicides that controls a wide spectrum of broadleaf weeds. Dicamba is not a standalone or a replacement of the Roundup Ready PLUS weed management system.

Residual herbicides and multiple modes of action are still recommended as part of a diversified weed management plan. Dicamba is another tool for farmers to use in their weed management program. More information on Monsanto and weed management can be found at RoundupReadyPLUS.com.

Pending regulatory approvals, the Roundup Ready 2 Xtend Soybean Crop System is expected to be available to U.S. farmers for the 2014 growing season. Once approved, the Roundup Ready Xtend Soybean Crop System will be available in all Monsanto soybean brands and broadly licensed.

“This information is for educational purposes only and is not an offer to sell Roundup Ready® 2 Xtend, Roundup® Xxtend or Xtendimax®. Roundup Ready 2 Xtend, Roundup Xxtend and Xtendimax are not yet deregulated, registered, or approved for sale or use anywhere in the United States.

Table 7.1. Contact information for South Dakota Monsanto and Pioneer agronomists who can provide assistance with their products.

<table>
<thead>
<tr>
<th>Company</th>
<th>Title</th>
<th>First Name</th>
<th>Last Name</th>
<th>Mobile</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monsanto</td>
<td>Territory Agronomist</td>
<td>Jeff</td>
<td>Fuls</td>
<td>605-651-1795</td>
<td><a href="mailto:jeffrey.g.fuls@monsanto.com">jeffrey.g.fuls@monsanto.com</a></td>
</tr>
<tr>
<td>Monsanto</td>
<td>Territory Agronomist</td>
<td>Jeff</td>
<td>Spieler</td>
<td>605-214-3075</td>
<td><a href="mailto:jeff.d.spieler@monsanto.com">jeff.d.spieler@monsanto.com</a></td>
</tr>
<tr>
<td>Monsanto</td>
<td>Technology Development Representative</td>
<td>Jesse</td>
<td>Barthe</td>
<td>605-237-4678</td>
<td><a href="mailto:jesse.r.barthe@monsanto.com">jesse.r.barthe@monsanto.com</a></td>
</tr>
<tr>
<td>Monsanto</td>
<td>Technology Development Representative</td>
<td>Kyle</td>
<td>Broughton</td>
<td>605-941-4567</td>
<td><a href="mailto:kyle.s.broughton@monsanto.com">kyle.s.broughton@monsanto.com</a></td>
</tr>
<tr>
<td>Pioneer</td>
<td>Field Agronomist</td>
<td>Kyle</td>
<td>Christensen</td>
<td>605-214-5629</td>
<td><a href="mailto:kyle.christensen@pioneer.com">kyle.christensen@pioneer.com</a></td>
</tr>
<tr>
<td>Pioneer</td>
<td>Product Agronomist</td>
<td>Wade</td>
<td>Gubrud</td>
<td>605-520-2506</td>
<td><a href="mailto:wade.gubrud@pioneer.com">wade.gubrud@pioneer.com</a></td>
</tr>
<tr>
<td>Pioneer</td>
<td>Field Agronomist</td>
<td>Curt</td>
<td>Hoffbeck</td>
<td>605-759-4995</td>
<td><a href="mailto:curt.hoffbeck@pioneer.com">curt.hoffbeck@pioneer.com</a></td>
</tr>
<tr>
<td>Pioneer</td>
<td>Product Agronomist</td>
<td>Ryan</td>
<td>Nuttall</td>
<td>605-695-0210</td>
<td><a href="mailto:ryan.nuttall@pioneer.com">ryan.nuttall@pioneer.com</a></td>
</tr>
<tr>
<td>Pioneer</td>
<td>Field Agronomist</td>
<td>Larry</td>
<td>Osborne</td>
<td>605-695-7809</td>
<td><a href="mailto:larry.osborne@pioneer.com">larry.osborne@pioneer.com</a></td>
</tr>
</tbody>
</table>

References and additional information

Acknowledgements
Funding was provided by USDA-AFRI, South Dakota Soybean Research and Promotion Council, and the South Dakota Drought Tolerance Center.

CHAPTER EIGHT

Fungicidal Seed Treatments for Soybeans

Kay Ruden (Kay.Ruden@sdstate.edu)

Planting high quality seed at an appropriate time is critical for optimizing soybean yields. However, planting seed too early can result in yield reductions if emergence is delayed or if soil diseases are a concern. Seed treatment can provide protection against diseases and insects pests. The purpose of this chapter is to discuss fungicide seed treatment options, classification, management, and impact on other inoculants. Key items for insuring good seed germination are provided in Table 8.1.

Table 8.1. Key items for insuring good seed germination.
1. Select high quality seed.
2. Select an appropriate variety and trait package.
3. Use crop rotations to reduce disease prevalence.
4. Know your disease problems by scouting the field.
5. Treat the seed with an appropriate fungicide.

Seed treatments

Treating seed with fungicide treatments is a useful tool that improves stand establishment and seedling vigor. An important advancement in plant disease management is the development of effective seed treatments. In general, fungicidal seed treatments are used to control seed rots, damping-off, and/or seedling blights. Most seed treatments do not control all types of fungal pathogens, so before using, do some background checking to know what specific fungal disease needs to be controlled. This information can be obtained by reviewing your scouting records and visiting with an Extension Field Specialist (Chapter 2).
Classification of fungicidal and seed treatments

Based on movement of the fungicide in relationship to the seed, fungicidal seed treatments can be classified as contact (protectants) and systemic fungicides. Contact treatments are effective only on the seed surface and provide protection against seed surface-borne pathogens and targeted control of soil-borne pathogens, with the exception of the root rotting organisms. These products generally have a relatively short residual. Examples of contact seed treatment fungicides are captan, thiram or fludioxonil.

Systemic fungicides are absorbed into the germinating seed and inhibit or kill the fungus on the emerging plant. Systemic fungicide seed treatment examples include azoxystrobin, carboxin, mefenoxam, metalaxyl, thiabendazole, trifloxystrobin and various triazole fungicides such as ipconazole. Mefenoxam and metalaxyl are primarily used to target the water mold fungi *Pythium* and *Phytophthora*. Biological control agents are also available and may provide some level of protection. It is important to note that not all fungicides are available as seed treatments, and not all fungicides have activity against the same range of organisms.

Disease management using seed treatment

Situations that favor disease development include: poor seed quality and adverse growing conditions (wet soil, compaction, and cool temperatures, <60°F). Seed treatments are important, but they are only one component of a multi-faceted integrated pest management (IPM) program. In many situations, problems can be avoided by:

1. Using high quality, disease-free seed to prevent the spread of seed-borne diseases and promote healthy stand establishment.
2. Selecting a well-adapted variety, for the growing region, with appropriate traits for disease resistance and maturity.
3. Using a crop rotation that includes non-host crops to reduce pathogen load. Soybean diseases, such as root rot, build up in soil when soybeans are in close rotations. The pathogen population can be decreased by lengthening rotations that include non-susceptible crops to three or four years between soybeans. When developing the rotation, care must be used in selecting the crop. Dry beans and soybeans may be infected by similar pathogens.
5. Checking the combine (during harvest) to minimize combine yield losses (Chapter 38). Volunteer soybean plants in the following year reduce the impact of rotations, and
6. Using fertilizers, herbicides, insecticides, and fungicides judiciously while following appropriate application guidelines. This can reduce losses, promote healthy plants, and prevent decreases in seed quality.
7. Matching problems with solution. Field history is a key component for managing soybean diseases with seed treatments (Chapter 2). Field areas that are routinely wet will have different requirements than areas that are well drained. Soils information can be obtained from the USDA-NRCS (Chapter 19).
Cropping sequence and disease or insect pests histories are important factors that should be considered when selecting a treatment. Proper identification of disease agents is also important. The South Dakota State University Plant Disease Clinic or Plant Pathology Extension Field Specialists at the regional centers can provide assistance. Contact information is below.

<table>
<thead>
<tr>
<th>SD State University Plant Disease Diagnostic Clinic</th>
<th>Plant Pathology Field Specialist</th>
<th>Plant Pathology Field Specialist</th>
</tr>
</thead>
<tbody>
<tr>
<td>605-688-5545 <a href="mailto:sdsu.pdc@sdstate.edu">sdsu.pdc@sdstate.edu</a></td>
<td>SDSU Extension Regional Center 605-782-3290</td>
<td>SDSU Extension Regional Center 605-842-1267</td>
</tr>
<tr>
<td>SPSB 117, Box 2108 South Dakota State University Brookings, SD 57007-1090</td>
<td>2001 E 8th Street Sioux Falls, SD 57103</td>
<td>PO Box 270, 325 S. Monroe St. Winner, SD 57850</td>
</tr>
</tbody>
</table>

Effective control varies with seed treatment product, rate, environmental conditions, and pests present. Seed treatments are most effective against seedling blights, and seed- or soil-borne diseases and provide some level of control for early season diseases.

**Application information**

Fungicide seed treatment products vary in formulation type, packaging, and use requirements. Products may be dry or liquid and in concentrate or ready-to-use formulations. While many seed treatments may be applied on farm, several products are limited to use only by commercial applicators using closed application systems.

**Seed treatment and rhizobia (N₂ fixation) inoculants**

Seed treatments containing fungicides or fungicide/insecticide combinations may adversely affect N₂ fixing inoculants applied to soybean seed. Captan and PCNB severely reduce Rhizobium survival on treated seed. If these seed treatments are selected, consider using an in-furrow Rhizobium inoculation approach (Chapter 23). In contrast, some seed treatments have moderate impact (carboxin) or little to no impact (thiram, fludioxonil, mefenoxam, and metalaxyl) on Rhizobium survival.

Producers should carefully read and follow label instructions and limitations for both the pesticide seed treatment and the inoculants. Liquid fungicides or fungicide/insecticide combinations should not be directly mixed with liquid inoculants prior to application, and care should be followed to limit the time that inoculants and pesticide seed treatments are in direct contact. The different products that are available for use in South Dakota are provided in Table 8.2.
Table 8.2. The 2012 seed treatment fungicides or fungicide/insecticide combinations currently labeled for use in South Dakota. The list is dynamic and prone to frequent modifications. Always check the product label. (Source: K. Ruden, SDSU)

<table>
<thead>
<tr>
<th>Diseases Listed on Label</th>
<th>Seed Treatment Products</th>
<th>Application Rate</th>
<th>Special Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed &amp; Seedling Rots</td>
<td>Fusarium Root Diseases</td>
<td>Pythium Root Diseases</td>
<td>Rhizoctonia Root Diseases</td>
</tr>
<tr>
<td>abamectin</td>
<td>Avicta 500 FS</td>
<td>See product label</td>
<td>For control of soybean nematodes.</td>
</tr>
<tr>
<td>abamectin + one of the following: mefenoxam, fludioxonil, and thiamethoxam. Avicta Complete Beans</td>
<td>See product label</td>
<td>For control of soybean nematodes.</td>
<td></td>
</tr>
<tr>
<td>azoxystrobin</td>
<td>Dynasty</td>
<td>0.153-0.459 fl oz/cwt plus suppression of white mold.</td>
<td>0.20-0.27 fl oz/cwt</td>
</tr>
<tr>
<td>azoxystrobin + metalaxyl</td>
<td>SoyGard L with Protege</td>
<td>See product label</td>
<td>See product label</td>
</tr>
<tr>
<td>Bacillus firmus I-1582 +</td>
<td>clothianidin Poncho/VoTIVO</td>
<td>See product label</td>
<td>For control of soybean nematodes. Do not graze or feed forage and hay to livestock.</td>
</tr>
<tr>
<td>Bacillus pumilus GB34</td>
<td>Yield Shield</td>
<td>0.1 oz/cwt</td>
<td></td>
</tr>
<tr>
<td>captan</td>
<td>Captain 400</td>
<td>1.5-2.5 fl oz/cwt</td>
<td></td>
</tr>
<tr>
<td>captan</td>
<td>Captain 400-C</td>
<td>1.5-2.5 fl oz/cwt</td>
<td></td>
</tr>
<tr>
<td>captain + carboxin</td>
<td>Enhance</td>
<td>5 oz/cwt</td>
<td>Do not graze or feed forage or hay from treated areas to livestock (Enhance).</td>
</tr>
<tr>
<td>captain + carboxin + imidacloprid</td>
<td>Enhance AW</td>
<td>5 oz/cwt</td>
<td>Do not graze or feed livestock on soybean forage or hay.</td>
</tr>
<tr>
<td>captain + carboxin + metalaxyl</td>
<td>Bean Guard Allegiance</td>
<td>2 oz/60 lb</td>
<td></td>
</tr>
<tr>
<td>captan + molybdenum</td>
<td>Hi Moly/Captan D</td>
<td>3.3 fl oz/cwt</td>
<td></td>
</tr>
<tr>
<td>carboxin</td>
<td>Vitavax-34</td>
<td>3-4 fl oz/cwt</td>
<td>Do not graze or feed livestock on forage or hay grown from treated seed.</td>
</tr>
<tr>
<td>Diseases Listed on Label</td>
<td>Seed Treatment Products</td>
<td>Application Rate</td>
<td>Special Notes</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------------------</td>
<td>------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>X</td>
<td>carboxin + metalaxyl + imidacloprid + Latitude</td>
<td>4 oz/cwt</td>
<td>Do not graze or feed livestock on forage and hay on treated areas for 6 weeks after planting.</td>
</tr>
<tr>
<td>X</td>
<td>carboxin + permethrin Kernel Guard Supreme</td>
<td>1.5 oz/50 lb</td>
<td>Do not graze or feed livestock on treated areas for 6 weeks after planting.</td>
</tr>
<tr>
<td>X</td>
<td>carboxin + thiram RTU-Vitavax-Thiram</td>
<td>6.8 fl oz/cwt</td>
<td>Do not graze or feed livestock on forage and hay grown on treated areas.</td>
</tr>
<tr>
<td>X</td>
<td>fludioxonil Maxim 4FS</td>
<td>0.08-0.16 fl oz/cwt</td>
<td>Green forage may not be grazed until 30 days after planting.</td>
</tr>
<tr>
<td>X</td>
<td>fludioxonil + mefenoxam ApronMaxx RFC</td>
<td>1.5 fl oz/cwt plus control of early season Phytophthora and suppression of seed-borne Sclerotinia.</td>
<td>Additional Apron XL can be added (ApronMaxx RFC, ApronMaxx RTA and Maxim XL) (See label for instructions).</td>
</tr>
<tr>
<td>X</td>
<td>fludioxonil + mefenoxam ApronMaxx RTA</td>
<td>5 fl oz/cwt plus control of early season Phytophthora and suppression of seed-borne Sclerotinia.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>fludioxonil + mefenoxam + thiamethoxam Maxim XL</td>
<td>0.167-0.334 fl oz/cwt plus early season Phytophthora control.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>fludioxonil + mefenoxam + thiamethoxam Warden RTA</td>
<td>5 fl oz/cwt plus control of early-season Phytophthora and suppression of seed-borne Sclerotinia.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>ipconazole Rancona 3.8 FS</td>
<td>0.085 fl oz/cwt</td>
<td></td>
</tr>
<tr>
<td>Diseases Listed on Label</td>
<td>Seed Treatment Products</td>
<td>Application Rate</td>
<td>Special Notes</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------------------</td>
<td>------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Seed &amp; Seedling Rots</td>
<td>Rancona Summit</td>
<td>4 fl oz/cwt</td>
<td>forage or hay (Rancona Xxtra).</td>
</tr>
<tr>
<td></td>
<td>Rancona Xxtra</td>
<td>3.5 fl oz/cwt</td>
<td></td>
</tr>
<tr>
<td>Fusarium Root Diseases</td>
<td>ipconazole + metalaxyl + clothianidin</td>
<td>4.74 fl oz/cwt</td>
<td>Do not graze or feed livestock on soybean forage or hay.</td>
</tr>
<tr>
<td>Pythium Root Diseases</td>
<td>Inovate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhizoctonia Root Diseases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed Treatment Products</td>
<td>Rancona Xxtra</td>
<td>4 fl oz/cwt</td>
<td></td>
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<tr>
<td></td>
<td>Inovate</td>
<td>4.74 fl oz/cwt</td>
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<tr>
<td></td>
<td>Apron XL</td>
<td>0.16-0.64 fl oz/cwt</td>
<td>(Use the higher rate for best early season Phytophthora protection.)</td>
</tr>
<tr>
<td></td>
<td>Apron XL LS</td>
<td>0.16-0.64 fl oz/cwt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Apron XL</td>
<td>0.16-0.64 fl oz/cwt</td>
<td></td>
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<tr>
<td></td>
<td>Apron Xxtra</td>
<td>4 fl oz/cwt</td>
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<tr>
<td></td>
<td>Inovate</td>
<td>4.74 fl oz/cwt</td>
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<tr>
<td></td>
<td>Apron XL</td>
<td>0.16-0.64 fl oz/cwt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Apron XL LS</td>
<td>0.16-0.64 fl oz/cwt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Apron Maxx RTA</td>
<td>5 fl oz/cwt</td>
<td>Additional Apron XL can be added (see label for instructions).</td>
</tr>
<tr>
<td></td>
<td>Moly</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Metalaxyl</td>
<td>0.10-0.375 fl oz/cwt plus early-season control of Phytophthora.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acceleron DX-309</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aquire</td>
<td>0.75-1.5 fl oz/cwt plus early-season control of Phytophthora.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Allegiance Dry</td>
<td>1.5-2.0 fl oz/cwt plus early-season control of Phytophthora.</td>
<td></td>
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<tr>
<td></td>
<td>Allegiance FL</td>
<td>0.75-1.5 fl oz/cwt plus early-season control of Phytophthora.</td>
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</tr>
<tr>
<td></td>
<td>Belmont 2.7 FS</td>
<td>0.75-1.5 fl oz/cwt plus early-season control of Phytophthora.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dyna-Shield</td>
<td>0.75-1.5 fl oz/cwt plus early-season control of Phytophthora.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Metalaxyl</td>
<td>0.75-1.5 fl oz/cwt plus early-season control of Phytophthora.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MetaStar ST</td>
<td>0.75-1.5 fl oz/cwt plus early-season control of Phytophthora.</td>
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<tr>
<td></td>
<td>Sebring 2.65 ST</td>
<td>0.75-1.5 fl oz/cwt plus early-season control of Phytophthora.</td>
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<tr>
<td></td>
<td>Sebring 318 FS</td>
<td>0.75-1.5 fl oz/cwt plus early-season control of Phytophthora.</td>
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<tr>
<td></td>
<td>Sebring 480 FS</td>
<td>0.50-1.00 fl oz/cwt plus early-season control of Phytophthora.</td>
<td></td>
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<tr>
<td></td>
<td>pyraclostrobin</td>
<td>0.4-1.5 fl oz/cwt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acceleron DX-109</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Diseases Listed on Label

<table>
<thead>
<tr>
<th>Seed &amp; Seedling Rots</th>
<th>Fusarium Root Diseases</th>
<th>Pythium Root Diseases</th>
<th>Rhizoctonia Root Diseases</th>
<th>Seed Treatment Products</th>
<th>Application Rate</th>
<th>Special Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>thiamethoxam</td>
<td>0.08-0.16 fl oz/cwt</td>
<td>for control of pod and stem blight.</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>thiram 42-S Thiram</td>
<td>2 fl oz/cwt</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>thiram + metalaxyl + molybdenum Protector-L-Allegiance</td>
<td>6.7 fl oz/cwt</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>thiram + molybdenum Protector-D</td>
<td>3.3 oz/cwt</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>trifloxystrobin Flowable</td>
<td>0.32 fl oz/cwt</td>
<td>Do not plant any other crop without trifloxystrobin tolerances until 30 days after planting.</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>trifloxystrobin + metalaxyl Trilex 2000</td>
<td>1 fl oz/cwt</td>
<td>Do not plant any other crop without trifloxystrobin tolerances until 30 days after planting.</td>
</tr>
</tbody>
</table>
References and additional information


Acknowledgements

Support for this chapter was provided by South Dakota State University.

Optimizing soybean profitability starts with producing and purchasing high quality seed. Seed testing information is critical in this decision. This chapter discusses the standard tests that are required to be completed on seed offered for sale, and additional tests that might provide insights into production questions and quality assurance programs. Key components are provided in Table 9.1.

### Table 9.1. Key components in producing and testing seed quality.

<table>
<thead>
<tr>
<th>1. Seed production:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Soil test your field and apply the appropriate nutrients.</td>
</tr>
<tr>
<td>b. Harvest seed when the moisture content is between 12 to 16%.</td>
</tr>
<tr>
<td>2. Test the seed following approved protocols.</td>
</tr>
<tr>
<td>3. Adjust the seeding rate based on germination, purity, and seed-count.</td>
</tr>
<tr>
<td>4. Recognize that soybean seed stored over a year may have a very low vigor rate.</td>
</tr>
</tbody>
</table>

## Seed Tests

### Seed testing

Most of the seed tests mentioned below can be conducted at the SDSU Seed Testing Lab. For other seed testing laboratories and their services, one can check the Association of Official Seed Analysts or the Society of Commercial Seed Technologists websites. A germination test takes only 7-8 days, and the accelerated aging test takes 10 days to run. Purity analyses and noxious weed seed exams usually only take one to three days to complete. Make sure to ask for a seed count (free with germination test) so you can better calculate planting rates. Seed counts in soybeans can range from 1500 to >9000 seeds per pound.
When time is an issue, producers can request the germination assessment potential using the tetrazolium (TZ) test. The TZ test is a biochemical test that can provide estimated germination results in 24 hours. You do not need to send payment with the sample at SDSU. The lab bills clients for samples after testing is complete.

Send samples to:
• SDSU Seed Testing Lab, Box 2207-A, Brookings, SD, 57007 (U.S. Postal Service)
  or
• SDSU Seed Testing Lab, 2380 Research Parkway, Brookings, SD 57006 (UPS/FedEx/Spee-Dee)

Please indicate which tests you need, your name and mailing address, telephone number, and—if you wish to receive e-mail results for a faster turn-around—provide your email address. You can also find us on the Web at www.sdstate.edu/ps/seed-lab/index.cfm. Seed sample envelopes may be obtained from Extension Service offices or by contacting us directly. Growers of certified seed are to use the mailing bag supplied to them after field inspection.

Required standard tests
To legally sell soybean seed in South Dakota, a standard analysis, following Association of Official Seed Analysts Rules for Testing Seeds (AOSA Rules) protocols for germination, purity, and the noxious weed exam is required. A seed count on the label or seed bag is also usually present. This standard analysis plus a seed count provides information needed to determine the seeding rate. For example, the seeding rate for a seed lot with 80% labeled germination requires more seed per acre than a seed lot with a 90% labeled germination.

Not having a seed label or seed testing information puts the producers and their investment at risk. At a minimum, seedsmen and savvy producers will always have a germination test, vigor test, and a seed count performed prior to cleaning a soybean seed lot. You should also have a moisture test if you do not have a moisture meter on-site as too high moisture levels (>13-14%) can lead to deterioration in storage, and too low moisture levels (<10-11%) will cause splitting or mechanical damage during cleaning. It is always wise to know if the seed is worth cleaning before making that investment.

Required tests for seed sale
In South Dakota testing for purity, noxious weeds counts, and seed germination are required before seeds can be offered for sale. In other Midwest states, precise seed counts are required when sold in bulk containers (40,000 or 50,000 seed bag units).

Purity analysis test: This test provides information about the physical make-up of the seed lot (% pure seed, % inert, % other crop seed present, and % weed seed).

Noxious weed seed examination: In South Dakota, it is prohibited to sell soybeans if they contain prohibited noxious weed seeds. A noxious weed list is available at http://legis.state.sd.us/rules/DisplayRule.aspx?Rule=12:36:03. If restricted noxious weed seed are found, the seed lot may still be sold, but any restricted weed seed present must be indicated by name and the rate of occurrence (number per pound) on the seed label. South Dakota Foundation, Registered, or Certified classes of seed cannot contain prohibited or restricted noxious weed seeds.

Germination test: This test tells you the percent germination of normal seedlings, ones that can be expected to grow and produce plants in the field. Laboratory germination tests are conducted under favorable conditions, which do not always occur in the field. Occasionally there is some dormancy (hard seed) in soybeans and the report will show % germination and % hard seeds. Typically hard seeds (having a
water impermeable seed coat) are not present in South Dakota soybeans, but if present it will probably be less than 5% and of no concern for the farmer. A germination test on soybeans takes 7-8 days. Please note—not all viable seeds are capable of completing their life cycle. A vigor test, which is not required, might provide this information. Generally, seeds lose vigor before they lose their ability to germinate. **Vigor testing is critical in all soybean seed production schemes.** Seed moisture represents the amount of moisture in the seed. Seed moisture affects the seed germination and vigor.

### Additional tests that provide useful information

**Vigor tests:** Not required by law, but is crucial in a Quality Assurance program. Soybean seed vigor is relatively short-lived (1-2 years) and the vigor is easily reduced by mechanical damage (due to low seed moisture) or storage at too high of moisture content under warm/hot conditions for too long.

**Cold test:** An excess moisture, field soil, and low temperature stress test that can be useful in determining the vigor level of soybean. (The cold test is not as consistent and reliable as the accelerated aging test as the variables are harder to control.)

**Accelerated Aging Test (AA):** A high humidity, high temperature stress test that is an excellent indicator of vigor in soybean seed. This test should be conducted in conjunction with a standard germination test. AA test time is 10 days. This is the most widely used vigor test in soybean seed. High vigor soybean should have an AA test result within 15% of the standard germination test (assuming a germination of ≥90%). Medium vigor is within 15-30% of the standard germination test, and the grower/seller needs to consider how much risk they want to take. If the AA test has a >30% difference from the standard germination test, it is recommended they do not clean or plant the seed, but rather sell it as grain.

**Seed Count:** This is not a required test, but is crucial in determining seeding rates. Seed counts in soybeans will vary from approximately 1500 seeds per pound to > 9000 seeds per pound. Genetics and the environment (moisture availability) definitely influence seed size. Most varieties grown in South Dakota range from ~2300 to 3300 seeds per pound.

**Herbicide tolerance/resistance trait test:** Most commercial soybean varieties on the market today are tolerant to one of the herbicides (Roundup, Dicamba, Liberty). There are different ways to check for the herbicide trait presence that are used by laboratories (seed bioassay, lateral flow strips, enzyme-linked immunosorbent assay (ELISA) tests, and Polymerase Chain Reaction (PCR) tests.

**Tetrazolium test (TZ)** This is a rapid (24-48 hour) chemical viability test which can be used to estimate the results of the germination test. This test also has other uses assesses vigor and mechanical damage.

- **Vigor:** When evaluating a TZ test, the seed can be subdivided into high, medium, and low vigor seeds based on staining intensities, which can be related to seed vigor.
- **Mechanical damage:** Mechanical damage can be observed in the test, whether the seed breaks or bruises. This is useful in determining point of injury (mechanical damage) during harvest or during the seed conditioning (cleaning) process.

**Hilum check:** Soybean varieties are almost always only one hila color. By examining seed hila color, varietal purity can be assessed. Hila colors are described as clear, yellow, tan, buff, brown, gray, imperfect black and black. The hila check is the most commonly used lab method to check for varietal purity.
Additional tests run by plant breeders

The peroxidase and hypocotyl color test are seldom run in routine testing of seed for sale, but plant breeders must provide the results in a Plant Variety Protection Act application. When there is doubt as to the proper identity of the variety, these are quick and inexpensive tests that can be also useful in variety determination.

Peroxidase test: Only the seed coat is used in this chemical test. The test result will either be a positive (color change) or a negative (no color change) and it is used in helping distinguish varieties.

Hypocotyl color test: This is a germination test run in soil with high light (or sun) exposure. The hypocotyl (stem) can either be a green, bronze, or purple color (which is also related to flower color). This test is used to help distinguish varieties.

Seed diseases and tests

There are several soybean seed diseases that cause seeding, seedlings, and production problems. Information on soybean diseases is available in Chapters 57-60.

Phomopsis seed rot (Diaporthe complex): This is a soybean seed disease that occurs when harvest is delayed by rainy, wet weather, and is more severe under warm conditions. Infected seed may look normal or it may be very symptomatic (shriveled, discolored whitish mold, cracked seedcoats). Severely infected seeds rarely germinate and need to be cleaned out of seed lots. Less infected seeds may germinate, but seedlings will be weaker. Phomopsis is a field fungus and will die out over time in storage. It is not unusual for an infected lot right out of the field to have a very low lab germination test, and then a few months later (2-4 months) increase in germination rate. Regardless, the seed lot will be of lower quality and seed life will be shortened.

Purple Seed Stain (Cereospora kikuchii): Purple seed stain is very evident as the seedcoat and/or hilum are discolored purple. This disease does not directly reduce yield, but can cause a grain quality special grade indicated as “purple stained or mottled” when it appears in grain at a certain level of infection. Rarely is this disease severe enough in South Dakota to lower seed quality.

Soybean Mosaic Virus (SMV): This virus is transmitted primarily by aphids. It can be seed transmitted, but seed transmission is thought only to be about 5% or less. Symptoms are expressed with either a brown or black mottling over the seedcoat. SMV can reduce seed yields, germination, and vigor when severe enough. In South Dakota, SMV has not been a significant problem to date.

Bean Pod Mottle Virus (BPMV): Transmitted by the bean leaf beetle, this disease exhibits seed symptoms that are the same as SMV. Seed transmission of this disease can occur, but transmission is thought to be below 1%. BPMV can severely reduce yields in infected fields. Control can be achieved with seed or foliar insecticides that control/reduce bean leaf beetles.

To verify if a seed lot has SMV or BPMV an Enzyme-Linked-Immuno-Sorbant Assay (ELISA) test can be conducted. This test is generally not needed if it is known that a seed field contained bean leaf beetles or aphids. Seeds that are infected with either virus cannot be separated from non-infected seed, and there is no effective seed treatment to control either virus. Planting infected seed does not automatically mean you will have the disease again. For SMV control, you should scout and control aphid infections if appropriate. For BPMV control, a seed insecticide and foliar-applied insecticide can be used to reduce bean leaf beetles. There is only a low level of genetic soybean resistance to SMV, while there is none to BPMV.
There are lots of seedling pathogens that can dramatically reduce seedling emergence or cause the death of emerged seedlings. Producers keep trying to plant earlier into colder and sometimes wetter soils, which only increases seedling emergence issues. A seed-applied fungicide is critical for control of early-season seedling diseases and should always be used. Many companies are also using seed-applied insecticides, whether needed or not. Talk to your local agronomist and seed dealer to determine appropriate seed treatments for your farm.

Producing and Purchasing High Quality Seed

**Fertility and moisture content**

High quality soybean seed production begins in the field. Soil fertility plays a crucial role in insuring the proper nutrients are present for quality seed/grain production. Another crucial factor is the seed moisture content at harvest. Soybeans should be harvested at 12-16% moisture content to minimize combine damage and subsequent cleaning and handling operation damage. Seed vigor and viability in soybeans is relatively (~ 1 year) short-lived and easily lost through improper handling during harvest and subsequent operations. Anything that causes mechanical damage to the soybean seed reduces vigor and viability.

The soybean seed structure with the hypocotyl (stem portion) and radicle (root) laying directly beneath the seed coat makes the seed exceptionally prone to mechanical damage during harvesting, handling, and cleaning operations. When soybean moisture is less than 10-11%, it is essential to handle seed beans as gently as possible. During harvest, you should stop every couple of hours and check for mechanical damage. One easy mechanical damage test you can run in the field in minutes is the Clorox soak test (see iGrow article, “The Clorox Soak Test,” at http://igrow.org/up/resources/03-1000-2012.pdf). If damage is above recommended levels, the combine should be adjusted to reduce damage. When combining seed that will be used as seed, it is not recommended to use metal augers. Brush or plastic augers can reduce mechanical damage. Belt conveyors are the best choice for moving soybeans as they cause the least damage.

**Cleaning soybean seed**

When cleaning soybean seed, they are much more prone to damage if the temperature is below freezing. Seed cleaning operations should not be done when soybeans are frozen. If soybean seed is un-cleaned, stored in bins and if the moisture is less than 10-11%, you may want to turn on aeration fans if the relative humidity (RH) is high enough for seeds to absorb moisture from the air prior to cleaning. Raising the moisture content can reduce mechanical damage during the cleaning operation.

When cleaning a low seed quality soybean seed lot (due to mechanical damage), cleaning will at best not damage it further, but you still will have a low quality seed lot. Planting of low quality seed lots can result in stand failures, over—or under—planting rates, and cause lower yield potential. Low quality seed lots will not store as well or as long as high quality seed lots. These seed lots typically deteriorate more rapidly and by planting time many will not meet in-house testing standards.

Soybeans have an inherently short lifespan (1-2 years) when compared to cereal grains (2-5 years). In general, when vigor test (accelerated aging) results are 30% lower or more from the standard germination test results, it is recommended to sell that seed as grain, and purchase another seed lot with higher vigor.

**Purchasing soybean seed**

There are many seed sources in the market. Check with your local agronomist for a variety with the appropriate maturity group and traits for your region or field. It may be an herbicide-resistant variety, a conventional variety (non-GMO), or an approved organic seed source (also a conventional variety). Most soybean seed sold in South Dakota is not certified. If you are interested in growing seed, there are several varieties in the South Dakota Certification program, both herbicide-resistant (Roundup Ready®) and conventional.
Almost all varieties (public or private) are protected under the Plant Variety Protection Act (PVP-94) and have a utility patent (Roundup Ready trait) which means they cannot be saved, replanted, or sold by the farmer. The exception to that are the conventional soybeans; they can be saved and replanted on your own farm only. Over 90% of the seed currently sold and planted in the state are Roundup Ready. Seed quality is crucial and it is recommended that you purchase seed from reputable producers.

**Left-over unplanted seed**

Often a producer purchases more seed than he/she plants, or the weather causes a change in planting plans and they wind up with some quantity of unplanted seed. Most soybean seed sold has been treated with a fungicide and therefore cannot be sold as grain. Due to the inherently short seed lifespan of soybean, seed should not be saved more than one year before planting. If it is saved for next year, it should be kept in a cool and dry environment. One to three months prior to planting, an accelerated aging test (vigor test) must be run to determine if it is still suitable for planting. If the vigor has dropped, the seeding rate should be increased. If the seed is not suitable, it must be disposed of properly.

Planting low quality seed can result in stand failures, over—or under—planting rates, and cause lower yield potential. In addition, low quality seed does not store as well as high quality seed. These seed lots typically deteriorate more rapidly and by planting time many will not meet in-house testing standards. Soybeans have an inherently short lifespan (1-2 years) when compared to cereal grains (2-5 years).

**References and additional information**

- SDSU Plant Diagnostic Clinic. Available at www.sdstate.edu/sdcas/resources/crops/plant-diagnostic-clinic.cfm
- SDSU Seed Testing Lab. Available at www.sdstate.edu/ps/seed-lab/index.cfm
- Society of Commercial Seed Technologists (SCST). Available at http://www.seedtechnology.net/
- South Dakota Crop Improvement Association. Available at www.sdstate.edu/ps/sdcia/index.cfm
- South Dakota Department of Agriculture. Available at http://sdda.sd.gov/Ag_Services/Agronomy_Services_Programs/Seed_Program/default.aspx

**Acknowledgements**

Support provided by South Dakota Seed Testing Laboratory.

Soybean Seeding Rate Recommendations for Narrow and Wide Rows

Robert Hall (Robert.Hall@sdstate.edu)

Optimizing yield requires that an appropriate seeding rate be followed. The seeding rate depends on the desired plant population, seeding approach (drilled vs. row seeded), germination rate, and the emergence rate. The germination rates are obtained from a seed testing laboratory, while the emergence rate depends on the soil, planter, and climate conditions following planting. The purposes of this chapter are to: 1) demonstrate how to calculate the seeding rate, 2) discuss advantages and disadvantages of narrow and wide row planting systems, and 3) present selected findings from a three-year study that investigated the influence of row spacing and plant populations on soybean yields.

Determining the seeding rate

The desired population and seeding rate are two different things. The desired population is the emerged population, while the seeding rate is the rate that the planter seeds. The seeding rate is always equal to or higher than the emerged population. Determining the seeding rate starts with reviewing the seed testing information (Chapter 9). In the example shown in Problem 10.1a, the seeding rate is calculated based on the germination rate, live seed purity, and emergence rate. Problem 10.1b shows a seeding rate calculation when only germination is known. The emergence rate is related to seed vigor (Chapters 9 and 13) and should not be confused with apparent emergence rate which represents the combined impact of germination, soil, seed purity, and the seed bed preparation technique.
Problem 10.1a. Calculating the seeding rate when germination, purity, and seeding vigor (emergence) are known.

In this example, the germination rate was 92% and seed lot is 98% pure. Seed emergence from soil also needs to be considered. In this calculation it is assumed that 90% of the seeds emerge in a clay type soil (Sample calculation is provided in problem 13.1). (Note: In a light textured soil the emergence rate estimate is often estimated to be 95%).

\[
\text{desired population} = \frac{135,000 \text{ plants at V2}}{\text{acre}} = \left( \frac{\text{seeding rate at } V2}{\text{acre}} \right) \times \left( \frac{0.92 \text{ germination rate}}{\text{seed}} \right) \times \left( \frac{0.98 \text{ pure seeds}}{\text{seed}} \right) \times \left( \frac{0.90 \text{ emergence}}{\text{seed}} \right)
\]

\[
\text{seeding rate} = \frac{\left( \frac{\text{desired population}}{100} \right)}{\left( \frac{\text{percent germination}}{100} \right) \times \left( \frac{\text{percent purity of seed lot}}{100} \right) \times \left( \frac{\text{percent emergence}}{100} \right) \times \left( \frac{0.92 \times 0.98 \times 0.90}{\text{acre}} \right) \times \left( \frac{165,000 \text{ seeds}}{\text{acre}} \right)}
\]

Problem 10.1b. Calculating the seeding rate when only apparent germination is known.

Data from last year shows that the apparent emergence rate was 90% (Chapter 13). The germination and purity values are assumed to be identical to last year. Determine the seeding rate for this field.

\[
\text{desired population} = \frac{135,000 \text{ plants at V2}}{\text{acre}} = \left( \frac{\text{seeding rate at } V2}{\text{acre}} \right) \times \left( \frac{0.90 \text{ apparent emergence}}{\text{seed}} \right) \times \left( \frac{\text{germination rate}}{\text{seed}} \right) \times \left( \frac{\text{pure seeds}}{\text{seed}} \right) \times \left( \frac{\text{emergence}}{\text{seed}} \right)
\]

\[
\text{seeding rate} = \frac{\left( \frac{\text{desired population}}{100} \right)}{\left( \frac{0.90 \text{ apparent emergence}}{\text{seed}} \right) \times \left( \frac{\text{germination rate}}{\text{seed}} \right) \times \left( \frac{\text{pure seeds}}{\text{seed}} \right) \times \left( \frac{\text{emergence}}{\text{seed}} \right) \times \left( \frac{165,000 \text{ seeds}}{\text{acre}} \right)}
\]

Narrow vs. wide rows

There has been considerable press on the advantages of narrow rows over wide rows. Research in South Dakota has been mixed and it shows that there are advantages and disadvantages to both systems (Table 10.1). Recommendations for heavy (clay soils) and light (sandy soils) are slightly different. The rates are generally higher for clay type soils than sandy soils because the apparent emergence rates are higher. Sandy soils are less likely to crust than clay soils.

<table>
<thead>
<tr>
<th>Table 10.1. Advantages and disadvantage of soybean planted in narrow and wide rows and seeding recommendations for narrow and wide row systems.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NARROW ROWS</strong></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>Grain drill can be used for planting</td>
</tr>
<tr>
<td>Higher yields in some years</td>
</tr>
<tr>
<td>Crop canopy is established faster</td>
</tr>
<tr>
<td>Canopy shade reduces weed competition damage</td>
</tr>
</tbody>
</table>

Seeding recommendation for 8-inch rows:
- Live plant population of 160 to 200,000 plants/acre in clay-based soils
- Live plant population of 140 to 200,000 plants/acre on sandy-based soils

<table>
<thead>
<tr>
<th><strong>WIDE ROWS</strong></th>
<th><strong>Disadvantages</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td>Increased potential for ground applied field treatments</td>
<td>Row crop planter used for planting</td>
</tr>
<tr>
<td>Lower seeding rates are required</td>
<td>More time needed for crop canopy closure</td>
</tr>
<tr>
<td>Reduced of damage from field traffic</td>
<td>More open canopy can increase risk of frost damage</td>
</tr>
<tr>
<td>Reduced risk of disease like white mold</td>
<td></td>
</tr>
</tbody>
</table>

Seeding recommendation for 30-inch rows:
- Live plant population of 135 to 175,000 plants/acre on clay-based soils
- Live plant population of 120 to 175,000 plants/acre on sandy-based soils
Findings from a population rate/spacing study

In 2009 the SDSU Crop Performance Testing (CPT) Program initiated a study funded by the South Dakota Soybean Research and Promotion Council. This study, conducted in Brown County, Brookings/Volga, and Beresford, evaluated two row spacings (8 and 30 inches) and three maturity classes (MG-0, MG-I, and MG-II). Findings from the Brown County study site are shown in Figure 10.1. Findings from this study are shown to demonstrate how different results can be observed in different years. Based on the findings from these studies, the recommendations provided in Table 10.1 were developed.

The yield response to row spacing for 2009 (Fig. 10.1) was much higher than the responses in 2010 or 2011. In addition, the yield response to row spacing in 2009 differed greatly between the row space treatments. Analysis showed that the response of the 8-inch rows to plant density was nearly flat over the range of plant densities tested (75,000 to 200,000 plant/acre). In contrast, the response to plant density of the 30-inch rows increased more per 1,000 plants per acre increase in plant density than did the 8-inch rows. In 2010 and 2011 there were not significant differences between the 8-inch and 30-inch rows so the data from both row space treatments were combined to describe the yield response to increasing increments of plant density.

The large difference in the yield between the 8 and 30-inch rows in 2009 was a surprise. Keep in mind that our soybean production is on the northwestern edge of the US soybean production area and we tend to grow some MG-II, a lot of MG-I, and a few MG-0 soybeans. Our region is subject to a highly variable environment with large fluctuations in spring seeding windows, early spring and summer temperatures, early-season available sub-soil moisture, summer rainfall patterns, and length of growing season. One reason many states east of South Dakota tend to have higher and more consistent yields is because they have less variable summer moisture patterns.

In summary, in the first year (2009) of a three-year study, there was a large difference between the 8- and 30-inch rows seeding approaches; However, in 2010 and 2011, there were no significant differences between the two approaches. These results suggest that soybeans seeded in 8-inch rows produce similar or in some cases higher yields than soybean planted in 30-inch rows. In general, the narrow rows required a higher seeding density than the 30-inch row spacing. In the past, at least 200,000 seeds per acre were recommended for narrow rows and 165,000 for 20- to 30-inch rows. Even though a yield advantage to the narrower row system pops up now and then, it does not do so with any consistency.

Figure 10.1. The influence of row spacing (8- and 30-inch rows) and year on the relationship between grain yield and live plant population. Included for each year is the equation for a straight line and the associated 95% confidence limits (curved lines) for the regression line. (Source: D.E. Clay, SDSU)
References and additional information


Acknowledgements

Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, SD Drought Tolerance Center, and South Dakota 2010 research program.

Obtaining an excellent soybean stand is a necessary step to successful soybean production. Preparing your land and planter for seeding is one of first steps required to optimize soybean yields (Fig. 11.1). Prior to seeding the field, planter maintenance should be completed and during planting the planter and seed placement should be routinely checked.

We recommend that soybeans be planted at a depth of from 1 to 1.5 inches. In South Dakota soybean production, the soil temperature is critical and in South Dakota in the early spring, deeper is colder. Soybeans require a warmer soil (54°F) to germinate than corn (50°F). Colder means slower growth and less nutrient uptake. Soybeans are more sensitive to seeding depth than is corn. Studies in Northern climates have consistently shown that seeding soybeans below 2 to 2.5 inches typically results in a seedling population reduction of 20% or more from the number of seeds planted.

The goal of this chapter is to provide guidance on seedbed and planter preparation. Seedbed and planter preparation requires planning and should be conducted at various times during the year.
Introduction

Chilling injury

Germination of soybean and corn seeds can be reduced by chilling injury. Chilling injury results from the seed uptaking cold water during germination. If the water is cold, from melting snow, it can cause the cell membranes to become rigid and rupture. A typical symptom is a swollen seed that has not germinated. This problem can be avoided by seeding soybean when the temperatures are optimum. Soybeans require a warmer soil (54°F) to germinate than corn (50°F). Soybean seeds germinate best when the temperatures are between 60 to 70°F. Many problems can occur if soybeans are seeded into cool soil. The surface (0-2 inches) soil temperature is the average of two measurements (early morning and late afternoon).

Residue management

The goal of seedbed preparation is optimize germination by improving soil to seed contact. This process starts with residue management. It is important to note that when preparing a seedbed, the prior crops residue should be considered. A long-term sustainability objective should include adopting tillage practices that leave as much residue on the soil surface as possible. This residue helps prevent surface sealing and reduces wind and water erosion. Tips for optimizing residue for soybean seedbed preparation include:

- Spreading the previous crops residues uniformly over the soil surface.
- Minimizing tillage in wet soil.
- Decreasing tillage.
- Using straight points or sweeps instead of twisted points.
- Driving more slowly.

Reduced-till systems require optimization of planting and the planter residue management system. A common misconception is that the planter residue manager can compensate for non-uniform residue distribution. Residue management begins at harvest, leaving as much residue in place as possible. Using stripper headers for harvesting wheat and other suitable crops allows straw to remain upright and attached, preventing residue from being moved by wind or water. In corn, this is accomplished by adjusting the strippers and rolls to keep the stalk intact and upright. Uniformly chaff spreading is particularly difficult when using large headers. Straw and plant stems that are chopped into small pieces, are difficult to distribute uniformly, and have a tendency to be moved into piles by wind or water.

Planter residue managers work best in situations where residue is uniform. When residue is not uniform, it is almost impossible to properly adjust residue managers. Moving residue is easier if it is cut before moving it. Single-disc fertilizer openers placed at the same depth and two to three inches to the side of the seed opener path can serve a dual purpose, cutting residue and placing the side-band fertilizer. When compared to conservation tillage, no-till soils generally remain cooler in the spring. Cooler soil temperatures can slow nitrogen (N) and sulfur (S) mineralization. Placing nutrients like N and S as a side-band improves early season plant vigor.

Planter

The planter is one the most valuable piece of machinery on the farm. Achieving optimal value depends on how well it performs in the field: placing seed at the correct depth, evenly spaced, at the correct population, and insuring optimal seed-to-soil contact. Evolving technology has improved all aspects of the planter's ability to maximize seed emergence. Technology has even addressed human error using guidance systems where guess rows are no longer a guess. Guidance systems have reduced operator fatigue, reducing
accidents and allowing planting to continue after sundown with significantly less error. However, the ability for the planter to achieve optimal seeding has always been and still remains dependent on skilled operation and regular maintenance. Since your planter can be responsible for a yield difference of 5 or more bu/acre of soybeans, how much time, effort, and money is warranted?

There are so many differences between makes, models, singulation mechanisms, and other components of planters. A thorough knowledge of a planter operational manual is the first place to start. In addition, knowledge of aftermarket components are also a must. Wear tolerances and instructions for replacement are usually provided. Maintenance, operation, and adjustment questions are best answered by factory-trained technicians.

Information on planter maintenance is available at https://www.pioneer.com/home/site/ca/template.CONTENT/guid.03EDD6D3-84B2-4E5F-A6C6-005380C343F0/.

If you do not already have one, consider the purchase and installation of an electronic seed metering monitor. There are a number of aftermarket systems that have been reported to be very accurate.

**Planter performance review and inspection**

When the snow is still on the ground, time spent is critical in reviewing field scouting records that relate to planter performance and inspection of equipment (Table 11.1).

<table>
<thead>
<tr>
<th>Table 11.1. Planter performance checklist.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Review your planting needs.</td>
</tr>
<tr>
<td>Is your current planter big enough to ensure timely seeding at a reasonable speed (&lt;5mph)? Increased profit from reduced yield loss because of late planting may pay for a planter with more row units.</td>
</tr>
<tr>
<td>2. Review the planter performance from last year.</td>
</tr>
<tr>
<td>Did the planter seed at the correct population and were the plants spaced evenly apart? Did you have high apparent emergence rates?</td>
</tr>
<tr>
<td>3. Review maintenance records for the planter.</td>
</tr>
<tr>
<td>Which components need replacing?</td>
</tr>
<tr>
<td>4. Inspect, clean, and replace singulation meter mechanisms as suggested by the operator’s manual.</td>
</tr>
<tr>
<td>Perform a calibration of the singulation meters. Consider aftermarket alternatives that may offer more accurate singulation.</td>
</tr>
<tr>
<td>5. Check the tires for wear.</td>
</tr>
<tr>
<td>6. Check all linkage between the tractor and openers.</td>
</tr>
<tr>
<td>Are linkages are tight throughout? Replace bushings at any and every point that appear to be loose.</td>
</tr>
<tr>
<td>7. Insure that planting units are operating parallel to the soil surface and that the planter is level side to side.</td>
</tr>
<tr>
<td>8. Check all singulation chains and sprockets.</td>
</tr>
<tr>
<td>The slightest amount of wear can result in an inch or two of increased standard deviation in plant spacing, which could cost significantly more than the repairs.</td>
</tr>
<tr>
<td>Insure that all parts are clean and meet manufactures specifications. Replace worn parts.</td>
</tr>
</tbody>
</table>
10. Check down pressure to ensure that gauge wheels and openers are creating a viable seed trench.

11. Check the amount of wear on disc openers and coulters.
   Insure that they are properly aligned and adjusted. Check the owner’s manual for wear specifications. If wear is excessive, replace worn parts.

12. Be certain that closing wheels are aligned with disk openers.
   If they are out of alignment, check for wear on the closing wheel supports. Replace bushings as needed.

13. Insure that row cleaners are properly set.
   Row cleaners should move residue from the row and not soil.

14. Be sure the seed firming mounting mechanisms do not alter the configuration of the seed delivery tubes.
   The use of seed firmers during periods of normal conditions have been shown to give positive results. Firmers may need to be removed for wetter planting conditions.

15. Inspect seed tubes to insure unobstructed movement of seed from the singulation meters to the discharge foot.
   Replace any worn components.

Seedbed management
Once the seed has accurately been discharged from the planter, seedbed management becomes critical. A seed's germination is improved when it is covered with loose material and firmly held from the sides at the right depth in warm, moist soil. The original corn planters were designed for use in well-tilled seedbeds. Consequently, with less intense tillage practices, modifications are needed to assure optimal seed placement and seed to soil contact.

Almost all row-crop planters have openers that utilize two discs to open the seed slot. The seed opener discs are often arranged so that the blades touch evenly at the front and have discs of equal size. Some manufacturers offset these discs so that one disc leads the other. Wiper/depth wheels can limit the problem of mud being brought to the surface and interfering with seed opener depth wheels. South American openers use offset double-disc openers with discs of different sizes; this design results in a differing angular momentum between the blades that is thought to improve the slicing action.

All disc openers require sharp blades; if they are not sharp, the residue can be pushed (hair-pinned) into the trench, resulting in crop residue contact rather than soil contact, which often results in uneven germination, uneven emergence, and uneven growth. Hair-pinning most often occurs when residue is cut into short lengths and soil structure is poor. Conventional tillage and continuous long-term, no-till systems have less of a problem with this issue. A correct combination of openers, gauge wheels, and appropriate down pressure, should leave a well formed V trench into which seed will be dropped.

Once the seed is placed in the trench, it needs to be pressed into the soil. The best way to accomplish this is to separate the firming (seed pressing) and covering operations. Several companies make seed-firming devices designed to press or lock the seed into the bottom of the trench. This speeds the rate at which the seed imbibes water and anchors it to the bottom of the trench. The lack of root penetration is often blamed on “sidewall” compaction, which can be traced to a poorly anchored seed.

There are also several companies that make aftermarket devices designed to press the seed into the bottom of the trench. In general, vertical wheels work better in most conditions; however, they are more expensive and harder to mount than those that use a sliding piece of plastic.
Once the seed is firmly pressed into the bottom of the trench, it needs to be covered. Standard closing systems on corn planters are designed to work in tilled seedbeds by packing the area under and around the seed, while leaving loose material above the seed. Standard rubber or cast-iron closing systems normally do not function well in less tillage-intense till systems because they have difficulty in properly closing the trench in well-structured or wet soils.

If the soil over the seed is packed too firmly, the corn plant may set its growing point too shallow. This makes it prone to damage from herbicides and late frosts. If the soil covering the seed is too loose, the seed trench may dry too fast, leading to stand loss. Many companies (Martin, May-Wes, Exapta, Yetter) make attachments designed to loosen the soil in the seed trench and place it over the seed.

One reason that strip-till may appear superior to no-till is that seed is planted into loose soil created by the strip tillage operation, thus allowing for optimal operation of standard closing wheels.

Fertilizer openers and residue management

Other attachments needed are fertilizer openers and residue managers. It is our opinion that the best fertilizer opener designs are single-disc openers with a depth-gauging and/or wiping wheel. These openers cut the residue and place fertilizer two to three inches to the side of the seed. In fine-textured soils, most of the N and P can be band-applied using this approach. However, in irrigated or sandy fields, limit N applied to one-third to one-half of the seasonal N requirement.

Using residue managers that cut residue before it is moved and replacing wide depth-wheels with narrow depth-wheels reduces the likelihood of planter plugging in heavy residue. Using a residue manager with a backsweped design helps keep residue from wrapping. Cutting the residue allows the residue managers to split the mat of residue without tearing it apart, which is especially important under damp conditions. Cutting residue reduces soil disturbance because residue managers do not have to engage the soil, therefore reducing problems with surface sealing or crusting, weed growth, and erosion.

There are many designs of residue managers. Test the ease of adjustment prior to selecting a residue manager. The bottom line with minimum till, ridge till, strip till, and no-till seeding equipment is that while it does not have to be complex, it needs to work effectively. Additional information is available at http://www.sdnotill.com and at http://www.dakotalakes.com.

References and additional information


Acknowledgements

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Land Rolling

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Kurtis Reitsma (Kurtis.Reitsma@sdstate.edu)

Many South Dakota soybean fields are routinely rolled. Proponents of land rolling argue that the practice improves contact between the seed and the soil, allows soybeans to be harvested closer to the ground, and reduces combine damage and yield losses in fields containing many rocks. Detractors of land rolling argue that yield advantages have not been documented and it may increase wind and water erosion. This chapter investigates the impact of land rolling on soybean yields.

Land rolling is simply pulling a large cylindrical roller over the field to smooth the ground (Fig. 12.1). The land roller has a packing force similar to the pressure from the planter closing wheels (3 lbs/in²) (DeJong et al., 2012). A wide assortment of rollers are available ranging from smooth to coil-type drums. Images of drums types are available at http://pierce.uwex.edu/files/2012/07/Ground-Rolling-in-the-MidWest.pdf. The drums exert a packing force of about three pounds per square inch similar to the pressure exerted by planter closing wheels.

Proponents have argued that land rolling:

1) pushes smaller rock into the soil;
2) improves contact between the soil and the seed;
3) improve seed emergence rates;
4) increases yields by reducing harvest losses;
5) reduces combine damage; and
6) helps break apart corn rootballs (Lenssen, 2009).
Disadvantages of land rolling are that it may compact the soil and increase erosion. In addition, it costs money, fuel, time, and if applied pre-emergence, land rolling can increase the risk of soil crusting. Benefits from land rolling are decreased if rock picking is conducted separately. Land rollers range in price and can cost up to $50,000. Custom land rolling rates in Iowa average $6.55/acre (Wolkowski, 2011).

Reducing equipment risk and harvest loss

Rollers effectively push rocks into the soil and level mounds left by burrowing rodents, thereby reducing the risk of damage to the combine. Mounds left by burrowing animals, such as pocket gophers, can bounce and jar spraying and harvest equipment, leading to structural or mechanical damage and malfunction. Broken or damaged equipment costs money to fix and can delay harvest. Land rolling can smooth these areas, and avoid undue stress on equipment.

Land rolling may reduce combine yield losses because the soybeans can be harvested closer to the ground. Rocky areas or soil mounds require the operator to raise the combine header and sacrifice low hanging pods, leaving them in the field. Calculating yield loss due to raising the combine head can be estimated with a simple formula (Fig. 12.2).

![Figure 12.2. Calculating yield loss from unharvested lower portions of a soybean plant.](image)

**Step one:** Count the number of pods remaining on plants along a row length. In this example, 50 pods are counted from a 4-foot row. The row spacing is 30 inches.

**Step two:** Calculate the yield loss in bu/acre assuming that 5 beans per ft² = 1 bu/acre and each pod contains 3 beans.

\[
\text{Yield loss} = \frac{\text{number of pods} \times \frac{\text{beans}}{\text{pod}} \times \frac{1 \text{ ft}^2}{\text{row length} \times \text{row width}}} {\frac{5 \text{ beans}}{1 \text{ bu/acre}}} = \frac{50 \text{ pod} \times \frac{3 \text{ beans}}{\text{pod}} \times \frac{1 \text{ ft}^2}{2 \text{.5 ft}} \times \frac{1 \text{ bu acre}}{5 \text{ beans}}} = 3 \text{ bu/acre}
\]

Land rolling and soil compaction

Land rolling may increase compaction by pushing rocks into the soil and also increase erosion potential. Compaction has long been recognized to reduce water infiltration and increase erosion. A study at Iowa State University measured water infiltration on several farms (Al-Kaisi et al., 2011). In this study, land rolling either reduced or did not influence water infiltration. One approach to reduce the negative impacts of land rolling is to use precision management. It may be possible to reduce the negative impacts of land rolling on compaction and erosion by targeted activities to areas containing rocks.

Post-emergence land rolling

Al-Kaisi et al. (2011) reported that at three locations in Iowa and Minnesota, land rolling before the third trifoliate leaf stage did not increase yields. When rolling was conducted at the sixth leaf stage, land rolling had the potential to reduce yields. Endres and Henson (2003) had slightly different results in North Dakota and reported that land rolling did not influence yield. However, post-emergence rolling delayed plant growth. In conclusion, land rolling can produce both positive and negative impacts on soybean yields. In areas containing many rocks, land rolling has the potential to reduce combine yield losses. The consequences of both factors must be considered prior to investing in this practice.
References and additional information

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Estimating the Soybean Plant Population and Seed Emergence Rate

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The efficiency of the seeding process can be determined by measuring the plant population and seed emergence. Seed emergence is used to calculate the seeding rate (Chapter 10) and assess the effective of planting system. These calculations require that the row spacing and plants per acre be estimated. The purpose of this chapter is to discuss guidelines for measuring seed emergence and the live population.

**Calculating apparent seed emergence**

Plant emergence information provides critical information to assess the effectiveness of the planting operation. The percent apparent emergence and seeding rate are equal to:

\[
\text{Apparent emergence} = 100\% \times \left(1 - \frac{\text{Seeding rate} - \text{live plant population}}{\text{Seeding rate}}\right)
\]

\[
\text{Seeding rate} = \frac{\text{Live plant population}}{\text{% germ.} \times \frac{\text{% pure seed}}{100} \times \frac{\text{% emergence}}{100}}
\]

In the first equation, the apparent emergence value is a function of the % germination, % pure live seed, and % emergence (Chapter 9). Information on germination and live seed purity are provided by the seller, while the % emergence can be calculated (Problem 13.1). This example shows that apparent emergence and emergence can be very different. The emergence can be influenced by many factors including seed bed preparation, crusting, and diseases.
Calculating plant population

The simplest way to estimate the actual plant population, in a rowed crop, is to measure the number of plants in \( \frac{1}{1000} \) of an acre. Because large soybean plants are bushy, our preference is to accomplish stand counts a week or two after emergence. Figure 13.1 shows the relationship between distance, in a single row, as a function of row spacing required for \( \frac{1}{1000} \) of an acre. The population is determined by counting the number of plants in that length of row and then multiplying that population by 1000. We recommend that you measure plant populations at a minimum of 10 separate locations within a field or to be more precise, 10 locations within a landscape position or predetermined grid area. An example is shown in Problem 13.2.

Problem 13.1. Calculate the % emergence if the % germination is 96%, percent pure seed is 99%, the seeding rate was 150,000 seed/acre, and measured population was 125,000 plants (at V2)/acre.

\[
\text{Seeding rate} = \frac{\text{Desired plant population}}{\text{% germ.} \times \frac{\% \text{ pure seed}}{100} \times \frac{\% \text{ emergence}}{100}}
\]

\[
150,000/acre = \frac{125,000/acre}{0.96 \times 0.99 \times \frac{\% \text{ emergence}}{100}}
\]

\[
\frac{\% \text{ emergence}}{100} = \frac{125,000/acre}{0.96 \times 0.99 \times 150,000/acre} = 87.7\% \text{ emergence}
\]

The apparent emergence was 80% \( (100\% \times (1 - (150,000 - 125,000)/150,000)) \). The emergence and apparent emergence values are very different and can lead to different interpretations. Low emergence can result from poor seed viability, soil crusting, or a number of factors.

Problem 13.2. To begin the procedure, one must use a measuring tape or rod to determine the row width. If your row width is 30 inches (as indicated in cell K5), to account for \( \frac{1}{1000} \) of an acre requires that you count the number of plants in a row that is 17 feet (cell K6) and 5.1 inches (cell K7) long.

If 124 soybean plants are within a row that is 17 feet and 5.1 inches long by 30 inches wide, then the population is 124,000 plants/acre (124 \( \times \) 1000).

What is the apparent emergence rate if the seeding rate was 130,000/acre?

\[
\text{Apparent emergence} = 100\% \times \left(1 - \frac{\text{planted seed population} - \text{live seed population}}{\text{planted population}}\right)
\]

\[
\text{Apparent emergence} = 100\% \times \left(1 - \frac{130,000/acre - 124,000/acre}{130,000/acre}\right) = 96\%
\]

then 96% of the seeds germinated and emerged from the soil:

\( (100\% \times (1 - (130,000 - 124,000)/130,000)).\)

As a second example, if you drilled soybeans into 8-inch rows (cell D5), you would count the soybean plants in 65 feet (cell D6), 4.1 inches (cell D7) of row. If you counted 191 emerged soybean plants in the 65 feet, 4.1 inches of a single row of 8-inch rowed beans, your field's population is 191,000 plants/acre.
The formulas used to create Figure 13.1 are shown in Figure 13.2. Note that the INT (integer) function in cell B6 keeps only the integer part of the calculation. If it is your desire to determine the length of row per 1/1000 of an acre for a row width not shown, you would develop a spreadsheet with formulas shown in Figure 13.2. Then you would replace the number in cell B5 (or any cell from B5 to K5) with the row width of interest. Your results may show more digits to the right of the decimal in cells B7:K7. We have formatted the cells B7:K7 to display one digit to the right of the decimal.

For soybeans planted in twin rows, (as an example, a row spacing of 21 inch, 7 inch, 21 inch, 7 inch) the average spacing [(7+21)/2] is 14 inches, so if you count only a single row, use 37 feet 4 inch, (the results for 14-inch spacing). If you count all plants in both of the twin rows (7 inches apart), use the results for the 28-inch (i.e., 21+7) spacing (18 feet, 8 inches of row).

References and additional information

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Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

High crop prices are encouraging producers to convert land enrolled in the conservation reserve program (CRP) to crop production (Fig. 14.1). A multitude of challenges must be overcome when converting CRP fields to row crop production (Table 14.1). The purpose of this chapter is to discuss key hurdles encountered when converting CRP to row crops.
CRP was created as part of the 1985 Food Security Act, enacted with the primary goal of removing highly erodible land (HEL) and other environmentally sensitive land from crop production. Because of the vulnerable nature of these soils, these fields should be farmed using no-till (or at least minimum till) farming practices. No-till has the potential of maintaining the quality soil structure that the CRP land typically develops over the length of the contract. If the land is HEL, consultation with Natural Resources Conservation Service (NRCS) is needed to assure that the field remains in compliance with federal law, rules, and regulations.

If you want to take land out of CRP contracts before it expires you will be required to pay back all of the money plus interest to the Federal government. In addition you will need to pay 25% of one year’s payment for liquidated damages. [http://thebeginningfarmer.blogspot.com/2008/03/taking-land-out-of-crp.html](http://thebeginningfarmer.blogspot.com/2008/03/taking-land-out-of-crp.html)

Most CRP land has received minimal management during the length of the CRP contract. Bringing this land back into row crop production will be similar to breaking out the prairie landscapes that the homesteaders experienced over 100 years ago. The homesteaders faced incredible hardships. They had to break through dense sods to plant their crops, they had to grow crops that had a minimum water requirement and low yield potential, and they had to carry water from streams to water their crops.

Even though we have similar problems, today’s farmers have high yielding cultivars that have been designed to withstand drought, pest problems, and pesticides. The question is how to sustainably grow row crops in CRP lands. When CRP land is brought back into production, it is important to scout the land before anything is done. During scouting it is not unusual to find extensive rodent activity, weeds, brush, trees, a high concentration of insects, and sod. It is important to point out that if weeds and rodents are a problem, solutions can be implemented with written approval from the NRCS.

### Challenges

**Excess biomass**

Planning is necessary when returning CRP land to row crop production. The difficulty results from trying to balance the maintenance of benefits obtained during CRP with the need to prepare the land to seeding. Excess biomass can be managed by burning, haying, tillage, and converting the land into a pasture. [http://gage.unl.edu/crpconversionofcropland](http://gage.unl.edu/crpconversionofcropland)

**Rodent activity**

There are CRP fields that are extremely rough. After the CRP contract expires but before planting, it may be necessary to roll the field or perhaps go over it with a light disking. The most effective treatment to eliminate or reduce rodent populations is to moldboard plow the field, but this may not be feasible if the field has been designated as HEL. Information on rodent control is available at [http://www.uwyo.edu/plantsciences/wyopest/trainingmanuals/smaniman.pdf](http://www.uwyo.edu/plantsciences/wyopest/trainingmanuals/smaniman.pdf).
Weeds (Additional information is available in Chapters 30, 31, 33, and 34)

When the field is scouted, an inventory of the weed types densities should be created. Based on this survey an action plan can be created. Various chemical options to control different species are available at https://www.sdstate.edu/sdces/resources/crops/weeds/index.cfm and http://www.extension.colostate.edu/SEA/Cropping/CRP%20press%20release.pdf.

When scouting the field, a GPS should be used to identify the coordinates of serious weed problems. These areas may require targeted activities. If corrective management is needed, it is possible that noxious weeds can be managed prior to the termination of the contract. Control of noxious weeds is required by South Dakota statute. Begin the process by reviewing your CRP contract and determining the release date. Ideally you would like to initiate a comprehensive weed control program years before the expiration of the CRP contract or at least in the fall of the final year of the CRP contract. However, prior to expiration of the CRP contract, all management must be coordinated with (and obtain written approval for your proposed management) your local Farm Service Agency (FSA) county committee and FSA personnel, and get technical assistance from the NRCS. If you receive written approval before the contract expiration or if the contract has expired, a comprehensive vegetative control program should be initiated.

Be advised that cool-season grasses may require a different control program than warm-season grasses and broadleaf weeds, brush, and even small trees. A troublesome noxious weed often found in large patches is Canada thistle (Cirsium arvense). There are several options for controlling this weed, although it may take several treatments before acceptable control is obtained. Another example, if the field contains trees and shrubs that are cut, the stumps should be treated with Tordon (picloram) shortly after cutting. However, if immediately going into soybean production, areas treated with Tordon will be injured for the minimum of one and up to five seasons, depending on rate, soil type, and climate conditions. A comprehensive CRP weed control document is available at http://www.sdstate.edu/ps/pubs/upload/FS525CRP.pdf or http://www.extension.colostate.edu/SEA/Cropping/CRP%20press%20release.pdf.

Insects (Additional information is available in Chapters 35, 36, and 37)

During scouting the extent and types of insects in the field should be noted. High populations of seed corn maggots, grubs, wireworms, cutworm, stalk borer, and army worms have been reported in CRP ground. Soybeans planted into CRP ground should be treated with a seed treatment insecticide (Chapter 8).

Disease (Additional information is available in Chapters 57, 58, 59, and 60)

Soil fungi that cause early-season diseases in soybeans can survive for long periods in the soil even in the absence of soybean crops. A fungicide seed treatment is advised. Planting should be delayed until soil temperatures are above 55°F to avoid damping-off and seedling blight. Many grasses present in the CRP may harbor diseases that row crops are susceptible to. For example, wheat is sensitive to take-all, a root and crown rot disease, that is harbored by brome and wheat grass. If diseases are a possibility, consider modifying your rotation. http://gage.unl.edu/crpconversionofcropland

Soil fertility (Additional information is available in Chapters 21, 22, 23, 25, and 26)

Soil sample to ensure that phosphorous and potassium levels are adequate. Fertilize according to SDSU recommendations based upon soil samples. It's likely that many soil nutrients may be in the low to medium categories. Since it is also likely that many years have passed since soybeans were last planted, it is advisable to use soybean rhizobia inoculants. It may also have been several years since fertilizer was applied, so consider using a starter fertilizer to increase early season plant growth. Rebuilding the soil nutrient levels may take many years.
References and additional information


Acknowledgements

Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

Developing a Tillage System that Increases Soybean Long-term Sustainability

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When South Dakota was homesteaded, tillage and cultivation were the primary means to manage residue, diseases, insects, weeds, and soil compaction. The consequence of 100 years of tillage was a 50 to 60% loss of our soils organic matter. Over the last 25 years, tillage intensity has been decreasing as indicated by a survey of in South Dakota (Fig. 15.1). Decreases in organic matter are attributed to: 1) improved equipment; 2) research investments made by the State of South Dakota, South Dakota producers, and USDA; and 3) improved weed control resulting from the release of herbicide resistant crops.

In many areas, no-tillage adoption has reduced erosion, increased carbon sequestration, increased the soils yield potential, improved soil water management, and increased wealth production. This chapter reviews tillage options for corn and soybeans grown in eastern South Dakota.

Rapid conservation tillage adoption

Across the Great Plains, tillage and cultivation were the primary means to prepare a seedbed and control pests. A consequence of over 100 years of intensive tillage was the loss of 50 to 60% of the soils organic matter (Clay et al., 2012), along with the loss of surface soil through wind and water erosion. Intensive tillage, reduced surface

Figure 15.1. No-tillage adoption in different regions of South Dakota. (Modified from Clay et al., 2012b)
residue, and declining soil organic matter contributed to the Dust Bowl of the 1930s. The result was reduced yield potential of millions of acres of farmland.

Improved equipment, transgenics (Roundup Ready® crops), and close collaborations between USDA, SDSU, and South Dakota farmers provided opportunities for fully integrating conservation tillage systems. (Fig. 15.1). No-till provided the ability to trade water lost through evaporation for yield and allowed row crop production to expand into drier regions.

<table>
<thead>
<tr>
<th>Table 15.1. Advantages and disadvantages of various tillage systems.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clean Tillage (Moldboard Plow)</strong></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>Suited to most soils</td>
</tr>
<tr>
<td>Well-tilled seedbed</td>
</tr>
<tr>
<td>Pest control</td>
</tr>
<tr>
<td>Quick soil warm up</td>
</tr>
<tr>
<td>Mixes nutrients</td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Conservation Tillage (Chisel Plow &amp; Rippers)</strong></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>Reduced erosion</td>
</tr>
<tr>
<td>Reduced cost</td>
</tr>
<tr>
<td>Mixes nutrients</td>
</tr>
<tr>
<td>Reduced water loss</td>
</tr>
<tr>
<td>Improved infiltration</td>
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<tr>
<td>Increased snow catch</td>
</tr>
<tr>
<td><strong>Ridge Tillage</strong></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>Reduced erosion</td>
</tr>
<tr>
<td>Saves water</td>
</tr>
<tr>
<td>Lower fuel costs</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Increased snow catch</td>
</tr>
<tr>
<td><strong>Strip Tillage</strong></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>Reduces soil erosion and runoff</td>
</tr>
<tr>
<td>Saves moisture</td>
</tr>
<tr>
<td>Reduced compaction</td>
</tr>
<tr>
<td>Increased snow catch</td>
</tr>
<tr>
<td>Reduced crop residue interference</td>
</tr>
<tr>
<td><strong>No-Till</strong></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>Greatly reduces soil erosion and run-off</td>
</tr>
<tr>
<td>Saves moisture</td>
</tr>
<tr>
<td>Lower fuel costs</td>
</tr>
<tr>
<td>Reduced compaction</td>
</tr>
<tr>
<td>Increased snow catch</td>
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</tbody>
</table>
Associated with the rapid adoption of conservation tillage across the state were wheat, soybean, and corn yields that increased 56, 33, and 102% from 1980-1984 to 2006-2010, respectively. In the central portion of the state, 60 to 90% of cropland acres are in no-tillage systems. Comparatively, no-tillage adoption in the eastern regions are between 20 to 40% of cropland acres. Recent statewide declines of no-tillage adoption have been observed and are likely due above average rainfall totals since 2009.

A review of no-tillage adoption in central and southern regions of the United States is available in DeFelice et al. (2006).

Creating a tillage system that fits your needs

There is no one tillage system that fits all cropping systems (Table 15.1). A tillage system used in one field may not be the best system in another field. Factors to consider when designing a tillage system include erosion potential, crop rotation, soil characteristics, nutrient management, pest problems, and available planting equipment. Tillage tends to reduce surface residue cover and increase erosion. Reducing surface residues can interrupt lifecycles of insects and diseases that can reduce yields.

Plant diseases are generally caused by a fungus, virus, or bacteria. Some can only live on one plant species, others may infect another species but may not harm it. Most disease pathogens overwinter on crop residue. Tillage buries residue reducing the chance of pathogen survival and infection of the upcoming crops. The exception is soybean cyst nematodes (SCN), which live in the soil. Some insects overwinter on crop residue. Burying those insects exposes them to soil microflora that may feed on them. Tillage can also expose insect larvae in the spring, leaving them vulnerable to predators and intolerable conditions.

Tilled fields tend to dry and warm quicker than no-tilled fields. Surface residues reduce evaporation as well as wind and water erosion, while improving soil structure, and enhancing water infiltration. http://clean-water.uwex.edu/pubs/pdf/residue.pdf

However, while surface residue helps increase moisture, it also reflects radiant heat energy from the sun, slowing spring soil warming, and may interfere with planting and seed-soil contact. Tillage is conducted to reduce compaction rather than cause it. However, it is not uncommon to find a plow pan (area of compacted soil) 4 to 8 inches (10 to 20 cm) below the surface. Disking can create layers of compaction at much shallower depths (See Fig. 15.2).

Silty clay loam to clay soils have the greatest compaction potential and even soils with higher sand and silt content can compact if field operations are conducted under wet conditions. Soil fertility and pest control strategies are directly influenced by tillage system. Nutrient loss is reduced and effectiveness of fertilizers and manure is increased when incorporated. In addition, selected herbicides and insecticides must be incorporated to be effective.

No-till systems leave little choice but to surface apply fertilizer, manure, herbicides, and insecticides. In this system, fall-applied P and K fertilizers, manure, and lime left on the surface can be carried off the field during spring snow melt-and early spring rainfall runoff events. Since P and K move very slowly through the soil profile, surface applied P and K can also be lost to erosion. In addition, surface-applied lime may take several years for it to move far enough into the profile to become beneficial.
One alternative to no-tillage is strip tillage, where soil in the crop row is mixed and fertilizers and pesticides are incorporated into that band. Strip tillage, like any other tillage system has positive and negative aspects. The following provides a discussion of selected tillage systems.

**Clean-till**

Clean tillage involves inverting the soil so that most of the residue is buried. Moldboard plowing followed by pre-plant disking is a common clean-till procedure (Fig. 15.3). For most situations, clean tillage is not a best management practice (BMP). Clean tillage often leads to depletion of soil organic carbon, and ultimately, loss of soil moisture. Because crop residue is buried, surface soil can be lost through wind and water erosion. In addition, clean tillage can result in soil compaction and a loss of productivity.

When used, clean-tillage should be used judiciously and is most often used in bottomland (toeslope positions) or poorly drained soils. However, clean tillage generally only provides temporary relief. The best solution to minimize compaction is to minimize field traffic and avoid field work when soil is too wet, regardless of tillage system selected.

**Conservation till**

Conservation tillage systems leave at least 30% of the soil covered with crop residue (Fig. 15.4). Conservation tillage tools include chisel plows, disks, mulch rippers, disk rippers, and minimum till rippers. These implements can be customized with various coulters, standards, ripper points, sweeps, and shovels. This flexibility allows producers to select tillage tools that are best suited to local soil conditions. Increasing the residue on the soil surface decreases the potential for erosion and soil water loss.

The amount of residue on the soil surface is directly related to evaporative water loss, available water, and the length of time needed for the soil to warm. Residue cover is indirectly related to the soil erosion potential. The amount of residue remaining on the soil surface can be increased by:

- Including a high-residue-producing crop in the rotation.
- Conducting tillage operations in the spring.
- Reducing the number of tillage passes.
- Using cover crops.
- Driving slower during tillage.
- Setting chisels and disks to work soil to a shallower depth.
- Using straight shanks and sweeps.
**Ridge-tillage**

Ridge-tillage is a conservation tillage system where crops are grown on permanent beds (or “ridges”) (Fig. 15.5). Ridge tillage consists of:

1. planting the crop,
2. cultivating to build the ridges,
3. harvesting the crop, while attempting to stay off the ridges,
4. spreading residue evenly, and
5. shaving off the top of the ridge, during planting, to plant your crop into a residue-free zone.

Ridge-tillage is used to help reduce heavy residue problems. If the ridge cleaners are working correctly, the seed bed will be relatively residue clean. If the ridge is not clean of residue, then the planter must be able to cut residue, penetrate the soil to the desired depth, and plant the seed. Following planting, cultivators are used to control weeds between rows and rebuild and shape the ridges. Ridge-tillage is well suited to relatively flat landscapes and is often furrow irrigated in arid climates.

In ridge-tillage, crop residue and organic matter tends to accumulate between the ridges. If mechanical cultivation and ridge building take place during the growing season, these materials are mixed into the surface soil. Relative to clean-tillage, ridge-tillage increases water infiltration and reduces run-off. Nitrogen leaching can be reduced by banding the fertilizer into the ridge. Herbicides may be applied to the ridge, with cultivation used for between-row weed control. Two disadvantages of ridge-tillage are: 1) specially designed equipment is needed, and 2) it is labor intensive.

In ridge-tillage, it is recommended that the soil samples for nutrient analysis be collected halfway between the center of the row and the crop row. When applying fertilizers into the ridge, care should be taken to minimize direct contact with the seed.

**Strip-till**

Strip-till is a conservation tillage system where the seedbed (8 to 10” wide) (20 to 24 cm wide) is tilled and cleared of residue (Fig. 15.6). Strip-till systems prepare a seedbed that is relatively free of residue, even in corn-following-corn situations. Strip-tillage may be conducted in the fall or spring. Spring strip-till uses a tillage tool that tills strips ahead of planter seed openers. If strips are tilled in a separate operation, prior to planting, it can be challenging to consistently follow the strip with the planter, although guidance systems are alleviating this problem. It is recommended to track the direction of travel of the tillage implement. Strip-tilled fields tend to warm faster than in no-till fields.

Strip-tillage does not eliminate erosion, and following rainfall, erosion can occur down the strip. Contour strip-tillage should be considered in high-slope situations. In some strip-till systems, when strips are tilled in the fall or spring, fertilizer is applied into the strip. Failing to follow the strips with the planter can affect fertilizer placement with respect to the seed. As with any tillage system, N fertilizer should not be fall-applied...
until soil temperatures are below 50°F. Starter fertilizer can be used. Many producers have problems when attempting to plant into fall-created strips in rolling terrain. If the seed row is either too close or too far away from the fertilizer band, plant vigor during early growth can be compromised.

**No-till**

Of the tillage systems discussed, properly managed no-till systems leave the most residue on the soil surface (Fig. 15.7). Compared to other systems, the soil retains the most moisture, has the highest infiltration rates, and least erosion potential. The effects of no-tillage on erosion are attributed to increased water infiltration and reduced run-off. Considering the benefits, no-tillage, it should be strongly considered by most South Dakota producers.

In South Dakota, no-till systems are largely responsible for expansion of row crop production into the mid and western regions of the state. This expansion has resulted in reduced soil water loss, reduced runoff, increased soil organic matter levels, and higher water infiltration rates.

No-till systems require optimization of planting and residue management systems. Residue management begins by leaving as much residue in place as possible. For example, use stripper headers for harvesting. In corn, this is accomplished by adjusting the strippers and rolls to keep the stalk intact and upright. Cutting corn plants 12 to 24 inches above the soil surface (http://www.ipm.iastate.edu/ipm/icm/2006/5-15/notill.html) may also reduced damage to equipment tires. In addition, standing residue is relatively easy to manage planting; and upright residue provides more protection from wind and water erosion.

During planting a residue manager can help prepare a good seedbed. However, a residue manager can compensate for non-uniform residue distribution. Residue managers work best in situations where residue is uniform. When residue is not uniform, it is almost impossible to properly adjust residue managers. Moving residue is easier if it is cut before moving it. Single-disc fertilizer openers placed at the same depth and two to three inches to the side of the seed opener path can cut surface residue and provide an opening for band applied fertilizer. When compared to conservation tillage, no-till soils generally remain cooler in the spring. Cooler soil temperatures can slow nitrogen (N) and sulfur (S) mineralization. Placing nutrients like N and S as a side-band improves early season plant vigor.
Additional references and information

Available at https://www.agronomy.org/publications/search?open-access=true&journal%5Baj%5D=aj&start=11


Acknowledgements
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Using Field Scouting or Remote Sensing Technique to Assess Soybean Yield Limiting Factors

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Obtaining real-time remote sensing information can be used to improve management by targeting scouting activities and identifying yield-limiting factors in areas that cannot be seen from the road. In addition, an improved understanding of the yield-limiting factors can be used to select appropriate genetic trait packages for next year. This chapter provides an overview of remote sensing and how it can be used to improve management (Chapter 29).

Scouting, identifying problems, and sensors

Soybean yields can be reduced by nutrient deficiencies, water stress, and weed, insect, and disease infestations. Information about the extent of problems can be identified by scouting the field from the air, the ground, or obtaining satellite images (Fig. 16.1). The traditional crop scouting method is to walk or drive a 4-wheeler on a random course, selected in advance, through a field with stops at a number of locations to look for damaged leaves, collect insects, or count weeds (Chapter 29). When using this approach, an attempt should be made to identify the cause and extent of a problem (Table 16.1). A disadvantage of this approach is that it is time-consuming and in many situations a large percentage of the time can be spent in evaluating healthy plants. In addition, random observations can miss areas of the field requiring corrective treatments. Remote sensing can be used to increase the efficiency of the ground scouting program (Table 16.1).
Table 16.1. Symptoms and possible causes that should be identified during scouting. In this table, NIR is reflectance in the near infrared band (700 to 1200 nm) and NDVI is a ratio of reflectance in the red (600 to 700 nm) and near infrared bands [NDVI = (NIR-red)/(NIR+red)]. Additional information about reflectance is available at [http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php](http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php).

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Possible Causes</th>
<th>Impact in Remote Sensing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor seedling emergence or young seedlings die</td>
<td>Low quality seed, soil crusting, incorrect planting depth, root rots, chemical carryover</td>
<td>Low NDVI values and low density of red color in false color image due to low density of green plants (Ahmadi and Mollazade, 2009).</td>
</tr>
<tr>
<td></td>
<td>High pest pressure, root rots, chemical injury from metribuzin or atrazine</td>
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</tr>
<tr>
<td></td>
<td>Damping off, Stems may show reddish-brown decay or appear water soaked</td>
<td></td>
</tr>
<tr>
<td>Yellow/brown leaves</td>
<td>Fe deficiencies, poor nodulation, nematodes</td>
<td>Low NDVI values and light/no red color in false color image due to low NIR reflectance from unhealthy plant leaves.</td>
</tr>
<tr>
<td></td>
<td>K deficiency</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brown spot</td>
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<tr>
<td></td>
<td>Root rots, on older plants tissue between the leaf veins turn yellow and dies, roots may be rotted</td>
<td></td>
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<tr>
<td>Mottling or distorted leaves</td>
<td>Pod and stem blight</td>
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<td></td>
<td>Bean pod mottle</td>
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<tr>
<td></td>
<td>Soybean mosaic virus</td>
<td></td>
</tr>
<tr>
<td>Poor plant growth</td>
<td>Chemical injury or insect damage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nematodes, drainage problems, drought, pests, chemical damage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low pH, nutrient deficiencies, lack of effective seed treatment</td>
<td></td>
</tr>
<tr>
<td>Holes in leaves</td>
<td>Hail damage or foliage-feeding insects</td>
<td></td>
</tr>
<tr>
<td>Stunted roots</td>
<td>Soil compaction, nematodes, chemical damage</td>
<td></td>
</tr>
</tbody>
</table>
Two alternative methods to field based weed scouting include using a W-pattern with 60 points or grid sampling (Clay et al., 1999). The W-pattern has been effective in collecting useful information on whole field weed populations, while the grid sampling approach, along with GPS (Global Positioning System) measurements, can be used to develop site-specific application maps. Grid sampling is much more labor intensive than a random sampling. It may be possible to develop a site-specific application map by using remote sensing targeted sampling.

In many situations, symptoms or anomalous areas can be easily identified using aerial or satellite images. Most multispectral satellite sensors measure reflectance at specific visible (blue, green, red) and near-infrared (NIR, 700 to 1200 nm) bands. When using remotely sensed images, it is important to remember that:

- Different sensors have different pixel resolution:
  - Each band generates an image and resolution represents the amount of detail within an image. The smaller the pixel the more spatial detail in the resulting imagery.
  - In agriculture, high resolution images are generally desirable. [http://www.ipni.net/publication/ssmg.nsf/0/095C22F8E6598FEA852579E50077EC0D/$FILE/SSMG-42.pdf](http://www.ipni.net/publication/ssmg.nsf/0/095C22F8E6598FEA852579E50077EC0D/$FILE/SSMG-42.pdf)
- Many problems have similar reflectance patterns (Table 16.1).
- Once problem areas are identified, causes should be confirmed.

Additional information on sensors is available at [http://www.satimagingcorp.com/characterization-of-satellite-remote-sensing-systems.html](http://www.satimagingcorp.com/characterization-of-satellite-remote-sensing-systems.html).

**Crop reflectance**

Changes in plant health can be measured using crop reflectance (Fig. 16.2). Healthy plants generally have lower reflectance in the visible bands and higher reflectance in the NIR bands than do unhealthy plants. The visible and NIR bands are combined in false color images (band combinations of green, red, and NIR) and the Normalized Difference Vegetation Index (NDVI). NDVI is a simple indicator that can be used to analyze remote sensing measurements and assess whether the observed target (field) contains live healthy plants (high index values) and unhealthy plants (low index values). In the false color images, the healthy plants have a very red color and the unhealthy plants have light red color.

![Figure 16.2. Spectral reflectance of healthy plant, unhealthy plant, and soil in visible and NIR wavelength.](http://extension.usu.edu/nasa/htm/on-target/near-infrared-tutorial/)
**Remote sensing for crop management**

A remote sensing program can be separated into four unique steps. These steps are discussed below.

![Diagram](Diagram: Jiyul Chang, SDSU)

**Figure 16.3. The concept of remote sensing technique for crop management.**

**Step 1. Determine if remote sensing can help.**

The first step in integrating remote sensing into your decision process is to determine if the remote sensing images can detect the stressed areas. If differences cannot be detected, using the resolution available, remote sensing cannot be used. The inability to detect a stress may be related to:

- not having fine enough resolution,
- not using appropriate indexes or bands,
- not using the appropriate sampling date,
- having healthy and stressed plants with similar reflectance values, and/or collecting images under cloudy or hazy conditions.

**Step 2. Develop a stress map.**

Once an image is collected, the area producing differential reflectance must be identified. The factors causing differential reflectance can be identified by using targeted sampling (Table 16.1). If the spatial resolution is low (large pixel size), it is hard to identify the stressed areas. The commercial satellite images with high spatial resolution are IKONOS, RapidEye, GeoEye, QuickBird, and WorldView. The range of spatial resolution (pixel size of image) of these images is 1.5 to 5 meters.

Another important factor to consider is sampling dates. These images can be collected for the same field every 1 or 3.5 days. High spatial resolution images can show the exact locations under stress at different times.

**Step 3. Identify the yield limiting factors.**

During ground scouting, the causes for poor growth need to be identified. This may involve collecting plant, soil, weed, and insect samples (Fig. 16.4). In Figure 16.4, soil samples revealed that areas with poor growth resulted from high soybean cyst nematode (SCN) populations. When soybean plants are severely...
infected by SCN, they become stunted, they appear chlorotic, and canopy closure may not occur. SCN areas typically are round or elliptical in shape and are elongated in the direction of tillage.

Many stresses have similar symptoms (Table 16.1) and may require additional information to make a diagnosis. Information that should be collected includes:

1) timing,
2) the location of stressed areas,
3) landscape position,
4) pattern in the field,
5) soil differences, and
6) plant symptoms.

Analysis of soil and plant samples can be used to help confirm a diagnosis.

Figure 16.4. IKONOS false color image (July 10, 2002) of a soybean field in southeastern South Dakota. Areas of very poor plant growth due to SCN and other factors are highlighted. The field across the road to the right was heavily infested with SCN; note poor reflectance in this field. (Source: http://www.umac.org/agriculture/ss/DeterminingtheExtentofSCNInfestationinSoybeanFields/detail.html)

Weed patches can be detected in early season (before canopy closure) for row crops such as soybean and corn. Weeds can produce mixed impacts on crop reflectance. Depending on timing, weeds can reduce or increase the NDVI value (Fig. 16.4; Chang et al., 2004).

Potassium (K) deficiencies and diseases generally decrease the NDVI value. The symptoms of K deficiency usually appear relatively late in the season. K-deficient soybean plants may have yellow leaves. The soybean fungus diseases with similar symptoms are Sudden Death Syndrome (SDS), Brown Stem Rot (BSR), and White Mold. When symptoms of SDS first appear, they may be confined to a few small areas or strips. Over the following two or three weeks, affected areas may enlarge, and other areas in the field may show symptoms. Leaf symptom development of BSR is greatest when air temperatures are high during the R3-to-R4 growth stages. The foliar symptoms may peak at R7.
Symptoms of feeding damage of soybean aphids include plant stunting and leaves covered with honey dew (a sticky substance excreted by aphids) and black sooty mold. Ian MacRae, a University of Minnesota Extension Service entomologist based in Crookston, Minn., has found that the soybean plants which had stress with high aphid populations had lower reflectance of infrared and near-infrared light than the healthy soybean plants have.

The soybean aphids usually appear around the first week of June as small populations as well as isolated pockets during most of June. Aphid populations peak during the R1-to-R4 growth stages.

Step 4. Develop corrective management solution.

Once yield-limiting factors are identified, corrective solutions need to be developed. For some problems, corrective solutions are only available for future years. If current solutions are possible, this information needs to be forwarded to the decision-maker as quickly as possible. Processing information for precision treatments requires the ability to identify the problem locations. To identify the problem boundaries, Differentially corrected Global Positioning System (DGPS) and Geographic Information Systems (GIS) may be needed. The GIS formats are point, line and polygon, which contain GPS coordinates. These data can be used to develop precision application maps.

References and additional information

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Assessing Your Fertilizer Program

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In 2012, South Dakota soybean producers spent $48.12/acre on fertilizers (Chapter 56). This expenditure represents a 106% increase over what was spent on fertilizers in 2011. To optimize profitability, the effectiveness of these costs needs to be assessed. There are a number of steps that can be followed in this assessment, leading to an ultimate development of an improved fertilizer program (Table 17.1). The purpose of this chapter is to discuss scouting, conducting nutrient budgets to assess nutrient mining, using chlorophyll meters and tissue sampling to assess nutrient deficiencies, and using well fertilized reference strips to determine economic benefits from improved fertilizer practices.
Step 1: Scouting a field.

Improving a fertility program starts with routine soil sampling and scouting of the field for nutrient problems. Details associated with soil sampling are available in Chapter 18 and details associated with field scouting are available in Chapter 29. When scouting a field for insects and diseases, take the opportunity to note potential nutrient deficiencies (Table 17.2).

A chlorophyll meter can also be used to quantify differences between healthy and unhealthy plants (http://www.ca.uky.edu/agc/pubs/agr/agr181/agr181.pdf). Based on differences in chlorophyll meter readings in healthy and un-healthy plants, corrective management can be identified. For example, a soybean plant that was not inoculated with N fixing bacteria (Chapter 23) or seeded into a high pH poorly drained area (iron deficiency chlorosis; Chapter 26) might have a meter reading of 72 while a healthy plant might have a value of 80. Based on these differences, you may decide to apply a Fe seed treatment.
Table 17.2. Soybean nutrient symptoms and possible solutions. Images of deficiency symptoms in soybeans are available at http://cropwatch.unl.edu/web/soils/soybean-nutrients

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Symptom</th>
<th>Plant Part</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>General yellowing</td>
<td>Older parts first</td>
<td>Treat seed with <em>Bradyrhizobium</em></td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Dark green or reddish purple leaves</td>
<td>Older parts first</td>
<td>Apply P fertilizer, check soil P level</td>
</tr>
<tr>
<td>Potassium</td>
<td>Wilting, interveinal chlorosis, and scorching of leaf margins starting at the edge</td>
<td>Older parts first</td>
<td>Apply K fertilizer, check soil K levels</td>
</tr>
<tr>
<td>Sulfur</td>
<td>General yellowing</td>
<td>Younger leaves first</td>
<td>Apply S fertilizer and check soil S level</td>
</tr>
<tr>
<td>Iron</td>
<td>Yellowing of veins of the leaves generally found in high pH soils. Whole leaf may turn white.</td>
<td>Younger leaves first</td>
<td>Use Fe efficient cultivars and treat seed with Fe (Chapter 26)</td>
</tr>
<tr>
<td>Zinc</td>
<td>Pale green plants; interveinal mottling (or interveinal chlorosis in drybean) of older leaves leading to bronze necrosis; green veins</td>
<td>Younger leaves first</td>
<td>Apply Zn fertilizer</td>
</tr>
</tbody>
</table>

In South Dakota, a common nutrient to limit yield is P. Soybeans growing in deficient soils may be stunted, have small leaflets, dark green or purple colored leaves, delayed maturity, and reduced yields (Fig. 17.1). Deficiency symptoms frequently are observed in older leaves first. If the soil is cold and wet, P deficiency may be particularly noticeable. If P deficiencies are observed, tissue samples should be collected and analyzed. Solutions to P deficiencies in high pH soils include broadcast applying relatively high P rates or banding P fertilizer below the seed. These soils often have low Olsen P soil test values.
Step 2: Track soil nutrient levels.

Information from a soil sampling program can provide critical information about available P. This approach is most useful when assessing soil fertility changes over a relatively long period of time. A decreasing soil P level with time suggests that P additions are less than P removal. For example, if the soil test P concentration decreases from 18 to 13 ppm over a 10-year period, this suggests that P is being mined. If nutrient mining (removal is greater than additions) has occurred, some nutrients may become limiting. When tracking spatial and temporal changes in soil P, it is important to understand that different extractants remove different amounts of nutrient and that changes in the soil sampling strategies can impact soil test results (Chapter 18).

Step 3: Determine nutrient budgets: mining or replacing.

Nutrient removal data, when combined with soil test information, can be used to assess soil nutrient mining and if additional fertilizer is required. In nutrient budgets, the nutrients removed by all crops must be considered in the calculations. Removal rates for selected crops are provided in Table 17.3. Nutrient removal rates for other crops are available in Clay et al. (2011).

Table 17.3. Estimates of nutrient removal of N, P, K, Mg, and S by major South Dakota crops.
(Source: Clay et al., 2011)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Plant Part</th>
<th>Unit</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>Mg</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>Grain</td>
<td>lbs/bu</td>
<td>0.9</td>
<td>0.38</td>
<td>0.27</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Stover</td>
<td>lbs/ton</td>
<td>16</td>
<td>5.8</td>
<td>40</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Soybean</td>
<td>Grain</td>
<td>lbs/bu</td>
<td>3.8</td>
<td>0.84</td>
<td>1.3</td>
<td>0.21</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>Stover</td>
<td>lbs/ton</td>
<td>40</td>
<td>8.8</td>
<td>37</td>
<td>8.1</td>
<td>6.2</td>
</tr>
<tr>
<td>Wheat</td>
<td>Grain</td>
<td>lbs/bu</td>
<td>1.5</td>
<td>0.6</td>
<td>0.34</td>
<td>0.15</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Straw</td>
<td>lbs/ton</td>
<td>14</td>
<td>3.3</td>
<td>24</td>
<td>2</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Removal rates are determined by summing the amount of nutrients removed over several years, while additions are determined by summing the nutrient additions, including manure (Problems 17.1, 17.2). Sample calculations are available in Clay et al. (2011). If excessive mining has occurred (outputs>inputs) and soil test values have decreased, consider changing the fertility program.

Problem 17.1. Estimating crop P removal in a corn and soybean rotation. (Clay et al., 2011)

P removed by 52 bu soybeans/acre and 150 bu corn/acre

Lbs P₂O₅/acre by soybean = \( \frac{52 \text{ bu}}{\text{acre}} \times \frac{0.84 \text{ lbs P}_2\text{O}_5}{\text{bu}} = 43.7 \text{ lbs P}_2\text{O}_5/\text{acre} \)

Lbs P₂O₅/acre by corn = \( \frac{150 \text{ bu}}{\text{acre}} \times \frac{0.38 \text{ lbs P}_2\text{O}_5}{\text{bu}} = 57 \text{ lbs P}_2\text{O}_5/\text{acre} \)

Total removal in a corn and soybean rotation is 101 lbs P₂O₅/acre.
Step 4: Plant tissue analysis.

An in-season assessment can be conducted through tissue samples. This approach can be used to compare the nutrient concentration in your plant material to relatively broad benchmarks that define expected values. This approach was originally designed to identify nutrient deficiencies. It is important to note that many of these benchmarks were defined over 30 years ago. Today visual deficiencies are rarely observed, and therefore it is difficult to include visual symptoms into an in-season assessment tool.

We believe that tissue sampling complements rather than replaces other assessment techniques. It is important to note that assessments based on concentrations are sometimes misleading because stunted plants may have high concentrations. These samples can be sent to most soil testing laboratories. A list of addresses of these laboratories is available in Chapter 18.

Soybean tissue sampling

Different sampling protocols are used for different plants and crop growth stages. For soybeans, 30 to 50 of the most recently mature trifoliates should be collected from early (R1) to mid-bloom (R3) (Rehm, 2006; Chapter 3). When collecting this number of leaves, care must be followed to insure that the leaves do not mold. At the seedling growth stage, collect the entire plant. These samples should be sent to a plant testing laboratory for analysis. If the analysis is below the expected range, that nutrient may limit growth.

Problem 17.2. Determine the amount of N and P removed in the grain of a 210 bu/acre corn crop and a 52 bu/acre soybean crop.

N removed by corn and soybean

\[
\text{Corn } N = \frac{210 \text{ bu}}{\text{acre}} \times \frac{0.9 \text{ lbs N}}{1 \text{ bu}} = 189 \text{ lbs N/acre}
\]

\[
\text{Soybean } N = \frac{52 \text{ bu}}{\text{acre}} \times \frac{3.8 \text{ lbs N}}{1 \text{ bu}} = 198 \text{ lbs N/acre}
\]

Total N = 189 + 198 = 387 lbs N/acre

P removed by corn and soybean

\[
\text{Corn } P = \frac{210 \text{ bu}}{\text{acre}} \times \frac{0.38 \text{ lbs P}_2\text{O}_5}{1 \text{ bu}} = 80 \text{ lbs P}_2\text{O}_5/\text{acre}
\]

\[
\text{Soybean } P = \frac{52 \text{ bu}}{\text{acre}} \times \frac{0.84 \text{ lbs P}_2\text{O}_5}{1 \text{ bu}} = 43.7 \text{ lbs P}_2\text{O}_5/\text{acre}
\]

Total P\(_2\)O\(_5\) = 80 + 44 = 122 lbs P\(_2\)O\(_5\)/acre

The N and P budget are determined by subtracting removal rates from additions. The N budgets have little meaning because soybeans have the capacity to convert atmospheric N\(_2\) to plant N (N fixation). For P, if the budget is negative (removal > additions), check the soil test and plant nutrient values. If the soil test values have decreased and the plant P level is below the critical P level, consider changing your P management program.
Corn tissue sampling

For corn, different plant parts should be collected for different growth stages. For seedlings, 15 to 20 whole plants should be collected. For plants 12 inches tall (30 cm) to tasseling, the first 15 to 20 fully developed leaves from the top of the plant should be collected. From tasseling to silking, 12 to 20 ear leaves should be collected (Bundy, 2004; Rehm, 2006; Clay et al., 2011). The ear leaf is the leaf directly below the ear. Again, care should be followed to make sure the plants do not mold. The plant samples should be sent off to an appropriate laboratory. The expected ranges for selected nutrients are provided in Table 17.5.

### Table 17.4. Expected ranges for soybean trifoliates collected between R1 and R3. (Modified from Rehm, 2006 and http://www.sdstate.edu/ps/extension/soil-fert/upload/Critical-Nutrient-Table-2012.pdf). Images of the plants at R3 are available in Chapter 3.

<table>
<thead>
<tr>
<th>Plant Nutrient</th>
<th>Unit</th>
<th>Expected Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>%</td>
<td>4.26-5.5</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>%</td>
<td>0.26-0.50</td>
</tr>
<tr>
<td>Potassium</td>
<td>%</td>
<td>1.71-2.50</td>
</tr>
<tr>
<td>Calcium</td>
<td>%</td>
<td>0.36-2.00</td>
</tr>
<tr>
<td>Magnesium</td>
<td>%</td>
<td>0.26-1.00</td>
</tr>
<tr>
<td>Iron</td>
<td>ppm</td>
<td>51-350</td>
</tr>
<tr>
<td>Zinc</td>
<td>ppm</td>
<td>20-50</td>
</tr>
<tr>
<td>Boron</td>
<td>ppm</td>
<td>21-55</td>
</tr>
<tr>
<td>Copper</td>
<td>ppm</td>
<td>10-30</td>
</tr>
<tr>
<td>Manganese</td>
<td>ppm</td>
<td>21-100</td>
</tr>
</tbody>
</table>

### Table 17.5. Expected ranges for soybean trifoliates collected between R1 and R3. (Modified from Rehm, 2006 and http://www.sdstate.edu/ps/extension/soil-fert/upload/Critical-Nutrient-Table-2012.pdf). Images of the plants at R3 are available in Chapter 3.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Unit</th>
<th>Seedling</th>
<th>Vegetative</th>
<th>Tasseling to Silking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>%</td>
<td>4.0-5.0</td>
<td>3.5-4.5</td>
<td>2.76-3.75</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>%</td>
<td>0.4-0.6</td>
<td>0.35-0.50</td>
<td>0.25-0.50</td>
</tr>
<tr>
<td>Potassium</td>
<td>%</td>
<td>3.0-5.0</td>
<td>2.0-3.5</td>
<td>1.75-2.75</td>
</tr>
<tr>
<td>Calcium</td>
<td>%</td>
<td>0.51-1.6</td>
<td>0.20-0.80</td>
<td>0.30-0.60</td>
</tr>
<tr>
<td>Magnesium</td>
<td>%</td>
<td>0.3-0.6</td>
<td>0.20-0.60</td>
<td>0.16-0.40</td>
</tr>
<tr>
<td>Sulfur</td>
<td>%</td>
<td>0.18-0.40</td>
<td>0.18-0.40</td>
<td>0.16-0.40</td>
</tr>
<tr>
<td>Iron</td>
<td>Ppm</td>
<td>40-500</td>
<td>25-250</td>
<td>50-250</td>
</tr>
<tr>
<td>Zinc</td>
<td>Ppm</td>
<td>25-60</td>
<td>20-60</td>
<td>17-75</td>
</tr>
<tr>
<td>Boron</td>
<td>Ppm</td>
<td>6-25</td>
<td>6-25</td>
<td>5.1-40</td>
</tr>
<tr>
<td>Manganese</td>
<td>Ppm</td>
<td>40-160</td>
<td>20-150</td>
<td>50-250</td>
</tr>
<tr>
<td>Copper</td>
<td>Ppm</td>
<td>6-20</td>
<td>6-20</td>
<td>3-15</td>
</tr>
</tbody>
</table>
Step 5: Assessing your fertilizer program.

Compile your survey, production records, nutrient budgets, and tissue sampling. Is there a relationship between tissue samples, nutrient budgets, and soil nutrient concentrations? Based on this field by field assessment, determine if additional work is needed.

Step 6: Consider conducting an on-farm study.

On-farm studies that include well fertilized reference control strips are a good strategy to field test specific practices, products, and rates (Fig. 17.2). Three basic approaches have been used in on-farm studies (Chapter 54). In the first method, the treatments are placed with a row up and down a landscape elevation gradient. This approach is used to test the treatment at the different landscape positions. In the second approach, treatments are placed perpendicular to the crop rows. In the third approach, treatments are applied at specific locations within your field. The yields from the treatments are then compared with your fertilizer program. Specific details of these techniques are provided in Chapter 54.

Figure 17.2. The placement of different treatments across a landscape.

References and additional information
Rehm., G., 2006. Plant analysis in today’s agriculture. Minnesota Crop News. Available at https://docs.google.com/viewer?a=v&q=cache:N6iPe8h3NB4J:www.extension.umn.edu/cropnews/2006/pdfs/06MNCN37.pdf+normal+and+expected+ranges+in+nutrient+concentrations+in+soybean+trifoliates&hl=en&gl=us&pid=bl&srcid=ADGEESgqOB4e7cysBGr57bC8J-X2ZwZBsH0DeOwa0WunDDU82XB4KitvXYoFw/CyEngw51yIrv654tXapT_n7gBOmBf_RH9mrb7CLLXetQNsCVboKS5rsHcKeREsp&sig=AHIEtbQ8yjW4ULAJnN6EWOiZC867QiE4psMg

Acknowledgements
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Collecting Representative Soil Samples for Fertilizer Recommendations

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A beginning point for many fertilizer recommendations is to collect a representative soil sample. Based on the amount of nutrients contained within the sample, fertilizer recommendations are developed. The ability of this sample to accurately portray the amount of nutrients contained in the soil depends on matching sampling protocol to prior management and the field's characteristics. This chapter provides soil sampling basics and discusses the importance developing field specific sampling protocols.

Soil sampling basics

Soil sampling and analysis provides a benchmark of the soil's ability to provide nutrients to the plant. However, the accuracy of the sample depends on prior management and how the sample was collected. Soils sampling basics are provided in Table 18.1.
The soil sampling protocol required to collect unbiased samples is influenced by how and when previous fertilizers were applied. If the fertilizer was broadcast applied, collect 15 to 20 cores to mix for a soil sample. If the fertilizer was band applied, different protocols may be needed. The sampling approach depends on where the N was placed. If the location of the band is unknown, follow the protocols above. If the N was band applied in the center of the interrow, we recommend that 15 to 20 cores be collected from the area half-way between the center of the band and the row (Clay et al., 1997). Sampling the old bands can result in underestimating the fertilizer requirement (Fig. 18.1).

In many fields, P is banded two inches (5 cm) over and two inches below the seed. Obtaining accurate measurements of P-banded fields is difficult. Kitchen et al. (1990) recommended that for a 30-inch (76 cm) row spacing, only one sample out of 20 should be collected from the band, and that the number of samples from the fertilizer band (S) can be estimated with the equation:

\[
S = \frac{8 \times \text{row spacing}}{12}
\]

example for a 30-inch rows spacing

\[
= \frac{8 \times 30}{12} = 20
\]
This calculation shows that if the row spacing is 30 inches, then one core should be collected from the band and 20 cores should be collected from other areas. If the row spacing is 15 inches (38 cm), then one core should be collected for every 15 collected from other areas. Over-sampling the P band increases the difference between the true soil P level and the measured value, which results in underestimating the P fertilizer requirement.

**Impact of old farmsteads on soil test values**

Old farmsteads may also influence the accuracy and precision of the fertilizer recommendation (Kleinjan, 2002). In many situations, soil samples collected from old farmsteads have higher P levels than the rest of the field (Fig. 18.2). These differences can exist for many years. Based on these results, we recommend that whole field composite samples exclude areas where old homesteads or feedlots were located. Because old homesteads may have been located near field entrances, we recommend that you do not collect samples from these areas. Old photographs can be obtained from the county USDA-NRCS office. Including subsamples from old homesteads in your composite samples can:

- Bias your results.
- Reduce P fertilizer recommendations.
- Reduce yields over large portions of a field and reduce profits.
References and additional information


Acknowledgements
Support for this guide was provided by the North Central Soybean Research Board, United Soybean Board, South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

Soil Testing Laboratories

Iowa State Soil Testing Laboratory
G501 Agronomy Hall
Iowa State University
Ames IA 50011-1010
Phone: (515) 294-3076
Fax: (515) 294-5567
Email: Soil Test
Web: http://www.agron.iastate.edu/soiltesting/

NDSU Soil Testing Laboratory (North Dakota)
Waldron Hall, NDSU
1360 Bolley Drive, PO Box 5575
Phone: (701) 231-8942
Email: NDSU.STL
Web: http://www.soilsci.ndsu.nodak.edu/soiltesting.html

Wyoming State Soil Testing Laboratory
Dept. of Renewable Resources, U of Wyoming
PO Box 3354
Univ. Station
Laramie WY 82071
Phone: (307) 766-5045
Email: Soil Test
Web: http://www.uwyo.edu/uwexpstn/soil_test.html

AgLab Express
3600 South Minnesota Ave.
Sioux Falls SD 57105
Phone: (605) 271-9237
Fax: (605) 271-9238
Email: Anthony Bly
Web: http://www.aglabexpress.com/index.htm

University of MN Soil Testing Laboratory
1902 Dudley Ave
Rm. 135 Crops Research Bldg.
St. Paul MN 55108-6089
Phone: (612) 625-3101
Fax: (612) 624-3420
Email: Soil Test
Web: http://soiltest.cfans.umn.edu/index.htm

Agvise Laboratory
902 13th St. North; PO Box 187
Benson MN 56215
Phone: (320) 843-4109
Fax: (320) 843-2074
Email: Agvise
Web: http://www.agvise.com

SGS Soil Testing Laboratories
236 32nd Ave
Brookings SD 57006
Phone: (605) 696-7611 Ext. 5
Fax: (605) 692-7617
Email: Angela Carlson
Web: http://www.cropservices.sgs.com/soil-testing-crop-services

Minnesota Valley Testing Laboratory
326 Center Street
New Ulm MN 56073
Phone: (800) 782-3557
Fax: (507) 233-7127
Email: mnssoil
Web: http://www.mvtl.com

Minnesota Valley Testing Laboratory
326 Center Street
New Ulm MN 56073
Phone: (800) 782-3557
Fax: (507) 233-7127
Email: mnssoil
Web: http://www.mvtl.com
Soybean yields can be reduced by iron chlorosis deficiency (IDC). Iron chlorosis deficiencies typically are observed in high pH soils containing high concentrations of carbonates. If the new leaves of a soybean plant are yellow with green veins, it may be experiencing an iron deficiency. The purposes of this chapter are to: a) discuss why iron (Fe) is important to soybeans and how soil impacts Fe availability; b) describe the key soil and other factors affecting iron availability; and c) provide a step-by-step procedure that can be used to identify fields likely limited by IDC. Soil fertility recommendations for IDC fields are located in Chapter 26.
Iron is an essential plant nutrient

Of more than 100 elements known on Earth, 18 are recognized as essential for plant growth (Brady and Weil, 2008). Iron is one of these. To be classified as an essential plant nutrient, it must:

1. be required to create the different plant organizational structures (e.g., cell walls, chlorophyll); and/or
2. be required in the chemical reactions of the plant or be used as a catalyst for required plant growth reactions (e.g., conversion of light energy into chemical energy); and
3. be required to complete the plant’s life cycle.

Essential plant nutrients can be divided into macronutrient and micronutrients. Macronutrients are required in large quantities (more than 500 parts per million, ppm) and include carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). The micronutrients are required in small amounts (less than 100 ppm) and include iron (Fe), manganese (Mn), Zinc (Zn), Copper (Cu), Molybdenum (Mo), Cobalt (Co), Boron (B), Chlorine (Cl), and Nickel (Ni). Micronutrients are just as essential as the macronutrients. A more complete description of the role of all of the nutrients is available in Brady and Weil (2008).

Iron, an essential micronutrient, exists in the soil either as ferric (Fe^{3+}) or ferrous (Fe^{2+}) iron. Most plants require between two to four lbs of Fe/acre (2 to 4 kg of Fe/ha). Under oxygen limited conditions (anaerobic and water-logged soil), Fe^{2+} is the dominant species, while under aerobic conditions, Fe^{3+} is often the dominant species. The plant actively uptakes ferrous iron (Fe^{2+}), which is most available when the soil pH is < 6.5. Soil properties like drainage, water table depth, soil temperatures, soil calcium carbonate (lime) content, erosion class, soil nitrate levels, % slope, parent material composition, and other factors, impact soil pH and plant available iron. Low soil pH values (very acidic conditions, soil pH values ≤4) can cause iron toxicity while high pH values (strongly alkaline, soil pH values >7.5) can cause an iron deficiency.

If Fe availability is limiting soybean growth, the leaves can turn yellow while the veins remain green (Fig.19.1). In many South Dakota fields, IDC is most dominant in low

Table 19.1. Hints for reducing iron deficiency chlorosis (IDC).

<table>
<thead>
<tr>
<th>Hints for reducing iron deficiency chlorosis (IDC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDC is most often found in high pH soil that contains high carbonate (e.g., CaCO3 or MgCO3) concentrations.</td>
</tr>
<tr>
<td>An easy test to assess if the soil contains high carbonates is to drip dilute acid on it. If the soil fizzes, it likely contains carbonates.</td>
</tr>
<tr>
<td>In IDC suspected fields, consider testing for soybean cyst nematode (SCN), which can mimic iron chlorosis symptoms.</td>
</tr>
<tr>
<td>In IDC fields, avoid stressing the plants further by carefully following pesticide-labeled directions.</td>
</tr>
<tr>
<td>Improve soil drainage to reduce excess moisture in high salt (electrical conductivity &gt;4 dS/m) areas.</td>
</tr>
<tr>
<td>Plant resistant varieties and use Fe (iron) seed treatments if needed.</td>
</tr>
</tbody>
</table>

A. Why iron (Fe) is important to soybeans

Iron is an essential plant nutrient

Of more than 100 elements known on Earth, 18 are recognized as essential for plant growth (Brady and Weil, 2008). Iron is one of these. To be classified as an essential plant nutrient, it must:

1. be required to create the different plant organizational structures (e.g., cell walls, chlorophyll); and/or
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If Fe availability is limiting soybean growth, the leaves can turn yellow while the veins remain green (Fig.19.1). In many South Dakota fields, IDC is most dominant in low

Figure 19.2. Soybean field with areas of moderate to severe iron deficiency chlorosis.
( Photo courtesy of D. Malo, SDSU)
areas (Fig. 19.2). Iron deficiency symptoms occur in the youngest, newest plant tissue and occurs in young plant parts because the nutrient is immobile. Under extreme conditions, the plant leaves may appear almost white. The first trifoliate of leaves does not exhibit Fe deficiency symptoms because there is enough stored iron in the seed to support leaf and plant growth through the first trifoliate stage (Chapter 4).

Even though most soils (40 inches or 102 cm depth) contain large quantities of Fe (400,000 to 700,000 lbs/acre, about 1 to 5 % of the total soil mass), only a very small fraction is plant-available. Maintaining an adequate supply of Fe for plant growth is difficult if the soil:

- has a high soil pH,
- contains a high concentration of carbonates (CaCO$_3$ or MgCO$_3$),
- contains little Fe,
- has poor aeration, and/or
- has high concentrations of P and nitrate, (NO$_3^-$).

Iron availability and IDC

Most soils do not lack Fe; rather, it is in a form that plants cannot use (Fig. 19.3). Soybean roots release organic acids and iron-reducing enzymes to increase iron's availability. IDC-resistant soybean plants are better at releasing organic acids than non-resistant plants. If the soil contains bicarbonate (HCO$_3^-$) or carbonate (CO$_3^{2-}$), then these compounds can react with Fe, reducing its availability. IDC is normally not a problem in soils with pH values less than 7.

Figure 19.3. Fe cycle in soils. (Modified from Havlin et.al., 2005; soybean image from http://ian.umces.edu/imagelibrary/albums/userpics/12789/normal_ian-symbol-soybeans.png, 2012)

B. Soil and plant factors affecting Fe availability

Soil pH

The soil pH is defined as the –log of the hydrogen ion concentration. Nutrient availability to plants is influenced by soil pH (Fig. 19.4). In alkaline conditions (pH > 7), Fe concentrations are low, causing IDC to develop in susceptible plants. IDC is not a problem in soils with pH values less than 7. At pH 3, Fe is soluble enough to meet plant needs by mass flow; however, at this pH, aluminum (Al) is toxic to plants. For each unit increase in soil pH, the Fe$^{3+}$ solubility decreases 1000 times and the Fe$^{2+}$ decreases 100 times (Havlin et al., 2005). As a result, at pH 7 the amount of iron in the soil solution is not adequate to meet plant needs.
Soil pH

Plants have developed other pathways (e.g., root exudates, humus decomposition products, organic acids, manures, leaf exudates carried by water into the soil, and microbial exudates) to reduce Fe deficiencies (Fig. 19.5). In an aerated soil (well drained), chelates bring Fe, usually as Fe$^{3+}$, to the root surface by mass flow and diffusion. Fe$^{3+}$ is released from the chelating structure. Fe$^{3+}$ is converted to Fe$^{2+}$. Plant root absorbs Fe$^{2+}$. And finally, the chelating molecule returns to the soil to pick up more Fe$^{3+}$ from the soil solution.

Figure 19.5. Fe uptake by plant roots using a chelating mechanism. (Modified from Lindsay, 1974, and Havlin et.al., 2005)

This model is influenced by other reactions that may reduce Fe$^{2+}$ availability. Soil wetness (poorly drained soils) and high nitrate concentrations can reduce Fe availability through several different mechanisms. Nitrate ($\text{NO}_3^-$) (Rehm, 2008; Chapter 25) has the potential to increase IDC because when the plant takes up this anion, it releases $\text{HCO}_3^-$ (bicarbonate) into the soil solution (Equation 1) which then reacts with Fe (Equations 2 and 3). Soil wetness and poor aeration can also increase IDC in soils because a soil wetness-induced increase in CO$_2$ concentration increases HCO$_3^-$ (Equation 3) concentration, which then reduces plant available Fe$^{2+}$ (Equation 2). Carbonates impact these processes because they are in equilibrium with HCO$_3^-$ (Equation 4).

1. $\text{HCO}_3^- + \text{H}_2\text{O} \rightarrow \text{CO}_3^{2-} + \text{H}_3\text{O}^+$
2. $\text{CO}_3^{2-} + \text{Fe}^{2+} + \text{H}_2\text{O} \rightarrow \text{FeCO}_3 + \text{H}_2\text{O}^+$
3. $\text{CO}_2 + 2\text{H}_2\text{O} \rightarrow \text{HCO}_3^- + \text{H}_3\text{O}^+$
4. $\text{CaCO}_3 + \text{H}_2\text{O} \rightarrow \text{Ca}^{2+} + \text{HCO}_3^- + \text{OH}$
These equations suggest that any event that increases $\text{HCO}_3^-$, such as wetness, compaction, high clay contents, high water table, flooding, ponding, or high nitrate concentration in association with high carbonate or bicarbonate contents, can contribute to soybean IDC. However, IDC is sporadic and is often associated with cool, wet conditions when soil aeration is poor and may lessen or disappear when soils dry and warm (Havlin et. al., 2005). In soils that contain no carbonates, $\text{Fe}^{2+}$ availability may increase under water-logged conditions.

The presence of high carbonate (lime) levels is a concern when erosion has removed the surface soil, which exposes carbonate-containing subsurface soils, classified as a Bk or C horizons. The presence of lime can be tested in the soil by using vinegar or a weak acid. Just drop the acid on the soil and if fizzing reaction occurs, there are carbonates present in the soil. The loss of topsoil may also increase soil compaction, which in turn reduces soil aeration and microbial activity. Land leveling or any other action that removes topsoil or brings calcareous material (e.g., construction, pipeline installation, and others) to the surface can cause IDC.

Most soil testing labs will routinely provide soil pH, salinity, texture, P, and nitrate N levels. Some soil testing labs will analyze for nutrients like Fe, Cu, Mn, Zn, and Mo. These soil tests and determinations can be used to make key soybean management decisions. Of particular interest in identifying Fe-limited soils are soil pH, electrical conductivity, and soil nitrate concentration.

Potential problem areas should be sampled separately from the rest of the field. Soil with pH values > 7 or high nitrate or available P concentrations could be at risk. Soils with high Mn, Cu, Zn, and Mo can also tie up Fe and cause IDC. One ratio used to predict potential IDC is the ratio of Fe:Mn+Cu (Havlin et al., 2005). As this ratio decreases the IDC potential increases.

**Plant genetic makeup differences**

Plants increase Fe availability by (Havlin et al., 2005):

1. Excreting $\text{H}^+$ and organic acids from the roots to lower the soil pH.
2. Excreting chelating agents to increase Fe solubility and availability (e.g., grass roots often exude phytosideropheres [amino acids] which chelate with $\text{Fe}^{3+}$ to bring the iron to the root surface and to enhance iron absorption).
3. Reducing $\text{Fe}^{3+}$ to $\text{Fe}^{2+}$ at the root surface.

Conditions like soluble salts, herbicides, and environmental extremes that place stress on the soybean plant can also accentuate IDC expression. Energy needed by the plant to overcome these stresses makes it less able to overcome IDC. In IDC-suspected fields, consider testing for soybean cyst nematode (SCN), which can mimic iron chlorosis symptoms.

**Developing a web-soil survey key for identifying at risk soils**

Based on the soil chemistry, a characterization key for identifying high risk soils was developed. These components include:

1. The surface soil has a high soil pH and contains carbonates.
2. May contain high nitrate ($\text{NO}_3^-$) concentrations.
3. Soil salinity (electrical conductivity of surface, subsoil, and parent material) may be relatively high.
4. The soil may be poorly drained.
5. Water table is high.
6. The soil likely has a fine soil texture (clay soil texture) and high compaction potential.
7. Soils likely reside in potholes or low areas of the field.
C. Developing a step-by-step guide for identifying at risk soils

Four sources of information can be used to identify potential IDC soils are the Web Soil Survey, Hydric Soil Lists, Soil Test Results, and Soil Taxonomy (soil classification). These different information sources are described below.

Web Soil Survey (WSS)

An extremely useful source of soils information is the Web Soil Survey (WSS). Additional information on how to use the Web Soil Survey is available (Malo, 2012). A new application, "SoilWeb: An Online Soil Survey Browser," that works with iPhone applications and Android OS smart phones is also available. http://casoilresource.lawr.ucdavis.edu/drupal/node/902

The kinds of data that one can obtain from the Web Soil Survey and with Soil Web include soil pH, lime concentrations, salinity levels, water table depth, water table duration, texture (% clay), drainage class, location of potentially problem soils, soil organic matter levels, and others. There are three basic steps in using WSS.

1. Identify and define the Area of Interest (AOI) where you need to obtain detailed soil information. The area can be a field, farm, or parcel of land.
2. Once the AOI is identified, the soils map is prepared and you can assess the suitability and limitations of soils for selected uses (e.g., soybean production). Maps and tables of selected soil physical/chemical properties and characteristics as well as land productivity information are available.
3. Electronically store and/or print the available data generated by the WSS session.

Step 1 – Identify the AOI

The first step in using WSS is to identify your AOI. The AOI is used by the WSS to generate tabular and visual data for use in later steps of the WSS. The AOI can be located either by using the various Quick Navigation options or the Interactive Map option (Fig. 19.6) in the WSS Navigation window. We will use the Legal Land Description (section, town, and range) option for this example to locate your AOI. Remember to select the proper Principal Meridian (PM) for your AOI. Use the drop-down helps in the program to assist you in picking the proper PM (Fig. 19.7). Additional ways to select your AOI are available (see the WSS help screens for AOI or see Malo, 2012).

Once the AOI has been located, the AOI boundaries need to be entered into WSS. Select one of the two boundary buttons (one for rectangular [box] method to create AOI. AOI are created by using polygons [click and drag your cursor]) near the top center on the page (Fig. 19.7). Once you have outlined the AOI, double click to electronically define and enter the AOI into WSS. After the AOI is defined and accepted, the acres and availability of soils data/maps and an air photo of the AOI are given (Fig. 19.8).

Figure 19.7. Using WSS (Web Soil Survey) legal land description quick navigation tool for locating area of interest (AOI). Principal Meridian drop-down box is located in center of the window. Example – Eastern South Dakota uses the Fifth Principal Meridian for legal land description.
### STEP 2a – Soil Map for AOI

After completion of Step 1 (AOI defined), click on the Soil Map Tab at the top of the WSS Web page to create a modern detailed soil survey map for the AOI (Fig. 19.9). The types information available include: the soil map and legend (tab on upper left side of image), the soil map unit (MU) name and symbol, number of acres of each soil MU, the percentage of AOI that each soil MU occupies, and tabular data for each MU. The tabular data (click on the MU name found in the AOI in the drop-down box on the left side of the Soil Map window, Fig.19.9) includes:

1. **MU setting** – elevation, annual precipitation, average annual temperature, and frost-free days.
2. **MU composition** – lists all the major and minor soil units with their composition %.
3. **Description of each major MU component** (named in the MU name):
   a. Setting for named series – landform, landscape position, slope shape (down and across), and parent material;
   b. Selected soil properties and qualities – % slope, restrictive layers, drainage class, permeability, depth to water table, flooding and ponding frequency, lime (calcium carbonate content), salinity (EC), sodium adsorption ratio (SAR), and profile plant available water holding capacity;
   c. Interpretive groups – Land Capability Classification, Ecological Site (formerly Range Site), and Other Vegetative Groups (e.g., Forage Suitability Groups); and
   d. Typical profile information (e.g., horizon depths and textures).
4. **A brief description of each minor MU component to explain how the minor soil differs from the named major MU component(s).**
If you would like a copy of the soil map or include the soil map in a custom soil survey report select the proper print tab in the upper right hand corner of the window (Fig. 19.10). There are two options (Printable Version or Add to Shopping Cart). The Printable Version option allows you to download a pdf version of just the soil map and associated documentation. The Add to Shopping Cart option adds the soil map to a file and saves the file until you are done with your WSS session. You can print the customized Web-based soil survey report including the soil map and tables as needed. Note that when either the Printable Version or the Add to Shopping Cart button is selected it will fade.

Figure 19.9. WSS (Web Soil Survey) Soil Map for Area of Interest (AOI) information.

Figure 19.10. Location of Printable Version tab and Add to Shopping Cart tab in upper right-hand corner of WSS (Web Soil Survey) window. Printable Version tab creates a pdf file of the current window on the computer monitor and the Add to Shopping Cart tab stores the current window contents and associated information for later retrieval in a final report.
Step 2b – Soil suitability/limitations/properties and characteristics

After generating the soil map, look at various soil properties, qualities, and uses (Suitabilities and Limitations). Select the Soil Data Explorer Tab at the top of the Web page (Fig. 19.11). A new window appears giving you the options of:

1. Intro to Soils (tutorial about soils and their use)
2. Suitabilities and Limitations for Use
3. Soil Properties and Qualities
4. Ecological Site Assessment
5. Soil Reports

Select the Suitabilities and Limitations for Use Tab. A new series of drop-down tabs appears on the left side of the Web page window (Fig. 19.11). If you press the Open All Tab then all the options for each category (e.g., Land Classification, Sanitary Facilities, Vegetative Productivity, etc.) in the box will open. The categories of Land Classification, Land Management, Vegetative Productivity, Waste Management, and Water Management are most commonly used for agricultural production and management decisions (see Table 2 for WSS Soil Suitabilities and Limitations ratings and maps available).

Soybean yield data (rating map, legend and description) for the AOI can be seen in Figures 19.12 and 19.13. For each soil suitability or limitation listed, you can look at the dominant condition within a MU, the dominant soil in a MU, all components of a MU, components of a certain percentage, or a weighted average of all components in a MU. You can print/save a single purpose map, associated legend, description information, and other related materials by using the Printable Version Tab or Add to Shopping Cart Tab in the upper right hand of the Web page window. Note that the tabs in the Add to Shopping Cart area fade when selected. When the report becomes large (>8 MB) the NRCS (Natural Resources Conservation Service) will send you the report by email as a pdf file after it is created.

![Figure 19.11. WSS (Web Soil Survey) suitabilities and limitations for use window with drop-down boxes on the left. If you want all options to be visible in the drop-down area, select the Open All tab.](image-url)
Table 19.2. Selected WSS (Web Soil Survey) suitability and limitation category information available for agricultural purposes. (Malo, 2012)  

<table>
<thead>
<tr>
<th>WSS Suitability/Limitation Category*</th>
<th>Category Options*</th>
<th>Explanation/Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Classifications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree and Shrub Groups</td>
<td>Lists trees/shrubs best suited for MU.</td>
<td></td>
</tr>
<tr>
<td>Ecological site ID and name</td>
<td>Forage Suitability Groups and Rangeland Sites.</td>
<td></td>
</tr>
<tr>
<td>Farmland classification</td>
<td>Identifies if land in prime farmland, land of state importance, land of local importance, unique land, or land not prime or of importance.</td>
<td></td>
</tr>
<tr>
<td>Hydric rating</td>
<td>The components of each soil mapping unit are evaluated for hydric criteria and the map unit is designated as all hydric, partially hydric, not hydric, or unknown.</td>
<td></td>
</tr>
<tr>
<td>Dryland land capability class and subclass (irrigated where available)</td>
<td>Soil limitations for crop, grass (range), and timber production.</td>
<td></td>
</tr>
<tr>
<td>Soil taxonomy classification</td>
<td>Soil classification based on Soil Taxonomy.</td>
<td></td>
</tr>
<tr>
<td>Land Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion hazard (off-road, off trail)</td>
<td>Soil loss from off-road and off trail areas disturbance.</td>
<td></td>
</tr>
<tr>
<td>Erosion hazard (road, trail)</td>
<td>Soil loss from unsurfaced roads and trails.</td>
<td></td>
</tr>
<tr>
<td>Fugitive dust resistance</td>
<td>Vulnerability of soil to go into suspension during a wind storm.</td>
<td></td>
</tr>
<tr>
<td>Potential for fire damage</td>
<td>Rating of potential fire damage to nutrient, physical, and biological soil properties/quality.</td>
<td></td>
</tr>
<tr>
<td>Soil degradation susceptibility</td>
<td>Susceptibility for soil degradation during disturbance on rangeland or woodland.</td>
<td></td>
</tr>
<tr>
<td>Soil restoration potential</td>
<td>Soil's inherent ability to recover from degradation (soil resilience).</td>
<td></td>
</tr>
<tr>
<td>Suitability for roads (natural surface)</td>
<td>Soil suitability for natural road surface.</td>
<td></td>
</tr>
<tr>
<td>Sanitary Facilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Septic tank absorption fields</td>
<td>Soil between 24 to 60 inches (60 to 152 cm) evaluated for use in septic tank absorption fields.</td>
<td></td>
</tr>
<tr>
<td>Sewage lagoon</td>
<td>Identify the soil feature and extent to which soils are limited by soil features impacting sewage lagoon construction and function.</td>
<td></td>
</tr>
</tbody>
</table>
Vegetative Productivity | Crop productivity index | Relative ranking of soils based on intensive crop production potential (not crop specific).

Forest productivity | Tree Site Index and cubic feet of wood/acre/year.

Range production | Amount of vegetation expected in favorable, normal, and unfavorable years in a well-managed area supporting a native plant community.

Yields of irrigated crops (by component or map unit) | Crop yields for selected crops suited to a county are presented (e.g., alfalfa hay, barley, bromegrass hay, bromegrass-alfalfa hay, corn, corn silage, grain sorghum, oats, soybeans, spring wheat, sunflowers, and winter wheat).

Yields of non-irrigated crops (by component or map unit) | Crop yields for selected crops suited to a county are presented (e.g., alfalfa hay, barley, bromegrass hay, bromegrass-alfalfa hay, corn, corn silage, grain sorghum, oats, soybeans, spring wheat, sunflowers, and winter wheat).

Waste Management | Manure and food waste management | Soil properties and features rated based on their impact on agricultural waste management.

Water Management | Excavated ponds (aquifer fed) | Soil suitability for excavated dugouts/pits to provide water from a ground water aquifer/water table.

Irrigation (general, sprinkler, and surface) | Rates soils suitability for installation and use of irrigation.

*Please note that not all WSS Suitability/Limitation categories or all options within a category are listed in this table. Some items listed in this table may not be available in all counties and different items of local importance may be present.

Figure 19.12. Sample WSS (Web Soil Survey) Soil Data Explorer window suitabilities and limitations for use tab (estimated soybean yields (bu/a)) for area of interest (AOI), right, and legend on the left. Note: Click the legend tab to cause the suitability map legend to appear.
In addition to soil suitability and limitations for use, there is a tab for Soil Properties and Qualities at the top of the Web page (Fig. 19.14). If you select this tab, a drop down-box with various categories (chemical, erosion, physical, and water) of soil properties and qualities appears on the left side of the window.

For each soil property or quality selected, you can look at the dominant condition within a MU, the dominant soil in a MU, components of a MU, components of a certain percentage, or a weighted average of all components in a MU. You also can select the soil depth range, e.g., surface, part of a profile, or all of a profile. Many different options are available for viewing maps (Fig. 19.15) and tables (Fig. 19.16 and Table 19.3). For water table information, you can select the months when excess water is a problem. You can print and/or electronically save a single purpose map, associated legend, description information, and other related materials by using the Printable Version tab or Add to Shopping Cart tab in the upper right hand of the Web page window.
Figure 19.14. WSS Soil Properties and Qualities window with drop-down boxes on the left. If you want all options to be visible in the drop-down area, select the Open All tab.

Figure 19.15. Sample WSS (Web Soil Survey) Soil Data Explorer window – Soil Properties and Qualities tab (Surface Soil pH) for Area of Interest (AOI), right, and Legend on the left. Note: Click the Legend tab to cause the soil property map legend to appear.
### Tables — pH (1 to 1 Water) — Summary By Map Unit

<table>
<thead>
<tr>
<th>Map unit symbol</th>
<th>Map unit name</th>
<th>Rating</th>
<th>Acres in AOI</th>
<th>Percent of AOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>BeA</td>
<td>Brandt silty clay loam, 0 to 2 percent slopes</td>
<td>6.7</td>
<td>201.7</td>
<td>31.4%</td>
</tr>
<tr>
<td>BeB</td>
<td>Brandt silty clay loam, 2 to 6 percent slopes</td>
<td>6.7</td>
<td>10.1</td>
<td>1.6%</td>
</tr>
<tr>
<td>Dn</td>
<td>Divide loam, 0 to 2 percent slopes</td>
<td>7.9</td>
<td>43.0</td>
<td>6.7%</td>
</tr>
<tr>
<td>EsB</td>
<td>Esteline silt loam, 2 to 6 percent slopes</td>
<td>6.7</td>
<td>37.2</td>
<td>5.8%</td>
</tr>
<tr>
<td>Fa</td>
<td>Fairdale loam, channeled</td>
<td>7.6</td>
<td>48.7</td>
<td>7.6%</td>
</tr>
<tr>
<td>Fc</td>
<td>Fordtown-Spottswood loams, 0 to 2 percent slopes</td>
<td>6.7</td>
<td>20.8</td>
<td>4.5%</td>
</tr>
<tr>
<td>Lk</td>
<td>Lamoure silt clay loam, 0 to 1 percent slopes</td>
<td>7.9</td>
<td>25.3</td>
<td>3.9%</td>
</tr>
<tr>
<td>Lm</td>
<td>Lamoure-Rauville silt clay loams, channeled</td>
<td>7.9</td>
<td>66.0</td>
<td>10.3%</td>
</tr>
<tr>
<td>M-W</td>
<td>Miscellaneous water areas</td>
<td></td>
<td>30.6</td>
<td>4.8%</td>
</tr>
<tr>
<td>Mr</td>
<td>Maryland loam, 0 to 1 percent slopes</td>
<td>8.2</td>
<td>74.3</td>
<td>11.6%</td>
</tr>
<tr>
<td>Mz</td>
<td>Moritz-Lamoure complex, 0 to 2 percent slopes</td>
<td>7.5</td>
<td>24.5</td>
<td>3.8%</td>
</tr>
<tr>
<td>Rp</td>
<td>Rauville silt clay loam, ponded</td>
<td>7.9</td>
<td>0.7</td>
<td>0.1%</td>
</tr>
<tr>
<td>RsC</td>
<td>Renshaw-Sioux complex, 6 to 9 percent slopes</td>
<td>7.0</td>
<td>50.9</td>
<td>7.9%</td>
</tr>
<tr>
<td><strong>Totals for Area of Interest</strong></td>
<td></td>
<td><strong>641.7</strong></td>
<td><strong>100.0%</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Description — pH (1 to 1 Water)

Soil reaction is a measure of acidity or alkalinity. It is important in selecting crops and other plants, in evaluating soil amendments for fertility and stabilization, and in determining the risk of corrosion. In general, soils that are either highly alkaline or highly acid are likely to be very corrosive to steel. The most common soil laboratory measurement of pH is the 1:1 water method. A crushed soil sample is mixed with an equal amount of water, and a measurement is made of the suspension.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.

Figure 19.16. Sample WSS (Web Soil Survey) Soil Data Explorer soil properties and qualities ratings and descriptive information for surface pH for map created in Figure 19.15. This information is located under (scroll down) the pH map.
Table 19.3. Selected WSS (Web Soil Survey) soil properties and qualities information available for agricultural purposes. (Malo, 2012)  continues on next page

<table>
<thead>
<tr>
<th>WSS Soil Properties and Qualities Category*</th>
<th>Category Options*</th>
<th>Explanation/Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Chemical Properties</td>
<td>Calcium carbonate (CaCO₃ - lime)</td>
<td>Percent calcium carbonate by weight in the &lt;2mm size fraction.</td>
</tr>
<tr>
<td></td>
<td>Cation exchange capacity (CEC-7)</td>
<td>Total amount of extractable cations that can be held by soil at pH 7.</td>
</tr>
<tr>
<td></td>
<td>Electrical conductivity (EC)</td>
<td>Conductivity of a saturated paste extract (mmhos/cm) – measure of water soluble salt concentration in soils.</td>
</tr>
<tr>
<td></td>
<td>Gypsum</td>
<td>Pct gypsum by weight in the &lt;2 mm size fraction</td>
</tr>
<tr>
<td></td>
<td>pH (1:1 Water)</td>
<td>Measure of acidity and alkalinity using 1 part water and 1 part soil (weight basis).</td>
</tr>
<tr>
<td></td>
<td>Sodium adsorption ratio (SAR)</td>
<td>Measure of the amount of sodium (Na⁺) relative to the calcium + magnesium (Ca²⁺+Mg²⁺) in a saturated soil paste extract.</td>
</tr>
<tr>
<td>Soil Erosion Factors</td>
<td>K Factor</td>
<td>Soil susceptibility to sheet and rill water erosion.</td>
</tr>
<tr>
<td></td>
<td>T Value</td>
<td>Maximum tolerated amount of wind and water erosion without reducing productivity.</td>
</tr>
<tr>
<td></td>
<td>Wind erodibility group/ index</td>
<td>Soil properties affecting soil susceptibility to wind erosion, index- numerical value indicating susceptibility to wind and water erosion.</td>
</tr>
<tr>
<td>Soil Physical Properties</td>
<td>Available water holding capacity</td>
<td>Amount of plant available water in the 0-25, 0-50, 0-100, and 150 cm depths.</td>
</tr>
<tr>
<td></td>
<td>Bulk density</td>
<td>Soil bulk density at 15, 1/10, and 1/3 bars are used to calculate shrink-swell potential, plant available water holding capacity, total pore space, and other soil properties. The soil bulk density indicates the pore space available for water and roots.</td>
</tr>
<tr>
<td></td>
<td>% Organic matter</td>
<td>Organic matter is decomposed and decomposing plant and animal residue in the soil. Organic matter content is determined on the soil particles &lt;2 mm and is % by weight.</td>
</tr>
<tr>
<td></td>
<td>% Sand, % Clay, % Silt</td>
<td>The percent of each soil separate by weight &lt;2 mm in diameter sized soil materials.</td>
</tr>
<tr>
<td></td>
<td>Saturated hydraulic conductivity or permeability (K_sat)</td>
<td>Transmission rate (ease) with which saturated soil pores allow water to move or pass through.</td>
</tr>
<tr>
<td></td>
<td>Surface texture</td>
<td>Representative soil textural class plus any appropriate coarse fragment modifiers.</td>
</tr>
<tr>
<td></td>
<td>Water content at 1/3 and 15 bars</td>
<td>Volumetric water content at 1/3 bar (field capacity) and 15 bar (wilting point) are used to define plant available water (=1/3 - 15 bar).</td>
</tr>
<tr>
<td><strong>Soil Qualities and Features</strong></td>
<td><strong>Depth to any soil restrictive layer</strong></td>
<td><strong>Depth to soil layer that significantly impedes root growth and/or water and air movement.</strong></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Drainage class</strong></td>
<td><strong>Frequency and duration of wet period that are expressed in the morphology of the soil.</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Water Features</strong></td>
<td><strong>Depth to water table</strong></td>
<td><strong>Water table refers to a saturated zone in the soil present long enough (1 month or more) to cause significant changes in soil properties and management. User defines the months to use. Depths are determined based on observed water table measurements and based on the presence of redox features (gray colors) in the soil.</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Flooding frequency</strong></td>
<td><strong>Temporary inundation caused by overflowing streams or runoff from adjacent slopes. Water standing for short periods after rainfall or snowmelt is not considered flooding, and water standing in closed depressions (e.g., prairie potholes/wetlands, swamps, and marshes) is considered ponding rather than flooding.</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Ponding frequency</strong></td>
<td><strong>Water standing in closed depressions (e.g., prairie potholes/wetlands, marshes, and others). Water is only lost through evaporation, transpiration, and deep percolation.</strong></td>
</tr>
</tbody>
</table>

*Please note that not all WSS (Web Soil Survey) Properties and Qualities categories or all options within a category are listed in this table. Some items listed in this table may not be available in all counties and different items of local importance may be present.*

In addition to the interpretive maps, you can download tabular data for your AOI. Tabular data is available when you use the Soil Reports Tab in the Soil Data Explorer window (Fig. 19.17, upper right-hand corner). The many possible options for tabular data found in the drop-down menu are located on the left-hand side of the Soil Reports window (Table 19.4 and Fig. 19.18).

After the tabular data is selected, view an explanation of what each table contains by using the View Description Tab or View Soil Report Tab on the left side of the window. You can print and/or save the tabular data, description information, and other related materials by using the Printable Version Tab or Add to Shopping Cart Tab (creates a composite report containing all the information you selected upon completion of your WSS session) in the upper right hand of the Web page window. The selected tables will be printed with interpretive maps and narrative information in the final custom soil survey report.
Figure 19.17. Sample WSS (Web Soil Survey) Soil Data Explorer window Soil Reports tab with drop-down boxes on the left. If you want all options to be visible in the drop-down area, select the Open All tab. Example – drop-down box for Non-irrigated Yields by map unit is shown. Selected crops for table creation are checked. AOI = Area of Interest. (Malo, 2012)
**Table 19.4. Selected tabular soils data available in the WSS (Web Soil Survey) Soil Report tab folder.**  
(Malo, 2012)

<table>
<thead>
<tr>
<th>WSS Soil Report Tabular Data Category*</th>
<th>Category Options*</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOI Inventory</td>
<td>Component legend</td>
</tr>
<tr>
<td></td>
<td>Map unit description</td>
</tr>
<tr>
<td></td>
<td>Soil interpretations</td>
</tr>
<tr>
<td>Building Site Development</td>
<td>Dwellings and small commercial buildings</td>
</tr>
<tr>
<td></td>
<td>Roads/streets, shallow excavations, lawns and landscaping</td>
</tr>
<tr>
<td>Construction Materials</td>
<td>Source for sand and gravel</td>
</tr>
<tr>
<td>Land Classifications</td>
<td>Conservation tree and shrub suitability groups</td>
</tr>
<tr>
<td></td>
<td>Hydric soils</td>
</tr>
<tr>
<td></td>
<td>Land capability classifications</td>
</tr>
<tr>
<td></td>
<td>Prime and important farmland</td>
</tr>
<tr>
<td></td>
<td>Taxonomic classification of soils</td>
</tr>
<tr>
<td>Land Management</td>
<td>Rangeland fencing, resistance to fugitive dust</td>
</tr>
<tr>
<td></td>
<td>Rangeland site description and fire damage susceptibility</td>
</tr>
<tr>
<td></td>
<td>Rangeland tillage, compaction resistance and soil restoration</td>
</tr>
<tr>
<td>Sanitary Facilities</td>
<td>Sewage disposal (e.g., septic systems and sewage lagoons)</td>
</tr>
<tr>
<td>Soil Chemical Properties</td>
<td>Cation exchange capacity (CEC), pH, lime (CaCO₃), gypsum, salinity, and sodium adsorption ratio (SAR)</td>
</tr>
<tr>
<td>Soil Erosion</td>
<td>Attributes for RUSLE2 equation (estimate soil erosion rates)</td>
</tr>
<tr>
<td></td>
<td>Windbreaks and environmental plantings</td>
</tr>
<tr>
<td>Soil Physical Properties</td>
<td>Engineering soil properties, particle size and coarse fragment content, % sand, % silt, % clay, bulk density, saturated hydraulic conductivity, plant available water holding capacity, % organic matter, erosion factors, linear extensibility (shrink/swell), wind erodibility group and index</td>
</tr>
<tr>
<td>Soil Qualities and Features</td>
<td>Restrictive layers (depth and type), frost action, corrosion (steel and concrete)</td>
</tr>
<tr>
<td>Vegetative Productivity</td>
<td>Crop yields for major and adapted crops (e.g., alfalfa hay, barley, bromegrass hay, bromegrass alfalfa hay, corn, corn silage, grain sorghum, oats, soybeans, spring wheat, sunflowers, and winter wheat)</td>
</tr>
<tr>
<td></td>
<td>Rangeland productivity and plant composition</td>
</tr>
<tr>
<td>Waste Management</td>
<td>Agricultural disposal of manure, food processing waste, and sewage sludge</td>
</tr>
<tr>
<td></td>
<td>Large animal carcass disposal</td>
</tr>
<tr>
<td>Water Features</td>
<td>Hydrologic group, surface runoff, water table (depth and duration), flooding (duration and frequency), ponding (duration and frequency)</td>
</tr>
<tr>
<td>Water Management</td>
<td>Irrigation (general, sprinkler, surface)</td>
</tr>
<tr>
<td></td>
<td>Ponds (reservoirs and aquifer-fed excavated ponds) and Embankments (dikes, levees)</td>
</tr>
</tbody>
</table>

*Please note that not all WSS (Web Soil Survey) Properties and Qualities categories or all options within a category are listed in this table. Some items listed in this table may not be available in all counties and different items of local importance may be present.*
Step 3. Creation of Custom Soil Survey Report for AOI

The table and maps can be converted to a customized report by clicking on the Add to Shopping Cart Tab, at the top center of the Web page (Fig. 19.19). This option allows you to create your own AOI customized detailed soil survey report. Review the Report Properties and report Table of Contents and make any additions or deletions you may need. When you are satisfied with the information in the Report Properties and the Report Table of Contents select the Check Out tab (upper right-hand corner of window).

For small reports (< 8 MB) a Check Out Options box will appear and you will have the option to receive the report online during the current WSS session or having the report sent by email (receipt within 24 hours) to you. The report (Fig. 19.20) is in pdf format and requires the current version of Adobe Acrobat Reader to open the file. http://get.adobe.com/reader/

![Figure 19.18. Sample WSS Soil Data Explorer window Soil Reports Table. Example created based on Figure 19.17. Yields are long-term yields with average management and average weather conditions. (Malo, 2012)](image)

**Use and limitation of Web Soil Survey (WSS) information**

WSS provides information that can be used to predict how sites differ under various land management systems. Examination of key soil properties and quality attribute information aids the user in making key planting, fertility, pest management, water/erosion conservation, tillage, and other crop-related management decisions. Along with site-specific data, management efficiency can be improved (Reitsma and Malo, 2011).

One key point to remember is that the soil maps in WSS were originally prepared at a scale of 1:20,000 and 1:24,000 for most of South Dakota. As a result, the smallest delineation that can be shown is about two acres. Most soil mapping unit descriptions include descriptions of these inclusions to let the user know that these other soils exist in the soil mapping unit. This limitation can be minimized by careful ground scouting.
Figure 19.19. Sample WSS (Web Soil Survey) Soil Shopping Cart window with the Check Out tab selected (upper right-hand corner). (Malo, 2012)

Figure 19.20. Sample WSS (Web Soil Survey) Report window. Report can be saved on your computer in pdf format for later use. (Malo, 2012)
**Hydric Soil Lists**

Another source of information for identifying IDC susceptibility is the hydric soil list. Hydric soils information can be obtained from the NRCS (Natural Resources Conservation Service) web site at [http://soils.usda.gov/use/hydric/](http://soils.usda.gov/use/hydric/) [verified October, 2012]. Hydric soils are soils which are wet enough (saturation, flooding, or ponding) long enough (at least 7 days) in the upper soil profile [6 (sandy textures) to 12 inches (15 to 30 cm) (loams and fine textures) to develop anaerobic conditions during the growing season (soil temperatures >41º F (5ºC) at the 22 inches (50 cm) soil depth)].

Hydric soil mapping units contain either major or minor hydric components. One needs to remember that some soil mapping units included on the list may have only 1 or 2% hydric soils present. The list is useful in identifying soil mapping units that may have hydric soils present but detailed on-site inspection is needed to verify and locate those soils with wetness problems. To obtain a hydric soil list:

2. Press the Select State button and scroll to find your state (e.g., SD, Fig. 19.22).
3. Select the County for which you need information (e.g., Minnehaha County, Fig. 19.23). Press the Select Survey Area button.
4. Press the Generate Reports button to create available reports for the selected county (Fig. 19.24).
5. A listing of all the soil mapping units appears along with a drop down box where you select the report(s) you would like for the county. For an entire county’s information press the Select All button and then all the soil mapping units for that county are highlighted (Fig. 19.25).
6. Check the Include Minor Soils and Include Description boxes and then press the Generate Report Button (Fig. 19.26) and the Hydric Report for the County is prepared (Fig. 19.27).
7. The hydric soil list shows:
   a. Soil map unit name.
   b. The hydric component of the soil mapping unit and its % of the soil mapping unit.
   c. The landscape location for the hydric soil.
   d. Hydric rating.
   e. Hydric criteria the soil meets (found at the end of the report; must check Include Description so that the hydric criteria are listed with the report).
### Figure 19.22. Step 1 – State selection (scroll through drop-down list to highlight your state) and press the Select County button.

http://soildatamart.nrcs.usda.gov/ (Verified October 2012)

### Figure 19.23. Step 2 – County selection (scroll through the drop-down box list to highlight the county of interest) and press the Select Survey Area button.

http://soildatamart.nrcs.usda.gov/ (Verified October 2012)

### Figure 19.24. Step 3 – Generate the list of county reports available (press Generate Reports button).

http://soildatamart.nrcs.usda.gov/ (Verified October 2012)
Figure 19.25. Step 4 – All soil mapping units are selected (press the Select All button) and the Hydric Soils report is selected from the drop-down box in the middle of the page. http://soildatamart.nrcs.usda.gov/ (Verified October 2012)

### Hydric Soils

Minnehaha County, South Dakota

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Component</th>
<th>Percent of Map Unit</th>
<th>Landform</th>
<th>Hydric Rating</th>
<th>Hydric Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>AaA:</td>
<td>Whitewood</td>
<td>5</td>
<td>Drainageways, Plains</td>
<td>Yes</td>
<td>2A</td>
</tr>
<tr>
<td>Ar:</td>
<td>Arlo, undrained</td>
<td>80</td>
<td>Flood plains</td>
<td>Yes</td>
<td>2B3</td>
</tr>
<tr>
<td></td>
<td>Lamo</td>
<td>3</td>
<td>Flood plains</td>
<td>Yes</td>
<td>2A</td>
</tr>
<tr>
<td>Bb:</td>
<td>Baltic, undrained</td>
<td>90</td>
<td>Potholes, Till plains</td>
<td>Yes</td>
<td>2B3, 3</td>
</tr>
<tr>
<td></td>
<td>Worthing</td>
<td>7</td>
<td>Potholes, Till plains</td>
<td>Yes</td>
<td>2B3, 3</td>
</tr>
<tr>
<td>Bo:</td>
<td>Baltic, ponded</td>
<td>90</td>
<td>Potholes, Till plains</td>
<td>Yes</td>
<td>2B3, 3</td>
</tr>
<tr>
<td></td>
<td>Worthing</td>
<td>7</td>
<td>Potholes, Till plains</td>
<td>Yes</td>
<td>2B3, 3</td>
</tr>
<tr>
<td>B1B:</td>
<td>Chancellor</td>
<td>5</td>
<td>Drainageways, Terraces</td>
<td>Yes</td>
<td>2A</td>
</tr>
<tr>
<td>B1E:</td>
<td>Worthing</td>
<td>1</td>
<td>Moraines, Potholes</td>
<td>Yes</td>
<td>2B3, 3</td>
</tr>
<tr>
<td>Bo:</td>
<td>Lamo</td>
<td>4</td>
<td>Flood plains</td>
<td>Yes</td>
<td>2A</td>
</tr>
<tr>
<td>Cb:</td>
<td>Chancellor</td>
<td>50</td>
<td>Drainageways, Till plains</td>
<td>Yes</td>
<td>2A</td>
</tr>
<tr>
<td></td>
<td>Tetonka</td>
<td>6</td>
<td>Closed depressions, Till plains</td>
<td>Yes</td>
<td>2B3, 3</td>
</tr>
<tr>
<td></td>
<td>Lamo, undrained</td>
<td>4</td>
<td>Flood plains</td>
<td>Yes</td>
<td>2B3</td>
</tr>
<tr>
<td></td>
<td>Saino</td>
<td>3</td>
<td>Flood plains</td>
<td>Yes</td>
<td>2B3</td>
</tr>
<tr>
<td>Cc:</td>
<td>Chancellor</td>
<td>50</td>
<td>Drainageways, Till plains</td>
<td>Yes</td>
<td>2A</td>
</tr>
<tr>
<td></td>
<td>Tetonka</td>
<td>30</td>
<td>Closed depressions, Till plains</td>
<td>Yes</td>
<td>2B3, 3</td>
</tr>
<tr>
<td></td>
<td>Worthing</td>
<td>7</td>
<td>Potholes, Till plains</td>
<td>Yes</td>
<td>2B3, 3</td>
</tr>
<tr>
<td></td>
<td>Saino</td>
<td>5</td>
<td>Flood plains</td>
<td>Yes</td>
<td>2B3</td>
</tr>
</tbody>
</table>

Soil Test Results

Soil tests on the soil you plan to use for soybean production provide valuable information on key soil properties related to IDC. Soil test results are only as accurate as the soil samples taken. Soil tests should be used to provide actual soil data for key management decisions. Utilize the Web Soil Survey maps and on-site inspection to determine where to sample for potential IDC problems. Be careful to sample the problem areas separate from the rest of the field.

Most soil testing labs will routinely provide soil pH, salinity, texture, P, and nitrate N levels. Some soil testing labs will analyze for nutrients like Fe, Cu, Mn, Zn, and Mo. These soil tests and determinations can be used to make key soybean management decisions.

As indicated in Part B of this chapter, soil pH values > 7 will cause a reduction of iron availability and thus a high pH tolerant soybean variety should be considered. Soils with high nitrites can induce IDC because of Fe being tied up with the bicarbonate ion released by the plant for NO$_3^-$ uptake. Soils with high nitrate levels may need a cover crop in the rotation to take up the nitrate and reduce the severity of IDC.

Ammnium (NH$_4^+$) based fertilizers could also be used to lower pH and increase iron availability. Soils with high P, Mn, Cu, Zn, and Mo can tie up Fe and cause IDC. One ratio used to predict potential IDC is the ratio of Fe:Mn+Cu (Havlin et al., 2005). As this ratio decreases, the IDC potential increases. One needs to check the soil test results to determine what soil parameter is causing the IDC and then select a proper management plan to implement to reduce the IDC potential or problem.

Soil Taxonomy

A fourth important source of information for identifying and locating IDC soils is Soil Taxonomy (soil classification). Soil Taxonomy is based on observable and definable soil properties and as a result one can use soil classification to identify soils that have properties. Listed below (Table 19.5) are soil classification terms that relate to the key soil properties identified in the Soil and Plant Factors (Section B) of this chapter.

Table 19.5. Soil taxonomic terms indicating potential problems which may induce iron deficiency chlorosis (IDC) in soybeans.

<table>
<thead>
<tr>
<th>Term</th>
<th>Letter Code*</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>aquic</td>
<td>aqu</td>
<td>Soil has periods of saturation (waterlogged) and reduction close to the soil surface (usually within 40 cm [16 in]).</td>
</tr>
<tr>
<td>calcic</td>
<td>calc</td>
<td>Soil has calcareous soil material at or near the soil surface and has a calcic horizon near the soil surface (within 100 cm [39 in]).</td>
</tr>
<tr>
<td>natric</td>
<td>natr</td>
<td>Soil has a natric (sodium, Na$^+$, affected) horizon in the soil profile resulting in high soil pH values and reduced permeability.</td>
</tr>
<tr>
<td>alpic</td>
<td>alb</td>
<td>Used with Mollisols (prairie derived soil) containing an albic horizon (E horizon, light-colored horizon near, usually within 40 cm [16 in], the soil surface). Usually found in wetlands with aquic conditions.</td>
</tr>
</tbody>
</table>

* If this letter code appears anywhere in the soil classification then that soil has the potential for causing IDC and more detailed lab and field tests, including on-site inspection with a soil scientist, are needed to check for possible IDC problems. (USDA-NRCS, 1999)
To obtain the classification of your soil, you can get that information from Web Soil Survey, from your county soil survey report, or—if you know the name of your soil—you can get the soil classification from the Official Soil Series web site. Shown below is how one could obtain the soil classification for a soil series.

http://soils.usda.gov/technical/classification/osd/index.html

**Obtaining soil classification information using the Soil Series**

After obtaining the name of the soil(s) where you plan to seed soybeans, go to the NRCS Official Soil Series Web Site (Fig. 19.28). Select the “View OSD by Series Name” option, shown by arrow on Figure 19.28. The next window (Fig. 19.29) will appear and you will need to type the name of the soil series in the text box as on the left-hand side of the page (see the arrow with the Tonka soil entered as an example).

After entering the name, press the "Find Series" Button (found under the soil name box). The classification information for the soil is then displayed in the next window (Fig 19.30). One can then look at the classification name and see if any of the letter codes listed in Table 19.5 are present in the soils of your field.

If one or more of the letter codes are present, there is a good chance that there is a potential for iron chlorosis in soybeans under normal environmental conditions. In this example, both “alb” and “aqu” are present so the Tonka soil has a wetness problem close to the soil surface. If you desire additional information on the named soil series, you can select the view description or view extent map or contract your local extension educator/specialist, the land-grant agricultural experiment station research scientists, and NRCS personnel.

**Summary**

Iron chlorosis may be a major limiting factor for soybean production in your fields. Information provided in **Part A, Why Iron (Fe) Is Important to Soybeans** of this chapter describes how and why iron is important. **The Soil and Plant Factor Section (Part B)** describes soil factors creating iron deficiencies, such as poor drainage, high-water tables, high soil calcium carbonate levels, slope, parent material composition, high soil pH and nutrient availability.

The rest of the chapter (Part C) is devoted to obtaining the knowledge of key soil properties present in your field allows you to enhance soybean production and minimize IDC impacts by using resources available through a number of websites. This knowledge is readily available to producers through online sources, through your local extension educator and specialists, the land-grant agricultural experiment station research scientists, and NRCS personnel.

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**Figure 19.28. Opening page of the NRCS (Natural Resources Conservation Service) Official Series Description home page. Arrow shows category to select when you have the soil series name.**

(Source: http://soils.usda.gov/technical/classification/osd/index.html) (Verified October 2012)
Figure 19.29. View by Name page in the NRCS (Natural Resources Conservation Service) Official Soil Series Descriptions web site. Arrow shows where to enter the name of the soil for which you want soil classification information. (Source: http://soils.usda.gov/technical/classification/osd/index.html) (Verified October 2012).

Figure 19.30. Soil Classification Information page for the Tonka Soil from the NRCS (Natural Resources Conservation Service) Official Series Description home page. Arrow shows the classification information for the soil selected. (Source: http://soils.usda.gov/technical/classification/osd/index.html) (Verified October 2012).
References and additional information


Acknowledgements
Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program

Abbreviations used in this chapter

AES = Agricultural Experiment Station
AOI = area of interest in WSS
B = boron
bu = bushels, bu/a = bushels per acre
C = carbon
Ca = calcium
CaCO$_3$ = calcium carbonate
CEC = cation exchange capacity
Cl = chlorine
cm = centimeters
Co = cobalt
CO$_3^{2-}$ = carbonate ion
Cu = copper
dS/m = decisiemens/meter
e$^-$ = electron
EC = electrical conductivity
Fe = iron
Fe$^{2+}$ = ferrous form of Fe
Fe$^{3+}$ = ferric form of Fe
H = hydrogen
ha = hectare
HCO$_3^-$ = bicarbonate ion
IDC = iron deficiency chlorosis
in = inches
K = potassium
K = soil erodibility factor used in soil erosion estimates
K$_{smt}$ = soil saturated hydraulic conductivity
kg = kilogram; kg/ha = kilogram per hectare
lbs = pounds; lbs/a = pounds per acre
MB = megabyte
Mg = magnesium
MgCO$_3$ = magnesium carbonate
Mn = manganese
Mo = molybdenum
MU = soil mapping unit in WSS
N = nitrogen
Ni = nickel
NO$_3^-$ = nitrate ion
NRCS = Natural Resources Conservation Service
O = oxygen
P = phosphorus
pdf = portable document format
pH = soil acidity level, negative log of the H$^+$ concentration
Soil Sampling for Precision Phosphorus Soybean Management

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Precision farming attempts to increase profitability by better matching solutions to problems. Precision farming information can be collected using number of approaches that include adopting improved soil sampling techniques, routine scouting of your field, conducting on-farm research designed to identify your yield-limiting factors, and using a combine equipped with a yield monitor to harvest your field.

We believe that precision farming starts by determining what is limiting your yield. Precision farming may or may not result in variable rate fertilizer applications. The purpose of this chapter is to provide guidance on how to use precision soil sampling for improved P management. Fields with Bray-1 P concentrations ranging from 14 to 22 ppm may produce the greatest economic return from precision P management. Olsen P values will be slightly lower.

**Precision soil sampling approaches**

Precision farming will not increase soybean yields in all fields. In South Dakota soybean production, the nutrients that routinely limit yield are Fe and P. Information on managing Fe deficiencies are provided in Chapters 19 and 26.

To better understand P management, it is important to understand that P and N have fundamental differences. These differences provide opportunities to increase corn and soybean profitability. One difference between these nutrients is that P stays where it is placed and generally does not leach, whereas nitrate is
subject to leaching in the soil profile. A second difference is that soybeans have the capacity to convert atmospheric N\textsubscript{2} to plant N (N fixation). Due to this capacity, N-based fertilizers generally are not applied to soybean fields.

We believe that the greatest opportunity to increase profitability with precision P management is when the whole field soil Bray-1 P concentrations range from 14 to 22 ppm. This opportunity exists because research shows that 60\% to 70\% of a field has a soil test value lower than the soil test value in the composite sample (Chapter 25). If the field composite P concentration is lower than 14 ppm, the entire field will receive some P fertilizer when seeded to corn and the percentage of the field not requiring P is relatively small. If the Bray-1 composite soil test value is greater than 22 ppm, it is likely that the percentage of the field requiring P for soybean production is relatively small. The higher the soil test value, the lower the percentage of the field requiring P.

Precision P management can be implemented using many different sampling schemes (Fig. 20.1). Whole field sampling may be appropriate when yield is consistent over the entire area, or if little or few differences occur in soil properties. However, more information can be gained if precision sampling techniques are employed. Different strategies can be implemented depending on the amount of field variation present, amount of labor available, or other factors.
In grid-cell sampling, the field is split into zones where a single composite soil sample is collected for each zone. This composite sample represents the entire zone. Zones generally are rectangular in shape and the sample is collected randomly from the entire area. If the field contains old homesteads or animal confinement areas, these zones should be separated from the rest of the field. The zones can be any size and they can be different for different parts of the field. This technique is easy to implement, well suited for today’s equipment, and does not require extensive training to develop a variable rate fertilizer application map.

One of the most commonly used techniques for collecting precision soil nutrient information is grid point sampling. In this technique, samples are collected at specified grid points. The grid points should be offset and their locations should be marked with a differentially corrected GPS. If samples are collected on a 100 x 100 ft grid (30 x 30 m), then approximately 676 samples are collected from a 160-acre field (65 ha).

Grid point sampling has been very useful in fields where prior management has changed the soil nutrient levels and in fields where several smaller fields have been merged into a larger field. At each grid point, “Good” sampling protocol should be followed (Chapter 18). While providing high resolution to the samples, drawbacks to this sampling scheme are labor and analysis costs. A 200 x 200 ft grid design (60 x 60 m) results in about 175 samples in a 160/A field, requiring less time and less analysis, but also less spatial resolution.

In soil type-based sampling, soil samples are collected from each soil. Most published soil surveys are Order 2 soil surveys. In many fields, Order 2 soil surveys-based sampling has not reduced fertilizer application errors. Order 2 soil surveys may be improved by using experiences, visual observations, and analysis from soil samples (Fleming et al., 1999; Mount, 2001).

Management zone sampling is an approach where the field is split into zones based on soil and crop variability. This approach has value if the different data layers show consistent patterns. Management zones can be developed based on apparent electrical conductivity, yield monitor data sets, remote sensing, historic records, field scouting, and personal preferences. In this approach, computer classification of the various data layers is used to identify management zones. Geographic information systems software (GIS) is routinely

### Table 20.1. Sampling approach and the skill required to implement them.

<table>
<thead>
<tr>
<th>Sampling Approach</th>
<th>Protocols</th>
<th>Skill Sampling</th>
<th>Required Interpretation</th>
<th>Reduction in Fertilizer Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole field sampling</td>
<td>Follow “good” protocols for collecting samples (Chapter 18). Do not collect composite samples from entrances or old homesteads.</td>
<td>Moderate to high</td>
<td>Low</td>
<td>Low to moderate</td>
</tr>
<tr>
<td>Grid cell</td>
<td>Samples are randomly collected from predetermined cells.</td>
<td>Low</td>
<td>Low</td>
<td>Moderate to high</td>
</tr>
<tr>
<td>Grid point</td>
<td>Use an offset pattern to collect 10 to 15 cores located 8 to 10 feet (2.5 to 3m) from the grid point center. The location of this point should be determined with GPS.</td>
<td>Low</td>
<td>High</td>
<td>Moderate to high</td>
</tr>
<tr>
<td>Soil type</td>
<td>Composite soil samples collected from NRCS defined soil map.</td>
<td>Moderate to high</td>
<td>Moderate</td>
<td>Low to moderate</td>
</tr>
<tr>
<td>Management zone</td>
<td>Soil samples collected from management zones.</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate to high</td>
</tr>
<tr>
<td>Sampling old homesteads separately from the rest of the field</td>
<td>Locate old homesteads on old USDA-NRCS photos and sample the homesteads separately from the rest of the field.</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate to high</td>
</tr>
</tbody>
</table>
used to process the data. Free software for conducting this analysis is available at http://www.umac.org/, and http://www.ars.usda.gov/is/ar/archive/aug03/zones0803.htm.

Once a zone is identified, a single composite sample, containing 15 to 20 individual cores per sampling area, should be collected. Good sampling protocols should be followed when collecting this sample (Chapter 18). This approach is not recommended for fields with recent manure application histories.

**The first step in precision soil sampling**

There are numerous soil nutrient maps that demonstrate that events that occurred over 50 years ago still impact soil nutrient levels today (Fig. 20.2). Site-specific sampling will help locate these areas. Accounting for this variability is critical for developing accurate recommendations today. For example, including a subsample from an old homestead in a whole field sample increases the soil test value and reduces the fertilizer recommendation. Old homesteads are routinely located near field entrances.

**The second step in precision soil sampling**

Start your program in fields with the greatest potential to produce an economic response. Three candidates that have the "good" likelihood of producing an economic returned include: 1) CRP land being converted back to crop production; 2) newly tile-drained fields; and 3) fields with a Bray-1 soil test P value ranging from 13 to 22 ppm. These topics are discussed in Chapter 26.

**Selecting a sampling protocol**

A one-size fits all sampling protocol is not available or recommended. To maximize the return of your investment, a different sampling protocol may be selected for each field. Information that you can use to make this decision is cost, amount of yield variability, expected return, and prior management (Table 20.1). A return on your precision farming investment is not guaranteed. The different soil sampling approaches have different investment requirements. Higher skill level means higher costs.

**Understanding the causes of your yield variability**

Soybean yield variability is caused by many factors (Fig. 20.3). In many fields the dominant limiting factor is water. Summit/shoulder areas can have yields reduced 50 to 60% by water stress. Water stress can impact the plants’ ability to control other pests. Recent research conducted in corn showed that water stressed corn plants down-regulated their ability to utilize nutrients and control pests. Research is being conducted.
to develop management practices for drought conditions. Currently our recommendation for these areas is careful management and proactive treatments.

Assessing your fertility program

A detailed program for assessing your soil fertility program is provided in Chapter 17. Soil nutrient contour maps can be used to track the effectiveness of your fertility program. A goal of your P program might be to gradually increase the P level in deficient areas and lower the P concentration in very high P areas. To make this assessment, areas with low and high nutrient concentrations should be sampled every two to four years.

Storing data

Precision farming helps convert current and historic information into increased profits. This information may have been collected over many years by many people. To make sense of this information, the yield data and associated cultural practices must be available. This is a very difficult problem that we have been concerned about for many years. Several possible choices are available:

- Store hard copies of all data.
- Save hard copies of critical information and summary reports.
- Use a data management company.
- Routinely update data to current data storage formats.

In summary, fields are a mosaic of habitats, each having unique characteristics that influence soil properties and crop yields. The effectiveness of matching solutions to problems rests on the ability to identify problems, characterize the site, and develop appropriate solutions. To conduct an assessment of a field’s fertility program, regular soil samples should be collected from targeted locations. This information needs to be stored for future use. Precision soil sampling can be used for many purposes including improving your understanding of your field and increasing profits. Precision farming by itself does not guarantee a return for your investment. Your return depends on how you use the information gathered through precision farming.

Figure 20.3. Soybean yield variability in a field located in east central South Dakota. (D.E. Clay, SDSU, 2013)
References and additional information


Acknowledgements
Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

Within the corn-followed-by-soybean rotation, N and P fertilizers are routinely applied. In many fields, enough N and P for both corn and soybeans are applied when corn is grown. The selection of the fertilizer source is dependent on producer preferences and available equipment, costs, fertilize efficiency, and availability. Fertilizers are routinely applied to optimize soybean yields. The purpose of this chapter is to discuss the different types of commercial fertilizers that are available. Rules of thumb are provided in Table 21.1.

### Application techniques

Fertilizers are applied to corn and soybeans using many different approaches. For example, fertilizers can be applied as seed treatment, as a popup fertilizer, in a band near the row or as a broadcast application. Each approach has strengths and weaknesses (McCauley et al., 2009). When applying fertilizer as popup, it is important to remember that soybean seed is much more sensitive to salt injury than corn seed.

For seed treatments, a small amount of fertilizer is mixed and applied to the seed prior to seeding. For soybeans, iron (Fe) deficiency chlorosis (IDC) yield losses in calcareous soils (high pH) can be reduced by seed-treating with Fe chelated EDDHA (Chapter 26).
Starter fertilizer, or popup fertilizer, is placed with or near the seed at planting to speed up seedling emergence. Starter fertilizers may be most useful in cold wet soils, but caution must be used because applying too much starter can inhibit soybean seed germination (Hergert and Wortmann, 2006). When using starter fertilizer, check the metering equipment to make sure it’s working. Maximum popup fertilizer rates for soybean are much lower (1/2) than corn. Starter fertilizers should not be confused with band placement or applying nutrient to overcome nutrient deficiencies. Band placement can promote early growth and provide the nutrients needed to optimize growth. Broadcast applications generally are surface applied. Different fertilizers are better suited for different application techniques.

### Table 21.2. Common fertilizers applied to soils in South Dakota.

<table>
<thead>
<tr>
<th></th>
<th>N %</th>
<th>P₂O₅ %</th>
<th>K₂O %</th>
<th>Density lbs/gal</th>
<th>S %</th>
<th>Cl %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solid fertilizers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>33</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Di-ammonium phosphate (DAP)</td>
<td>18-21</td>
<td>46-53</td>
<td>0</td>
<td>0-1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mono-ammonium phosphate (MAP)</td>
<td>11-13</td>
<td>48-55</td>
<td>0</td>
<td>0-1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium chloride (KCl)</td>
<td>0</td>
<td>0</td>
<td>62</td>
<td>47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium nitrate (KNO₃)</td>
<td>13</td>
<td>0</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea (NH₄)₂CO</td>
<td>46</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrophosphates (Many products are available)</td>
<td>21</td>
<td>7</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triple superphosphate</td>
<td>28</td>
<td>14</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elemental S</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium Sulfate (NH₄)₂SO₄</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gypsum CaSO₄</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Liquid fertilizers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea-ammonium-nitrate (UAN)</td>
<td>28-32</td>
<td>0</td>
<td>0</td>
<td>10.6-11.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium polyphosphate</td>
<td>10</td>
<td>34</td>
<td>0</td>
<td>11.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>37</td>
<td>0</td>
<td>11.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thiosulphates: ATS, (NH₄)₂S₂O₃</td>
<td>12</td>
<td>0</td>
<td>11.2</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KTS, K₂S₂O₃</td>
<td>0</td>
<td>25</td>
<td>0</td>
<td>12.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gas fertilizer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anhydrous ammonia</td>
<td>82</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Seed treatment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe-EDDHA (dry)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6%</td>
<td></td>
</tr>
</tbody>
</table>

**Sources**

Liquid, solid, and gas fertilizer can be used to return nutrients to the field (Table 21.2). When selecting the fertilizer materials, prices, nutrient concentrations and amounts, potential losses, and special handling requirements should be considered. Each fertilizer type has individual requirements and may require slightly different calculations. For example, liquid and dry fertilizers can be applied to the soil surface while gas fertilizers need to be injected into the soil.

All fertilizers are characterized by their grade. In the U.S., the grade provides information relative to the percentage of N, P₂O₅, and K₂O (shorthand for nitrogen, phosphorus and potassium fertilizers) contained in the material (Table 21.2). Examples for converting P₂O₅ to P or K₂O to K and a discussion of fertilizers on soil pH are provided in McCauley et al. (2009).
Liquid fertilizers are also characterized by their density, or concentration (lbs/gal). Different fertilizers are better suited for different applications. For example, liquid urea ammonia nitrate (UAN) is well suited for in-season N application, while anhydrous ammonia is well suited for cultivated land. A rule of thumb for UAN (28-0-0) is that one gallon of fertilizer contains three lbs of N. When working with liquid fertilizers, the density is used to convert gallons to lbs or lbs to gallons. All fertilizers should be applied following protocols that minimize losses.

**Chelated Fe**

Research conducted across the U.S. North Central region suggests that iron deficiency chlorosis (IDC) yield losses in calcareous soils can be reduced by seed treating with Fe chelated EDDHA (Chapter 26). In some situations, yields can be increased even if tolerant cultivars are seeded. The fertilizer rate depends on the degree of iron deficiency, but most data suggest that the rate should between 1 to 4 lbs product per acre (Ferguson et al., 2006).

Fe-EDDHA is a dry product that can be mixed with water prior to seed treatment (Ferguson et al., 2006). Products are being marketed as soygreen (http://www.westcentralinc.com/Product/Soygreen.aspx) and ironworks (http://www.fertilizerandchemicals.com/ironworks.html). Both products are relatively inexpensive and contain approximately 6% iron that is chelated with Fe-EDDHA.

**Phosphorus Fertilizers**

The production of most commercial phosphate fertilizers begins with the conversion of rock phosphates to phosphoric acid. The phosphoric acid is heated, driving off the water, to produce superphosphoric acid. Ammonia is then added to superphosphoric acid to create the liquid, 10-34-0, which can be mixed with a finely ground potash (0-0-62), water, and urea-ammonium nitrate solution (28-0-0) to form many different grades. When ammonia is added to the phosphoric acid that has not been heated, mono-ammonium phosphate (11-52-0) or di-ammonium phosphate (18-46-0) is produced, depending upon the ratio of the mixture.

It is important to consider that P fertilizers are produced from rock phosphate, which is mined. These resources, like oil, are limited. Table 21.3 presents guidance for the use the P fertilizers. The United States is one of the leading producers of apatite (calcium phosphate minerals).


Plant available P consists of water and citrate soluble P. Water soluble P is the P solubilized in water, while citrate soluble P is the amount of non-water solubilized P that is solubilized when placed in citrate. Fertilizer can also contain polyphosphate and orthophosphate forms. Polyphosphate is produced by heating orthophosphate to remove the water. This process converts 40 to 60% of the ortho-P to poly-P.

**Mono-ammonium phosphate (MAP)**

MAP fertilizer grades range from 11-13 for N and 48-55 for $P_2O_5$. MAP [$\left(\text{NH}_4\right)_2\text{HPO}_4$], if pure, would have a fertilizer grade of 12.2-61.7-0. MAP contains less ammonia than DAP, making it a preferred popup fertilizer. http://www.ipni.net/specifcs

Depending on the manufacturing process, MAP may contain some S.


**Di-ammonium phosphate (DAP)**

The fertilizer grade of DAP can range from 18-21 for N% and 46-53% for $P_2O_5$. DAP [$\left(\text{NH}_4\right)_2\text{HPO}_4$], if pure, would have a grade of 21.2% N and 53.8% $P_2O_5$. Information about DAP is available at http://www.ipni.net/specifcs. Depending on the manufacturing process DAP may contain some S.

**Polyphosphates**

Polyphosphates contain both orthophosphate and polyphosphate. Two common ammonium polyphosphate fertilizers have N-P₂O₅-K₂O composition of 10-34-0 or 11-37-0. These liquid fertilizers do not require special handling and storage; however, equipment should be made of resistant materials.

http://www.fluidfertilizer.com/newsletters/fertilizer_newsletter2.html

To minimize problems, storage over the summer should be minimized. 10-34-0 is not compatible with Aqua or Anhydrous Ammonia.

http://www.liquidproducts.net/SpecSheets/10-34-0_spec_shet.pdf

10-34-0 can be sprayed on to the soil surface and incorporated into the soil. The salting out temperature, separation of liquid and solid components, for 10-34-0 and 11-37-0 are 0° and 32°, respectively.

http://www.fluidfertilizer.com/newsletters/fertilizer_newsletter2.html

**Nitrophosphates**

This material is produced by reacting phosphate rock with nitric acid. The products are phosphoric acid and calcium nitrate. Information about this project are available at http://www.ipni.net/specifs. Depending on your needs, a range of products are available. This product absorbs moisture and should be stored accordingly.

**Table 21.3. Rules of Thumb for P Fertilizers.**

• MAP and DAP have very high water solubilities.
• Manure can add a significant amount of P to the soil. Generally P from organic sources is slightly less available when compared to dry or liquid fertilizers. In the year following manure applications, 60 to 80% of the P will be available to the plant.
• Ortho or polyphosphate fertilizers are produced by removing the water from phosphoric acid.
  ➤ The resulting products will contain approximately 40 to 60% orthophosphate with the remaining portion in the polyphosphate form.
  ➤ Examples of fertilizers containing orthophosphates (H₃PO₄) are MAP and DAP.
  ➤ Polyphosphates have the chemical formula H₄P₂O₁₀. A fertilizer that contains polyphosphates is 10-34-0.
  ➤ Ortho and polyphosphates are generally considered equally available.

Pink or red to white. White potash is often higher in analysis. One of the advantages of potash is that it provides chlorine. This material should be stored in a dry location. Heat or cold will have little effect on this fertilizer. KCl can be blended safely with both N and P fertilizer to make grades such as 10-30-10, 8-24-24, or 13-13-13. KCl is readily soluble in water and can be applied as a liquid fertilizer.

http://www.ipni.net/specifs

**Potassium sulfate**

Potassium sulfate can be used to apply both K and S. The K₂O content of this fertilizer ranges from 48 to 53%, while the S ranges from 17 to 18%. This fertilizer can be applied when additional Cl is undesirable. The salting effect per unit K of K₂SO₄ is less than KCl. http://www.ipni.net/specifs
Nitrogen Fertilizers

N fertilizers generally are not recommended for soybeans. The source of N in most fertilizers is the air. In the manufacturing of N fertilizers, atmospheric N\textsubscript{2} is combined with H from natural gas to form anhydrous ammonia (NH\textsubscript{3}), which has a grade of 82-0-0. Producing anhydrous ammonia requires a large amount of energy. For example, the amount of energy required to produce 5 lbs of ammonia fertilizer is approximately equivalent to the energy contained in a gallon of gasoline. Anhydrous ammonia can be used to produce a variety of N products. All ammonia-based products slowly reduce soil pH.

Urea

Urea is commonly purchased as a solid fertilizer with a grade 46-0-0. To minimize volatilization losses, urea must be incorporated into the soil. Urea is a neutral compound that can be moved into the soil with percolating water. After application, urea is hydrolyzed into ammonia and CO\textsubscript{2}. Ammonia can be volatilized if the urea is not incorporated. The application of urea with the seed will reduce germination; however, it can be placed in a band two inches to the side and two inches below the seed. Additional information on fertilizer placement is available in Jones and Jacobsen (2009). Urea can be blended with MAP or DAP. It should not be blended with superphosphate because it reacts with the superphosphate molecule.

Since urea does not adsorb as much water from the air as ammonium nitrate, it has fewer problems with sticking and caking. Urea should not be mixed with ammonium nitrate because, when mixed together, they absorb atmospheric water and can form a slurry. http://www.ipni.net/specifics

Ammonium nitrate

It is the only commonly used solid fertilizer that contains N in the NO\textsubscript{3} form. The chemical formula for ammonium nitrate is NH\textsubscript{4}NO\textsubscript{3}. Ammonium nitrate is considered to be a hazardous material because of its combustible and explosive properties. If ammonium nitrate comes in contact with oxidizable carbonaceous materials, such as oily substances (petroleum, diesel fuel, herbicides, pesticides, elemental S or powdered metals), they are capable making ammonium nitrate more combustible. If contaminated with any of these materials, it can become explosive. Because ammonium nitrate absorbs water from the air, it should be stored carefully.

Anhydrous ammonia

Anhydrous ammonia (NH\textsubscript{3}) is one of most inexpensive, commercially available N fertilizers. Injection is required for this N source. This product is a flammable and toxic alkaline gas that is stored as a liquefied gas. The fertilizer grade is 82-0-0 and its price is linked to the price of natural gas. In addition to its use as a fertilizer, it is a key ingredient in the illegal production of methamphetamine. When using this material always follow safety protocols. http://www.ipni.net/specifics

N solutions

These are liquid fertilizers with grades ranging from 28-0-0 to 32-0-0. They are mixtures of urea and ammonium nitrate. Because the solubility of UAN increases with temperature, UAN solutions are made more dilute in regions with cold winter temperatures. These solutions do not have a vapor pressure and can be sprayed or dribbled on the soil surface. 28-0-0 is nonflammable, nontoxic, and therefore is relatively safe and easy to handle, ship, and store. These fertilizers can be corrosive to some metals.

When applied to the soil, volatilization losses can occur. Volatilization losses are the highest when applied to warm high pH soils. When applied to high residue soils, N will likely be immobilized in the residue. To reduce immobilization losses, broadcast applications are not recommended in high residue soils. http://www.ipni.net/specifics
**Slow release fertilizer**

Slow release fertilizers are one approach for overcoming the need for multiple application dates. In a slow release fertilizer, only a portion of the fertilizer is immediately available. Commercially available products include ureaform (38-0-0) that is a combination of urea with formaldehyde, sulfur-coated urea (36-0-0), and isobutylidene diurea (IBDU).

**Micronutrients**

Two common S-containing liquid fertilizers are ammonium polysulfide and ammonium thiosulfate. Ammonium polysulfide is a dark red solution that contains about 20% N and 40% S. It has a density of 9.4 lbs/gal and can be mixed with anhydrous ammonia or ammonia solutions. Ammonium thiosulfate (12-0-0-26S) has a density of 11.1 lbs/gal and is compatible with aqua ammonia and UAN. This fertilizer should not be placed in contact with a seed or mixed with anhydrous ammonia or phosphoric acid. When ammonium thiosulfate is mixed with UAN, the rate that the urea is hydrolyzed (urea-N → NH₄⁺) may be slowed, which in turn can reduce N losses. [http://www.ipni.net/specifcs](http://www.ipni.net/specifcs)

**Chloride**

Chlorine can be applied with potassium chloride (0-0-60), which is 47% chlorine, ammonium chloride (NH₄Cl), calcium chloride (CaCl₂), and magnesium chloride (MgCl₂). In many situations, compound fertilizers are applied to soils. These fertilizers can provide both macro- and micro-nutrients. [http://www.ipni.net/specifcs](http://www.ipni.net/specifcs)

**Potassium chloride (KCl)**

This fertilizer is often called muriate of potash or just potash. The fertilizer provides both K and Cl. Potassium chloride is approximately 47% chlorine. Other fertilizers providing Cl⁻ are ammonium chloride (NH₄Cl), calcium chloride (CaCl₂), magnesium chloride (MgCl₂), and sodium chloride (NaCl). Potash can be either pink to white. White potash generally has a higher analysis than pink potash.

**Sulfur Fertilizers**

Sulfur-based fertilizers are used to mitigate sodic soils as well provide S to sulfur deficient crops. **Ammonium sulfate** (21-0-0-24S) is a product that provides both N and S to the plant. This material will not help mitigate sodic soils. **Elemental S** (0-0-0-90S) is made available to plants when it is transformed to sulfate ions by soil bacteria. When added to soil, this product will decrease soil pH and help mitigate sodic soils. The transformation to sulfate ions may take a year or more. **Calcium sulfate** (gypsum) (0-0-0-24S) is a neutral salt that that is used in sodic soil mitigation. **Ammonium polysulfide** [20-0-0-(40-50S)] can be directly applied to soil, applied with irrigation water or and metered into irrigation water, or mixed with ammonia solutions. Ammonia polysulfide is not completely compatible with all liquid fertilizers. **Ammonium thiosulfate** can be applied in irrigation water and it is compatible with aqua ammonia, nitrogen solutions containing ammonium nitrate, urea solutions, and most nitrogen, nitrogen-phosphate, or complete fertilizer solutions. Do not mix ammonia thiosulfate with anhydrous ammonia or acid solutions such as phosphoric acid.

**Compound Fertilizers**

A compound fertilizer contains multiple nutrients in each granule. These fertilizers differ from blends, where the fertilizers are mixed together. Compound fertilizers are often more expensive than blended fertilizers.
Blended Fertilizers

Many custom blends of N-P₂O₅-K₂O are available. Common dry blends are 20-10-10, 10-20-20, 8-32-16, and 6-24-24. With dry-blended fertilizers, segregation can occur when these materials are transferred from a bin to a truck or a truck to a bin.

Manure

Mass balance calculations show that manure returns much of the nutrients removed in the harvested grain. Different livestock handling systems are more effective than others at efficiently returning these nutrients to the soil. Average amounts of N and P₂O₅ contained in different manures are shown in Table 21.4.

Table 21.4. Amounts of N and P₂O₅ by livestock type. (Based on Lorimor and Powers, 2004)

<table>
<thead>
<tr>
<th>Type of Livestock</th>
<th>Liquid Manure Norganic</th>
<th>Liquid Manure Ninorganic</th>
<th>Solid Manure Norganic</th>
<th>Solid Manure Ninorganic</th>
<th>P₂O₅ Liquid</th>
<th>P₂O₅ Solid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb N/1000 gal</td>
<td>lb N/1000 gal</td>
<td>lbs N/ton</td>
<td>lbs N/ton</td>
<td>lbs/1000 gal</td>
<td>lbs/ton</td>
</tr>
<tr>
<td>Swine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farrowing-finish</td>
<td>12</td>
<td>16</td>
<td>8</td>
<td>8</td>
<td>24</td>
<td>7</td>
</tr>
<tr>
<td>Nursery</td>
<td>11</td>
<td>14</td>
<td>8</td>
<td>5</td>
<td>19</td>
<td>8</td>
</tr>
<tr>
<td>Farrow-feeder</td>
<td>10</td>
<td>11</td>
<td>5</td>
<td>5</td>
<td>18</td>
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<td>Dairy</td>
<td></td>
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<tr>
<td>Cow</td>
<td>25</td>
<td>6</td>
<td>8</td>
<td>2</td>
<td>15</td>
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</tr>
<tr>
<td>Heifer</td>
<td>26</td>
<td>6</td>
<td>8</td>
<td>2</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Calf</td>
<td>22</td>
<td>5</td>
<td>8</td>
<td>2</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Herd</td>
<td>25</td>
<td>6</td>
<td>7</td>
<td>2</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Beef</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Beef cow</td>
<td>13</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>Feeder calves</td>
<td>19</td>
<td>8</td>
<td>6</td>
<td>3</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>Finishing cattle</td>
<td>21</td>
<td>8</td>
<td>7</td>
<td>4</td>
<td>18</td>
<td>7</td>
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<td>Poultry</td>
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<tr>
<td>Broilers</td>
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<td>13</td>
<td>24</td>
<td>12</td>
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<td>53</td>
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<tr>
<td>Layers</td>
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<td>37</td>
<td>22</td>
<td>12</td>
<td>52</td>
<td>51</td>
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<tr>
<td>Tom turkeys</td>
<td>37</td>
<td>16</td>
<td>32</td>
<td>8</td>
<td>40</td>
<td>50</td>
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<tr>
<td>Hen turkeys</td>
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<td>20</td>
<td>32</td>
<td>8</td>
<td>38</td>
<td>50</td>
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<tr>
<td>Ducks</td>
<td>17</td>
<td>5</td>
<td>13</td>
<td>4</td>
<td>15</td>
<td>21</td>
</tr>
</tbody>
</table>
Additional references and information
Available at http://www.plantmanagementnetwork.org/crn/

Acknowledgements
Support for research activities was provided by South Dakota Soybean Research and Promotion Council USDA-AFRI, NASA, South Dakota 2010 Initiative, and North Central SARE program.

Use of Starter Fertilizers for Soybean

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Many producers routinely use starter fertilizer to stimulate early-season soybean growth (Figure 22.1). The use of starter fertilizer in soybean production has produced mixed results. Keys for using starter are provided in Table 22.1. Care must be used with starter fertilizer in soybeans because the soybean seed is much more sensitive to salt injury than the corn seed. High rates of starter fertilizer can damage seed and seedlings, reducing stands and yield. This chapter discusses the use of starter fertilizers in soybean production.

Figure 22.1. The application of starter fertilizer to a soybean field. (Photo courtesy of Montag Manufacturing, Emmetsburg, IA)
Starter fertilizer

Starter fertilizer is usually a planter-applied band placing relatively small amounts of nutrients with or near the seed. With soybeans, phosphorus (P) is generally the nutrient of concern. Fertilizer P is placed near the developing root system to stimulate early-season nutrient uptake and crop vigor. Early-season response to starter fertilizer is common in corn, but not as predictable in soybean.

Starter fertilizer has a chance of increasing yield when considering the width of the planter and the starter fertilizer selected. These can greatly influence the amount of nutrient that can be applied with the seed at planting (Table 22.2). Starter fertilizer rates are not influenced by seeding rate. Table 22.2 provides maximum recommended fertilizer rates assuming moist, medium-fine textured soil and a tolerable stand loss of 20%.

More precise recommendations can be calculated using a computer application (Fertilizer Seed Decision Aid) available at http://www.sdstate.edu/ps/extension/soil-fert/index.cfm.

Table 22.1. Keys for using starter fertilizer.

1. The field has a very low P concentration.
2. Soybeans are planted into cool soils. Many soils are relatively cool:
   a. early in the season (early planting),
   b. in residue covered no-tillage fields, and
   c. in poorly drained areas.
3. Planting in newly drained or previously flooded field. In newly drained fields (high O2), extractable P levels may decrease. This decrease is associated with: 1) Fe3+ being a dominant ion in aerobic soils (high O2), while Fe2+ is the dominant ion in anaerobic soil (water logged); and 2) Fe3+ form more stable complex with the phosphate ion than Fe2+.
4. When poorly drained soils are drained or when a flood recedes, soil P levels can drop rapidly.
5. Planting CRP land that is being converted to crop land.
6. In many situations, soybeans have a minimal response to starter fertilizers. The mixed results are attributed to:
   a. Soybean is twice as sensitive to salt injury than is corn. Salt injury is also higher in dry and course course-textured soils.
   b. Soybean are generally seeded following corn, which results in warmer soil temperatures. Warmer soils encourage root growth and soil P uptake.
   c. High P rates are generally applied to corn prior to soybean in the rotation.
   d. Germinating soybean are very sensitive to fertilizer salts, therefore, extreme caution should be followed when using starter in soybeans.

Table 22.2. Maximum fertilizer rate to apply with soybean seed.1,2

<table>
<thead>
<tr>
<th>Planter Row Width</th>
<th>MAP (11-52-0) - dry</th>
<th>10-34-0 - liquid</th>
<th>9-18-9 - liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>------ lb/a ------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td>30</td>
<td>18</td>
<td>42 (3.6)</td>
<td>29 (2.6)</td>
</tr>
<tr>
<td>15</td>
<td>36</td>
<td>84 (7.2)</td>
<td>58 (5.3)</td>
</tr>
<tr>
<td>7.5</td>
<td>72</td>
<td>167 (14.4)</td>
<td>116 (10.6)</td>
</tr>
</tbody>
</table>

1 From Fertilizer Seed Decision Calculator found at: http://www.sdstate.edu/ps/extension/soil-fert/index.cfm
2 Listed rates assume a moist, medium-fine textured soil and tolerated possible stand losses of 20%.
Placing fertilizer farther away from the seed reduces the risk of stand loss and allows increased fertilizer rates. Starter fertilizer can be applied over the top of the row after seed furrow closure or in a band to the side and/or below the seed. Starter fertilizer bands commonly have been applied two inches below and two inches to the side of the seed (2x2).

Double disk opener planter attachments with liquid or dry fertilizer holding and delivery systems are available for these types of applications. Liquids traditionally have been used for starter applications but are more prone to spills and equipment corrosion. Planter air carts easily and effectively handle dry fertilizers for starter application. Cost difference between liquid and dry fertilizers on a plant nutrient basis should be considered when investing in new or retrofitting planting equipment for starter fertilizer application.

**Comparing banded and broadcast applied P fertilizer**

Soybean grain yield response to banded fertilizers is similar to broadcast placement for Minnesota (Rehm, 2005); Iowa (Malarino et al., 2005); Nebraska (Ferguson et al., 2006); and North Dakota (Franzen, 1999). Research comparing the two methods of P application is lacking in South Dakota, but it is assumed that soybean response will be similar to neighboring states. Therefore, method of application should be selected based on cost, equipment availability, and ease of application. It is not uncommon to apply two years of P on corn in a corn-soybean rotation. Studies confirm soybean yield responses to P when applied the previous year (Claypool et al., 1990; Woodard et al., 1992; Randall et al., 2001).

Band application of recommended P fertilizer at planting is an option especially if relatively low rates are needed. Spring broadcast application prior to planting is a viable option. However, P fertilizers commonly available in the marketplace include nitrogen (N) (e.g., 11-52-0). Although only small amounts of N are applied, it is unlikely that soybeans will benefit from additional N and may suppress N fixation via symbiosis of soybean and N fixing bacteria (bradyrhizobia japonicum).

Some soils may limit plant P availability by “fixing” fertilizer P with soil calcium. These soils may benefit from band applying P compared to broadcast applications. However, there are relatively few of these soils in South Dakota. If long-term P soil test values have not been increasing even though P application rates have exceeded P crop removal, P fixation may be occurring.

**Using starter to reduce iron chlorosis**

Soybeans growing in high pH soils may appear yellow, resulting from iron chlorosis deficiency (IDC). This deficiency can be reduced by seeding plants with improved Fe uptake characteristics and/or a Fe seed treatment. IDC has also been linked to high nitrate concentrations. Iron chlorosis or IDC in soybean is not uncommon in South Dakota (Chapter 15). Starter application of the iron chelate, ortho EDDHA, at 2-3 lbs per acre has proved to be effective. The linkage between nitrate and IDC suggests that Fe seed treatments may be critical when the prior year was a drought.

References and additional information


Acknowledgements
Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program

Energy efficiency and profitability can be improved by including legume plants, such as soybeans, in the rotations. These plants in collaboration with soil bacteria, have the capacity to convert atmospheric N\textsubscript{2} to plant N (N fixation). In soybeans, the soil bacteria responsible for this process are called *Bradyrhizobia japonicum*. Each plant type that has the capacity to fix N requires a different bacteria, and if the soil does not contain that bacteria, it cannot fix N. Tips for increasing N fixation are provided in Table 23.1.

Inoculums can be applied as an in-furrow granular or as a solid or liquid treatment to the seed. Inoculants are live organisms and should be treated carefully. The purpose of this chapter is to discuss soybean seed treatment with *Bradyrhizobia japonicum*.
The importance of rotations in N fixation

Prior to the development of commercial N fertilizer industry, the primary source of N for row crop production was N$_2$ fixation by legumes. Different cultures have integrated legumes and other soil amendments using a variety of approaches. North American native peoples seeded corn, beans, and squash in the same area, while the Incas collected guano from the bird-islands.

In Europe, the linkages of the livestock with rotations that included legumes has been partially credited with providing the food needed for the English population to increase from 5.7 in 1750 to 16.6 million people in 1850. Associated with the population growth was a change in the rotational sequence from a crop rotation that included a cereal (oats, rye, wheat, and barley), legume (peas and beans), and fallow to a four-year

Table 23.1. Tips for increasing N fixation.

1. Soybean seed should be inoculated:
   a. if the field has not been seeded to soybean within the previous 5 years;
   b. if the field is being converted from CRP to soybean;
   c. if soil has been flooded for over a week; and
   d. if soil has a pH less than 6.0 or greater than 8.5.

2. To minimize plant stress, follow P and K recommendations, seed at an appropriate time, and control pests.

3. Use care when handling or combining seed treatments; take note of all safety precautions for seed treatments.

4. Under moderate drought stress, monitor the soil N supply. N fixation is one of the first activities to be reduced under water stress. [http://arkansasagnews.uark.edu/4859.htm](http://arkansasagnews.uark.edu/4859.htm)

5. For corn-following-soybeans, subtract the appropriate N credit from the N fertilizer recommendation.

6. If cover crops cocktails include legumes, they should be inoculated with an appropriate bacteria.

7. N credits from soybeans and cover crops should be subtracted from next year's N recommendation.
rotation that included wheat, barley, turnips and clover. Turnips replaced fallow in the rotation, provided forage for livestock, and reduced weed pressure. The net result was wheat and pulse yields that increased 68% and 44% from 1750-1759 to 1850-1859. In addition, stocking densities for milk cows, sheep, and swine increased 46, 25, and 43%, respectively (Broadberry et al., 2010).

These cultures learned that soil fertility is critical for productive agriculture and that N fixation by legume crops increase the yields in following crops. N fixation is conducted by plants that have the capacity to form symbiotic relationships with N fixing soil bacteria. In rice production, the free living bacteria, blue green algae, provide N to rice, while in South Dakota soybean fields *Bradyrhizobia japonicum* have this capacity. Other legumes with this capacity are peas, clovers, and beans. In forest systems, N is fixed by both legumes and non-legume plants. In row crop production, each legume requires a different N fixing organism.

In N$_2$ fixation, energy is used to break the triple bond holding the two N atoms together. The equation that converts atmospheric N$_2$ to plant N is:

$$N_2 + 8H^+ + 8e^- + 16\text{ATP} = 2NH_3 + H_2 + 16\text{ADP} + 16\text{Pi}$$

In this reaction, the ATP represents energy. This reaction is energy intensive and requires approximately 10 lbs carbohydrates for each pound of N produced. The ammonia (NH$_3$) is subsequently converted to an amino acid such as glutamine.

The protein complex that facilitates this reaction is nitrogenase, which is composed of an iron and molybdenum-iron proteins. N fixation by nitrogenase is inactivated when exposed to oxygen. Different organisms use different technique to reduce O$_2$ inactivation. For example, in rhizobium, leghaemoglobin (closely related to our hemoglobin) is used to reduce O$_2$ concentrations, while in cyanobacteria N$_2$ fixation is conducted in specialized cells (heterocysts) where only photosystem I (oxygen is not produced) is used. N fixation can also be reduced by stresses that reduce plant activity.

In soybeans, N fixation is conducted by *Bradyrhizobia japonicum*. In this symbiotic relationship, the plant obtains N while the bacteria obtains energy required for growth and development. Nitrogen fixation is inhibited by a high nitrate concentration. After germination, *Bradyrhizobia japonicum* invade the seedling root hairs and nodules begin to form. The first nodules can be observed several weeks after seedling emergence at V2-V3. Active nodules turn red or pink when cut in half while inactive nodules are a grey color.

N fixation can be reduced:

1) when the temperatures are cold or hot (optimum temperature is between 60 to 80°F),
2) high soil nitrate levels,
3) drought,
4) excessive wetness, *and*
5) soil compaction.

**N fixing inoculants**

If *Bradyrhizobia japonicum* inoculants are needed, it is important to remember that they are live organisms. The basic choices are solid, liquid, and freeze-dried. Seed inoculations can be conducted as an in-furrow or directly to the seed. In-furrow materials generally are dry, granular materials. These products should be stored flat on a pallet at temperatures ranging from 8 to 12°C.

Direct seed treatments generally are dry or liquid materials that may be a broth culture or frozen concentrate. They can be metered and mixed with the seed by the auger when filling the planter or drill. The inoculants should be fresh, stored using appropriate techniques, and treated with care. Labeled directions should be followed. Care should be used when using seed treatments. Inoculants are very sensitive to Captan and PCNB.
When treating soybean seed:

1) check the expiration date,
2) do not expose the inoculants to heat or direct sunlight,
3) follow labeled directions for different mixtures, and
4) plant treated seed quickly and do not leave treated seed in the planter box overnight.

Liquid inoculants should be stored as cool as possible without freezing. Granular inoculants should be stored flat on a pallet (8-12°C).

**Impact on the following crop**

Nitrogen fixation by the soybean and other legumes can reduce the N requirement in the following crops. These credits are provide in Table 23.2. When no-tilling into legume green manure, use a half credit. For the second year following alfalfa and a legume green manure, use a half credit.

**Table 23.2. Nitrogen credit that can be subtracted from the N recommendation for corn production.** (Source: Gerwing and Gelderman, 2005)

<table>
<thead>
<tr>
<th>Previous Crop</th>
<th>Population plants/ft²</th>
<th>Credit lbs N/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean, edible beans, peas, lentils and other annual legumes</td>
<td>&gt;5</td>
<td>150</td>
</tr>
<tr>
<td>Alfalfa and legume green manure crop</td>
<td>3-5</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>1-2</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>&lt;1</td>
<td>0</td>
</tr>
</tbody>
</table>

**Cover crops**

If you are using cover crops in your rotation and the cover crop cocktail contains a legume, the legume seed needs to be inoculated with an appropriate organism to insure N fixation. N credits from cover crops currently is being evaluated.

**References and additional information**


Conley, S.P., and E.P. Christmas. 2005, Using inoculants in a corn-soybean rotation. SPS-100-W. Purdue University, Purdue Extension. Available at http://www.extension.purdue.edu/extmedia/sps/sps-100-w.pdf


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In-season N applications has been proposed as a management tool to increase soybean yields in high-yield environments as well as to increase yields when the soybean plant does not have effective nodules (Fig. 24.1). This chapter investigates the feasibility of using this practice to increase South Dakota soybean yields.

**N fixation problems**

Soybeans can obtain over 50% of their N from the soil, with the remainder being provided through N fixation. N fixation is a biological process where N\(_2\) is converted to plant N. This process requires a great deal of energy. The bacteria responsible for this conversion, *Bradyrhizobium japonicum*, requires oxygen (Fig. 24.1). Effective N fixation will not occur if the soil does not contain this bacteria, the soil contains high amounts of inorganic N, and soil conditions do not provide an adequate amount of oxygen. The bacteria convert N\(_2\) gas into ammonia and then into amino acids. The energy for this conversion is derived from photosynthesis.

Biological nitrogen fixation can occur in many organisms including legumes, bluegreen algae, and lichens. Nitrogen fixation can be reduced by stresses that reduce plant activity. Nodules can be seen on soybean roots shortly after emergence with fixation starting between V2 to V3 (Fig. 24.2). To assess nodulation, dig up at least 10 plants 5 to 6 weeks after seeding. At this time the nodules should be large and active. The soil can be removed from the roots by immersing them in water. There should be 8 to 20 large active nodules per plant. [http://msue.anr.msu.edu/news/evaluating_soybean_nodulation](http://msue.anr.msu.edu/news/evaluating_soybean_nodulation)
Nodule activity can be checked by cutting them open. Active nodules have pink centers while inactive nodules are grey. The pink color is caused by leghemoglobin. Oxygen causes this iron-containing compound to turn red. Leghemoglobin helps reduce the inactivation of the enzyme nitrogenase by oxygen. If they are small and white, they are not actively fixing N. Green, brown or mushy nodules are not fixing N. Poor nodulations can result from:

- Low bacteria populations in the soil resulting from soybeans not being grown for several years.
- High or low levels of residual inorganic N.
- Coarse-textured soil.
- Flooded or high soil bulk density.
- Low (<5.5) or high (>7.3) soil pH.

Under certain conditions, N provided by the soil and by N₂ fixation may not meet the plant needs. Soybeans without effective nodules will respond to N like any other crop. Nitrogen deficiencies resulting from ineffective nodulation can be minimized by the application of 50 to 100 lbs N/acre (Scharf and Wiebold, 2003; Ferguson et al., 2006). These N deficiencies are fundamentally different than late-season N applications that are designed to increase yields from 60 bu/acre to 70 bu/acre.

**High yielding fields: Late-season N additions**

In South Dakota, soybean yields can be limited by too little or too much water. The spatial variability across our fields can be very high. For example, low-yielding areas may be < 25 bu/acre while high-yielding positions may be > 50 bu/acre (Fig. 24.3). The question is, can the yields in low- and high-yield areas be increased by adding late season N.

Research conducted in other states suggests that benefit from late-season N (R2 to R6) can be obtained under very high yield conditions (Westley et al., 1998). These yield increases are attributed to the N fixing bacteria not having the capacity to meet the plants’ N requirement under very high-yielding conditions. In dryland fields, late season N has produced mixed results because rainfall is required to move this N into the soil (Kharel et al., 2011; Kim et al., 2008).
Soybean response to water stress

In the low-yielding zones, often located in high elevation areas, soybeans respond to water stress by closing the stomata. Closing the stomata reduces the CO$_2$ concentration in the leaves, which in turn reduces CO$_2$ fixation, transpiration, leaf size, leaf area index, biomass production, seed size and numbers, and accelerates leaf senescence (Souza et al., 1997). In addition, water stress in soybeans can reduce nodule activity (Serraj and Sinclair, 1996; Serraj et al., 1998). Serraj et al. (1998) hypothesized that water-stressed plants maybe N limited because Bradyrhizobium may be more sensitive to water stress than the plant. Purcell and King (1996) tested this concept and reported that due to the extreme sensitivity of nodules to drought, it may be possible to increase yields in water-stressed areas by adding N fertilizer (Sall and Sinclair, 1991).

Summary

In summary, N fertilizer may increase soybean yields if nodulation is poor and if the N fixation does not meet the plant requirement. Benefits from in-season N may not increase yields in all fields and years. Research conducted in other states suggests that benefits are unlikely in moderate-yielding environments. As we attempt to push our yields from 50 to 60 or even 70 bu/acre, late-season N applications may become common. However, this needs to be confirmed by research.

References and additional information


Acknowledgements
Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

Phosphorus is an essential plant nutrient and is used by soybeans to enhance the root development, photosynthesis, and energy transfer throughout the growing season. Phosphorus is added to the soil by fertilizers and manure and removed from the soil primarily when crops are harvested (Fig. 25.1). Additional, smaller losses of P can occur through runoff and erosion. When added to soil, P generally stays where it is applied, and its uptake is reduced under drought conditions.

For many producers, a soil P management program starts with collecting a representative soil sample. This sample is then analyzed, using the Bray-1 and Olsen P tests, to determine your P recommendation. The Bray-1 test was designed for acid soils (pH<7.3) while the Olsen test was designed for basic soil (pH>7.3). The purpose of this chapter is to demonstrate how to determine your current recommendation.

Figure 25.1. Phosphorus cycle in many agricultural soils. (Source: http://www.epa.gov/oecaagct/ag101/printbeef.html)
**Phosphorus and soybeans**

Having a sufficient supply of P is especially important during the early stages of plant development, when the root system is not yet extensive. During early vegetative stages, roots take up P very quickly—much more quickly than they do later in the season (Barber, 1978). The greatest plant demand for P occurs in later vegetative stages (V10) and continues through mid reproductive stages (R5) (Fig. 25.2; Hanway and Weber, 1971). The P taken up during this period accounts for about 75-80% of the total P taken up by the plant by physiological maturity. After about R5 (beginning seed), P is rapidly lost from the leaves, petioles, stems, and pods and is repartitioned into the developing beans. Approximately half of the P in mature seeds come from these plant fractions. At harvest, approximately 73% of the total P in the plant is in the mature seed.

The primary purpose of P is to help soybeans manage energy produced during photosynthesis. When P is limiting, soybeans have a reduced ability to tolerate stress (Monsanto, 2010) and the probability of a response to P fertilizer decreases with increasing soil test P level (Fig. 25.3). When soil P supplies are low, more than 50% of the P in the soybean plant may come from P fertilizer while under high P supplies, fertilizer may contribute less than 30% of total uptake (Bureau et al., 1953).

Adequate P nutrition can reduce the susceptibility and or incidence of diseases such as Asian rust and soybean mosaic virus (Pacumbaba et al., 1997; Piccio et al., 1980) and may also help overcome yield limitations from soybean cyst nematodes (Howard et al., 1998). Phosphorus deficiencies in soybeans generally are typified by spindly plants with small leaflets. The leaves may have a dark green or bluish green tint (Chapter 17; Monsanto, 2010). Phosphorus deficiency also adversely affects nitrogen nutrition by impairing the functioning of nodules (Sa and Israel, 1995). Maintaining the soil pH between 5.5 and 7 generally increases P availability.
Phosphorus, soil, and the environment

In soil, P can exist in plant-available and plant-unavailable forms. Plants take up only P that is dissolved in the soil solution. Sources of this solution P come from both inorganic and organic sources. Inorganic sources include P minerals and P chemically bonded to other soil minerals, like iron and aluminum oxides and calcium minerals. P in these inorganic forms is often referred to as being “fixed,” even though it can be released into the soil solution over time through weathering and other soil chemical reactions. Organic sources include manures, biosolids, and crop and animal residues. Phosphorus in organic forms is released into the soil solution through microbial degradation. In both inorganic and organic forms, there is a portion of the P that is more readily released into the soil solution, making it potentially available for crop uptake (Fig. 25.1).

Soil test extractants have been created to access both the solution P and the P that can potentially become plant available. It is important to note that no soil test extractant measures all of the P that is potentially plant available. Consequently, soil test results provide only an index of P availability and not a complete accounting. What makes soil tests useful in production agriculture is the field research that relates specific soil test readings to crop response, as shown in Figure 25.3. The Bray-P1 extractant is designed for soils with a pH < 7.3 while the Olsen extractant is designed for soils with a pH > 7.3 (Watson and Mullen, 2007; http://infohouse.p2ric.org/ref/17/16690.pdf).

Phosphorus can be transported from production fields to streams and lakes with eroding soils. To minimize transport, the following practices should be followed:

- Use soil sampling to define P fertilizer rates and follow recommendation guidelines.
- Consider manure as an important resource as opposed to a waste product.
- Consider all sources of P when determining P application rates.
- Place P sources below the soil surface.
- Use management techniques that reduce erosion.
- Install vegetative filter strips on hillsides and well-placed vegetative buffer zones along streams.
- Use the 4Rs (right source, right rate, right time, and right place). http://www.ipni.net/4r

Precision P management may also be a high priority in newly tile-drained fields. In these fields, the removal of excess water will likely stimulate the conversion of Fe$^{2+}$ to Fe$^{3+}$, which in turn can reduce available P. Until new equilibrium P levels are reached we recommend careful monitoring. Careful monitoring is also recommended for CRP land that is converted back into farm land (Chapter 14). In these soils the lack of fertilizer applications for 10 to 15 years may have drastically reduced available P. When P is added following the above recommendations it will gradually increase. Soil test P values in these fields should be carefully tracked.

Soil sampling

For many producers, a P recommendation program starts with collecting a soil sample (Chapter 18). Soil samples are collected both to estimate nutrient levels in a field and to estimate the amount of residual nutrients contained in the soil. For accurate estimates, representative soil samples must be collected. Accuracy improves by increasing the number of subsamples composited into a bulk sample and by avoiding areas that once were feedlots, farmsteads, and fence lines. Details on soil sampling and sample handling are available in Chapter 18, Clay et al. (2002) and Gelderman et al. (2005). For P, soil samples are collected from the 0-6 inch depth, while for N the samples are collected from two depths (0-6 and 6-24 inches).

Samples can be collected from grid points, grid cells, and whole fields (Chapter 20). Based on grid point and grid cell sampling site-specific fertilizer recommendations can be developed. Grid point or grid cell soil values can be combined with yield monitor data to make more precise decisions.
Understanding your P soil test

If a single soil sample is collected from a field, the soil test P value of that sample represents the average value (Fig. 25.4). If the field had a normal population distribution, half of the field would have a P concentration less than that value. However, many fields have a skewed distribution, resulting in 60 or 70% of the field having a P concentration less than that value. This means that if the Olsen P concentration is 16 ppm then most of the field may require significant amounts of P fertilizer. These fields may warrant precision P management (grid cell sampling).

![Figure 25.4. The relationship between a soil sample value and the likely P population distribution.](Source: L. Sanghun, SDSU)

P fertilizer recommendations

South Dakota P fertilizer recommendations are calculated based on the soil P test level and the soybean yield goal. Phosphorus is not a mobile nutrient in the soils and thus the movement of P is less than a few inches even in light-textured soils. Therefore, soil samples collected from the surface six inches can be used to determine the soil P level. Soil sampling protocols are provided in Chapter 18. Suggested phosphate fertilizer recommendations for soybean are shown in Tables 25.2 and 25.3.

Table 25.1. General rules of thumb for collecting accurate soil samples.

- Do not sample dead furrow, turn-rows, waterways, old fence line, old farmsteads or any other area that does not represent the field.
- Reduce fertilizer recommendation errors by compositing as many sub-samples as possible.
- In P banded fields, do not oversample the P bands. Over-sampling bands produces a larger fertilizer error error than under-sampling bands.
- Track soil P levels in flooded, new tile drainage lands, and in CRP land converted to row crops.
Table 25.2. Phosphorus fertilizer recommendations for soybean in South Dakota. (Modified from Gerwing and Gelderman, 2005). The Bray-P1 test is routinely used in acid soils (pH<7.3), while the Olsen test is used in calcareous soils (pH>7.3).

<table>
<thead>
<tr>
<th>Yield</th>
<th>Bray-P1</th>
<th>Olsen</th>
<th>Soil Test Phosphorus (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VL</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>0-5</td>
<td>0-3</td>
<td>6-10</td>
<td>11-15</td>
</tr>
<tr>
<td>0-3</td>
<td>4-7</td>
<td>8-11</td>
<td>12-15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Yield</th>
<th>Bray-P1</th>
<th>Olsen</th>
<th>Soil Test Phosphorus (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VL</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>0-5</td>
<td>0-3</td>
<td>6-10</td>
<td>11-15</td>
</tr>
<tr>
<td>0-3</td>
<td>4-7</td>
<td>8-11</td>
<td>12-15</td>
</tr>
</tbody>
</table>

Table 25.3. Phosphorus fertilizer recommendations for corn in South Dakota. (Modified from Gerwing and Gelderman, 2005). The Bray test is routinely used in acid soils (<pH,7.3), while the Olsen test is used in calcareous soils (pH>7.3).

<table>
<thead>
<tr>
<th>Yield</th>
<th>Bray-P1</th>
<th>Olsen</th>
<th>Soil Test Phosphorus (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VL</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>0-5</td>
<td>0-3</td>
<td>6-10</td>
<td>11-15</td>
</tr>
<tr>
<td>0-3</td>
<td>4-7</td>
<td>8-11</td>
<td>12-15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Yield</th>
<th>Bray-P1</th>
<th>Olsen</th>
<th>Soil Test Phosphorus (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VL</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>0-5</td>
<td>0-3</td>
<td>6-10</td>
<td>11-15</td>
</tr>
<tr>
<td>0-3</td>
<td>4-7</td>
<td>8-11</td>
<td>12-15</td>
</tr>
</tbody>
</table>

Problem 25.1. Determine the P_{2}O_{5} recommendation for a soil with a Bray-1 soil test value of 10 ppm and a soybean yield goal of 50 bu/acre and a corn yield goal of 200 bu/acre.

Use the soil test value to determine the two year P rate, as shown below.

Soybean: \( \frac{(55 - 0.10 \times 10) \times 50}{27.5} = 27.5 \text{ lbs P}_{2}O_{5}/\text{acre} \)

Corn: \( \frac{(70 - 0.035 \times 10) \times 200}{70} = 70 \text{ lbs P}_{2}O_{5}/\text{acre} \)

Based on these calculations, the P recommendation is 97.5 lbs P_{2}O_{5}/acre.
Determining P rate for a corn followed by soybean rotation

To take advantage of the N contained in the MAP or DAP fertilizers many producers apply the P fertilizer to corn in the corn followed by soybean rotation. The two-year \( P_2O_5 \) recommendation is determined by using the soil test result to determine the P rate for both corn and soybean. The soybean and corn P recommendations are provided in Table 25.4. Sample calculations are provided in Problem 25.1.

### Table 25.4. Soybean and corn P recommendation equations and sample calculations.

**Soybean Bray-P1 recommendation equation**

\[
\text{lbs P}_2\text{O}_5/\text{acre} = (1.55 - 0.10 \times \text{Bray-P1}) \times \text{yield goal}
\]

**Corn Bray-P1 recommendation equation**

\[
1 \text{ lbs P}_2\text{O}_5/\text{a} = (0.70 - 0.035 \times \text{Bray-P1}) \times \text{yield goal}
\]

**Soybean Olsen P recommendation equation**

\[
\text{lbs P}_2\text{O}_5/\text{acre} = (1.55 - 0.14 \times \text{Olsen-P}) \times \text{yield goal}
\]

**Corn Olsen P recommendation equation**

\[
\text{lbs P}_2\text{O}_5/\text{a} = (0.70 - 0.044 \times \text{Olsen-P}) \times \text{yield goal}
\]

**Sample soybean fertilizer calculation using Olsen P**

Soil test P = 5 ppm (Olsen) and the yield goal is 60 bu/acre

\[
\text{lbs P}_2\text{O}_5/\text{acre} = (1.55 - 0.14 \times 5) \times 60 = 51 \text{ lbs P}_2\text{O}_5/\text{acre}
\]

Selecting a yield goal for P recommendations

There are many different approaches to calculate a yield goal. One of the easiest is to determine the average value from previous years, and then remove any outliers (Table 25.5). These yield estimates can be modified for poor and good soil moisture. For good soil moisture conditions the yield estimates may be increased 10%, while for poor soil moisture conditions the yield estimates are decreased 10%.

Your P program can be fine tuned by routine scouting, tracking nutrient levels, determining P mass balances and using a more rigorous soil extracting solution. Details on scouting, tracking nutrients, and determining P mass balances are in Chapter 17. Information on the P2 soil test is below.

### Table 25.5. An example showing how to estimate a yield goal.

<table>
<thead>
<tr>
<th>Year</th>
<th>Yield Goal bu/acre</th>
<th>Soil Moisture Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>Good</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>Poor</td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td>Good</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>Very poor</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>Excellent</td>
</tr>
<tr>
<td>6</td>
<td>55</td>
<td>Excellent</td>
</tr>
<tr>
<td>7</td>
<td>42</td>
<td>Good</td>
</tr>
<tr>
<td>8</td>
<td>38</td>
<td>Good</td>
</tr>
<tr>
<td>Average</td>
<td>40.625</td>
<td></td>
</tr>
</tbody>
</table>

Excluding year 4

Estimated yield (bu/acre) = \((40+35+45+60+55+42+38)/6=45\) bu/acre
**Using multiple soil P tests**

Some laboratories may also offer the Bray-P2 test. The Bray-P2 test is similar to the P1 test, however it contains a higher concentration of HCl. The difference between the Bray-P2 and Bray-P1 test has been related to active reserves. In South Dakota research needs to be conducted to better define how the Bray-P2 test can be used to improve P recommendations.

It has been proposed that the Bray-P1 and Bray-P2 tests can be used to assess readily and moderately available P sources. In South Dakota the current P recommendation system is built on the Bray-P1 or Olsen test.

It has been suggested that a Bray-P2 value that ranges from 40 to 60 ppm is desirable. In this interpretation, a high Bray-P2/Bray-P1 ratio (>3) indicates that P fixation is a problem, while a low ratio (<2) indicates that the soil has a low P fixing capacity. Research on the value of the Bray-P2 test for South Dakota needs to be conducted. It has not currently been proven that certain Bray P2 ranges or ratios with Bray P1 values are diagnostic of crop response to P additions in the short term (one season) or long-term (multiple seasons).

Banding the fertilizer is an approach used to reduce P fixation. Many farmers band the P two inches below and two inches to the side of the seed. When compared with seed placement, this approach reduces the risk of salt injury. When placed with or near the seed, using MAP rather than DAP can reduce risks of ammonia toxicity to seeds or seedlings, particularly when ammonium forms or urea forms of nitrogen are co-applied, soils are dry, CEC is low, free calcium carbonates exist, and/or soil pH is basic.

Research on the benefits of banding is mixed. Bly et al. (2006) reported that if moisture is adequate, soybean yields have usually been slightly higher for P broadcast than banded treatments. Gelderman et al. (2002) had different results and reported that broadcast incorporated and banded P rates produced similar yields. Rehm et al. (2001) had similar results in Minnesota. Recent research suggests that yields might be increased by banding the fertilizer directly below the seed (Yin and Vyn, 2003).

In some situations, the P effectiveness may be limited by low soil pH. When N fertilizer is applied, soil pH values slowly decrease. In acid soils (pH < 5.5), iron and aluminum minerals react with applied P to form insoluble compounds with limited availability. If the soil pH is less than 5.4, it may be possible to increase soybean yields by adding lime (Bly et al., 2004, 2005).

**References and additional information**


Acknowledgements
Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, SDSU, and South Dakota 2010 research program. The current South Dakota P program was developed through collaborations between the public soil testing laboratories, university soil scientists, commodity groups, crop consultants, and individual producers over many years.

Iron is an essential plant nutrient and in certain soils, Fe deficiencies can reduce South Dakota soybean yields. In the soybean plant, Fe deficiencies appear as the yellowing of new trifoliate. The symptoms for Fe deficiencies generally first appear within several weeks of emergence. This is most often observed in high pH soils containing lime. In soybean, Fe deficiencies have been named iron (Fe) deficiency chlorosis (IDC). Tips to reduce IDC risks are available in Table 26.1. The purpose of this chapter is to discuss management recommendations for Fe, K, Cl, and S. In South Dakota, consistent benefits in soybean production from K, Cl, and S fertilization have not been observed.

Figure 26.1. Iron deficiency chlorosis (IDC) in soybean in the plant and in a field. (left, John Sawyer, Iowa State; right, Ferguson et al., 2006). Available at http://www.agronext.iastate.edu/soilfertility/photos/secmicro/4ironchjs.html and http://www.ianpubs.uni.edu/pages/publicationD.jsp?publicationId=146
Iron Chlorosis Deficiencies

Impact on the plant

Iron (Fe) plays an important role in plant respiration, nitrogen fixation, and photosynthesis. If soybean plants are not able to take up the required amount of Fe, yields can be reduced. The common symptoms for IDC are chlorosis (yellowing) of younger leaves, while the veins remain green (Figure 26.1). In severe conditions, the leaves can appear yellow for the entire season. IDC may reduce N fixation. Deficiency symptoms may be increased by low temperatures in the spring. One solution to IDC is to plant appropriate cultivars. IDC-tolerant varieties are available from most soybean seed companies. In addition, soybean cultivars entered in the North Dakota crop testing program are assessed for IDC tolerance. http://www.ag.ndsu.edu/varietytrials/soybean

Soil characteristics

Iron deficiency has been identified in some poorly drained South Dakota soils that have high pH (7.4 or higher) and calcium carbonate concentrations (Bly and Woodard, 2007). Rehm (2008) notes: “The problem is always associated with calcareous soils (soil pH>7.4). But IDC is not found on all calcareous soils.” According to Rehm (2008), the extent of the problem is related to the relative amount of free calcium carbonate and soluble salts. He suggests that IDC risk increases with free calcium carbonates.

It has been hypothesized that soils with high nitrate concentrations will have a greater risk for IDC (Kaiser et al., 2011). This hypothesis is based on the plant releasing the negatively charged biocarbonate ion (HCO$_3^-$) when it takes up the negatively charged nitrate ion (NO$_3^-$) (Kaiser, 2011). The biocarbonate ion then reacts with iron to form a relatively insoluble complex.

Kaiser et al. (2011) suggest applying EDDHA chelated Fe to the seed or adopting management practices such as planting an oat cover crop to reduce nitrate concentrations, as well as IDC risk. EDDHA is chelate that reduces Fe reaction to soil and increases its availability to the plant. If Fe was applied without the chelate, it would not be available to the plant. In some situations, seed treatment with EDDHA-Fe can increase yields even if tolerant varieties are selected (Rehm, 2012).

IDC recommendation summary

Research conducted across the United States North Central region suggests that IDC yield losses in calcareous soils can be reduced by seed treating with Fe chelated EDDHA (Table 26.2). In some situations, yields can be increased even if tolerant cultivars are seeded. The fertilizer rate depends on the degree of iron deficiency, but most data suggest that the rate should be between 1 to 4 lbs product per acre (Ferguson et al.,

Table 26.1. Tips to reduce the risk of iron deficiency chlorosis. (Ferguson et al., 2006; Kaiser et al., 2011; Rehm, 2012)

1. Plant tolerant varieties.
2. Use management strategies that minimize nitrate-N carry over.
   a. Seed a winter cover crop.
   b. Reduce the N rate to the prior crop.
3. Apply EDDHA-Iron fertilizer on the seed.
   a. EDDHA is a compound that reduces Fe reactions with soil, which thereby increases its availability to the plant.
   b. Target Fe seed treatments to soil zones with soils containing high calcium carbonate concentrations (Chapter 19).
Fe-EDDHA is a dry product that can be mixed with water (Ferguson et al., 2006). Table 26.3 shows popular EDDHA iron products available in South Dakota. At this point, a soil test for available Fe is not a reliable predictor for the Fe-EDDHA requirement.

Table 26.2. The effect of EDDHA (ortho-ortho) chelated iron seed treatment on soybean yield at Brookings, SD, in 2007. (Modified from Bly and Woodard, 2007)

<table>
<thead>
<tr>
<th>Iron Treatment (lb/acre)</th>
<th>Grain Yield (bu/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check</td>
<td>40.0</td>
</tr>
<tr>
<td>1 lb EDDHA Fe + 4 lbs gypsum</td>
<td>49.0</td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Table 26.3. Current available EDDHA (ortho-ortho) chelated iron seed treatments.

<table>
<thead>
<tr>
<th>Product</th>
<th>Manufacturer/Distributor</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ironworks</td>
<td>AG Specialties</td>
<td><a href="http://www.fertilizerandchemicals.com/ironworks.html">http://www.fertilizerandchemicals.com/ironworks.html</a></td>
</tr>
<tr>
<td>Ferrilene 6</td>
<td>Helena Chemical</td>
<td><a href="http://www.pacgro.co.nz/ProductDetails/40-3080.html">http://www.pacgro.co.nz/ProductDetails/40-3080.html</a></td>
</tr>
</tbody>
</table>

Potassium (K)

Deficiency symptoms

Soybeans require potassium (K) for protein synthesis, photosynthesis, water regulation, disease resistance, vegetative growth, drought tolerance, and lodging control. For K deficiencies, yellowing starts on the margins of older leaves (Fig. 26.2). In severe cases, most of the affected leaf edge may turn brown and die. A good approach to confirm K deficiencies is to use soil and plant analysis. Details on soil sampling are provided in Chapter 18 and details on plant sampling are provided in Chapter 17.

Figure 26.2. Potassium deficiency in soybean. (Source: John Sawyer, Iowa State University. Available at http://www.agronext.iastate.edu/soilfertility/photos/potassium/2potjs.html)
Soybean typically utilizes and requires more K than corn (Table 26.4). Around 65 lb of K₂O per acre (1.3 lbs K₂O/bu) are removed in a 50 bu/acre soybean crop. Even though soybeans use relatively large quantities of K, South Dakota agricultural soils seldom need K fertilizer. However, K responses may be observed in:

- Sandy and/or eroded soils.
- Soils with low K values.
- No-till systems. (Gelderman et al., 2002-2005)

K deficiencies may be more apparent during springs that are cool and wet. A soil test (of the top six inches of soil) is the best way to determine the need for K fertilizers. K fertilizer recommendations are based on yield and soil test K values (Table 26.5).

### Table 26.4. Potassium recommendations for soybean in South Dakota. (Gerwing and Gelderman, 2005)

<table>
<thead>
<tr>
<th>Soil Test Potassium (ppm)</th>
<th>VL</th>
<th>L</th>
<th>M</th>
<th>H</th>
<th>VH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield bu/acre</td>
<td>0-40</td>
<td>41-80</td>
<td>81-120</td>
<td>121-160</td>
<td>161+</td>
</tr>
<tr>
<td>30</td>
<td>55</td>
<td>33</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>73</td>
<td>44</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>92</td>
<td>55</td>
<td>19</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>60</td>
<td>110</td>
<td>66</td>
<td>22</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>70</td>
<td>128</td>
<td>77</td>
<td>26</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>80</td>
<td>147</td>
<td>88</td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 26.5. Sample calculations for soybean K fertilizer recommendations.

\[
Lbs \ K_2O/acre = (2.2 - 0.0183 \times \text{soil test K}) \times \text{yield goal}
\]

**Sample calculation**

- Soil test K = 150 ppm and the yield goal is 50 bu/acre
  
  \[
  = (2.2 - 0.0183 \times 150) \\
  = 18.5 \text{ lbs } K_2O/acre
  \]

### K fertilizer type and placement

Potassium chloride or muriate of potash (0-0-60) is the primary K fertilizer available in South Dakota. Potassium sulphate can be used if S is needed and/or if chloride toxicity is a concern (discussed below). Potassium fertilizer can be broadcasted or banded at seeding. If K fertilizer is banded at seeding, it should be located at least two inches away from the seed to avoid seed injury. To avoid seedling salt injury, do not band more than 75 lb K₃O per acre. Broadcasting and incorporating K prior to planting is also a good application method. The banded and broadcast placements have been compared and Rehm et al. (2001) concluded that the placement methods are not consistently superior if adequate K rates are used.
**Chloride (Cl) Fertilizer Recommendations**

Soybean yields generally are not limited by too little chloride (Table 26.6). However, too much chloride can reduce yields under some situations. High soil Cl concentrations can result when high rates of KCl are applied. When chloride toxicity is a concern, producers should consider applying K$_2$SO$_4$.

Table 26.6. The effect of chloride on soybean yield at Aurora, SD.
Chloride applied as CaCl$_2$ or KCl as surface broadcast after planting. Soil test Cl (0-24” depth) is 28 in 2005 and 16 lb/acre in 2006. (Bly et al., 2005 and 2006)

<table>
<thead>
<tr>
<th>Chloride treatment (60 lb/acre)</th>
<th>Grain yield (bu/acre)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Check</td>
<td>47.2</td>
<td>26.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaCl$_2$</td>
<td>46.3</td>
<td>23.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KCl</td>
<td>45.2</td>
<td>24.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSD$_{(0.05)}$</td>
<td>1.4</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sulfur (S)**

In South Dakota, S deficiencies in soybean typically are not a problem (Gelderman et al., 2000). However, soybeans may respond to sulfur:

1) if no-till is used,
2) if the crop residues are routinely harvested and manure is not applied,
3) if soybeans are seeded in sandy and eroded soils, and
4) if the climatic conditions are cool and wet. (Gelderman et al., 2000; Bly et al., 2001)

Sulfur deficiency symptoms include stunted growth and the yellowing of younger leaves (N typically is observed on older leaves first). Sulfur responses are most likely when the surface two feet of soil contain less than 30-35 lb SO$_4$-S per acre (Table 26.7). Check Chapter 21 for fertilizers containing S.

Table 26.7. Sulfur recommendations based on the amount of S contained in the surface two feet of soil.

<table>
<thead>
<tr>
<th>Soil Test S</th>
<th>Coarse Textured</th>
<th>Medium/Fine Textured</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tilled</td>
<td>No-till</td>
</tr>
<tr>
<td>lbs S/2 ft soil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-9</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>10-19</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>20-29</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>30-39</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>&gt;40</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Other nutrients**

South Dakota soils typically contain adequate amounts of boron, zinc, and manganese (Bly et al., 2005; Bly et al., 2006; Bly and Gelderman, 2007; Gerwing et al., 2005). Therefore, application of these micronutrients for soybean production is not recommended.
References and additional information


Rehm, G. 2012. For this, variety selection is not the answer. University of Minnesota Extension. AgBuzz. Available at http://minnesotafarmguide.com/app/blog/?p=581

Acknowledgements

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Emerging Disease, Insect, and Weed Pests in South Dakota Soybean Production

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New pests are always around the corner. As with other crop species introduced from other parts of the world, the pests of these plants frequently follow the plant. Once here, these pests often thrive because they do not have their natural predators. A recent example of a pest following the soybean plant is the Asian soybean aphid. The soybean aphid was first documented in North America in July of 2000. From then, its population rapidly grew and it’s now part of the South Dakota soybean grower’s annual insect pest management.

This chapter discusses emerging soybean disease, insect, and weed pests that may be of concern for South Dakota soybean growers. The emerging pests covered include frogeye leaf spot, sudden death syndrome, Asian soybean rust, brown marmorated stink bug, kudzu bug, and herbicide-resistant Palmer amaranth (pig weed).

Figure 27.1. Soybean leaf showing frogeye leaf spot lesions. (Photo courtesy of Clemson University – USDA Cooperative Extension Slide Series, Bugwood.org)
**Frogeye Leaf Spot**

Frogeye leaf spot is a common foliar disease of the southern soybean-growing states. Typically the disease can occur sporadically in the central states, but can be seen farther north when weather conditions are favorable. Frogeye leaf spot favors warm, humid weather for development. Spores are spread short distances by wind or splashing rain. Dry weather severely limits disease development. The disease period in South Dakota is July through August. Occurrence is considered rare and is mainly seen in the southeastern parts of state.

Symptoms for frogeye leaf spot include small lesions on leaves that are circular to angular spots which vary in size (Fig. 27.1). The lesions are first visible on the upper surface of the leaf. Frogeye leaf spot lesions have distinctive brown spots that are surrounded by narrow red or dark reddish-brown margins. The central area of the aging lesions becomes ash-grey to light brown. Older lesions are light to dark brown and frequently are translucent, having a grey to white center which may contain minute dark spots. Smaller lesions may coalesce to form larger, irregular spots on leaves.

Young leaves are more susceptible to the infection than older leaves. During a wet year, frogeye leaf spot symptoms may appear uniformly over the foliage. In years with intermittent wet periods, symptoms may appear layered within the plant canopy. When plants are heavily infected, leaves may die and fall prematurely. This can result in early defoliation of soybean plants. Persistent high rainfall and humidity may cause stems and seed pods to become infected. Lesions on pods are reddish brown, may appear sunken, and are circular or elongated in shape. Older lesions on pods become brown to gray, usually with a narrow, dark-brown border.

The fungus that causes frogeye leaf spot will survive in infested soybean residues and infected seed. Therefore, tillage and crop rotation are very effective in reducing the population from one season to the next. If tillage is an option, earlier tillage operations are more effective in reducing pathogen populations. It is best to till infested residues directly after the soybean harvest, rather than after a subsequent corn rotation.

Another management consideration is soybean variety selection. Some soybean varieties are less susceptible to frogeye leaf spot than others.

![Figure 27.2. Leaf showing sudden leaf collapse and distinct foliar symptoms from sudden death syndrome. (Photo courtesy of SDSU Extension Plant Pathology)](image)

**Sudden Death Syndrome**

Sudden death syndrome (SDS) is a major soybean disease in many Midwestern U.S. areas (Fig. 27.2). SDS was first discovered in 1971 in Arkansas and since then has been confirmed throughout most soybean-growing areas of the U.S. Currently, the occurrence of SDS in South Dakota is considered rare; however, it is suspected to be in the state. SDS is a fungal disease that also occurs in a disease complex with the soybean cyst nematode (SCN, *Heterodera glycines*). SDS is among the most devastating soil-borne soybean diseases seen in the United States. It can be difficult to assess the total crop losses, but yield losses of up to 80% have been reported.
The disease symptoms seem to be more pronounced after flowering. SDS foliar symptoms may appear any time from bloom through pod fill. Normally symptoms appear between the R3 and R6 growth stages. Timing of symptom expression depends on weather conditions, maturity group and other characteristics of the cultivar, and general vigor of plant. Other symptoms include inter-venial chlorosis resembling brown stem rot symptoms; yellow blotches between the veins progress to large irregular patches. Yellow patches turn brown and die, while the veins remain green. Symptoms are more pronounced on top leaves. Infected leaves drop, but the petioles remain on the stems. Pod drop may also occur. No stem browning develops as with brown stem rot. SDS conversely may cause a root rot. Infection is favored by cool moist soils.

Sudden death syndrome can be managed by choosing resistant or shorter season cultivars, practicing a crop rotation program, and burying crop residue. Do not irrigate after soybean flowering.

**Asian Soybean Rust**

Asian soybean rust is a foliar disease caused by the fungus *Phakopsora pachyrhizi*. It is an aggressive disease capable of causing defoliation and significant yield loss. Asian soybean rust was found for the first time in North America in November 2004. Since then it has become a problem in the southern U.S. soybean-growing states. Soybean rust requires very moist and mild temperatures to successfully overwinter and its spores are rapidly transported long distances by air currents.

To cause outbreaks in the northern soybean-growing states, the fungus has to spread north via southern winds during the spring and summer. Air temperatures and relatively humid conditions in the North Central region of the U.S. are generally not conducive for soybean rust development, and harsh winter weather conditions reduce its overwintering ability.

Based on the historical spread and general trajectories, it is unlikely that soybean rust will be serious problem in South Dakota and if it does occur, soybeans will most likely have progressed beyond their vulnerable crop stages.

**Brown Marmorated Stink Bug**

The brown marmorated stinkbug (*Halyomorpha halys*) is a relatively new invasive pest in the U.S. It was first found in Pennsylvania around the year 2000. Since then it has been gaining prominence in the eastern U.S. This is a very mobile insect, and it spreads quickly to other parts of the country. When populations are high, it can damage fruit, vegetable, and field crops including corn and soybean. It can also be a household pest because of its habit of coming into homes in the fall (much like the Asian ladybeetle does). Figure 27.3 shows where brown marmorated stink bug was found through early 2011. It remains to be seen how well this insect will fare in northern states.

![Brown Marmorated Stink Bug Detections in the United States](image-url)
Brown marmorated stink bug is similar in appearance to other stink bugs occasionally found in South Dakota soybean fields. The brown marmorated stink bug has several distinct features (Fig. 27.4) that include white bands on the antennae, white triangular notch shapes along the abdomen and a smooth edge (not toothed) along the pronotum or "shoulders," which have rounded tips.

Insects that resemble brown marmorated stink bug include the brown stink bug (only very rarely a soybean pest in northern states) and spined soldier bug (a beneficial predatory insect, Fig. 27.5). Both of these species have sharp, pointy shoulders which quickly distinguish them from brown marmorated stink bug.

Brown marmorated stink bugs have one generation per year. They overwinter as adults and emerge in the spring. They feed on plant juices through straw-like mouthparts, and preferentially feed on fruiting bodies. In soybeans, they shrivel seeds within the pods (Fig. 27.6) and in corn they attack developing kernels.

Japanese Beetle

The Japanese beetle (Popillia japonica) is an invasive insect that has been in the U.S. for several decades. It has a very broad host plant range and feeds on a wide variety of horticultural crop plants, crops, and turf grass. Recently it has been reported as an occasional pest of corn and soybean in Ohio, Illinois, Iowa, and Nebraska. It has been found in South Dakota in urban areas associated with ornamental plants. In the future, the Japanese beetle may become a significant pest in soybean fields.

The Japanese beetle is ⅓ to ½ inch long and has a bright metallic green head and shiny brown wings (Fig. 27.7). It has one generation per year and spends about 10 months of this as a white grub in the soil, feeding on root hairs. Adults emerge in late June and are found feeding on plant foliage in July and August. Adults chew
around leaf veins, causing a lacy or "skeletonized" defoliation pattern on soybean (Fig. 27.8). On corn, they may feed on silks and ear tips in addition to foliage.

**Kudzu Bug**

Kudzu bug (Megacopta cribraria) is also known as the bean plataspid or globular stink bug (Fig. 27.9). This is an emerging soybean pest found in the southeastern U.S. It was first found in Georgia in 2009 and has rapidly spread to surrounding states. In Georgia it has been reported to affect soybean yields up to 47%. Little is known about the kudzu bug's basic biology. It overwinters on kudzu, an invasive weed in southern states. It is not known whether other plants may also serve as an overwintering host. The distribution of kudzu does not extend as far north as South Dakota. If the kudzu bug requires kudzu as an obligate overwintering host, it is unlikely to become a problem in South Dakota.

**Herbicide-resistant Palmer Amaranth (pig weed)**

Palmer amaranth is a fast-growing annual weed in the pigweed family (Fig. 27.10). Other members of the pigweed family are red root pigweed and waterhemp. A native to most of the southern half of North America, Palmer amaranth populations are expanding northward. Palmer amaranth is a dioecious plant (plants are either male only or female only) and it can hybridize with other pigweed species.

This weed produces an enormous amount of seed (500,000 seeds/plant), is fast-growing, and is highly competitive. Plants can grow up to 10 feet in height. Palmer amaranth has become one of the most troublesome weeds in the Southeast because of its fast growth rate, high seed production, and development of
herbicide resistance. The resistance issue is why so many soybean growers in the southern U.S. are concerned with this weed. Different populations of this weed have developed resistance to the Photosystem II inhibitors herbicides (Atrazine, Diuron, etc.), to the Dinitroanilines herbicides (Pendimethalin, Trifluralin, etc.), to the ALS inhibitors herbicides (Imidazolinones, Sulfonyleureas, etc.), and to the Glycines herbicides (Glyphosate).

Currently no populations of Palmer amaranth contain resistance to all classes of these herbicides, but there are some populations with plants resistant to two of the four. Unfortunately, given time and improper management, Palmer amaranth has proven its potential to become resistant to any herbicide that is repeatedly used. Following management guidelines can help slow the growth of this weed (Table 27.1).

Table 27.1. Palmer amaranth guidelines.

1. Use both pre-mergence and post-emergence herbicides that have different modes of action.
2. Reduce soil seed banks by continuously maintaining good weed control.
3. When scouting fields, survey weed populations each season and record observations, especially weeds that escape known herbicide application.
4. Prevent the infestation of this weed in your field and hand remove if necessary.
5. In fields where herbicide resistance is known or highly suspected, clean vehicles and equipment prior to moving to fields where resistance is not suspected.
6. Do not continue to treat weeds with herbicides that continue to show an inability to control the target weed.

Figure 27.10. Mature Palmer amaranth plant. (Photo courtesy of Joe Daubenmier, Dupont Co., Inc.)
References and additional information


Acknowledgements
Support was provided by USDA through the NIFA/IPM program.

Soybean Scouting and Management Calendar

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Scouting the soybean field is an integral part of the management plan for a grower. A regular scouting program helps to prevent serious pest infestations that could reduce yield. Scouting information is essential for decision making. The following scouting and management calendar is designed for soybean production in South Dakota. The time guidelines are based on averages from year to year. As you look at your current cropping year, considerations should be made for growing degree days (GDD), climatic variations, location in the state, and management changes in the operation.
## Soybean Management Schedule

### Growth Stages

**Begin planning**
- Scouting for spring pests, including corn cutworm. (Accomplish weekly and when there is a change in temperature)

**Chapter 41: Stored Grain Pests of Soybeans**

**Chapter 2: Field Evaluation based on Past Management**

**Chapter 18: Collecting Representative Soil Samples**

**Chapter 17: Fertilizers Used in Soybean Production**

**Begin planting**
- Scouting for black cutworm in soybeans. (watch for black cutworm)
- Scouting for white grubs on soybean. (watch for white grubs)

**Chapter 34: Wood Management**

**Soil Evaluation**
- Scouting for phytophthora root and stem rot on soybean. (http://wiki.bugwood.org/NPIPM:Phytophthora_root_and_stem_rot_on_soybean, additionally, Chapter 59 Soybean BMP manual)

**Chapter 36: BMP manual**

**Soil management**
- Scouting for damping-off and seed decay on soybean. (http://wiki.bugwood.org/NPIPM:Damping_off_and_seed_decay_on_soybean, additionally, Chapter 59 Soybean BMP manual)

**Chapter 4: Seedcorn maggot on soybean**

**Seasonal weeds**
- Scouting for wireworms on soybean. (http://wiki.bugwood.org/NPIPM:Wireworms_on_soybean)

**Chapter 34: Wood Management**

**Soil management**
- Scouting for bean leaf beetle. (http://wiki.bugwood.org/NPIPM:Bean_leaf_beetle, additionally, Chapter 36 Soybean BMP manual)

**Chapter 34: Wood Management**

**Soybean Management Schedule**

### Growth Stages

**Chapter 10: Seeding Rates, Dates, and Row Spacing**

**Chapter 34: Wood Management**

**Survey no till and early season weeds**
- Scouting for Phytophthora root and stem rot. (http://wiki.bugwood.org/NPIPM:Phytophthora_root_and_stem_rot_on_soybean)

**Chapter 36: BMP manual**

**Watch for root rots and Rhizoctonia** (specific conditions)

**Chapter 34: Wood Management**

**Evaluate crop stand**
- Scouting white grubs (watch for plant clipping) (http://wiki.bugwood.org/NPIPM:White_grubs_on_soybean)

**Chapter 13: Estimating The Plant Population**

**Scout soybean mosaic virus**
- Scouting for soybean mosaic virus on soybean. (http://wiki.bugwood.org/NPIPM:Soybean_mosaic_virus_on_soybean, additionally, Chapter 60 Soybean BMP manual)

**Chapter 34: Wood Management**

**Watch for SCN females in roots** (10 days after planting)
- Scouting for soybean cyst nematode. (http://wiki.bugwood.org/NPIPM:Soybean_cyst_nematode, additionally, Chapter 57 Soybean BMP manual)

**Chapter 13: Estimating The Plant Population**

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**Note:** The schedule includes key dates and stages for soybean management, emphasizing the importance of regular scouting and monitoring to prevent and manage potential pests and diseases.
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<td>Accomplish fall soil sampling</td>
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<td>Soil sample for next years crop</td>
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### References and additional information

Available at: [http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC932.pdf](http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC932.pdf)

Available at: [http://wiki.bugwood.org/NPIPM](http://wiki.bugwood.org/NPIPM)

### Acknowledgements

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Field Crop Scouting Basics for Soybean Production

Darrell Deneke (Darrell.Deneke@sdstate.edu)

Field scouting along with good field records provides excellent information for current and future management decisions. The purpose of this chapter is to discuss the basics of field scouting (Table 29.1).

Table 29.1. Key factors to consider when field scouting.

- Provide information when pest population thresholds exceed cost of control.
- Frequency and intensity of field scouting should be based on the crop, pest, and control practices.
- Provide location, intensity and extent of pest problem.
- Avoid costly mistakes by checking field records and the soybean trait package.
- Put the information into your field records.
- Use pest specific sampling protocols.

Field history and scouting

The purpose of field scouting is to provide information, from which economically-based recommendations are developed. The economic-based pest threshold is the population level at which the yield loss equals the cost of the controlling the pest (Clay et al., 2011). Examples for determining the threshold levels are available in Clay et al. (2011).

Scouting can be conducted by a variety of people including the grower, a crop consultant, and/or a commercial agronomist. With the wide range of soybean genetic trait packages available (Roundup Ready®, LibertyLink®, Banvil® tolerance, HPPD herbicide tolerance, 2,4-D tolerance), it is important to check the recommendation for genetic compatibility.
Scouting starts by assembling the needed tools. A list of recommended tools is provided in Table 29.2. In addition to these tools, a recent image of the field is very useful. These images can be used to direct scouting activities (Chapter 16). Images can be obtained from a number of sources including Google Earth.

http://www.google.com/earth/index.html

<table>
<thead>
<tr>
<th>Table 29.2. Useful tools to use when scouting production fields.</th>
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<tbody>
<tr>
<td>• Clipboard or notebook</td>
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<tr>
<td>• Clear plastic ziplock bags or screw-top vials</td>
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<tr>
<td>• Scouting sheet</td>
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<td>• Isopropyl alcohol</td>
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<tr>
<td>• Plastic bucket</td>
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<tr>
<td>• Forceps or tweezers</td>
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<tr>
<td>• A good sweep net</td>
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<tr>
<td>• Trowel or hand spade</td>
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<td>• Drop (beat) cloth (2 feet long)</td>
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<tr>
<td>• Hand counter</td>
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<tr>
<td>• Hand lens – (at least 10X magnification)</td>
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<td>• Shovel</td>
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<tr>
<td>• Measuring wheel</td>
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<tr>
<td>• Soil sampling probe</td>
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<tr>
<td>• Sampling square (20 X 20 inches)</td>
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<td>• Paper bags</td>
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<tr>
<td>• Tape measure or yard stick</td>
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<tr>
<td>• Pest ID guides</td>
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<tr>
<td>• GPS</td>
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<tr>
<td>• Field flags</td>
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<tr>
<td>• Sharp pocket knife or single-edged razor</td>
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<tr>
<td>• Camera/video recorder</td>
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<td>• Marker for writing on paper and/or plastic bags</td>
</tr>
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</table>

**Scouting frequency and guidelines**

Scouting frequency will vary by crop, crop stage, pest species and their severity. In general, scouting should be conducted weekly. However, when a pest infestation approaches the economic threshold or when weather conditions favor rapid development, daily monitoring is recommended. Scouting can be conducted for specific pests or all pests. In most areas, different pest species invade at different times. Refer to the pest calendar (Chapter 28) for information on pest timing. When scouting for pests, the number of observations collected in a field is dependent on field size, pest, date, and grower expectations. Generally your recommendation improves with the number of observations collected.

With field scouting, it is a good idea to break a field into sections of 40 to 50 acres that have similar field characteristics and management systems. Don't sample field borders, fence rows, ditch banks, or other non-typical areas of the field unless specific pest protocols suggest this.

Go into the field at least 75 feet or about 30 rows before you start sampling. While walking through field borders, ditches, and fence lines, note any signs of developing problems. This may be an opportunity
to prevent future problems. For fields of less than 100 acres, check or sample a minimum of five locations unless pest-specific protocol is suggested. Fields that are larger than 100 acres need to have a minimum of 10 locations checked or sampled. Differing landscape characteristics and information from field history can also be used to subdivide a field. If the field was in two different crops the previous year and one crop the current year, it should be subdivided as the previous year’s crop area.

Sampling methods also vary according to pest and crop. Sampling options include sweeps of a sweep net for a specific area, insects on a drop or beat cloth, insects on leaf or specific plant part, disease symptoms on plants, weeds per row length (100’), or some measure of land area. A common method for counting insects is using a sweep net. To use a sweep net, swing the net from side to side in a full 180º arc. Tilt the net opening so that the lower edge of the rim is slightly ahead of the upper rim to catch insects as they fall from the plants. Sampling data is generally reported as average number of insects per sweep. A video demonstrating how to use the sweep net is available at http://www.youtube.com/watch?v=-4o2_ym2L0c.

Some insects are easier to count if they are dislodged from the plants by shaking and allowing the insects to fall into a bucket or onto a white drop cloth or beat cloth. This works well for insects that have coloration that allows them to blend in with crop foliage. The cloth can be unrolled on the ground and placed between rows. Plants or both sides of the row are vigorously shaken to dislodge the insects. The same procedure can be done with a white bucket and counts are measured as insects per plant. Count the insects; if you don't know what they are, they can be identified later. For assistance in identifying insects, contact an expert at http://igrow.org/about/our-experts/.

The most common means of sampling (scouting) soybean plants in the field is through visual observation, which works well with many insects and diseases. Specific plant samples can be taken and visual observation of insect and insect stages can be used to predict pest severity and development. Plant nutrient symptoms can also be detected through observation, and plant samples can be taken for analysis. Refer to Chapter 28 to 41 for specific information about individual pests, sampling procedures, and economic thresholds.

Scouting patterns in the field units will help to ensure that the sampling results are representative of the whole field. There are several possible data collection and observation patterns that can be used when scouting fields. These are based on various pest distribution patterns and field layout configurations. As with the sampling options, scouting patterns are specific to pests and soil fertility programs. The three most common field scouting patterns are described below.

**W scouting pattern**

Use the **W pattern** when scouting for pests that are uniformly distributed throughout the field (Fig. 29.1). The sampling sites should be evenly distributed across the field excluding obvious influencing factors such as field edges, hills, and low-lying areas. Alternative patterns may follow an X, Y, W, or Z shape. This pattern is used for identifying leaf diseases, soybean aphids, and armyworms. The value of scouting can be increased by finding your sampling locations with a GPS. At these locations, images can be collected with your smart phone to identify problems.

![Figure 29.1. A W sampling pattern. This pattern is most appropriate when pests are uniformly distributed across a field.](image-url)
**Targeted sampling protocol**

A targeted sampling pattern is used to target pests that favor specific characteristics such as highlands, lowlands, excessively wet or dry areas, or areas high in organic matter (Fig. 29.2). Targeted sampling can be used based on pest characteristics, prior sampling procedures, or remote sensing that identifies where pest populations may be high (Chapter 16). This sampling protocol is designed to concentrate scouting in areas most likely infected with the pest. In this sampling approach, compare pest populations in areas with good growth with areas with poor growth. Some examples of pests that fit this sampling pattern include quackgrass, root rots, and cutworms.

![Figure 29.2. IKONOS false color image (July 10, 2002) of a soybean field in southeastern South Dakota. Areas of very poor plant growth due to SCN and other factors are highlighted. The field across the road to the right was heavily infested with SCN; note poor reflectance in this field. (Source: http://www.umac.org/agriculture/ss/DeterminingtheExtentofSCNInfestationinSoybeanFields/detail.html)](image)

**Targeted sampling-field borders**

This pattern is used when pests are at the edges of fields (Fig 29.3). Scout these pests by walking along the field edges, fence lines or ditches. Examples of pests that invade fields from the boarders include grasshoppers, flea beetles, cheatgrass, and Canada thistle.

![Figure 29.3. A design example for target sampling field borders.](image)

**Other considerations**

Scouting reports may show high populations in one field and not another. These differences may be caused by any number of factors including the soybean trait package, soybean planting date, row spacing, incorrect sampling protocol, and alternate pest hosts around the field. For example, one field may routinely have a higher aphid population than another. These differences may be caused by a winter host, such as buckthorn along the field borders. Soybean acts as the summer host while buckthorn, a shrub common in shelterbelts and woods, serves as the winter host. In South Dakota, aphids migrate to buckthorn in early
autumn where they overwinter. Aphids are also important because they can be a vector for spreading the soybean alfalfa mosaic and alfalfa mosaic viruses.

When scouting for insects, the objective is to identify the insects present in that field and determine which ones maybe problematic. It is very important to determine the insect species and refer to local information on life cycles and economic thresholds prior to designing an appropriate control action. This information is provided in Chapters 28 through 41.

It is helpful to be aware of the presence of any beneficial insects and to estimate if they are influencing the pest population. The beneficial insects have potential to keep the insect pests in check on their own. Because pest populations can change rapidly, it is important to check fields at least weekly during times that insect pest populations are increasing.

Fields can be scouted simultaneously for insects, weeds, and diseases. When scouting for crop diseases, be aware of the disease symptoms, which are common to the area. Plant diseases can be influenced by weather, fertilizers, nutrient deficiencies, herbicides, and soil problems. In many cases, the cause of the problem may not be obvious and may require samples to be taken to a diagnostic laboratory.


The goal of weed scouting is to assess/monitor the infestation level in the field, detect new weeds, and provide weed control recommendations. When new weeds show up, even at low levels, it should be noted so actions can be taken to control or prevent them from becoming a concern. Early detection of new weed problems will allow the implementation of control strategies to prevent future major problems.

South Dakota soybean growers need to implement management plans that minimize the risks of soybean cyst nematodes (SCN) (Chapter 57). SCN can cause above-ground symptoms that are similar to other problems. Some of these symptoms would include streaking, yellowing, and early crop maturation. SCN can be confirmed by using two different sampling approaches. In the first approach, the roots should be checked for living female nematodes. These tiny, lemon-shaped, white to yellow females can be observed four to five weeks after planting. They reach maximum population in July and August.

The second approach is to collect soil samples that will be analyzed for nematode eggs. To collect these samples, a one-inch diameter soil probe should be used to collect soil samples from the surface eight inches of soil. Placement of the probe into the soil can have a tremendous effect on how many egg clusters are removed. Angle the soil probe underneath the soybean row into the root zone. If corn or another non-host crop was the last crop grown in the field, soil cores do not need to be collected from beneath the crop row. However, if soybeans were the previous crop, then collect soil cores from underneath the soybean crop rows. Collect about 15 to 20 samples in a zigzag pattern from no more than 20-acre areas in the field. Be sure these areas are representative of the sampling area. Mix multiple soil cores very well in bucket before placing in the sampling bag. Soil samples can be sent to the South Dakota State University Plant Disease Clinic for SCN analysis.
Contact information is below.

SDSU Plant Disease Clinic
605-688-5545
sdsu.pdc@sdstate.edu

PO Box 2108, PSB 117
South Dakota State University
Brookings, SD 57007-1090

References and additional information


Wilson, H.R. 1990. I.P.M. field scouting. FCPM Circular #2. The Ohio State University, Ohio State University Extension, Columbus, OH. Available at http://ohioline.osu.edu/icm-fact/fc-02.html

Acknowledgements

Support was provided by USDA through the NIFA/IPM program.

There are many grass or grass-like weeds that reduce soybean yields. This chapter provides yield loss potentials, emergence information, and keys for identifying important grass or grass-like weeds. Selected characteristics of grass and grass-like weeds are provided in Table 30.1.

<table>
<thead>
<tr>
<th>Weed Emergence Timing</th>
<th>Weed</th>
<th>Yield Loss Potential</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Early-season</td>
<td>Volunteer corn</td>
<td>High</td>
<td>May be WSSA Group 9 (glyosate) (if RR cultivars planted); WSSA Group 2 (ALS inhibitors) (e.g., sulfonylureas and imidiazilinones) (if Clearfield cultivars planted); or WSSA Group 10 (glufosinate) (if LibertyLink cultivars planted).</td>
</tr>
<tr>
<td>Early-season</td>
<td>Woolly cupgrass</td>
<td>Moderate</td>
<td>Post emergence grass herbicide provides good control, and is not controlled by most pre-grass herbicides.</td>
</tr>
<tr>
<td>Early-season</td>
<td>Giant foxtail</td>
<td>Moderate</td>
<td>May be resistant to WSSA Group 1 (ACC-ase inhibitors) (e.g., sethoxydim); Group 2 (ALS inhibitors) (sulfonylureas and imidiazilinones); Group 3 (mitosis inhibitors) (e.g., trifluralin); and Group 5 (photosystem II inhibitors) (e.g., metribuzin).</td>
</tr>
<tr>
<td>Early-season</td>
<td>Yellow foxtail</td>
<td>Moderate</td>
<td>May be resistant to WSSA Group 1 (ACC-ase inhibitors) (e.g., sethoxydim); Group 2 (ALS inhibitors) (sulfonylureas and imidiazilinones); Group 3 (mitosis inhibitors) (e.g., trifluralin); and Group 5 (photosystem II inhibitors) (e.g., metribuzin).</td>
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<tr>
<td>Mid-season</td>
<td>Green foxtail</td>
<td>Moderate</td>
<td>May be resistant to WSSA Group 1 (ACC-ase inhibitors) (e.g., sethoxydim); Group 2 (ALS inhibitors) (sulfonylureas and imidiazilinones); Group 3 (mitosis inhibitors) (e.g., trifluralin); and Group 5 (photosystem II inhibitors) (e.g., metribuzin).</td>
</tr>
<tr>
<td>Early-season</td>
<td>Foxtail barley</td>
<td>Moderate</td>
<td>No resistance reported.</td>
</tr>
<tr>
<td>Late-season</td>
<td>Longspine sandbur</td>
<td>Low</td>
<td>No herbicide resistance reported.</td>
</tr>
<tr>
<td>Late-season</td>
<td>Barnyardgrass</td>
<td>Low</td>
<td>May be resistant to photosystem II inhibitors (WSSA Group 5, metribuzin) and ACC-ase inhibitors (WSSA Group 1, e.g., sethoxydim).</td>
</tr>
<tr>
<td>Late-season</td>
<td>Large crabgrass</td>
<td>Low</td>
<td>May be resistant to ACC-ase inhibitors (WSSA Group 1) (e.g., sethoxydim).</td>
</tr>
<tr>
<td>Late-season</td>
<td>Witchgrass</td>
<td>Low</td>
<td>May be resistant to photosystem II inhibitors (WSSA Group 5) (e.g., metribuzin).</td>
</tr>
<tr>
<td>Late-season</td>
<td>Wild proso millet</td>
<td>Moderate to High</td>
<td>No resistance reported.</td>
</tr>
<tr>
<td>Late-season</td>
<td>Fall panicum</td>
<td>Moderate</td>
<td>No resistance to herbicides in the U.S.</td>
</tr>
<tr>
<td>Late-season</td>
<td>Scouring rush</td>
<td>Low</td>
<td>No resistance reported, although difficult to control; found in areas that may have been flooded or very wet.</td>
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<tr>
<td>Field horsetail</td>
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When choosing an herbicide, always read and follow label instructions. It is a violation of federal pesticide laws to use an herbicide in a manner inconsistent with labeling as to rate, timing, and other restrictions. Read the entire label prior to use. Always follow applicator safety instructions. Protect water quality, by preventing accidents and spills, back siphoning, mixing and applying away from water sources. There is no intent to specify product performance guarantees. Users are responsible for following all herbicide label directions and precautions.
Volunteer Corn (Zea mays)

**Time of emergence:** Volunteer corn typically emerges early, before, or just after planting depending on soil temperature and moisture conditions.

**Life cycle and reproduction:** Annual, reproducing from seed lost during combining at harvest.

**Areas of infestation:** Typically occurs in localized areas. Problems are heightened when rotating into a long-term corn monoculture system or when a herbicide-resistant variety was planted the previous year.

**Yield loss potential:** Volunteer corn may cause yield losses up to 40%. Control should be implemented if volunteer corn density is about 1 plant/yd² (about 1 plant/m²) (Fig. 30.1).

**Suggested management:** If a glyphosate-tolerant corn variety was planted, use a pre or post-emergent grass herbicide or cultivate inter-row areas if soybeans are in 30” rows.

**Herbicide resistance:** Hybrid-dependent based on transgenic traits; glyphosate (Roundup Ready® varieties), glufosinate (LibertyLink® varieties), or ALS-inhibiting herbicides (Clearfield® varieties).

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**Figure 30.1. Volunteer corn densities.** (Produced and prepared by Purdue University Extension Weed Science)
Woolly cupgrass (*Eriochloa villosa*)

**Time of emergence:** When soil temperatures are favorable, woolly cupgrass emerges before or just at soybean planting. Typically, woolly cupgrass germination period is short (all seedlings emerge within two weeks after initial emergence).

**Life cycle and reproduction:** Woolly cupgrass is an annual that reproduces by seed.

**Distinguishing characteristics:** The cotyledon and first true leaf are very wide. Leaves are covered in fine soft hair (hence the name woolly) and one of the leaf margins generally is crinkled. This plant is often confused with foxtails, but typically does not tiller as much as a foxtail plant. The seed head is a distinctive panicle with compressed rows of seed. The seed is oval and vary in color from tan to brown to green.

**Areas of infestation:** Found in fertile loam to clay loam soils.

**Yield loss potential:** Moderately competitive, especially plants that emerge early in the season.

**Suggested management:** Typically uncontrolled by pre-emergence grass herbicides in the acetanilide family (metolachlor, acetochlor) (WSSA Group 15) although early suppression may be seen. Mitosis inhibitor herbicides such as pendimethalin (WSSA Group 3) may give good control. Post-emergence grass herbicides give good to excellent control.

**Herbicide resistance:** None has been reported.

![Figure 30.2. Woolly cupgrass seedling, collar region, and seed head.](image-url) (Top photo & drawings courtesy of Iowa State University; bottom photo courtesy of Michael Moechnig)
**Giant foxtail (Setaria faberii), Yellow foxtail (S. pumila), and Green foxtail (S. viridis)**

**Time of emergence:** Giant foxtail often emerges before soybean planting. Yellow and green foxtails emerge toward the end of planting.

**Life cycle and reproduction:** Each of these weeds is an annual that reproduces by seed.

**Distinguishing characteristics:** Giant foxtail is infrequently found in South Dakota. Soft short hairs are found on the leaf blade and the plant has a hairy ligule. Plants can grow up to seven feet tall. Yellow and green foxtails infest most eastern South Dakota fields. Yellow foxtail has long yellow hairs near the ligule, a flattened stem, and large seeds. Green foxtail has no or few hairs on the leaf blade, a round stem, and seeds are small.

**Areas of infestation:** Common in several soil types and in many climates.

**Figure 30.3. Giant foxtail ligule (left) and mature plant (right).** (Left, photo courtesy of The Weed Science Society of America; right, photo courtesy of Pacific Northwest Weed Handbook)

**Yield loss potential:** Soybean yield losses can reach 20% if densities are >2 plants/ft². The potential for yield loss is greater with giant foxtail compared to yellow or green foxtail at similar densities.

**Suggested management:** Tillage, crop rotation, and post-emergence cultivation can effective control measures. Green and yellow foxtail can be controlled with a variety of both pre- and post-emergence grass herbicides typically used in soybean.

**Herbicide resistance:** Biotypes of all these foxtails have shown resistance to a number of herbicides with different modes-of-action. Giant foxtail has been reported to be resistant to photosystem II inhibitors (e.g., metribuzin WSSA Group 5); ALS inhibitors (sulfonylureas and imidazolinones WSSA Group 2); and ACC-ase inhibitors (e.g., sethoxydim WSSA Group 1). Yellow foxtail has been reported to be resistant to ALS and photosystem II herbicides. Green foxtail has been reported to be resistant to mitosis inhibitors (e.g., dinitroaniline herbicides such as trifluralin) (WSSA Group 3), ALS, ACC-ase inhibitors, and photosystem II inhibitors.
Foxtail barley (*Hordeum jubatum*)

**Time of emergence:** This cool-season grass emerges early in the season.

**Life cycle and reproduction:** This perennial native cool-season grass is a bunchgrass found in patches. This shallow-rooted plant reproduces by seed. Overwintering plants can start growth very early in the growing season and will produce a seedhead by late May or early June.

**Distinguishing characteristics:** Vegetative stems are round and have no hair. The ligule is membranous, blunt, and with a few hairs. Clasping auricles are found at the collar region. The glumes and lemma of the seed have long (0.5” to 3”) awns that are often purplish in color.

**Areas of infestation:** Foxtail barley grows well in saline, wetland sites and is often found in field edges and roadsides. This plant is more problematic in no-till fields due to lack of tillage disturbance.

**Yield loss potential:** Moderate.

**Suggested management:** Burndown with glyphosate prior to planting. Soil management to decrease water and salt problems in infested areas may be warranted.

**Herbicide resistance:** None reported.
Longspine sandbur (*Cenchrus longispinus*)

**Time of emergence:** Longspine sandbur is a non-native warm-season grass emerging after planting.

**Life cycle and reproduction:** Longspine sandbur is an annual that reproduces from seed.

**Distinguishing characteristics:** Sandbur has stems that are flattened with hairs; leaves may be rough to the touch. The plant has a short, fringed, hairy ligule. Seeds are enclosed in sharp, spiny, hairy burs that are characteristic and give the plant its name.

**Areas of infestation:** Found in sandy soils, although may be found in fertile loam to clay loam soils.

**Yield loss potential:** Yield loss is often low. Nuisance plant due to sharp burs.

**Suggested management:** Tillage is effective when sandbur is small. Competition with shading reduces growth. Many pre-emergent and post-emergent grass herbicides typically used in soybean give good to excellent control. However, pre-emergence seedling shoot inhibitor herbicides (e.g., metolachlor, WSSA Group 15) have been shown to provide only marginal control for sandbur.

**Herbicide resistance:** None has been reported for field sandbur.
Barnyardgrass (Echinochloa crus-galli)

Time of emergence: Barnyardgrass is a warm-season grass that emerges later in the season after planting.

Life cycle and reproduction: Annual plant that reproduces by seed.

Distinguishing characteristics: This warm-season grass has flattened, smooth, and branched stems without an auricle or ligule. This grass has broad leaves and typically is reddish or purple at the base of the plant. Barnyardgrass size can vary from two inches tall with only one tiller to over four feet tall with 50+ tillers. Larger plants are found around field edges, in wet areas, or in areas with poor canopy cover.

Areas of infestation: Found in wetter areas.

Yield loss potential: Yield loss is often low due to late emergence.

Suggested management: Tillage is effective when plants are small. Shade under a crop canopy reduces growth. Pre-emergent herbicides that contain PPO inhibitors (e.g., sulfentrazone, WSSA Group 14), microtubule inhibitors (e.g., trifluralin, WSSA Group 3), or seedling shoot inhibitors (e.g., metolachlor, WSSA Group 15) provide good to excellent control of barnyardgrass. Post-emergent grass herbicides such as ACCase inhibitors (e.g., fluazafop, WSSA Group 1) are often effective. Depending on herbicide-resistant variety planted, glyphosate (WSSA Group 9) and glufosinate (WSSA Group 10) will provide excellent post-emergence control.

Herbicide resistance: Biotypes have been reported to be resistant to photosystem II inhibitors (e.g., metribuzin WSSA Group 5); ACCase inhibitors (e.g., sethoxydim WSSA Group 1); and other chemicals.

Figure 30.8. Barnyardgrass collar region and seed head. (Photos, M. Moechnig)
Large crabgrass (*Digitaria sanguinalis*)  
**Time of emergence:** This warm-season grass emerges after soybean emergence.  
**Life cycle and reproduction:** Large crabgrass is an annual that reproduces by seed.  
**Distinguishing characteristics:** Hairs found everywhere on plant, flattened stem, ligule membranous, seedhead finger-like spikes. This grass can grow from six inches to two feet tall.  
**Areas of infestation:** No specific growing requirements.  
**Yield loss potential:** Low even at high densities.  
**Effective management:** Tillage, crop rotation, and post-emergence cultivation may be effective management tools to reduce stand numbers. This grass is often difficult to control post-emergence and should be controlled with pre-emergence chemicals.  
**Herbicide resistance:** Herbicide resistance has been reported to ACCase inhibitors (e.g., sethoxydim WSSA Group 1) in Wisconsin.  

![Figure 30.9. Large crabgrass collar region and mature plant. (Photos, M. Moechnig)](image)

Wild proso millet (*Panicum miliaceum*)  
**Time of emergence:** Typically late in the season, after soybean planting.  
**Life cycle and reproduction:** Wild proso millet is an annual that reproduces by seed.  
**Distinguishing characteristics:** This warm-season grass has a round stem with membranous ligule tipped with a fringe of hair. Seedlings look like corn but are hairy. Leaf blades are flat. Hairs may or may not be on the blade and sheath, but hairs are present at nodes. This grass can grow up to six feet tall. Seeds large, shiny, and white, green striped, olive brown, or black and often remain on the root of seedlings which helps in identification. Nonblack seeds in soil are usually not viable after two seasons; black seeds have been reported to remain viable for up to four years.  
**Areas of infestation:** Tolerates sandy, dry soils and high temperatures.  
**Yield loss potential:** Yield loss is moderate to high.  
**Suggested management:** Tillage is effective when plants are small. Shading by the crop canopy reduces growth. Fair or poor control is obtained when pre-emergent grass herbicides are used. However, post-emergent weed control is rated as good if using herbicides that contain ACCase inhibitors (WSSA Group 1). Sanitation of equipment is suggested to prevent spread.  
**Herbicide resistance:** None noted at this time.
Witchgrass (*Panicum capillare*)

**Time of emergence:** This warm-season annual grass emerges after soybean emergence.

**Life cycle and reproduction:** This annual weed reproduces by seed.

**Distinguishing characteristics:** Witchgrass has a flat stem with long, soft hairs covering most of the plant. The ligule is a fringe of hair. Panicles are an open inflorescence, spreading, hairy, and large. When mature, the panicle can break off and tumble along the ground.

**Areas of infestation:** Grows well in sandy, droughty soil.

**Yield loss potential:** Low, even at high densities.

**Suggested management:** Tillage, crop rotation, and post-emergence cultivation can be effective control measures reducing stand numbers. Pre- and post-emergent grass herbicides typically used in soybean can be used for control.

**Herbicide resistance:** A biotype of witchgrass, resistant to photosystem II herbicides (e.g., metribuzin WSSA Group 5) has been reported in Canada.
Fall panicum (*Panicum dichotomiflorum*)

**Time of emergence:** This warm-season grass emerges late in the season, after soybean has emerged.

**Life cycle and reproduction:** This annual weed reproduces by seed.

**Distinguishing characteristics:** Vegetative stems are sometimes confused with witchgrass, although fall panicum has few hairs. Sheath is round. Blade is hairless and midrib is usually white and prominent. Seeds are bigger than witchgrass seed.

**Areas of infestation:** Fall panicum grows well in sandy or droughty soil types.

**Yield loss potential:** Moderate.

**Suggested management:** Pre-emergence grass herbicides can be effective against this grass weed.

**Herbicide resistance:** Worldwide; only Spain has reported resistance to photosystem II inhibiting compounds in WSSA Group 5 (e.g., metribuzin).
**Scouring rush** (*Equisetum hyemale*) and **Field horsetail** (*Equisetum arvense*)

**Time of emergence:** These warm-season grass-like plants emerge after soybean emergence.

**Life cycle and reproduction:** These perennial weeds reproduce from rhizomes and spores. They are slow to establish.

**Distinguishing characteristics:** Both plants have hollow stems; reproduce by spores and not seed. Scouring rush has erect, green, and unbranched stems. Most field horsetail plants have many branches that occur in whorls in the joints. Stems of both plants contain silica and were used to scrub pans.

**Areas of infestation:** Commonly found in wet roadside ditch areas. Encroaches into field edges and seasonally wet areas, but is often slow to spread.

**Yield loss potential:** Low, even at high densities, although soybean growth may be hampered in the wet soils, exaggerating the importance of these weeds.

**Suggested management:** Due to the perennial rhizomes of these weeds, tillage may spread the problem. Flumetsulam (ALS inhibitor, WSSA Group 2 herbicide) has been shown to give some control to these weeds. However, these plants are not on the label and no control is guaranteed.

**Herbicide resistance:** None reported.

References and additional information
Center for Invasive Species and Ecosystem Health. Available at http://bugwood.org/

Acknowledgements
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The effective management of broadleaf weeds can improve soybean yields. The purpose of this chapter is to discuss the biology and management of broadleaf weeds routinely found in South Dakota soybean fields. Characteristics of selected broadleaf weeds are in Table 31.1.


<table>
<thead>
<tr>
<th>Weed Emergence</th>
<th>Weeds</th>
<th>Yield Loss</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>May overwinter from</td>
<td>Field pennycress</td>
<td>Low</td>
<td>May be a host to soybean cyst nematode.</td>
</tr>
<tr>
<td>fall</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>May overwinter from</td>
<td>Horseweed</td>
<td>High</td>
<td>Resistant to WSSA Group 9 (glyphosate).</td>
</tr>
<tr>
<td>fall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May overwinter from</td>
<td>Evening primrose</td>
<td>Low</td>
<td>No herbicide resistance reported.</td>
</tr>
<tr>
<td>fall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overwinter to late</td>
<td>Common mallow</td>
<td>Not reported</td>
<td>No resistance reported.</td>
</tr>
<tr>
<td>season emergence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early spring</td>
<td>Common sunflower</td>
<td>High</td>
<td>Resistant to WSSA Group 2 (ALS inhibitors).</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Early spring</td>
<td>Smartweed</td>
<td>Moderate</td>
<td>Resistant to WSSA Group 5 (photosystem II inhibitors).</td>
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<tr>
<td>Early spring</td>
<td>Common lambsquarters</td>
<td>High</td>
<td>Resistance to WSSA Groups 2 (ALS inhibitors) and 5 (photosystem II inhibitors).</td>
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<tr>
<td>Early spring</td>
<td>Giant ragweed</td>
<td>High</td>
<td>Resistant to WSSA Groups 2 (ALS inhibitors) and 9 (glyphosate).</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Early spring</td>
<td>Russian thistle</td>
<td>High</td>
<td>Resistance to WSSA Group 2 (ALS inhibitor).</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Early spring</td>
<td>Canada thistle</td>
<td>High</td>
<td>Resistance to WSSA Group 4 (auxin type).</td>
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<td></td>
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<td></td>
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<tr>
<td>Early spring</td>
<td>Hedge bindweed</td>
<td>Low to</td>
<td>No resistance reported.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>moderate</td>
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</tr>
<tr>
<td>Early spring</td>
<td>Dandelion</td>
<td>Low</td>
<td>No resistance reported.</td>
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<tr>
<td>Early spring</td>
<td>Volunteer elm</td>
<td>Not reported</td>
<td>No resistance reported.</td>
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<tr>
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<td></td>
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</tr>
<tr>
<td>Early spring</td>
<td>Perennial sowthistle</td>
<td>Not reported</td>
<td>No resistance reported.</td>
</tr>
<tr>
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<tr>
<td>Early spring</td>
<td>Jerusalem artichoke</td>
<td>High</td>
<td>No resistance reported.</td>
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<tr>
<td>Early spring</td>
<td>Kochia</td>
<td>High</td>
<td>Resistance to WSSA Groups 2 (ALS inhibitors), 5 (photosystem II inhibitors), 9 (glyphosate), and 4 (auxin type).</td>
</tr>
<tr>
<td>Early spring to mid-</td>
<td>Wild buckwheat</td>
<td>Low to</td>
<td>Tolerance to WSSA Group 9 (glyphosate) and 4 (auxin type).</td>
</tr>
<tr>
<td>summer</td>
<td></td>
<td>moderate</td>
<td></td>
</tr>
<tr>
<td>Mid-spring</td>
<td>Common ragweed</td>
<td>Moderate to high</td>
<td>Resistance to WSSA Group 2 (ALS inhibitors).</td>
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<tr>
<td>Mid-spring</td>
<td>Velvetleaf</td>
<td>Moderate</td>
<td>Resistance to WSSA Group 5 (Photosystem II inhibitors).</td>
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<tr>
<td>Mid-spring</td>
<td>Redroot pigweed</td>
<td>High</td>
<td>Resistance to WSSA Groups 5 (photosystem II inhibitors) and 2 (ALS inhibitors).</td>
</tr>
<tr>
<td>Mid-spring to early</td>
<td>Field bindweed</td>
<td>High</td>
<td>Tolerance to WSSA Group 9 (glyphosate).</td>
</tr>
<tr>
<td>summer</td>
<td>Common cocklebur</td>
<td>High</td>
<td>Resistance to WSSA Group 2 (ALS inhibitors).</td>
</tr>
<tr>
<td>Early summer</td>
<td>Wild mustard</td>
<td>High</td>
<td>No resistance reported.</td>
</tr>
<tr>
<td>Early summer</td>
<td>Black nightshade</td>
<td>High</td>
<td>Resistance to WSSA Groups 2 (ALS inhibitors), 5 (photosystem II inhibitors), and 22 (photosystem I inhibitors).</td>
</tr>
<tr>
<td>Early to mid-summer</td>
<td>Venice mallow</td>
<td>Low</td>
<td>Resistance not reported.</td>
</tr>
<tr>
<td>Early to mid-summer</td>
<td>Common waterhemp</td>
<td>Moderate to high</td>
<td>Resistance to WSSA Groups 2 (ALS inhibitors), 5 (photosystem II inhibitors), 9 (glyphosate), and 14 (PPO inhibitors).</td>
</tr>
<tr>
<td>Mid-summer</td>
<td>Buffalobur</td>
<td>Low to</td>
<td>No resistance reported.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>moderate</td>
<td></td>
</tr>
</tbody>
</table>
Annual weeds

Weeds can be characterized by their life cycle. Annual weeds are those that germinate from seed every year and only live for a single season. Annual weeds can germinate during the spring, summer, or fall. Fall or very early spring emerging weeds include field pennycress, horseweed (marestail), and evening primrose. Weeds that emerge in early to late spring (weeks prior to soybean planting) include common sunflower, Pennsylvania smartweed, ladysthumb, common lambsquarters, and giant ragweed. Weeds that typically emerge at or soon after soybean planting are common ragweed, velvetleaf, Russian thistle, redroot pigweed, and kochia. Annual weeds that emerge at the end of soybean planting include common cocklebur, wild mustard, black nightshade, venice mallow, and wild buckwheat. Weeds that typically emerge after soybean emergence include common waterhemp and buffalobur.

Biennial weeds

These plants germinate from seed in the spring and overwinter as a rosette. The second year, the plant produces flowers and seeds. Examples of biennial weeds are biennial wormwood and common mallow.

Perennial weeds

These plants can germinate from seed, and/or may produce new shoots from buds, roots, or rhizomes. The shoots from the buds can emerge very early and grow quickly due to the carbohydrate storage in the perennating structures. Perennials are often found and flourish in no-till systems. Examples of perennial weeds are Canada thistle, field bindweed, hedge bindweed, dandelion, volunteer elm tree, perennial sowthistle, and Jerusalem artichoke.

Field pennycress (Thlaspi arvense)

Time of emergence: May overwinter as a rosette and bolt in the spring or emerge in the spring very early before, or just at planting.

Life cycle and reproduction: This annual plant reproduces from seed.

Distinguishing characteristics: Young plant is a rosette (like a dandelion). Older plants bolt and develop a flower stalk. Flower stalks have many branches. The flowers are very small and are generally white. Fruit is a silicle, broad and elliptical, and look like a “penny.”

Areas of infestation: Found in roadsides and fields.

Yield loss potential: Historically, seldom dense enough to warrant control. However, this plant was shown to be a moderate alternate host to soybean cyst nematode (SCN) in Ohio studies (Venkatesh et al. 2000), so control is warranted. In the future, higher densities may become a problem as field pennycress is being examined as an alternative oil seed crop.

Effective management: Control in late fall or as the overwintering population prior to soybean planting. ALS inhibitor (WSSA Group 2) (if not resistant) herbicides provide good to excellent control and may be used in combination with glyphosate (WSSA Group 9) in the fall or as a burndown prior to planting. In the cases where resistant biotypes may be a problem, the use of tillage, crop rotation, and post emergence cultivation may be required.

Herbicide resistance: ALS-resistant biotypes have been reported in Canada.
Horseweed (*Conzya canadensis*)

**Time of emergence:** May overwinter as a rosette and bolt in the spring or emerge in the spring very early before, or just at planting.

**Life cycle and reproduction:** This annual weed reproduces by seed.

**Distinguishing characteristics:** The plant has numerous linear, hairy (although some are plants are without hair) leaves crowded on the stem. The flowers are very small and are generally white.

**Areas of infestation:** Tolerates drought conditions well.

**Yield loss potential:** Historically, seldom dense enough to warrant control. With resistant biotypes (seen in South Dakota, Indiana, Nebraska, and Ohio), the problems with this weed have become worse in recent years. High densities in soybean have had >80% yield loss.

**Effective management:** Control overwintering population in the spring prior to planting. PPO inhibitor (WSSA Group 14) and ALS inhibitor (WSSA Group 2) (if not resistant) herbicides provide good to excellent control. In the cases where resistant biotypes may be a problem the use of tillage, crop rotation, and post emergence cultivation may be needed.

**Herbicide resistance:** This weed typically has been sparse in fields. In South Dakota, biotypes of glyphosate (WSSA Group 9) resistant horseweed have been documented. However, biotypes in neighboring states have been documented that are resistant to other herbicides including photosystem II inhibitors (WSSA Group 5, metribuzin), glyphosate (WSSA Group 9), ALS inhibitors (WSSA Group 2), and paraquat (WSSA Group 22). These biotypes and their quick spreading nature make this weed very problematic.
Evening primrose (Oenothera sp.)

Time of emergence: May overwinter as a rosette and bolt in the spring or emerge in the spring very early before, or just at, planting.

Life cycle and reproduction: Winter annual, or early spring emergence. The plant reproduces by seed.

Distinguishing characteristics: There are 20 species of primrose in the Great Plains. The plants that emerge in the fall overwinter as a rosette. Leaves are lance-like to oblong and are hairy. The plant has numerous linear, hairy (although some are plants are without hair) leaves on the stem. The flowers are yellow to reddish yellow. The fruit is a cylindrical capsule tapering at the tip.

Areas of infestation: Often found in reduced tillage systems. Tolerates drought conditions and sandy soil types. This plant is being explored as an alternative oil seed crop.

Yield loss potential: Historically, this plant is not dense enough to warrant control.

Effective management: Control overwintering rosette population prior to planting. Many studies suggest glyphosate + 2,4-D as a preplant burndown application if this weed is a problem. Use other control methods such as tillage, crop rotation, and post-emergence cultivation for management.

Herbicide resistance: No herbicide resistance reported at this time; however, the plant may be difficult to control with typical soybean herbicides.
Common mallow (or Roundleaf mallow) (*Malva neglecta*)

**Time of emergence:** This plant reproduces from seeds and can behave as an annual, winter annual, or under warmer conditions as a biennial, or short-lived perennial. Seedlings emerge in several flushes throughout the season.

**Life cycle and reproduction:** This plant reproduces by seed. However, if the winter is mild or if the site is protected, the plant may be longer lived and survive more than one season.

**Distinguishing characteristics:** The first true leaves of seedlings are round. The leaves, which are hairy, are alternate and oval to kidney-shaped with wavy, lobed edges. The plant is prostrate to the ground, but may grow taller than 1.5 feet. It may also be vine-like and spreading. Fruit is disk-shaped and flattened with a cheesewheel appearance.

**Areas of infestation:** Rare in cultivated fields although heavy infestations may occur. Deep, taprooted plant that can survive drought and cold temperatures.

**Yield loss potential:** Soybean yield reduction has not been assessed. However, when present the plant can cause problems in cutter bars at harvest due to the vining characteristic of the plant.

**Effective management:** Common mallow can be controlled preplant with 2,4-D; however, soybean planting must be delayed by at least seven days. Pre-emergent herbicides containing PPO inhibitors (WSSA Group 14) are recommended for control. Post-harvest control with PPO inhibitors (WSSA Group 14) + glyphosate (WSSA Group 9) was an effective combination in NDSU trials, whereas glyphosate alone was not. Prevention and cultural control should be implemented in addition to chemical management.

**Herbicide resistance:** No resistant biotypes of this plant have been reported at this time.

Common sunflower (*Helianthus annuus*)

**Time of emergence:** Typically early; weeks before soybean planting.

**Life cycle and reproduction:** This annual weed reproduces by seed.

**Distinguishing characteristics:** The cotyledon is oval to spatulate in shape. The leaves are alternate with toothed margins. As the plant matures, the stem, which is covered with stiff hairs, becomes many branched and has characteristic yellow flowers.

**Areas of infestation:** Typically occurs in drier areas of South Dakota, although some infestations may be found in wetlands.

**Yield loss potential:** One of the most highly competitive plants with soybean (often ranked #1 in competitive ability) with up to 70% yield reductions even at relatively low densities.

**Effective management:** In SDSU trials, pre-emergent herbicides are rated only as fair to good for control. Many post-emergent ALS inhibitor (WSSA Group 2) herbicides are rated as providing excellent control of common sunflower (if not resistant, see below). Glyphosate (WSSA Group 9) and glufosinate (WSSA Group 10) also give excellent control, if the appropriate GMO soybean type is planted. Tillage, crop rotation, and post-emergence cultivation should also be considered as management tools to reduce stand numbers.
Herbicide resistance: Common sunflower biotypes have been reported to be resistant to ALS inhibitor (WSSA Group 2) herbicides in neighboring states.

Smartweed sp. (Pennsylvania smartweed and Ladysthumb) (*Polygonum* sp.)

**Time of emergence**: Typically early; weeks before soybean planting.

**Life cycle and reproduction**: This native annual plant reproduces by seed.

**Distinguishing characteristics**: The cotyledon is linear to oar-shaped. The leaves are alternate in arrangement with the leaf surface smooth to slightly hairy. Nodes on the stem are swollen (jointed) stem with a papery sheath at each node (ochrea). Flowers are pink and the inflorescence type is a raceme.

**Areas of infestation**: Typically occurs in wetter areas of South Dakota fields.

**Yield loss potential**: Moderate loss (~15%) at higher densities.

**Effective management**: In SDSU trials, pre-emergent herbicides in the ALS inhibitor (WSSA Group 2); photosystem II inhibitor (WSSA Group 5); and PPO inhibitor (WSSA Group 14) groups have been rated as good for control. Many post-emergent ALS inhibitor (WSSA Group 2) herbicides are rated as good and Basagran (bentazon) (WSSA Group 6) is rated as providing excellent control of smartweed sp. Glyphosate (WSSA Group 9) and glufosinate (WSSA Group 10) also provide good control if the appropriate GMO soybean type is planted. Tillage, crop rotation, and post-emergence cultivation should also be considered as management tools to reduce stand numbers.

**Herbicide resistance**: Smartweed biotypes have been reported to be resistant to photosystem II inhibitor herbicides (WSSA Group 5) in neighboring states.
Common lambsquarters (*Chenopodium album*)

**Time of emergence:** The first flush typically emerges early, usually before soybean planting; however, several flushes of lambsquarters can occur with emergence continuing through early summer.

**Life cycle and reproduction:** This annual weed reproduces by seed.

**Distinguishing characteristics:** Emerging plants are very small. Leaves are opposite and covered with a mealy powder, especially on the underside. The stems are erect, may have green or red stripes, and can grow to almost 6 feet tall under certain conditions. The flowers are nonshowy and without petals.

**Areas of infestation:** Found in disturbed sites

**Yield loss potential:** Up to 40% soybean yield reductions reported at densities of 0.5 plants/ft² if early emerging plants are left uncontrolled.

**Effective management:** Pre-emergent broadleaf herbicides—including PPO inhibitors (WSSA Group 14) and ALS inhibitors (WSSA Group 2)—provide good control in SDSU trials. Postemergent herbicides work best on very young plants although most give no greater than “good” control. Herbicides used on GMO soybean also provide no better than “good” control. This weed is very difficult to control after the 6” stage of growth. Prevention and cultural control should be implemented in addition to chemical management.

**Herbicide resistance:** Biotypes of this plant have been reported to be resistant to ALS inhibitors (WSSA Group 2) and photosystem II inhibitors (WSSA Group 5). Reduced sensitivity to glyphosate (WSSA Group 9) has been reported in some populations.
Giant ragweed (*Ambrosia trifida*)

**Time of emergence:** The first flush typically emerges early, usually before soybean planting; if weather turns warm, usually germination ends.

**Life cycle and reproduction:** This annual weed reproduces by seeds.

**Distinguishing characteristics:** Cotyledons are spatulate (spoon-shaped). Leaves are opposite and divided into three to five lobes. The stems are erect, branched, and can grow to almost 6 feet tall under certain conditions. The flowers are nonshowy and without petals.

**Areas of infestation:** Typically found at disturbed sites that have moist soil.

**Yield loss potential:** Up to 40% soybean yield reductions reported at densities of 0.5 plants/ft² if early emerging plants are left uncontrolled.

**Effective management:** Pre-emergent broadleaf herbicides—including PPO inhibitors (WSSA Group 14) and ALS inhibitors (WSSA Group 2)—provide good control in SDSU trials. Post-emergent herbicides in these groups also give fair to excellent control. Glyphosate (WSSA Group 9) gives excellent control if resistance is not a problem. Overuse of the same chemical should be avoided to maintain the effectiveness of the herbicide. Prevention and cultural control should be implemented in addition to chemical management.

**Herbicide resistance:** Biotypes of this plant have been reported to be resistant to ALS inhibitors (WSSA Group 2) in many states, and glyphosate (WSSA Group 9) has been reported in some populations in Minnesota, Iowa, and Nebraska. Biotypes resistant to both ALS and glyphosate have also been reported.
Russian thistle (*Salsola iberica*)

**Time of emergence:** Typically emerges early, before soybean planting.

**Life cycle and reproduction:** This annual weed reproduces by seeds.

**Distinguishing characteristics:** Seedlings have threadlike leaves and resemble a small pine tree. Leaves of older plants become spine-like with the leaf surface from smooth to hairy. The plant has small, nonshowy flowers. The entire plant breaks off at the base and disperses seed as it tumbles in the wind (plant also known as tumbleweed).

**Areas of infestation:** Russian thistle flourishes on dry sites. It is very drought and salt tolerant.

**Yield loss potential:** Up to 60% soybean yield reductions reported depending on density.

**Effective management:** Pre-emergent herbicides give excellent control. Post-emergent herbicides work best on very young plants; however little or no control is achieved after the plant becomes spiny. Prevention and cultural control should be implemented in addition to chemical management.

**Herbicide resistance:** Biotypes have been reported to be resistant to ALS inhibitor (WSSA Group 2) herbicides.

![Figure 31.9. Russian thistle seedling and mature plant.](Photos, M. Moechnig)

Canada thistle (*Cirsium arvense*)

**Time of emergence:** Root buds can produce seedlings that typically emerge before soybean planting. Seedlings can be found later as the soil warms.

**Life cycle and reproduction:** Perennial plant with a deep extensive root system. Infestations are spread through root pieces, although seedlings often are found in fields. Canada thistle is a noxious weed in South Dakota.

**Distinguishing characteristics:** Emerging plants from seed are very small. The stems are erect, ridged surfaces, stems are hollow. Leaves are alternate and margins have short spines. Under certain conditions, the height of Canada thistle can exceed four feet. The plants have imperfect flowers, with male and female colonies. Flower color is white to purple.

**Areas of infestation:** Typically found at disturbed sites.

**Yield loss potential:** Up to 40% soybean yield reductions reported depending on density.

**Effective management:** Herbicides can control seedlings, but older plants should be treated with herbicide when plants are in the bud stage or in the fall after the first frost. Roundup Ready® soybean has helped in controlling this weed even in areas with previously high densities.

**Herbicide resistance:** Biotypes of Canada thistle in Europe have been reported to be resistant to auxin-type growth regulator (WSSA Group 4) herbicides.
Hedge bindweed (Calystegia sepium)

**Time of emergence:** Typically emerges early, before soybean planting.

**Life cycle and reproduction:** This perennial vine-type plant reproduces by seeds and rhizomes.

**Distinguishing characteristics:** Seedlings have kidney-shaped cotyledons and the leaves have a long petiole and pointed tip. The flowers are large, funnel-shaped, and are white to pink in color.

**Areas of infestation:** Often found at disturbed sites.

**Yield loss potential:** This plant is not as aggressive as field bindweed. However, it can cause problems during harvest.

**Effective management:** Prevention and cultural control should be implemented in addition to chemical management. PPO inhibitor type herbicides (WSSA Group 14) and Basagran (bentazon) (WSSA Group 6) have been reported to burn down vines during early growth. The addition of 2,4-DB has been reported to enhance herbicidal activity. High temperatures, high humidity, and good soil moisture help with control. Spot spray after harvest and if regrowth occurs.

**Herbicide resistance:** To date, herbicide resistance has not been reported.
**Dandelion** (*Taraxacum officinale*)

**Time of emergence:** Typically emerges early, before soybean planting. Seeds can germinate throughout the season if moisture is adequate.

**Life cycle and reproduction:** Perennial reproducing by seeds and regrowing from tap roots.

**Distinguishing characteristics:** Basal rosette with long, lanceolate-lobed leaves. Milky juice throughout the plant. Bright yellow inflorescence arranged in heads.

**Areas of infestation:** Most problematic in no-till and minimum till fields.

**Yield loss potential:** This plant is not as aggressive as other perennials due to its low-growing rosettes.

**Effective management:** Prevention and cultural control should be implemented in addition to chemical management. Preplant burndown treatments with glyphosate (WSSA Group 9) or combinations of paraquat (WSSA Group 22) with photosystem II inhibitors (WSSA Group 5) could be used. 2,4-D + paraquat as a preplant burndown has provided excellent control. If 2,4-D is used, soybean planting must be delayed by at least seven days. Post-harvest herbicide applications should be considered for long-term control.

**Herbicide resistance:** To date, herbicide resistance has not been reported.

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**Volunteer elm** (*Ulmus* sp.)

**Time of emergence:** Typically emerges early, before soybean planting. Seeds can germinate throughout the season if moisture is adequate.

**Life cycle and reproduction:** This perennial reproduces by seeds and regrowth from sprouting perennial tissues.

**Distinguishing characteristics:** Leaves alternate and toothed and serrated margins. Dark green upper leaf surface; pale green lower surface. Twigs are flexible. Extensive shallow root system when young.

**Areas of infestation:** Because it may escape from roadside areas, it often invades fields from the edges. This weed is most problematic in no-till and minimum-till fields and it can grow quite rapidly if undisturbed.

**Yield loss potential:** This plant is not as aggressive as other perennials and little research has been done to examine harvest losses.

**Effective management:** Prevention and cultural control should be implemented in addition to chemical management. There is little information from any University trials on control in soybean. However, preplant burndown treatments with glyphosate (WSSA Group 9) or combinations of paraquat (WSSA Group 22) with photosystem II inhibitors (WSSA Group 5) may be tried along with 2,4-D + paraquat; however, if 2,4-D is used soybean planting must be delayed by at least seven days

**Herbicide resistance:** To date herbicide resistance has not been reported.
Perennial sowthistle (*Sonchus arvensis*)

**Time of emergence:** Typically emerges early from rhizomes. Young plants can start from creeping roots almost any time during the year. Seeds can germinate throughout the season if moisture is adequate.

**Life cycle and reproduction:** This perennial reproduces from seeds and regrowth from tap and creeping roots. Perennial sowthistle is a noxious weed in South Dakota.

**Distinguishing characteristics:** This plant has a dandelion-like rosette and it bolts to produce a flower stalk. It has a smooth stem, milky juice, and whitish coating on the leaf surface. It has long, lobed leaves with spiny edges and a yellow flower that is dandelion-like.

**Areas of infestation:** It commonly escapes from roadside areas to the field boundaries. It is most problematic in no-till and minimum-till fields.

**Yield loss potential:** This plant can form dense colonies; however, little research has been done to examine harvest losses.

**Effective management:** Prevention and cultural control should be implemented in addition to chemical management. Preplant or pre-emergence applications with ALS inhibitor (WSSA Group 2) provides fair to good control. ALS inhibitors when applied in the early to mid-rosette stage provide suppression to fair control. GMO glyphosate-resistant soybean could be treated with glyphosate to provide suppression.

**Herbicide resistance:** To date, herbicide resistance has not been reported in perennial sowthistle, but other species of sowthistle have been reported to be ALS inhibitor (WSSA Group 2) resistant.

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**Figure 31.14.** Perennial sowthistle rosettes, plant with flowers and seeds, leaf base near the stem, asexual reproduction by producing satellite plants from rhizome growth, and control of plant using Classic herbicide. (Photos courtesy of www.courses.missouristate.edu; Weed Science Society of America; ag.ndsu.nodak.edu; minidoka.id.us; and omafra.gov.on.ca)
Jerusalem artichoke (*Helianthus tuberosus*)

**Time of emergence:** Typically emerges early from tubers with many plants appearing in a small area.

**Life cycle and reproduction:** This perennial reproduces by seed, tubers, and rhizomes.

**Distinguishing characteristics:** Jerusalem artichoke has a sunflower-like rosette appearance, leaves that are opposite, and yellow ray and pale yellow disk flowers. This plant’s height can exceed 10 feet.

**Areas of infestation:** Typically found in wet soils in fields that use no-tillage or minimum tillage.

**Yield loss potential:** This plant is can be extremely aggressive due to its tall stature. Yield losses of almost 100% have been reported in oat and corn crops.

Effective management: Prevention and cultural control should be implemented in addition to chemical management. Suppression can be achieved with glyphosate (WSSA Group 9) in glyphosate resistant soybean, although two or more applications are needed. ALS inhibitor herbicides post-applied may also give suppression. Split applications of ALS herbicides provide better control than a single application. Make applications when the plant is less than eight inches tall and has fewer than eight leaves. If a second application is applied, apply 14 to 21 days later.

**Herbicide resistance:** To date herbicide resistance has not been reported in Jerusalem artichoke.

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Figure 31.15. Jerusalem artichoke seedlings and mature plants. (Photos courtesy of Weed Science Society of America and floridata.com)

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Kochia (*Kochia scoparia*)

**Time of emergence:** Typically emerges very early, before soybean planting.

**Life cycle and reproduction:** This annual weed reproduces from seeds.

**Distinguishing characteristics:** Seedlings can be very small with over 1000 present in a 1 ft² area. Leaf margins are fringed with hair, whereas the leaf surfaces range from being without hair to being highly pubescent. Wind-blown plants will disburse seed in the fall.

**Areas of infestation:** Kochia is generally found in disturbed sites.

**Yield loss potential:** Up to 40% soybean yield reductions have been seen in South Dakota trials depending on density and time of emergence.

**Effective management:** Pre-emergent broadleaf herbicides often give season-long control. Post-emergent herbicides work best on very young plants. Plants are difficult to control after the 6” stage of growth. Prevention and cultural control should be implemented in addition to chemical management.

**Herbicide resistance:** Biotypes of kochia have been found to be resistant to many herbicide types including ALS inhibitors (WSSA Group 2) in South Dakota; glyphosate (WSSA Group 9); auxin type growth regulators (WSSA Group 4); and photosystem II inhibitors (WSSA Group 5).
Wild buckwheat (Polygonum convolvulus)

Time of emergence: Typically early; before planting or just at planting. Late flushes may occur depending on soil temperature and moisture conditions.

Life cycle and reproduction: This annual weed reproduces from seeds.

Distinguishing characteristics: An ochrea (white to brown sheath) is located at the base of each leaf on the stem. This plant is often confused with the perennial, field bindweed. Triangular seeds, ochrea, very small flowers, heart-shaped leaves, and root structure that is shallow and lacks root buds and rhizomes all help distinguish wild buckwheat from field bindweed.

Areas of infestation: Often grows well in wet field areas, whereas field bindweed is often found in dry sites.

Yield loss potential: Depending on density, wild buckwheat can reduce yields by 30%. At low densities, it has a minimal impact on yield. However, the vines twining up soybean plants may become tangled in harvest equipment. High water content of wild buckwheat seeds may lead to spoilage in grain bins.

Effective management: When applied, pre-emergence to soybean, saflufenacil (WSSA Group 14, a PPO inhibitor) gives fair to good control. Some sulfonylurea type herbicides (WSSA Group 2) and Ignite (WSSA Group 10) in LibertyLink soybean applied post-emergence give fair to good control. Tillage, crop rotation, and post-emergence cultivation may be management tools to reduce stand numbers.

Herbicide resistance: No resistance reported, but this plant tolerant to glyphosate and 2,4-D (in 2,4-D-resistant soybean varieties). The tolerance to glyphosate makes wild buckwheat a problem even in glyphosate-resistant soybean varieties.
Common ragweed (*Ambrosia artemisiifolia*)

**Time of emergence:** The first flush of common ragweed typically emerges just before soybean planting.

**Life cycle and reproduction:** This annual weed reproduces by seed.

**Distinguishing characteristics:** Cotyledons are spatulate (spoon-shaped). Leaves are opposite on the lower stem and alternate on the upper stem. The leaves are finely divided. The stems are erect, branched, and grow to one to two feet. The flowers are nonshowy and without petals.

**Areas of infestation:** This weed is typically found in disturbed sites.

**Yield loss potential:** Soybean yield reductions are typically less than 10% at moderate densities, but can be severe at high densities or if the plants grow taller than the soybean canopy.

**Effective management:** Pre-emergent broadleaf herbicides—including PPO inhibitors (WSSA Group 14) and ALS inhibitors (WSSA Group 2)—provide good control in SDSU trials. Post-emergent herbicides in these groups also give fair to excellent control. Glyphosate (WSSA Group 9) gives excellent control if resistance is not a problem. Overuse of the same chemical should be avoided to maintain the herbicide effectiveness. Prevention and cultural control should be implemented in addition to chemical management.

**Herbicide resistance:** Biotypes of this plant have been reported to be resistant to ALS inhibitors (WSSA Group 2) in many states. In South Dakota, glyphosate (WSSA Group 9) resistant biotypes have been documented.
**Velvetleaf (Abutilon theophrasti)**

**Time of emergence:** Typically velvetleaf emerges shortly after soybean planting starts.

**Life cycle and reproduction:** This annual weed reproduces from seeds.

**Distinguishing characteristics:** Seedlings have round cotyledons and alternate heart-shaped leaves. Leaves are covered with soft hairs giving it a “velvet” feel. The plant can grow above the soybean canopy and can reach six feet in height.

**Areas of infestation:** Found in productive fields and roadsides.

**Yield loss potential:** Soybean yields can be reduced 20% in moderate infestations (1-2 plants/ft²).

**Effective management:** In South Dakota trials, pre-emergent PPO inhibitor herbicides (WSSA Group 14) and bleaching herbicides (WSSA Group 13) have provided excellent control. Post-emergent PPO herbicides also can provide good to excellent control. It should be noted that glyphosate only provides fair to good control of velvetleaf.

**Herbicide resistance:** Biotypes in Minnesota and other areas have been reported to be resistant to photosystem II inhibitor (WSSA Group 5) herbicides.

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![Figure 31.19. Velvetleaf seedling and mature plant. (Photos, M. Moechnig)](image)

**Redroot pigweed (Amaranthus retroflexus)**

**Time of emergence:** Typically redroot pigweed emerges before and just at soybean planting.

**Life cycle and reproduction:** This annual weed reproduces from seeds.

**Distinguishing characteristics:** Cotyledons thin and linear. Leaves are lance-like with alternate arrangement and the lower surface is hairy. The stems are stout and the lower portion is reddish (hence the name redroot). Seeds are black, shiny, and numerous. A large plant can produce over 800,000 seeds. This plant may hybridize with other Amaranthus species, with hybrid plants having highly variable physical characteristics.

**Areas of infestation:** Redroot pigweed is often found in disturbed areas that have high soil nutrient levels.

**Yield loss potential:** Depending on density and when emergence occurred, soybean yield losses can be as high a 55%.

**Effective management:** Many different pre-emergent and post-emergent herbicides that are PPO inhibitors (WSSA Group 14), and ALS inhibitors (WSSA Group 2) have provided excellent control in SDSU trials. Care must be taken as some resistant biotypes have been reported in other states. An integrated program combining cultivation and appropriate herbicides should facilitate effective redroot pigweed control.

**Herbicide resistance:** Biotypes of redroot pigweed have been shown to be resistant to photosystem II inhibitor (WSSA Group 5) and ALS inhibitor (WSSA Group 2) herbicides.
Field bindweed (*Convolvulus arvensis*)

**Time of emergence:** Field bindweed emerges in the late spring to early summer. Plant regrowth from rhizomes occurs early in the season. Seed germination occurs later.

**Life cycle and reproduction:** This perennial plant has deep spreading roots, and it can reproduce from rhizomes or seeds.

Distinguishing characteristics: Leaves are arrow-shaped on a twining stem. The root system can be extensive. Flowers are white to pink and bell- or trumpet-shaped.

**Areas of infestation:** This plant grows well in dry soils.

**Yield loss potential:** Up to 50% soybean yield reductions reported depending on density. The vining nature of the plant can cause problems with harvest equipment.

**Effective management:** Combination of cultivation (if done often enough), chemical control, and competitive crops.

**Herbicide resistance:** Tolerant of glyphosate (WSSA Group 9) applications. Biotypes have been reported to be resistant to auxin-type growth regulator (WSSA Group 4) herbicides.
Common cocklebur (*Xanthium strumarium*)

**Time of emergence:** Common cocklebur typically emerges at the end of soybean planting.

**Life cycle and reproduction:** Common cocklebur is an annual plant that reproduces from seeds.

**Distinguishing characteristics:** Cotyledons of the seedling are linear and thick, shiny green. Leaves are alternate and large with wavy margins. Seeds are in burs that stick to animal coats.

**Areas of infestation:** Typically occurs in wet field areas where soybean growth is poor.

**Yield loss potential:** Highly competitive with soybean with up to 70% yield reductions reported even at relatively low densities. Because soybean does not grow well in areas where common cocklebur does, the yield losses are compounded.

**Effective management:** In SDSU trials, pre-emergent herbicides provide only fair to good control. Post-emergent ALS inhibitor (WSSA Group 2) herbicides provide excellent control (if not an ALS-resistant biotype). Glyphosate (WSSA Group 9) provides excellent control in Roundup Ready soybean. Tillage, crop rotation, and post-emergence cultivation should also be considered as management tools to reduce stand numbers.

**Herbicide resistance:** Cocklebur biotypes have been reported to be resistant to ALS inhibitor (WSSA Group 2) herbicides.
Wild mustard (Brassica kaber)

Time of emergence: Typically emerges later, during, or after soybean planting.

Life cycle and reproduction: Wild mustard is an annual plant that reproduces from seeds.

Distinguishing characteristics: Seedlings have kidney-shaped cotyledons. Leaves alternate, few hairs. Bright yellow flowers with four petals. Fruits are long and linear.

Areas of infestation: This plant is often found in disturbed sites.

Yield loss potential: Densities of 1 plant/ft² can reduce soybean yields 40%.

Effective management: Prevention and cultural control should be implemented in addition to chemical management. Pre-emergence and post-emergence herbicides that are PPO inhibitors (WSSA Group 14) or ALS inhibitors (WSSA Group 2) have provided excellent control in SDSU trials. 2,4-DB has been reported to also provide excellent control.

Herbicide resistance: Herbicide resistance has not been reported.

Black nightshade (Solanum ptychanthum)

Time of emergence: Typically emerges at the end of soybean planting.

Life cycle and reproduction: This annual weed reproduces from seeds.

Distinguishing characteristics: Cotyledons of the seedling are ovate, green on upper surface and purple on lower surface. Leaves are alternate and oval in shape with few hairs, and they may have holes due to flea beetle feeding (although not effectively controlled by the insect). The flowers are white to bluish, and the seeds are in berries, with each containing 50 to 100 seeds. The juice of the berry stains soybean seeds which reduces their value.

Areas of infestation: Typically occurs in disturbed sites.

Yield loss potential: Yield losses of 80% can result from moderate infestations (1 plant/ft²). In addition, the berry juice can stain the seed which reduces its value. When berry juice is mixed with chaff, the combination can plug the combine.

Effective management: In SDSU trials, good to excellent control when using pre-emergent applications of PPO inhibitors (WSSA Group 14) or ALS inhibitors (WSSA Group 2). Excellent control is reported with a few of the ALS inhibitors (WSSA Group 2) when used post-emergence, although others in this group are rated as poor (see specific labels for details). Glyphosate (WSSA Group 9) provides good control in Roundup Ready® soybean. Tillage, crop rotation, and post-emergence cultivation should also be considered as management tools to reduce stand numbers.

Herbicide resistance: Black nightshade biotypes have been reported to be resistant to ALS (WSSA Group 2) and photosystem II inhibitors (WSSA Group 5), as well as photosystem I inhibitor herbicides (WSSA Group 22, e.g., paraquat).
Venice mallow (*Hibiscus trionum*)

**Time of emergence:** Typically emerges at the end of soybean planting.

**Life cycle and reproduction:** This annual weed reproduces from seeds.

**Distinguishing characteristics:** Cotyledons of the seedling are round. Leaves are alternate with 3 to 7 distinct lobes. Leaf surface with hairs. Flowers are white to pale yellow. Fruits are an inflated capsule.

**Areas of infestation:** Typically occurs in disturbed sites. The plant is drought tolerant and can grow in gravely and acid soils.

**Yield loss potential:** Usually low (<5%) yield loss at moderate infestations, although season-long competition can increase this loss.

**Effective management:** In SDSU trials, good to excellent control when using pre-emergent applications of PPO inhibitors (WSSA Group 14). Post-emergence herbicides that provide excellent control include contact photosynthesis inhibitors (WSSA Group 6) and some ALS inhibitors (WSSA Group 2). Glyphosate (WSSA Group 9) and glufosinate (e.g., Ignite®) (WSSA Group 10) provide excellent control in their respective GMO soybean types. Tillage, crop rotation, and post-emergence cultivation should also be considered as management tools.

**Herbicide resistance:** None reported at this time.
Common waterhemp (*Amaranthus rudis*)

**Time of emergence:** This weed typically emerges late in the season after soybean emergence.

**Life cycle and reproduction:** Common waterhemp is an annual plant that reproduces from seeds.

**Distinguishing characteristics:** The first true leaves of seedlings are more lance-like than the oval leaves seen on redroot pigweed. Leaf surfaces are not hairy. This plant has male and female plants. The inflorescence of the female plant is more highly branched than the inflorescence of the redroot pigweed plant. In SDSU trials, the female plant has been shown to produce over one million shiny black seeds if early germinating plants are not controlled. Plants that emerge after V5 of soybean may produce 200 seeds or less per plant.

**Areas of infestation:** This plant grows well in disturbed areas with high fertility.

**Yield loss potential:** Up to 55% soybean yield reductions reported depending on density and emergence date.

**Effective management:** Common waterhemp is difficult to control and often is seen after layby operations; some resistant biotypes have been reported in other states. Prevention and cultural control should be implemented in addition to chemical management.

**Herbicide resistance:** Biotypes of this plant have been reported to be resistant to ALS (WSSA Group 2), PPO (WSSA Group 14), photosystem II inhibitor (WSSA Group 5) herbicides, and glyphosate (WSSA Group 9).

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**Figure 31.26.** Common waterhemp seedlings and late season infestation in soybean. (Photos, M. Moechnig)

**Figure 31.27.** Comparison of redroot pigweed (left) and common waterhemp (right) inflorescence. (Photos courtesy of Weed Science Society of America)
Buffalobur (*Solanum rostratum*)

**Time of emergence:** Buffalobur typically emerges after soybean emergence.

**Life cycle and reproduction:** This annual plant reproduces from seeds.

**Distinguishing characteristics:** The first true leaves of seedlings are lance shaped. Leaves are many lobed, alternate. Leaf surfaces and stems are spiny with long yellow spines. The spiny capsules hold the fruit.

**Areas of infestation:** Buffalobur grows best in well drained disturbed soils. It does not grow well in wet soils.

**Yield loss potential:** Typically buffalobur is found as scattered plants and soybean yield reduction is low to moderate depending on density and emergence date.

**Effective management:** Buffalobur can be controlled postemergence with PPO inhibitors (WSSA Group 14). Prevention and cultural control should be implemented in addition to chemical management.

**Herbicide resistance:** No resistant biotypes of this plant have been reported at this time.

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Biennial wormwood (*Artemisia biennis*)

**Time of emergence:** From seed, although named biennial wormwood (implying vegetative stage first year and reproductive stage the second), the plant may behave as an annual, flowering later in the first year of growth. Typically emerges in late June to early July after soybean planting.

**Life cycle and reproduction:** This biennial plant reproduces from seeds.

**Distinguishing characteristics:** The first true leaves are finely divided, and are often mistaken for common ragweed. Biennial wormwood has sharp leaf edges and are hairless, whereas common ragweed has rounded leaf edges with hairs. Rosette type growth of the vegetative plants. Flower stalk can grow up to six feet tall and produce over 400,000 seeds/plant.

**Areas of infestation:** This plant grows well in disturbed, poorly drained soils.

**Yield loss potential:** Soybean yield reduction can be up to 40% with 1 plant/ft². If the infestation is high, yield losses can approach 100%.

**Effective management:** Biennial wormwood can be controlled pre-emergence with PPO inhibitors (WSSA Group 14) and translocated photosystem II inhibitors (WSSA Group 5). Post-emergence herbicides include contact photosystem II inhibitors in WSSA Group 6, and in GMO soybean glyphosate (WSSA group 9) and glufosinate (WSSA group 10) herbicides. Herbicide applications must be done before the plant is 3” tall, as tolerance to all herbicides becomes an issue. Prevention and cultural control should be implemented in addition to chemical management.

**Herbicide resistance:** No resistant biotypes of this plant have been reported at this time.
References and additional information
Photo references include: Pacific Northwest Weed Management Handbook. Available at http://pnwhandbooks.org/weed/;
Floridata.com http://www.floridata.com/lists/contents.cfm; omafra.gov.on.ca; ag.ndsu.nodak.edu; minidoka.id.us; Center for Invasive Species and Ecosystem Health available at http://bugwood.org/;

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Soybean Herbicide Injury

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Failure to follow a pesticide label or plants experiencing drift or tank contamination can exhibit dramatic, yet characteristic plant symptoms. If the damage occurs early and is not severe, yield loss may not occur. However, if injury occurs during a critical growth stage or is severe, the damage may result in a total crop loss. The purpose of this chapter is to describe and illustrate typical plant symptoms due to herbicide injury and to discuss the mechanism or mode of action of commonly used herbicides. Symptoms and images of selected herbicides are provided below.

Herbicide Control Mechanisms

Herbicides have been characterized by the method by which they control susceptible plants. The methods can be divided into mechanism or mode of action groups. Herbicides can produce similar symptoms on susceptible plants (target weeds and soybeans). These categories are provided in Table 32.1. A more complete discussion is provided at http://wssa.net/wp-content/uploads/WSSA-Mechanism-of-Action.pdf. To minimize resistance, weed management strategies should integrate herbicides with different mechanisms of action.
Table 32.1. Weed Science Society of American (WSSA) suggested herbicide mechanism-of-action (MOA) group number, mechanism, and examples.

<table>
<thead>
<tr>
<th>MOA Group</th>
<th>Mechanism</th>
<th>Herbicide Chemistry Examples</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>ACETYL COA CARBOXYLASE (ACCase) INHIBITORS</td>
<td>Aryloxyphenoxypropionate (FOPs) Cyclohexanedione (DlMs) Phenylpyrazolin (DENs)</td>
</tr>
<tr>
<td>2</td>
<td>ACETOLACTATE SYNTHASE (ALS) or ACETOHYDROXY ACID SYNTHASE (AHAS) INHIBITORS</td>
<td>Imidazolinones (Imis) Pyrimidinylhydrobenzoates Sulfonylanilinoxypropionitrile triazolinones Sulfonylureas (SU) Triazolopyrimidines</td>
</tr>
<tr>
<td>3</td>
<td>MICROTUBULE ASSEMBLY INHIBITOR</td>
<td>Benzamide Benzooic acid (DCPA) Dinitroaniline Phosphoramidate Pyridine</td>
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<tr>
<td>15</td>
<td>VERY-LONG-CHAIN FATTY ACID INHIBITOR</td>
<td>Acetamide Chloroacetamide Oxyacacetamide Tetrazolinone herbicides</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td>Carbetamide, chlorpropham, and propah (Note: Group 23 types of herbicides are no longer or very rarely used in U.S. crop production.)</td>
</tr>
<tr>
<td>4</td>
<td>SYNTHETIC AUXINS</td>
<td>Benzoic acids Phenoxycarboxylic acids Pyridine carboxylic acids Quinoline carboxylic acids</td>
</tr>
<tr>
<td>5</td>
<td>PHOTOSYSTEM II INHIBITORS</td>
<td>Phenylcarbamates Pyridazinones Triazines Triazinones Uracils</td>
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<tr>
<td>6</td>
<td>Site A</td>
<td>Benzothiadiazinones Nitriles Phenylpyridazines</td>
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<tr>
<td>7</td>
<td>Site B</td>
<td>Amide Ureas</td>
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<tr>
<td>8</td>
<td>FATTY ACID AND LIPID BIOSYNTHESIS INHIBITORS</td>
<td>Phosphorodithioates Thio-carbamates</td>
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<td>16</td>
<td>ENOLPYRUVYL SHIKIMATE-3-PHOSPHATE (EPSP) SYNTHASE INHIBITORS</td>
<td>Glicines (glyphosate)</td>
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<tr>
<td>9</td>
<td>GLUTAMINE SYNTHETASE INHIBITORS</td>
<td>Phosphinic acids (glufosinate and bialophos)</td>
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<tr>
<td>10</td>
<td>CAROTENOID BIOSYNTHESIS INHIBITORS (bleaching herbicides)</td>
<td>Amitrole</td>
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<tr>
<td>12</td>
<td></td>
<td>Amides Anilide Furanones Phenoxybutan-amides Pyridazinones Pyridines</td>
</tr>
<tr>
<td>13</td>
<td>Inhibits DOXP synthase</td>
<td>Clomazone</td>
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<tr>
<td>27</td>
<td>Inhibits 4-HPPD enzyme</td>
<td>Callistemones Isoxazoles Pyrazoles Triketones</td>
</tr>
<tr>
<td>14</td>
<td>PROTOPORPHYRINOGEN OXIDASE (PPG oxidase or Protox) INHIBITORS</td>
<td>Diphenylethers N-phenylthiophalimides Oxadiazoles Oxazolidinediones Phenylpyrazoles Pyrimidinidones Thiadiazoles Triazolinones</td>
</tr>
</tbody>
</table>
Herbicide Symptoms on Soybeans

**MOA Group 4 – Synthetic Auxins**

**Phenoxy-carboxylic acids**

Herbicide examples: 2,4-D; MCPA; Stinger®

Mechanism-of-action: Acts as a synthetic auxin, disrupting nucleic acid metabolism and protein synthesis, which ultimately leads to plant death.

Injury symptoms: Most injury occurs as drift from roadside applications or tank contamination. Rolled, puckered leaves, and bending stems can be present within hours after application (Fig. 32.1). The injury can be seen even if the plant is exposed to \( \frac{1}{100} \) of a normal application rate. New leaves may have parallel venation and be “strapped” and root growth will be stunted if exposed to higher rates of chemical. Although symptoms are present, crop yield loss can range from none to severe depending on climate following the injury. Fewer problems with these herbicides will be observed when new resistant varieties to 2,4-D are released.

**Soybean injury symptoms from synthetic auxins**
- Rolled leaves
- Leaf strapping
- Root stunting
- Parallel leaf venation
- Bending and twisting of stems (epinasty)

**Injury cause**
- Drift from adjacent fields
- Tank contamination (improper cleaning from previous application)

Figure 32.1. Plant damage due to 2,4-D application. (Photo courtesy of Michael Moechnig, SDSU)
**Benzoic acids**

**Herbicide example:** Dicamba (Banvel®, Clarity®)

**Mechanism-of-action:** Acts as a synthetic auxin; see 2,4-D.

**Injury symptoms:** Symptoms are similar to 2,4-D (Fig. 32.2). New varieties are being released that are dicamba resistant.

![Figure 32.2. Leaf damage due to dicamba application.](Photo courtesy of Michael Moechnig, SDSU)

**Soybean injury symptoms from benzoic acid herbicides**

Same as 2,4-D, but may occur at lower application rates than 2,4-D

**Injury cause**
- Drift
- Tank contamination

**MOA Group 1 – Acetyl CoA Carboxylase (ACCase) Inhibitors**

(also known as Lipid Synthesis Inhibitors)

**Herbicide examples:** Quizalofop (Assure II®)

**Mechanism-of-action:** Inhibits the formation of lipids used for membranes and stops growth of new tissue of grasses.

**Injury symptoms:** The ACCase inhibitors rarely injure soybean. However, some injury symptoms such as bleached areas and white spots followed by browning and necrotic areas can occur with these herbicides (Fig. 32.3). In this case, the inert solvent used in the manufacture of Assure II® caused spotting on the soybean leaf after a high application rate was applied to control grasses. This injury is often cosmetic and rarely results in yield loss.

![Figure 32.3. Quizalofop application damage to soybean.](Note: The herbicide did not damage the soybean. The solvent in Assure II® was the source of the injury when applied at high rates. (Photo courtesy of [http://www.btny.purdue.edu/extension/weeds/HerbInj2/InjuryHerb2.html](http://www.btny.purdue.edu/extension/weeds/HerbInj2/InjuryHerb2.html) and [http://ipm.illinois.edu/pubs/soyinjury.pdf](http://ipm.illinois.edu/pubs/soyinjury.pdf))
MOA Group 9 – Enolpyruvyl Shikimate-3-phosphate (EPSP) Synthase Inhibitor (also known as Amino Acid Derivative Herbicides)

**Herbicide examples:** Glyphosate (Roundup®)

**Mechanism-of-action:** Amino acid synthesis inhibitor; stops synthesis of aromatic amino acids (those that contain a phenyl ring).

**Injury symptoms:** Initially yellowing on plant, followed by plant death. Environmental conditions that slow growth (e.g., extreme heat, cold, or drought) reduce the effects of glyphosate. Youngest leaves near the growing point yellow and die first, then whole plant is affected (Fig. 32.4). Early on, symptoms may appear to be potassium deficiency or soybean cyst nematode damage. Causes of injury to nonresistant glyphosate varieties may be drift from another field, misapplication after emergence to fields planted to nonresistant glyphosate varieties, or tank contamination.

**Figure 32.4. Glyphosate damage to soybean. (Photo courtesy of Michael Moechnig, SDSU)**

### Soybean injury symptoms from EPSP synthase inhibitors
- Yellow then brown foliage
- Growing point dies

**Injury cause**
- Misapplied to nonresistant varieties after emergence
- Tank contamination

MOA Group 10 – Glutamine Synthetase Inhibitors (also known as Phosphoric Acid Type Herbicides)

**Herbicide examples:** Glufosinate (Liberty®)

**Mechanism-of-action:** Glufosinate stops the conversion of glutamate + ammonia to the amino acid glutamine, resulting in the accumulation of toxic levels of ammonia in leaf tissue.

**Injury symptoms:** Symptoms appear within 3 to 5 days after treatment. Water-soaked lesions may appear and then leaves become pale yellow (such as nitrogen deficiency) or purple (may look like phosphorus deficiency) (Fig. 32.5). Often occurs if the field was planted with a nonresistant herbicide variety.

**Figure 32.5. Glufosinate damage to soybean. (Photo courtesy of Michael Moechnig, SDSU)**

### Soybean injury symptoms from Glutamine synthetase inhibitors
- Pale yellow or purple leaves
- Whitening of the leaves
- Water-soaked lesions

**Injury cause**
- Misapplied or tank contamination
MOA Group 2 – Sulfonylurea (SU) Herbicides and Imidazalinone (Imi) Herbicides

Herbicide examples: Triburon (Express®); thifensulfuron (Harmony®); metsulfuron (Ally XP®)

Mechanism-of-action: Both SU- and Imi-type chemistries of herbicides inhibit the formation of branched chain amino acids.

Injury symptoms: Injury symptoms appear 7 to 10 days after exposure. Sensitive plants generally show overall yellowing (chlorosis) and stunting. Purpling of the veins is often noted (Fig. 32.6) and roots may show a bottle-brush appearance (Fig. 32.7).

If applied at the correct rate, injury symptoms are often temporary. Symptoms may be noticed even if applied according to the label rates and timings if temperatures and humidity are high, although plants often recover with no yield loss. SU and Imi herbicides typically are applied at low rates (ounces of active ingredient per acre) and tank contamination may be a problem. In high pH soils, carryover of the SU chemistry types may be problematic, whereas carryover of Imi chemistry-type herbicides is more likely in low pH soils.

Figure 32.6. Sulfonyl herbicide damage to soybean showing purple veins. (Photo courtesy of Michael Moechnig, SDSU)

MOA Groups 27 and 13 – Inhibits DOPX synthase or 4 HPPD enzyme

Herbicide examples: Group 27 – isoxaflutole (Balance®), tembotrione (Laudis®), and mesotrione (Callisto®); Group 13 – clomozone (Command®)

Mechanisms-of-action: There are several herbicides with different specific mechanisms of action that have similar symptoms although they have different specific target enzymes. Both block enzymes that do not allow for carotenoid pigments to be formed, but the enzymes differ. Carotenoids are plant pigments that include chlorophyll or protect membranes from destruction by reactive oxygen species (ROS).

Injury symptoms: White areas on plants or albino plants appear during emergence. Command® carryover may be seen early in the season; plants may recover from early season injury (Fig. 32.8).
MOA Group 14 – Protoporphyrinogen Oxidase (PPG oxidase, PPO, or PROTOX) Inhibitors

**Herbicide example:** Carfentrazone (Aim®) (can be applied pre-emergence); Acifluorfen (Blazer®) (applied post-emergence only)

**Mechanism-of-action:** Inhibits protoporphyrinogen oxidase causing a cascade of events, which eventually result in cell membrane destruction and death of the plant.

**Injury symptoms:** If applied pre-emergence to soybean, stem lesions, or burning of the cotyledon leaves is apparent (Fig. 32.9). More apt to occur if heavy rain occurs after application but before emergence. If applied post-emergence, appearance of necrotic (dead tissue) speckling on leaves within a few days after exposure (Fig. 32.10). Note that the new leaves are unaffected by the application. The herbicide is a contact herbicide, which means the herbicide does not move throughout the plant. Symptoms occur if applications are made during hot, humid weather, or if cool conditions occur after application. If applied at the correct rate, the symptoms are often cosmetic and do not lead to yield losses.
**MOA Group 22 – Photosystem I Inhibitors**

**Herbicide example:** Paraquat (Gramoxone®)

Mechanism of action: Herbicide accepts electrons from Photosystem I and forms an herbicide radical. This radical reduces molecular oxygen to form superoxide radicals. The radicals are extremely reactive and destroy membrane fatty acids, which lead to the destruction of the cell membrane and death.

**Injury symptoms:** Symptoms are often observed within hours, especially on sunny days. Leaves develop water-soaked lesions, very quickly, and then speckling and dead tissue are observed (Fig 32.11). Note, this is a contact herbicide and the new leaves show no injury symptoms. However, the plants shown in Figure 32.11 are severely injured and plants may not survive.

![Figure 32.11. Paraquat injury to soybean.](Photo courtesy of Michael Moechnig, SDSU)

**Soybean injury symptoms from Photosystem I inhibitors**

<table>
<thead>
<tr>
<th>Injury symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limp leaves</td>
</tr>
<tr>
<td>Within hours, water-soaked appearance</td>
</tr>
<tr>
<td>(looks like frost damage)</td>
</tr>
<tr>
<td>Within days, brown tissue</td>
</tr>
<tr>
<td>where water-soaked areas were first</td>
</tr>
<tr>
<td>observed</td>
</tr>
</tbody>
</table>

**Injury cause**

- Drift
- Tank contamination
MOA Group 5 – Photosystem II Inhibitor - Triazine

Herbicide examples: Atrazine (Aatrex®); metribuzin

**Mechanism-of-action:** Stops electron flow during photosynthesis, which slows plant growth. These herbicides bind at site A in PSII and they may also impact lipid and protein oxidation, which leads to leaky cell membranes and plant death.

**Injury symptoms:** Atrazine is not labeled on soybean, but injury may occur if there is soil carryover from the previous year (Fig. 32.12). Carryover may occur if the soil pH is high (>7.8) or if weather was cool and dry during the prior year. Carryover injury can be made more severe if an application of metribuzin is applied in the current year. In addition, tank contamination from previous applications may occur. Triazine carryover injury symptoms start as yellowing of the seedling and then death of the oldest leaves. Roots are malformed. If severe, plants will not survive. Metribuzin can be applied to soybean, but it has a short tolerance window. As always, read and follow labeled instructions. In addition, some varieties are less tolerant to metribuzin.

![Atrazine injury](http://ipm.illinois.edu/pubs/soyinjury.pdf)

**Soybean injury symptoms from triazine herbicides**

Yellow and brown leaves with outer edges of the leaf and older leaves most affected

**Injury cause**

Cool wet conditions slowing soybean growth
Crop oil synergy if metribuzin is applied post-emergence

MOA Group 6 – Photosystem II Inhibitor - Benzonitriles

**Herbicide example:** Bentazon

**Mechanism-of-action:** Stops electron flow in photosynthesis in Photosystem II, but unlike atrazine, binding of the herbicide occurs at site B. The final effects are similar to atrazine if applied post as a tank-contamination or drift problem.

**Injury symptoms:** Symptoms appear as leaf tip chlorosis, general wilting, speckling, and necrotic lesions to tissue where application has occurred (Fig. 32.13). Young tissues that emerge after application are generally unaffected as the herbicide does not translocate within the plant. Injury may occur if cool or very high temperatures occur after application or high crop oil concentrations are used. Recovery is generally rapid. This is often variety specific with some more tolerant than others.
MOA Group 3 – Mitosis Inhibitor - Microtubule Assembly - Dinitroanlines

Herbicide examples: Trifluralin (Treflan®); pendimethalin (Prowl®)

Mechanism-of-action: Inhibits the growth of roots or shoots of seedlings by binding to tubulin, which leads to loss of microtubules assembly, structure, and function. This in turn leads to stoppage of cell division.

Injury symptoms: Symptoms are apparent during or soon after plant emergence (Fig. 32.14). Symptoms include shortened, thickened, and swollen roots (root clubbing). They may also be purple in color. Injury occurs if DNA herbicide is incorporated too deeply into the seeding zone. Factors contributing to plant injury include wet, cool soils, compaction, and drought.

Soybean injury symptoms from benzointrile herbicides
Yellow and brown leaves

Injury cause
Crop oil with the post-emergence application

Soybean injury symptoms from dinitroanlines
Stunted plants
Roots short and thick

Injury cause
Carryover
Misapplication
Over-application
MOA Group 15 – Mitosis Inhibitor - Very-long-chain Fatty Acid Inhibitor - Acetanilides

**Herbicide examples:** Metolachlor (Dual®); acetochlor (Harness®)

**Mechanism-of-action:** Growth inhibitor that stops the formation of very long fatty acids. This stoppage has effects on the formation of all cell membranes. Seedling roots and shoots of susceptible plants stop growing.

**Injury symptoms:** Death of the plant occurs soon after emergence or no plants emerge in the area. Plants that survive may appear heart-shaped due to shortened mid-veins of the leaves (draw-string) leaves (Fig. 32.15). Roots may also be shortened.

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**Figure 32.15. Acetanilide injury.** (Photo courtesy of Michael Moechnig, SDSU)

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**Soybean injury symptoms from acetanilides**
- Poor emergence
- Stunted plants
- Poor root development
- Heart-shaped leaves on emerged plants

**Injury cause**
- Over-application or high rates used
- Cool, wet soils

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MOA 8 and 16 – Fatty Acid and Lipid Biosynthesis Inhibitor

**Herbicide example:** EPTC (Eptam®)

**Mechanism-of-action:** Inhibit biosynthesis of fatty acid and lipids (not through ACCase); biosynthesis of proteins; and inhibits gibberellin synthesis.

**Injury symptoms:** Appear during or soon after plant emergence. Reduction in cuticular wax deposition that may lead to increased disease and stress severity (Fig. 32.16). Injured seedlings may show reduced coleoptile length, stunting, or delayed emergence. Leaves may stick together and have cupped or crinkled necrotic edges. Leaf buds may not open.
Figure 32.16. EPTC injury. (Photo courtesy of http://weedscience.missouri.edu/herbinjsymptoms/thiop.htm)

Soybean injury symptoms from EPTC
Stunted plants
Leaves stuck together
Uneven emergence across field

Injury cause
Over-application
Cool, wet soils

References and additional information
Summary of herbicide mechanism of action according to the Weed Science Society of America (WSSA).


Acknowledgements
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Herbicide-Resistant Weeds in Soybeans

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Widespread planting of Roundup Ready® crops and the use of glyphosate have been linked to reduced herbicide costs and improved profitability. However, continued use of a limited weed control strategy has resulted in increased herbicide resistance. To reduce selection for herbicide-resistant weeds, weed management programs must be diversified. The purpose of this chapter is to discuss herbicide sites of action and glyphosate-resistant weeds confirmed in South Dakota.

Glyphosate-resistant weeds in South Dakota soybeans

Weeds become resistant to an herbicide when offspring from a weed develops a characteristic that makes it less susceptible to an herbicide. Resistance may occur from a biochemical change, such as enhanced production of a sensitive enzyme, or a physical change that reduces herbicide uptake or translocation within the plant.

Repeated use of that herbicide allows the offspring that possesses these characteristics to survive, produce seed, and develop noticeable densities after approximately three years. Therefore, preventing herbicide resistance requires a diversified weed control program so that weeds that tolerate or adapt to one control method are at least suppressed by an additional control method used in the management program.

Since field-scale changes in weed species composition may occur slowly over several years, it may be more practical to utilize a diverse management program that proactively minimizes selection for resistance rather than respond after the resistance has occurred, populations have become widespread across the field, and the weed seed bank has increased.

Diversified weed management programs may include pre-emergence herbicides, herbicide tank-mix partners with glyphosate, and rotating to crops that do not require the use of glyphosate for weed control. Crop rotation may include different crop species, such as wheat, or crops that require different herbicide programs, such as conventional or LibertyLink® varieties (Problem 33.1).
Controlling glyphosate-resistant weeds requires the use of herbicides with different sites of action. In Roundup Ready® soybeans, a pre-emergence herbicide and a post-emergence tank-mix partner will likely be required for complete control of moderate to high weed densities. Although low weed densities may be controlled with only a post-emergence application of glyphosate plus an herbicide tank-mix partner, a pre-emergence herbicide is still recommended to ensure consistent weed control.

When using a pre-emergence and post-emergence herbicide, it is best to use herbicides with different sites of action to avoid selecting for resistance to another herbicide site of action. In addition, it is also important to avoid using herbicides with similar sites of action during two consecutive years. The Weed Science Society of America (WSSA, http://www.wssa.net/) has developed a numbering system to distinguish herbicides with different sites of action (Table 33.1).

### Problem 33.1
An herbicide program that routinely relies on glyphosate has been effective and has reduced my costs. What is an alternative program that rotates herbicide sites of action on my farm?

**Answer:** One successful management strategy may include rotating Roundup Ready® soybeans with LibertyLink® corn. Glufosinate (Liberty®) may be less consistent than glyphosate, particularly during dry conditions, but two post-emergence herbicide applications per season or pre- and post-emergence herbicide applications can result in very good weed control. Rotating crops with different life cycles, such as winter annuals (e.g., winter wheat), annuals (e.g., corn or sunflowers), or short-season annuals (e.g., spring wheat, field pea, or millet), can disrupt weed life cycles and enable different control options.

**Note:** To minimize problems of not matching herbicides with crop characteristics, good field records are required. In addition always follow labeled instructions.

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### Table 33.1. WSSA group numbers associated with different soybean herbicide sites of action.

<table>
<thead>
<tr>
<th>WSSA Group Number</th>
<th>Site of Action</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ACCase inhibitor</td>
<td>Clethodim, quizalofop</td>
</tr>
<tr>
<td>2</td>
<td>ALS inhibitor</td>
<td>Imazethapyr, cloransulam</td>
</tr>
<tr>
<td>3</td>
<td>Microtubule inhibitor</td>
<td>Pendimethalin, trifluralin</td>
</tr>
<tr>
<td>4</td>
<td>Growth regulator</td>
<td>2,4-D</td>
</tr>
<tr>
<td>5</td>
<td>Photosynthesis inhibitor (triazine)</td>
<td>Metribuzin</td>
</tr>
<tr>
<td>6</td>
<td>Photosynthesis inhibitor (contact)</td>
<td>Bentazon</td>
</tr>
<tr>
<td>9</td>
<td>EPSP inhibitor</td>
<td>Glyphosate</td>
</tr>
<tr>
<td>10</td>
<td>Glutamine synthetase inhibitor</td>
<td>Glufosinate</td>
</tr>
<tr>
<td>13</td>
<td>HPPD inhibitor or “Bleacher”</td>
<td>Clomazone</td>
</tr>
<tr>
<td>14</td>
<td>Cell membrane disrupter (PPO inhibitor)</td>
<td>Carfentrazone, lactofen</td>
</tr>
<tr>
<td>15</td>
<td>Seedling shoot inhibitor (VLCA inhibitor)</td>
<td>Acetochlor, metolachlor</td>
</tr>
<tr>
<td>22</td>
<td>Cell membrane disrupter (PS1 inhibitor)</td>
<td>Paraquat</td>
</tr>
</tbody>
</table>

In no-till fields, added challenges associated with managing herbicide-resistant weeds have caused some people to abandon no-till practices. However, tilling fields may prolong the persistence of herbicide-resistant weed seed banks. SDSU research has demonstrated that common ragweed seed left on the soil surface may cause greater weed densities the following year relative to tilled fields, but the seed bank may be depleted
more rapidly in subsequent years. These results indicate that herbicide-resistant weed seed banks may be depleted most rapidly by maintaining no-till practices and modifying herbicide programs and/or crop rotations (Moechnig et al., 2012).

As herbicide-resistant biotypes become more common in a region, it will become increasingly important to minimize movement of weed seed among fields. It is always important to clean tillage and harvesting equipment before entering different fields to prevent the spread of weed species. However, it is commonly believed among many weed scientists that new infestations of glyphosate-resistant weeds are mostly caused by independent selection within that field rather than movement of seed among fields. Nevertheless, some weeds may be adapted particularly well to movement into different fields.

“Tumbleweed” species, such as kochia, may roll to adjacent fields while spreading weed seeds (Fig. 33.1 and Fig. 33.2). Other weed species may be so problematic that preventing new infestations may justify the time required to clean equipment.

Palmer amaranth (*Amaranthus palmeri*) is an annual weed that may appear very similar to waterhemp, but may have a slightly faster growth rate and may adapt to herbicides more quickly. Glyphosate-resistant Palmer amaranth has been a very challenging weed to control in soybean and cotton fields in the southern U.S. Now there is a concern that it may move to South Dakota and other northern states as a contaminant of cotton seed used as livestock feed. This has already occurred in Michigan. Palmer amaranth is already established in Great Plains states from Nebraska and south, so harvesting equipment that migrates north could also transfer Palmer amaranth seed. There has been at least one confirmed patch of Palmer amaranth in Sully County, S.D., but it is not known if that patch has survived or spread.
Management recommendations for glyphosate-resistant weeds

In 2007, a common ragweed biotype was the first glyphosate-resistant weed identified in South Dakota. Since then, glyphosate-resistant biotypes of waterhemp, kochia, and horseweed have been confirmed. Among these, kochia and waterhemp have become the most problematic. Figure 33.3 shows the locations of where glyphosate-resistant biotypes have been confirmed, but unconfirmed populations are much more extensive. Herbicide-resistant weeds in South Dakota and other states are also reported on the Internet at www.weedscience.org.

![Confirmed glyphosate resistant weeds in South Dakota](image)

Figure 33.3. Approximate locations of confirmed glyphosate-resistant weed species in South Dakota.

South Dakota Glyphosate-Resistant Weeds

**Waterhemp**

A glyphosate-resistant biotype of the annual weed waterhemp (*Amaranthus tuberculatus*) was confirmed in 2010. Since then, field surveys suggest that glyphosate-resistant waterhemp is becoming more common. In many cases, effective management may require pre-emergence and post-emergence herbicide applications to ensure consistent waterhemp control. To avoid selecting for additional herbicide-resistant weed biotypes, herbicides with different sites of action should be used when possible. Most of the waterhemp in South Dakota is also resistant to Group 2 herbicides (ALS inhibitors), so those herbicides will not control glyphosate-resistant waterhemp.

The most effective post-emergence herbicides include Group 14 herbicides (PPO inhibitors) such as fomesafen (Flexstar®) and lactofen (Cobra®). Some of the most effective pre-emergence herbicides are also Group 14 herbicides, such as sulfentrazone and flumioxazin. Group 15 herbicides, such as acetochlor (Warrant®) and pyroxasulfone, and Group 5 herbicides, such as metribuzin, may also provide good residual waterhemp control while diversifying herbicides with different sites of action. Glyphosate-resistant waterhemp may also be controlled with glufosinate (Liberty®) in LibertyLink® soybeans.

![Figure 33.4. Waterhemp. (Photo, M. Moechnig)](image)
Like Group 14 herbicides (PPO herbicides), glufosinate is a contact herbicide that primarily desiccates weeds, so it must be applied to small (less than four inches tall) waterhemp and may require using more water per acre as a carrier to ensure thorough herbicide coverage on the weeds. Waterhemp seed may survive in the soil for 4-5 years (Buhler and Hartzler 2001 and Steckel et al., 2007), so seed bank depletion may require aggressive control for several years.

Aggressive control would require pre- and post-emergence herbicides, at labeled use rates, in soybeans and rotational crops, such as corn. In addition, field edges may be treated with selective herbicides (those that do not injure grasses) to control waterhemp plants that may be a seed source for future infestations.

Kochia

Glyphosate-resistant kochia (Kochia scoparia) may be one of the most challenging weeds to control in soybeans. Glyphosate-resistant kochia was first confirmed near Gettysburg in 2009. Since then, scouting reports suggest that it has been expanding. Kochia is a very prolific seed producer as plants may produce approximately 500 seeds/g shoot biomass (Nyamusamba et al., 2012), which is nearly three times as much as lambsquarters and five times as much as giant foxtail (Moechnig et al., 2003).

Post-emergence herbicide options in soybeans are limited. Lactofen (Cobra®) or acifluorfen (Blazer®) may be some of the most effective options, but these are Group 14 herbicides, so they must be applied to small (less than two inches tall) plants, they require at least 20 gallons per acre as a carrier, and they may stress soybeans during adverse growing conditions. With these herbicides, it will become increasingly important to control weeds like kochia early in the growing season. A pre-emergence herbicide, such as sulfentrazone or flumioxazin, will likely be necessary to minimize dependence on a post-emergence herbicide.

In no-till fields, kochia may be one of the first weeds to emerge in the spring. Therefore, an effective burn-down herbicide program prior to soybean planting may eliminate much of the kochia population. However, effective burn-down herbicide options are not well known as glyphosate has previously been the standard herbicide. 2,4-D is common burn-down herbicide, but that will not likely be effective on many kochia populations. Potentially effective options could be paraquat (Gramoxone®), glufosinate (Liberty®), or lactofen (Cobra®). Since kochia emerges very early in the spring, a late fall application of a soil residual herbicide, such as flumioxazin or sulfentrazone, may provide suppression or control in early spring.

LibertyLink® soybeans may be an alternative option. Since Liberty® is somewhat like a contact herbicide as it has limited mobility in plants, the first application must be applied to small weeds (less than four inches tall) with few growing points. Like contact herbicides, glufosinate requires the use of more water per acre (15 gallons) than glyphosate, but this will be necessary for any post-emergence herbicide for glyphosate-resistant kochia.

The lack of kochia seed dormancy may be a characteristic that could be exploited to minimize densities in soybeans. Recent research at SDSU and elsewhere indicates that less than 10% of kochia seed may survive in soil for longer than a year. Therefore, it may be possible to reduce kochia densities in soybeans by aggressively managing it in rotational crops, such as corn or wheat, making it possible to control kochia in soybeans with a well-timed burn-down application and/or a pre-emergence herbicide application.

The prolific seed production potential of kochia will require nearly complete control in the rotational crops in order to deplete the seed bank. In addition, since the kochia shoot acts as a tumbleweed, fencerows can have extremely high densities of seedlings that could result in over 10 mature plants/ft² by the end of the
growing season (Wolf, 1998). Treating these areas with a selective herbicide may reduce one potential source of future kochia infestations.

**Horseweed (marestail)**

Glyphosate-resistant horseweed (*Conyza canadensis*) has become relatively common in eastern South Dakota no-till fields. Horseweed is generally a winter annual species that emerges in the fall and continues growth in the spring, but some plants may emerge in the spring after burn-down applications. Consequently, fall herbicide applications may reduce horseweed densities the following year. Spring burn-down herbicide programs may require herbicides that have foliar and soil residual activity. Herbicides with foliar activity include 2,4-D, saflufenacil (Sharpen®), or cloransulam (FirstRate®). Soil residual herbicides include saflufenacil, products containing cloransulam and Group 14 herbicides (Sonic®, Authority First®, or Gangster®), or flumetsulam (Python®).

Post-emergence herbicide options are limited and they must be applied while horseweed is small (less than 4-6 inches). In spring to early summer, cloransulam (FirstRate®) may be the only herbicide that can be applied after soybean emergence that will provide horseweed suppression. However, the goal should always be to control horseweed prior soybean emergence.

**Common ragweed**

Glyphosate-resistant common ragweed (*Ambrosia artemisiifolia*) was first confirmed in 2007, which was the first confirmed glyphosate-resistant weed in South Dakota. However, occurrences of resistance seem to be expanding much more slowly than kochia and waterhemp. Effective post-emergence herbicides include cloransulam (FirstRate®) or fomesafen (Flexstar®). However, a pre-emergence herbicide will also likely be required to manage glyphosate-resistant common ragweed. Effective soil residual herbicides include those that contain cloransulam (Sonic®, Authority First®, Gangster®), metribuzin (Authority MTZ®), fomesafen (Prefix®), or flumioxazin (Valor®).

Fields should be closely monitored for resistant common ragweed as seed bank depletion may require aggressive control for several years. SDSU research indicates approximately 5-10% of the seed may germinate each year for the first four years after production, but less than 1% may emerge thereafter.

Maintaining no-till practices that leave seed on the soil surface can hasten the decline of the seed bank (Moechnig et al., 2012). Therefore, part of a long-term strategy to control
glyphosate-resistant common ragweed may be to maintain no-till practices. In tilled fields, emergence may occur over a longer period of time than in no-till fields, so including a soil active residual herbicide may be even more important to maintain consistent control.

**Controlling volunteer crops**

Although volunteer crops are often not considered typical weeds, they do reduce yields. In addition they may be glyphosate resistant. Volunteer corn is perhaps the most common volunteer crop weed in soybeans. It can cause yield loss, inhibit harvesting, contaminate soybean seed, and act as a host for insect (Krupke et al., 2009) or diseases that may infest the subsequent corn crop. Volunteer corn may be effectively controlled with Group 1 herbicides (ACCase-inhibiting), such as clethodim, quizalofop, sethoxydim, and others. Figure 33.9 demonstrates the potential soybean yield loss that may occur from volunteer corn in South Dakota.

![Figure 33.9. Volunteer corn in a soybean field. (Photo, M. Moechnig)](image)

Volunteer corn density (plants/m²)  
0 1 2 3 4 5 6  
Soybean yield loss (%)  
20 40 60 80 100  
Yield loss=30*x/(1+0.3*x)  
Figure 33.10. Soybean yield loss associated with volunteer corn density (x = volunteer corn density as plants/m²).

Volunteer canola may be more difficult to control than corn in soybeans. Although canola is generally not grown in South Dakota, seed may enter a field as a fertilizer contaminant or by other means. It often occurs at very low densities and is likely more of an aesthetic problem rather than a yield loss concern. Herbicides containing imazethapyr (Pursuit®, Extreme®, etc.) may be most effective.

**Avoiding selection for additional herbicide-resistant weeds biotypes**

Diversifying weed management programs to control one glyphosate-resistant weed biotype in a field does not mean that another species will not be selected in the future. Most herbicides are effective on only a limited number of weed species. There are many weeds that are not resistant to glyphosate, but are difficult to control because they are less sensitive to glyphosate (Chapter 33). If not carefully managed, these weeds could produce glyphosate-resistant biotypes.

It is important to consider other challenging weed species when developing a management plan to control glyphosate-resistant species. For example, adding fomesafen with glyphosate may effectively control glyphosate-resistant waterhemp, but would provide only limited additional control of common lambsquarters or velvetleaf, which means resistant biotypes could be selected. Therefore, it will be important to monitor populations of these other difficult species, make management adjustments if necessary, and be sure to use effective management programs for these species in rotational crops. Weed species and densities changes may be evaluated over time by entering this information into your field records annually (Chapter 2).
References and additional information


Websites
Weed Science Society of America: http://www.wssa.net/Weeds/Resistance/index.htm
The glyphosate, weeds, and crops web site: http://www.glyphosateweedsandcrops.org/
International survey of herbicide-resistant weeds: at http://www.weedscience.org

Acknowledgements
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The widespread adoption of Roundup Ready® soybeans has greatly simplified soybean herbicide programs but excessive dependence on glyphosate has resulted in glyphosate-resistant weed species in several fields. Other weeds continue to be a problem in soybean production systems, regardless of the herbicide management system. These problems result from late emergence or partial or near complete tolerance to glyphosate. The purpose of this chapter is to discuss management of problem weeds in soybean production systems (Table 34.1). As always, it is important to read and follow herbicide label instructions.
Soybeans in cropping systems for weed management

Including soybeans in crop rotations provides many benefits for managing several soil and pest problems, including weed control. Prior to the introduction of Roundup Ready® crops, including soybeans in a corn-soybean crop rotation was important for managing annual grass weed species in the soil seed bank as herbicide options for grass control were limited in corn, and broadleaf control in corn was much easier than in soybeans.

The widespread adoption of Roundup Ready® technology has greatly simplified weed control in corn and soybeans, but excessive dependence on glyphosate has resulted in glyphosate-resistant weed species in several fields. In recent years, soybean has been an important rotational crop because it is planted at a later time than corn enabling control of several weeds prior to soybean emergence. In addition, soybeans allow the use of different herbicide sites of action to control glyphosate resistant weeds resulting in more consistent weed control and avoiding selection of resistance to additional herbicides. Therefore, it is still important to include at least two crop species in a crop rotation to manage weed seed banks and minimize future weed management challenges.

Soybeans are generally less competitive with weeds than other common crop species (Colquhoun et al., 2001), which may be one potential limitation associated with including soybeans in a crop rotation. Narrower rows (less than 30 inches apart) and higher plant populations can increase soybean's competitive

Table 34.1. Problem weeds, possible control options, and notes. Tolerant weeds were never susceptible to glyphosate and resistant weeds are those that have become less susceptible after several years of herbicide use. (Source: M. Moechnig)

<table>
<thead>
<tr>
<th>Problem Weed</th>
<th>Possible Weed Control Options</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual grass weed species</td>
<td>Clethodim, quizalofop, sethoxydim, glyphosate</td>
<td>Generally easy to control.</td>
</tr>
<tr>
<td>Wild buckwheat</td>
<td>Post-emergence Pursuit ®+glyphosate or Extreme®</td>
<td>Approximately 60% control by glyphosate alone.</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>Post-emergence Cadet®, Resource®, or glyphosate. Pre-emergence Sonic®, Authority First® or Gangster®</td>
<td>May emerge later than soybean and still be competitive.</td>
</tr>
<tr>
<td>Waterhemp</td>
<td>Post-emergence Flexstar® or Cobra®. Residual soil active herbicides to control late emerging plants</td>
<td>May emerge late (see Chapter 33 for discussion on glyphosate-resistant biotypes).</td>
</tr>
<tr>
<td>Common lambsquarters</td>
<td>Post-emergence Harmony®, Cadet®, Resource®. Several effective pre-emergence herbicides.</td>
<td>Cool temps can decrease its susceptibility to glyphosate. Becomes less susceptible to glyphosate as it ages.</td>
</tr>
<tr>
<td>Biennial wormwood</td>
<td>Early glyphosate application or tank mix 2,4-D prior to planting soybeans. Several pre-emergence herbicides to control late emerging plants. Post-emergence herbicide options are very limited.</td>
<td>Most problematic in wet no-tillage fields. Becomes tolerant to glyphosate at it ages.</td>
</tr>
<tr>
<td>Evening primrose</td>
<td>Pre-plant 2,4-D for suppression.</td>
<td>Most problematic in wet no-tillage fields. Near complete tolerance to glyphosate.</td>
</tr>
<tr>
<td>Elm</td>
<td>Fall glyphosate + 2,4-D ester if leaves still green. Herbicides generally provide suppression only.</td>
<td>Only a problem in some no-tillage fields.</td>
</tr>
<tr>
<td>Scouring rush</td>
<td>MCPA desiccates top growth. Permit and Python may provide suppression</td>
<td>Persistent in wet no-tillage fields. Glyphosate not effective.</td>
</tr>
<tr>
<td>Field horsetail</td>
<td>Treat similarly as for scouring rush. Herbicides may only provide suppression</td>
<td>Most common in wet no-tillage fields. Glyphosate not effective</td>
</tr>
</tbody>
</table>
The exceptional efficacy of glyphosate in Roundup Ready® soybeans negated the drawback associated with weed competition with soybeans, but as tolerant or resistant weeds become more common, it will become increasingly important to rely on more diverse herbicide programs and controlling weeds in crop rotations to minimize the weed seed bank.

**Standard weed management programs**

Currently, weeds are mostly controlled with post-emergence herbicide applications, but it is becoming increasingly important to apply pre-emergence and post-emergence herbicides to ensure consistent weed control. Glyphosate alone may control the weeds that have emerged prior to the application, but will not have soil activity to control weeds emerging after the application.

SDSU research indicates that weeds may emerge at an average rate of 5 weeds/ft$^2$ per day from mid-May to mid-June (Nyamusamba, 2009). Therefore, additional weeds may quickly replace weeds controlled on the day of a glyphosate application if soil residual herbicides are not used. This is particularly important for controlling late emerging weeds, such as waterhemp, that may emerge after the last glyphosate application and produce seed that may replenish the weed seed bank. Some soil residual herbicides may be applied early post-emergence, but herbicide options are more limited than for pre-emergence applications and efficacy may be less consistent as rainfall may be more erratic at that time of year.

Although soybeans may tolerate early-season weed competition more than corn, it may be important to control weeds prior to the V3-V4 growth stage (three to four weeks after emergence (Chapter 3) to avoid yield reduction. Figure 34.1 illustrates the results from a study conducted at the Brookings Agronomy Farm in 2007 where soybeans were weed-free for zero to five weeks after soybean emergence or weeds were allowed to grow for two to six weeks after soybean emergence. The results indicated that late emerging weeds (up to three weeks after soybean emergence) could reduce soybean yield. In addition, weeds allowed to grow in soybeans for more than three to four weeks after emergence could cause yield loss even if they were controlled after that time.

In this study, weed populations were high as the weeds in the untreated treatments caused approximately 80% yield loss. Low to moderate weed densities would likely not cause as much yield loss if controlled late (after the V4 growth stage). Consequently, pre-emergence herbicide applications would likely reduce weed densities enough to prevent yield loss associated with early-season weed competition and enable greater flexibility in post-emergence herbicide application time.

**Figure 34.1. Effect of weed removal time on soybean yield.** Open squares (☐) indicate treatments where weeds were controlled for different periods of time and then allowed to grow thereafter whereas the solid circles (•) indicate treatments where weeds were allowed to grow for different periods of time and then controlled thereafter. (Source: [http://www.sdstate.edu/ps/weed-mgmt/weed-mgmt-crops.cfm](http://www.sdstate.edu/ps/weed-mgmt/weed-mgmt-crops.cfm))
**Difficult weeds in South Dakota soybeans**

Annual grass weed species can be controlled with ACCase-inhibiting herbicides (WSSA Group 1 herbicides) such as clethodim, quizalofop, sethoxydim, and others. Broadleaf species, on the other hand, are the primary challenge associated with most herbicide programs in soybeans (Fig. 34.2).

Since nearly 98% of soybean acres in South Dakota are herbicide tolerant (NASS 2012), the most challenging weeds are generally those that are not highly susceptible to glyphosate or glufosinate (Liberty®). Some of these weed species may be considered glyphosate tolerant, which means they were never highly susceptible to glyphosate. Glyphosate-resistant weed species are those that were once susceptible, but biotypes have become less susceptible due to selection for plants that are biologically different than the original susceptible population.

**Wild buckwheat**

Wild buckwheat (*Polygonum convolvulus*) (Fig. 34.2) is a common annual weed throughout South Dakota. Glyphosate often only suppresses populations (about 60% control). It may be controlled with post-emergence herbicide applications by tank mixing imazethapyr (Pursuit®) with glyphosate or using premixed products (e.g., Extreme®). Several pre-emergence herbicides also provide suppression. Seed banks can be managed with aggressive control in rotational crops such as corn or wheat.

**Velvetleaf**

Velvetleaf (*Abutilon theophrasti*) (Fig. 34.3) is a common annual weed around the eastern edge of South Dakota, with populations less common in central South Dakota (e.g., west of Hwy 281). However, areas of velvetleaf infestation continue to expand. Although glyphosate often severely injures velvetleaf, some plants may eventually grow out of the injury symptoms. In addition, velvetleaf’s large seed size results in large seedlings that can emerge later than soybeans but still eventually grow taller than the soybean canopy.

Velvetleaf may be controlled with post-emergence applications of fluthiacet (Cadet®), flumiclorac (Resource®), and other herbicides. Pre-emergence herbicides containing cloransulam (Sonic®, Authority First®, Gangster®, etc.) are generally very effective for controlling emerged seedlings and provide soil residual activity to control later emerging plants.

**Waterhemp**

Waterhemp (*Amaranthus tuberculatus*) (Fig. 34.4) is common throughout much of eastern South Dakota, but is less common in the north central part of the state. This weed is problematic in soybeans because its duration of emergence may extend later than many other weed species enabling many plants to emerge after a late post-emergence herbicide application, produce seed, and replenish the seed bank. Consequently, using soil active residual herbicides is one way to deplete moderate to high waterhemp densities.
SDSU research indicates that early emerging waterhemp can grow above the soybean canopy and produce more than 1 million seeds/plant whereas late emerging plants are kept in control by the dense soybean canopy, producing fewer than 100 seeds/plant (Uscanga-Mortera, 2004). Waterhemp plants may be male (pollen producing) or female (seed producing), so plants must cross with other plants to reproduce. This creates much genetic diversity within waterhemp populations allowing waterhemp to adapt to herbicides more quickly than other weed species.

**Common lambsquarters**

A common annual weed throughout South Dakota, common lambsquarters (*Chenopodium album*) (Fig. 34.5) can be challenging to control in soybeans because adverse growing conditions, such as cool temperatures or night time herbicide applications, can decrease its susceptibility to glyphosate. In addition, it can become less sensitive to glyphosate as it grows taller (greater than six inches). Common lambsquarters can be very persistent in the weed seed bank due to its relatively hard seed coat that increases dormancy rates and its prolific seed production (Colquhoun et al., 2001).

**Biennial wormwood**

Biennial wormwood (*Artemisia biennis*) is an annual or biennial weed present throughout eastern South Dakota. It is most problematic in wet no-till fields (Fig. 34.6). As a young plant, it can be easily confused with common ragweed (see Fig. 34.6). It is challenging to control in soybeans because it becomes more tolerant to glyphosate as it becomes taller (greater than 5-10 inches). It must be adequately controlled prior to soybean emergence because there are few effective alternative herbicide options.

Growth regulator herbicides, such as 2,4-D, may be effective if applied prior to soybean planting. Read the label, as planting soybean may require a preseeding interval. Some biennial wormwood plants may emerge during or after soybean emergence, so soil active residual herbicides may also improve control. Biennial wormwood is a very prolific seed producer so populations can increase rapidly if it is not adequately controlled.

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Figure 34.4. Waterhemp common through much of eastern South Dakota. (Photo, M. Moechnig)

Figure 34.5. Common lambsquarters is a common weed throughout South Dakota. (Photo, M. Moechnig)

Figure 34.6. Mature biennial wormwood plant (above left). Young common ragweed (above middle) and biennial wormwood (above right). (Photos, M. Moechnig)
Evening primrose

Evening primrose (*Oenothera biennis*) is a biennial weed that is found mostly in no-till fields (Fig. 34.7). It is nearly completely tolerant to glyphosate and there are few post-emergence herbicide options in soybeans. Pre-plant applications of growth regulator herbicides, such as 2,4-D, may provide some suppression or control. Fortunately, populations of this weed rarely increase so it is generally not a problematic weed. However, survivors after glyphosate applications often cause concern.

![Evening primrose](image)

Figure 34.7. Evening primrose is a problem weed in no-tillage fields. (Photos, M. Moechnig)

American elm

Elm trees (*Ulmus americana*) (Fig. 34.8) are often not considered a weed, but they can persist in no-till fields and are generally very difficult to control with herbicides. Effective control options are not well known. Perhaps early fall applications of glyphosate + 2,4-D ester may provide suppression if the leaves are still green at the time of application, but this has not been verified in SDSU trials.

![Elm](image)

Figure 34.8. Elm can persist in no-tillage fields. (Photo, M. Moechnig)

Scouring rush

Scouring rush (*Equisetum hyemale*) (Fig. 34.9) is a perennial weed that can spread by roots and spores. It is very persistent in wet areas that are not tilled. Scouring rush accumulates high concentrations of silica on its surface making it nearly completely tolerant to glyphosate. Effective herbicide options are not known.

MCPA may defoliate shoot growth, but new shoots will eventually grow from the roots. Halosulfuron (Permit*) and flumetsulam (Python*) have seemed to inhibit new growth in some SDSU trials, but more verification is needed. Scouring rush patches often become so dense that crops may not be planted into them. Perhaps tillage of infested areas during dry periods in the fall or spring may be the most practical control option.

![Scouring rush](image)

Figure 34.9. Scouring rush is persistent weed in wet areas that are not tilled. (Photo, M. Moechnig)
Field horsetail

Field horsetail (*Equisetum arvense*) (Fig. 34.10) is a perennial weed that is most common in wet areas of no-till fields. It is similar to scouring rush, but it has whorls of leaf-like structures at the nodes and is often much shorter. Like scouring rush, field horsetail is nearly completely tolerant to glyphosate. Effective herbicide options are not well known. Crops with dense canopies, such as wheat, may suppress field horsetail, but this has not yet been verified.

Figure 34.10. Field horsetail is a perennial weed common in wet no-tillage fields. (Photo, M. Moechnig)

Summary

The diverse growth characteristics among the several weed species in any field may enable weeds to quickly adapt to management practices. Using only one method of weed control will quickly select for the weed species best adapted to that management method resulting in inconsistent control and increases in the weed seed bank. Multiple methods of weed control, including more than one herbicide site of action and good agronomic practices that optimize crop competitiveness and crop rotations that disrupt weed life cycles, and will contribute to effective and consistent weed control. In addition, fields must be closely monitored to identify changes in weed species composition so that management adjustments may be made before the weed seed bank increases.

References and additional information


Acknowledgements

Support was provided by South Dakota Soybean Research and Promotion Council, IPM, and South Dakota State University.
The soybean aphid (*Aphis glycines*) is a significant insect pest of soybean in the North Central region of the U.S., and if left untreated can reduce regional production values by as much as $2.4 billion annually (Song et al., 2006). The soybean aphid is an invasive pest that is native to eastern Asia, where soybean was first domesticated. The pest was first detected in the U.S. in 2000 (Tilmon et al., 2011) and in South Dakota in 2001. It quickly spread across 22 states and three Canadian provinces. Soybean aphid populations have the potential to increase rapidly and reduce yields (Hodgson et al., 2012).

This chapter reviews the identification, biology and management of soybean aphid. Treatment thresholds, biological control, host plant resistance, and other factors affecting soybean aphid populations will also be discussed. Table 35.1 provides suggestions to lessen the financial impact of aphid damage.

**Table 35.1. Keys to reducing economic losses from aphids.**

- Use resistant aphid varieties; several are now available.
- Monitor closely because populations can increase rapidly.
- Soybean near buckthorn should be scouted first.
- Adults can be winged or wingless
- Determine if your field contains any biocontrol agents (especially lady beetles).
- Control if the population exceeds 250 aphids/plant.
Description

Adult soybean aphids can occur in either winged or wingless forms. Wingless aphids are adapted to maximize reproduction, and winged aphids are built to disperse and colonize other locations. Immature soybean aphids resemble adults but are smaller and always wingless. Wingless soybean aphids are pear-shaped, $\frac{1}{16}$" long, and range from pale yellow to lime green in color (Fig. 35.1). On late-season soybeans, some aphids may be pale and smaller and often occur on lower leaves of the plant. Adults have dark-tipped cornicles ("tailpipes") at the end of the abdomen (Fig. 35.1). Winged soybean aphids have a dark thorax (central body segment) and cornicles, and transparent wings that extend well past the abdomen.

Biology

On soybean, aphids are all female and reproduce asexually (without mating) by giving live birth to all-female offspring that are themselves only days away from being able to reproduce. This feature gives soybean aphids the ability to increase very rapidly when conditions are favorable. The optimal developmental temperature is 82°F. Under favorable conditions, populations can double every 6-7 days. Their density on soybean can become quite high, sometimes reaching thousands per plant. At other times, depending on conditions, soybean aphids may never exceed a few aphids per plant. When conditions are favorable, populations can increase rapidly and wingless aphids can produce winged offspring, which can then colonize other fields. Population increase often begins during flowering (R1-R2).

Figure 35.1. Winged and wingless soybean aphid, *Aphis glycines*. (Photo courtesy of Roy Scott, USDA-ARS)

Figure 35.2. (Left) Common buckthorn (*Rhamnus cathartica*). Note the serrated leaf edges. (Right) Soybean aphids on buckthorn leaves. (Photos courtesy of Chris Evans, Illinois Wildlife Action Plan; Christina DiFonzo, Michigan State University, Bugwood.org)
Soybean aphids alternate between summer and winter hosts. Soybean acts as the summer host while buckthorn (*Rhamnus* spp.), a shrub common in shelterbelts and woods, serves as the winter host (Fig. 35.2). At the end of the soybean growing season during the early autumn, the aphids migrate to buckthorn. Buckthorn is a critical part of the soybean aphid life cycle—without this plant, they cannot spend the winter in a given area. Common buckthorn (*Rhamnus cathartica* L.) is the most widely infested, though it may also overwinter on *R. alnifolia*. Winged females leave soybean in search of buckthorn, where they feed and deposit a generation of wingless females. Winged males from soybean (the only male generation produced during the year) seek these females on buckthorn, where mating, oviposition (egg laying) and overwintering (in the egg stage) occur.

The overwintering egg is cold-hardy and can survive temperatures down to -34°C. Eggs hatch during spring and several generations develop on buckthorn. As soybeans germinate, colonies on buckthorn produce winged founder females, which colonize soybeans in the early vegetative growth stage (V1-V5) by late spring/early summer. Soybean fields near buckthorn are often the first to be colonized in early summer, and should be scouted early to detect emerging problems.

Soybean aphids have piercing-sucking mouthparts that are used to feed on phloem sap. Heavily infested plants are stunted (Fig. 35.3) and usually covered with the sugary secretions ("honeydew") that the aphids produce. When honeydew is heavy it becomes a food source for fungi that produces a layer of black sooty mold on leaf surface (Fig. 35.4). Heavy infestations can result in yellow and wrinkled leaves, stunted plants and aborted pods.

Soybean aphids can transmit plant viruses. They have been shown to transmit both Soybean Mosaic Virus (SMV) and Alfalfa Mosaic Virus (AMV) to soybean, though the frequency of this transmission in the field is unknown. It may also vector diseases to other temporally-visited crops, such as Cucumber Mosaic Virus (CMV) in snap bean and Potato virus Y (PVY) in potato. Its economic importance as a vector in North American soybean and other crops is yet to be determined.

**Figure 35.3.** A soybean plant stunted by heavy aphid pressure (thousands per plant). The plant on the right contains the *Rag1* aphid resistance gene. (Photo courtesy of Roy Scott, USDA-ARS)

**Figure 35.4.** Sooty mold on soybean leaf surface associated with honeydew secreted by soybean aphids. (Photo courtesy of Christina DiFonzo, Michigan State University, Bugwood.org)
**Scouting**

Scouts are advised to check fields weekly from mid-June through late August, the period when aphids colonize soybean fields. When scouting for soybean aphids, walk a broad U or X pattern through the field and examine at least 20 to 30 plants, spread out over the field. Aphids can occur in “hot spots,” but treatment decisions should be based on a broad sample of randomly-selected plants. Count the number of aphids per plant—early in the season, soybean aphids are usually concentrated on the newest trifoliates, but later in the season they are more evenly distributed on the plant.

Treatment decisions should be based on the action threshold described below. Producers who are near but not at threshold should consider checking the field again before treatment (3-4 days after the initial treatment decision is made). If aphid numbers have decreased, or are still near the economic threshold and have not increased noticeably, or if many natural enemies such as ladybeetles are present, producers may wish to delay treatment, as populations can sometimes decline naturally before reaching damaging levels. A speed scouting protocol is also available (see Additional Information below); though less accurate, this can reduce the time needed for sampling.

**Action threshold and economic injury level**

During the early to mid-reproductive stages of soybean (R1-R5), the action threshold for treatment is when populations exceed 250 aphids per plant when at least 80% of the plants are infested and the population is still increasing (Ragsdale et al., 2007). Once soybeans reach the R6 growth stage (Chapter 4), soybeans are much less susceptible to yield loss from aphids (and, therefore, many more aphids can be tolerated). Thresholds for R6 soybeans have not been developed because natural aphid infestations in this late growth stage are uncommon, but research to develop R6 treatment guidelines is underway.

In aphid management, it is important to make the distinction between the action threshold and the economic injury level. The economic injury level is the point where the amount of insect injury justifies the control cost. This value varies with both commodity value and control costs. The action threshold, also called the economic threshold, is a lower value—not when economic loss is occurring, but when a decision should be made to take action to keep a pest population from climbing to the economic injury level.

The action threshold builds in time to react to an insect population before it becomes a problem, and is based on how quickly the population can be expected to grow, relative to the economic injury level. With a crop value of $15/bushel and a control costs of $8/acre, the economic injury level is 460 aphids/plant. At this economic injury level, an action threshold (decision point) of 250 aphids/plant allows about four days to make treatment before this injury level is reached. At lower crop values, the economic injury level is also lower, allowing more time between the decision point and the treatment point.

Another important concept in aphid management is the “damage boundary,” which is the minimum number of insects required to cause yield loss that can be detected and measured. Research in South Dakota and in other parts of the North Central region indicates that producers are unlikely to see a positive yield return at treatment points below 250 aphids/plant because this value is below the damage boundary. In other words, yield cannot be improved by eliminating pests that are at too low a density to cause measurable yield loss.

Prophylactic or “insurance” insecticide application below the action threshold is not recommended because it may not serve the intended purpose of eliminating future problems. Pest resurgence or secondary pest outbreaks (for example, by spider mites) is a common issue following insurance treatments; a single well-timed application as indicated by scouting and threshold use is more economical than two or more badly timed applications.

Some chemical control options for soybean aphid and other pests described here are listed in Table 35.2. Before applying chemical treatments check the pesticide labels.
### Table 35.2. Pesticides labeled for soybean pests in South Dakota.

<table>
<thead>
<tr>
<th>Product</th>
<th>Compound</th>
<th>Class</th>
<th>Pre-Harvest Interval</th>
<th>Pests Labeled For</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>SBA</td>
<td>SM</td>
</tr>
<tr>
<td>Asana XL*</td>
<td>esfenvalerate</td>
<td>pyrethroid</td>
<td>21</td>
<td>-</td>
</tr>
<tr>
<td>Baythroid 2*</td>
<td>Cyfluathrin</td>
<td>pyrethroid</td>
<td>45</td>
<td>+</td>
</tr>
<tr>
<td>Dimethoate</td>
<td>Dimethoate</td>
<td>organophosphate</td>
<td>21</td>
<td>+</td>
</tr>
<tr>
<td>Lorsban 4E*</td>
<td>chlorpyrifos</td>
<td>organophosphate</td>
<td>28</td>
<td>+</td>
</tr>
<tr>
<td>Mustang Max*</td>
<td>zeta-cypermethrin</td>
<td>pyrethroid</td>
<td>21</td>
<td>+</td>
</tr>
<tr>
<td>Nufos 4E*</td>
<td>chlorpyrifos</td>
<td>organophosphate</td>
<td>28</td>
<td>+</td>
</tr>
<tr>
<td>Pennca M*</td>
<td>methyl parathion</td>
<td>organophosphate</td>
<td>20</td>
<td>+</td>
</tr>
<tr>
<td>Proaxis*</td>
<td>gamma-cyhalothrin</td>
<td>pyrethroid</td>
<td>30</td>
<td>+</td>
</tr>
<tr>
<td>Warrior*</td>
<td>lambda-cyhalothrin</td>
<td>pyrethroid</td>
<td>30</td>
<td>+</td>
</tr>
</tbody>
</table>

SBA: soybean aphid; SM: spider mite; BLB: bean leaf beetle; GH: grasshopper; GC: green cloverworm; FA: fall armyworm; BA: beet armyworm; YA: yellowstriped armyworm; WBC: woollybear caterpillars

*Restricted-use insecticide

Note: The label of any of these pesticides may have changed since this table was compiled. Always check and follow current labels.

### Aphid-resistant soybean varieties

Aphid-resistant varieties are becoming increasingly available, and have the potential to be an important management tool as part of an integrated pest management program. Host-plant resistance in the form of both antibiosis (reduced survival and number of offspring) and antixenosis (non-attractive or repellent plants) to the soybean aphid have been discovered.

At least four resistance genes have been identified: Rag1 (Hill et al., 2004a), Rag2 (Mian et al., 2008b), and rog3 and rog4 (Zhang et al., 2009). [Capital letters indicate a dominant trait and lower case letters indicate a recessive trait.] Rag1 (an abbreviation for Resistance to *Aphis glycines* gene 1), is a single-gene source of antibiosis developed at the University of Illinois. Rag1 soybean lines first became commercially available in the U.S. on a limited basis in 2009; varieties containing other resistance genes are likely to follow. In field trials, the Rag1 trait significantly reduces aphid populations compared to aphid-susceptible lines.

In spite of the promise of aphid-resistant varieties, it should be noted that Rag1-containing soybeans are not aphid-free, and economically relevant populations sometimes occur. Thus, resistant varieties should be considered one part of an integrated pest management program which also includes scouting and threshold use. Biotypes have already been identified which can overcome Rag1 and Rag2 resistance (Kim et al., 2008; Hill et al., 2010). How quickly and to what extent biotypes will arise that significantly limit the usefulness of host plant resistance is not yet known.

### Biological control

Field studies of soybean reveal a diverse community of natural enemies, which help suppress soybean aphid colonization and population growth. These natural enemies include ladybeetles, lacewings, pirate bugs, and entomophagous (insect-killing) fungi. One of the most important predators of soybean aphid is the multicolored Asian ladybeetle, *Harmonia axyridis* (Fig. 35.5 A). This ladybeetle is often considered a household nuisance because of its habit of entering houses during the fall for overwintering, but it is one of the dominant soybean aphid predators in the U.S. (Gardiner et al., 2009).
Natural enemies have a significant impact on soybean aphid populations and contribute to their control. In the absence of predation, soybean aphid population growth is significantly faster (2-7 times) (Costamagna and Landis, 2006). Prophylactic application of broad-spectrum pesticides can increase aphid pressure or cause secondary outbreak of other pests such as spider mites by removing the natural enemies that often keep pest populations in check (Ohnesorg et al., 2009; Koch et al., 2010).

**Figure 35.5.** (Left) Asian ladybeetle (*Harmonia axyridis*). The adults range in color from pale orange-yellow to orange-red, and vary greatly in the number of spots. A pattern of black dots resembling the letter “M” behind the head is typical. (Right) Asian ladybeetle larva. (Photos courtesy of Allen E. Knutson, Texas A&M University, Bugwood.org)

**References and additional information**


Websites
For biology and management information on a variety of soybean and corn insect and disease pests in the North Central region, and a free smartphone app, available at www.npipm.org
For instructions and a worksheet on soybean speed aphid scouting, available at http://www.soybeans.umn.edu/crop/insects/aphid/aphid_sampling.htm

Acknowledgements
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Bean Leaf Beetle Identification, Biology, and Management

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Though problems with bean leaf beetles in soybean are sporadic and often localized, this is the second most common insect pest found in South Dakota soybean fields. Under certain conditions this pest can reduce yields. This chapter discusses bean leaf beetle identification, biology, and management.

Bean leaf beetle (*Cerotoma trifurcata*) description and biology

*Description*

The adult bean leaf beetle is about ¼ inch long, and can be yellow, tan or reddish in color. Typically, the bean leaf beetle wing covers are adorned with four rectangular black markings and a dark lining on the margin, but variants without these markings exist. Regardless of the presence of the rectangular markings, a black triangle is always present on the front part of the wing covers (Fig. 36.1).

*Figure 36.1. Adult bean leaf beetle (*Cerotoma trifurcata*) with four rectangular markings and wing covers linings. (Photo courtesy of: Natasha Wright, Florida Department of Agriculture and Consumer Services, Bugwood.org)*
The eggs, larvae and pupae of bean leaf beetles are found in the soil, making scouting for these life stages difficult and impractical. The egg is about \( \frac{3}{100} \) of an inch long, lemon-shaped, and orange in color. The bean leaf beetle larva is cylindrical, white in color with dark brown plates on both extremes. The size of the larva depends on its developmental stage. A mature larva is about \( \frac{1}{3} \) of an inch long. The beetle pupates within an earthen vessel in the soil.

**Bean leaf beetle biology**

Adult bean leaf beetles survive winter under leaf debris in woodlots and crop residue in soybean fields. When the average spring temperatures reach 50 to 55°F, surviving adult beetles emerge from their overwintering sites and move to various legumes such as alfalfa and sweet clover to feed and mate. In South Dakota, this usually occurs between April and May. Bean leaf beetles are strong flyers and will move to soybean when the seedlings emerge. The feeding activity of these overwintered beetles may produce appreciable damage on seedling soybean.

The female overwintered beetles move into soybean already pregnant. Throughout its life time, a female beetle can lay up to 40 clusters of egg with 10-30 eggs per cluster. Egg clusters are deposited in the soil surface near the base of the plant.

At a constant temperature of 82°F, the eggs take a week to hatch. At lower temperatures, this process takes longer. Hatching eggs produce larvae, which feed on soybean roots and root nodules. Depending on soil temperature, it takes between three to six weeks of root feeding before the larvae start to pupate. About a week after pupation, adult bean leaf beetles emerge from the soil. Bean leaf beetles typically have two generations per year in South Dakota.

Adult bean leaf beetles feed by chewing on soybean foliage and pods. This feeding produces characteristic round holes ("shot-holes") quite different from the jagged feeding holes produced by grasshoppers and caterpillars. Foliage feeding by the beetle may affect the yield by reducing the total leaf area available for photosynthesis (Fig. 36.4). Soybean in the vegetative growth stage is often able to tolerate defoliation and compensates by growing more leaves. Yet, defoliation tolerance depends on the quality of the growth environment. Thus in drought years, soybeans may have lower ability to tolerate defoliation.

During pod filling, bean leaf beetles feed on the pod surface. This injury can act as entry points for bacterial and fungal secondary infection. The seeds on scarred pods may become shrunken, discolored, and moldy. Occasionally bean leaf beetles feed on soybean pod stalks, clipping the pod in the process. It has been estimated that an average of one pod per beetle is lost every eight days due to beetle feeding on pod stalks.

Bean leaf beetles also acts as a vector of Bean pod mottle virus (BPMV). Overwintering beetles may retain BPMV from the previous year, although the importance of retained virus in epidemics the following year is not clear. Apart from soybean, BPMV is also found on tick-trefoil. Tick-trefoils are legumes that are generally used as a green manure. Bean leaf beetle adults that emerge in the spring may feed on infected perennial tick-trefoil, thereby acquiring the virus. The virus is transmitted to soybeans when the infected beetles move to the soybean seedlings. The subsequent generations of bean leaf beetle continue to spread the virus within and between soybean fields.

Soybeans infected with bean pod mottle virus show a range of symptoms including chlorotic mottling, leaf distortion, and leaf necrosis (Fig. 36.2). Plants infected early in the season or during period of rapid growth shows the most obvious symptoms. Soybean infected by BPMV produces 3-52% lower yield depending on the soybean cultivars and the time of infection. Bean pod mottle virus infection occurring in early vegetative phase (VC or between V2-V3) causes the highest yield reduction. The seeds produced by BPMV-infected soybean may show mottled seed coats, reducing the quality of the seed (Fig. 36.3). Bean pod mottle virus infection on soybean also increases the risk of Phomopsis seed infection.
Cultural management methods for bean leaf beetles

The risk of bean leaf beetles can be reduced by seeding the soybean as late as possible (Chapter 14) within the recommended planting period. The location of late-planted soybean needs to be carefully considered. Bean leaf beetles may migrate from an adjacent infested field to a field that was seeded late.

Pesticide management of bean leaf beetles

High populations of bean leaf beetle, especially in the reproductive stage of soybean, may cause economic damage. Chemical control of bean leaf beetle may be justified when the injuries due to beetle feeding exceed an economic threshold. Defoliation and pod feeding are the two main ways bean leaf beetles inflict injury; and the beetle is not the only defoliating pests infesting soybean. When other defoliators, such as grasshoppers and caterpillars, coexist in a soybean stand, it is useful to consider their accumulative damage when making a control decision. This can be done by estimating the amount of leaf area lost to all insect feeding in the field; a decision to treat or not is based on the overall defoliation rate based on the guidelines below. Some labeled pesticides for bean leaf beetle are provided in Table 35.2.
Estimating insect-inflicted defoliation rate on soybean

1. Randomly select 10 plants from the field and pick a trifoliate leaf from the top, middle, and lower third of these plants.
2. Discard the most and least damaged leaflets from each trifoliate. This will leave you 30 leaflets to assess the defoliation rate.
3. Compare each leaflet with the illustration provided in Figure 36.4, record the defoliation percentage of each leaflet, and determine the average defoliation percentage of the whole batch.
4. Repeat Steps 1-3 at four or more randomly selected sites within the field.

Treatment is warranted if defoliation exceeds 40% during vegetative stages of soybean development and is expected to increase (i.e., if insect feeding activity is still evident in the field). During pod-forming and pod-filling stages, a field should be treated if defoliation rate exceeds 20%. Because bean leaf beetles also feed on pods, damage to pods should also be monitored. Control is warranted if pod damage exceeds 10% during pod-fill.

References and additional information

Websites
www.npipm.org
www.planthealth.info

Acknowledgements
Support for this chapter was provided by South Dakota State University, South Dakota Soybean Research and Promotion Council, and the United Soybean Board.

Soybean fields can frequently contain many minor pests which occasionally require control. This chapter discusses the identification, biology, and management of two-spotted spider mites, grasshoppers, caterpillars, and woolly bear caterpillars.

Description, Biology, and Management of Two-spotted Spider Mites

Description

Two-spotted spider mites (Tetranychus urticae) are tiny arachnids (<0.002 inch) with a yellowish to greenish translucent body and two distinctive dark spots on the sides of the body (Fig. 37.1). The telltale spots are caused by food particles that accumulate in specific sites within the body. In the field, a 10x hand lens is sufficient for mite scouting, but accurate identification of two-spotted spider mites requires a specialized microscope.
Biology of two-spotted spider mites

Two-spotted spider mites overwinter as adults on broadleaf plants and crop residues. The overwintering mites neither feed nor lay eggs. In spring, surviving mites resume active feeding and mating. Two-spotted spider mites migrate into soybean fields in spring or summer. Infestations often begin on field edges. Female spider mites lay their eggs on the lower side of soybean leaves. The eggs hatch in 3-4 days and the nymphs take 5-10 days to develop into adults. Hot and dry summer stimulates the buildup of mite population.

Mites puncture plant cells and suck on the cell content. The accumulated punctures are visible as yellow or whitish spots on the lower side of soybean leaves. The appearance of these spots is commonly known as leaf stippling (Fig. 37.2). Mite feeding injury causes water loss and reduces leaf photosynthetic capability. Two-spotted spider mites also spin silk webbing that covers the leaf surface (Fig. 37.3). Heavy mite infestation causes early leaf senescence and pod shattering and when it occurs between late vegetative and early reproductive stages, between 40 to 60% of soybean yield may be lost.
Natural enemies of spider mites

Field spider mite populations are naturally regulated by predators and fungal pathogens. Both larvae and adult of Stethorus beetles, for example, feed on all stages of mites (Fig. 37.4). Adult stethorus beetles can eat over 50 mite eggs or 10 adult mites per day. Application of broad spectrum pesticide may kill the predators and interrupt the natural regulation of mite populations, resulting in a sudden bouncing back of the mite population.

Figure 37.4. Stethorus sp. beetle, a predator of two-spotted spider mites. (Photo courtesy of Sonya Broughton, Department of Agriculture and Food Western Australia, Bugwood.org)

Pesticide management approaches for spider mites

Confirming mite presence on stippled leaves is important since foliar disease, drought stress, and herbicide injury may cause similar symptoms. Start scouting at field edges, especially near ditches and alfalfa fields where the mites are likely to overwinter. Examine whole plants for stippled leaves, silk webbing and mite presence. Tap a stippled leaf over a black paper sheet (such as construction paper) and examine the sheet using 10x hand lens for mites. The presence of silk webbing on soybean leaves confirms mite infestation on the plant. If mites are found at the edge of the field, start scouting the inner field. Walk the field in a U pattern, stop randomly at 20 sites, and examine at least two plants at every site (Chapter 29). Score each plant according to Table 37.1.

After scoring the plants, divide the total score by the number of plants examined to arrive at the field average score. In drought conditions, mite populations may build up rapidly. If the field average score is equal to or greater than 3 and injury is found throughout the field, chemical control is recommended. If the field average score is lower than three but drought condition persists, scout the field every 4-5 days.

Some pyrethroid insecticides have been shown to aggravate mite infestation. Pyrethroids may kill two-spotted spider mites natural enemies or perhaps even boost the mite's reproduction rate. Thus, pyrethroid insecticide application should be followed up with mite scouting within 10-14 days of application (Chapter 35, Table 35.2).
Description, Biology, and Management of Grasshoppers

Two species of grasshoppers are common on soybean: the red-legged grasshopper (*Melanoplus femurrubrum*) and the differential grasshopper (*Melanoplus differentialis*). Other species of grasshopper may also occur on soybean, albeit less commonly.

**Description of grasshoppers**

Both red-legged and differential grasshoppers lay their eggs as elongated egg pods about 0.5-2 inches below the soil surface. A red-legged grasshopper egg pod contains 25-30 eggs while a differential grasshopper egg pod contains 50-150 eggs. When grasshopper eggs hatch, nymphs emerge. Grasshopper nymphs are similar to adults in shape, but smaller with undeveloped wings. Depending on the developmental stage, the nymphs of both grasshopper species range between 0.15 and 1.25 inches in length.

A characteristic broad pale band runs on each side of the head of red-legged grasshopper nymphs. The band starts around the gena (cheek area) and runs backward crossing the side of the thorax (main body trunk) through the first segment of a nymph’s abdomen (Fig. 37.5). A similar band runs on each side of the thorax of differential grasshopper nymphs. On differential grasshopper nymphs, the band does not start around the gena, but directly behind the head.

Adult red-legged grasshoppers are 0.9-1.3 inches long with reddish brown upper body color, a bright yellow underside and characteristic red hind legs (Fig. 37.6). Adult differential grasshoppers are 1.1-1.7 inches long with yellowish brown color and distinct v-shaped black markings on the hind legs (Fig. 37.7).

<table>
<thead>
<tr>
<th>Score</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No spider mites or injury observed.</td>
</tr>
<tr>
<td>1</td>
<td>Stippling on lower leaves; no premature yellowing observed.</td>
</tr>
<tr>
<td>2</td>
<td>Stippling common on lower leaves; no premature yellowing observed.</td>
</tr>
<tr>
<td>3</td>
<td>Heavy stippling on lower leaves with some stippling progressing into middle canopy. Mites present in middle canopy with scattered colonies in upper canopy. Lower leaf yellowing common. Small areas with lower leaf loss.</td>
</tr>
<tr>
<td>4</td>
<td>Lower leaf yellowing readily apparent. Leaf drop common. Stippling, webbing and mites common in middle canopy. Mites and minor stippling present in upper canopy.</td>
</tr>
<tr>
<td>5</td>
<td>Lower leaf loss common. Yellowing or browning moving up plant into middle canopy. Stippling and distortion of upper leaves common. Mites present in high levels in middle and lower canopy.</td>
</tr>
</tbody>
</table>

Figure 37.5. A red-legged grasshopper nymph (*Melanoplus femurrubrum*). Notice the pale band starting on the side of the head and crossing the thorax. (Photo courtesy of Joseph Berger, Bugwood.org)
Grasshopper biology and feeding

Female grasshoppers lay eggs in the soil during summer to mid-fall. Undisturbed grassy sites, including field borders, roadsides, prairie and pastures, are among the preferred egg-laying sites. Following an outbreak year, grasshopper eggs are also found in cultivated sites such as alfalfa, clover, and soybean fields. Grasshopper eggs hatch the following spring. Because female grasshoppers lay their eggs in a scattered manner, each egg pod may be exposed to a unique set of soil temperature and moisture conditions. As a result, the timing of the egg hatch may be extended to several weeks or even months and grasshopper nymphs may be evident in the field throughout summer.
Typically, red-legged grasshopper nymphs are found in the field 1-2 weeks earlier than differential grasshopper nymphs. The nymphs molt 4-5 times, becoming larger each time, to become a fully developed adult. Red-legged grasshopper nymphs take about 40 days to develop into adults while differential grasshopper nymph-to-adult development take about 32 days. Adult red-legged grasshopper may disperse, but most stay nearby the hatching eggs and feed on available plants. In contrast, both nymph and adult differential grasshoppers move actively in search of green tissue. Adult differential grasshoppers are strong flyers and their populations grow well on soybean, sunflower, and wheat.

Weather is a key factor driving the grasshopper population highs and lows. Low rainfall is associated with high rates of egg laying and survival, encouraging high initial grasshopper populations the following year. Two or more consecutive drought years may lead to a grasshopper outbreak. Early hard freeze in the fall may disrupt the egg-laying period by killing adult grasshoppers. Warm humid weather, for an extended period, may stimulate a disease outbreak and a reduction in the grasshopper population.

Grasshoppers are occasional pests of soybean. Both nymphs and adult grasshoppers feed on soybean leaves and pods. Defoliation is usually most severe in late summer, when the adult grasshopper population is the highest (Fig. 37.8). Grasshoppers can also chew through pod walls to feed on soybean seeds, directly reducing yield. Additionally, grasshopper-chewed pods are prone to secondary fungal infection.

Chemical and cultural management of grasshoppers

Scouting for grasshopper-inflicted injury should start early in the growing season to determine the incidence and extent of grasshopper problems. This time period coincides with nymph emergence from soil. Economic thresholds are based on defoliation percentage estimate of the field. Chemical control is recommended when defoliation in the field exceeds 40% pre-bloom, or exceeds 20% between blooming and pod fill. The details of scouting for defoliation percentage are described in Chapter 36. Some of the insecticides labeled for grasshoppers are listed in Table 35.2 in Chapter 35 on soybean aphids.

Tillage and small grain stubble has a mixed impact on grasshopper populations. Tillage of small grain stubble deters egg-laying by adult grasshoppers, while tillage after eggs are laid is ineffective since it does not cause sufficient egg mortality.

Description and Biology of Caterpillars

A number of caterpillars invade soybean plants. Among these, green cloverworm (*Plathypena scabra*), armyworms and woolly bears are relatively common in South Dakota soybean, though they do not frequently reach economically important levels.

Cloverworms

*Description of green cloverworm*

Fully grown green cloverworms are about 1 inch long, pale green with two white stripes along each side of the body (Fig. 37.9). The green cloverworm has three pairs of prolegs (fleshy legs apart from the three pairs of true legs near the head) in the middle of the body and a pair of prolegs at the back end of the body. Green cloverworm wiggle vigorously when disturbed. The adult moth of green cloverworm has a wingspan of about 1 inch. The female moth has charcoal-colored wings with brown and silver patches, while the male moth wings are more uniformly charcoal in color.
Biology of green cloverworm

The green cloverworm overwinters in the southern states of the U.S. and migrates to South Dakota in spring. Migrating moths arrive in early June and mated female moths lay eggs singly on the underside of soybean leaves. After 3-4 days, the eggs hatch and the green cloverworms start to feed on the leaves. In about 14 days, green cloverworms develop through 6 instars (growth stages). Most of the leaf feeding occurs when the cloverworms are in the 4th to 6th instars. Mature green cloverworms burrow into the soil or plant debris to pupate. 7-10 days after pupation, the adult moths emerge, mate and lay eggs. The green cloverworm typically produce two generations in the South Dakota, but cannot overwinter here.

The green cloverworm feed on leaf tissues between the main veins. Early instar larvae scrape leaf tissues creating a transparent skin on the leaf surface. Feeding by mature larvae produces holes on the leaves. A green cloverworm is estimated to consume 8.5 in² of soybean leaf throughout its life. The green cloverworm population only occasionally reaches economically damaging levels on soybean in South Dakota. Outbreak years are usually associated with an unusually high number of migrants from the southern states.

Armyworms

There are three species of armyworms commonly found on soybean: fall armyworm, Spodoptera frugiperda; beet armyworm, Spodoptera exigua; and yellowstriped armyworm, Spodoptera ornithogalli. All armyworms are general herbivores, capable of infesting many crops and vegetables. Armyworms feed on both leaves and pods of soybean.

Description of armyworms

Fall armyworms have a prominent white inverted Y-shape on the head (Fig. 37.10). Additionally, four dark spots are usually visible on the upper side of the caterpillar's eight abdominal segments.
Beet armyworms are green to black in color with a black spot on each side of the second segment of the thorax or chest-area. Unlike the fall armyworm, the beet armyworm body is smooth with fewer hairs or spines and the head bears no prominent Y-shaped marking (Fig. 37.10). Yellowstriped armyworm caterpillars are usually dark with a yellow or light colored bands running along the body sides (Figs. 37.11 and 37.12). A black spot can usually be seen on each side of the first abdominal segment.

Armyworm biology

Fall armyworms overwinter in southern states and migrate northward in spring and summer. At a constant temperature of 77°F, there are about 31 days between egg hatch and adult emergence. Cooler temperatures typically slow the fall armyworm development. In South Dakota there is one generation of fall armyworms produced in a year.

Similar to fall armyworm, beet armyworms cannot withstand South Dakota winters and spend the winter in southern states, migrating northward in spring and summer. One to two generations of beet armyworm are produced annually in South Dakota.

The yellowstriped armyworm life cycle requires 23-25 days to complete, although in cooler climates it may take a month or more. Typically, three generations per year of yellowstriped armyworm are produced in South Dakota.

Fall armyworm caterpillars infesting seedling soybean may cut the stems and reduce the crop population below the optimal level. In their early life stages, beet and yellowstriped armyworms feed in groups, producing skeletonized leaves with the fleshy leaf tissues eaten and the leaf veins intact. As the caterpillars mature, they disperse and the resulting patches of leaf defoliation become more irregular.

Armyworms are an occasional pest of soybean. Soybean is capable of compensating foliage loss, especially if it happened before flowering. However, high level infestation and resulting severe defoliation damage can retard further plant growth.
Woolly Bear Caterpillars

Description of woolly bear caterpillars

Woolly bear caterpillars are larvae of various moths from the family Arctiidae. These caterpillars are generalists, feeding on broadleaf weeds and various vegetables including beans, beets, cabbage, carrots, celery, lettuce, tomato and many others. The caterpillars are generally characterized by numerous elongated hairs (setae) protruding from the body. The hairs are typically bunched on fleshy warts on the surface of the caterpillar's body.

While there are multiple species of woolly bear caterpillars that feed on soybean, the yellow woolly bear caterpillar, Spilosoma virginica, is quite common on South Dakota soybean. The yellow woolly bear ranges from white to yellow and reddish in color, about 0.19 inch long and densely covered with long and short hairs of uniform color (Fig. 37.13). The adult moth of yellow woolly bear caterpillar is nearly pure white except for the abdomen. The wings are white with a few black spots.

Biology of woolly bear caterpillar

Yellow woolly bear caterpillars overwinter as pupae inside thick silken cocoons heavily covered with hairs from the caterpillar body. The adult moths emerge from the cocoons in spring and lay their eggs in clusters on the underside of host leaves. After eggs hatch, caterpillars feed until pupation. Egg hatch to pupation takes anywhere between one and two months. Typically, two generations of yellow woolly bear caterpillar are produced in South Dakota.

Young caterpillars feed gregariously on the tissues between leaf veins, skeletonizing the leaves at high infestation levels. The mature caterpillars feed alone on more exposed sites and may chew sizable holes in the leaves. The population of these caterpillars is easily overestimated due to the striking appearance of the caterpillars and the conspicuous injuries the mature larvae inflict on plants (Fig. 37.14).
Management of Caterpillars in Soybean

In seedling soybean, examination of whole plants in rows is the best method to scout for armyworm injury. Cut seedling stems may be a hint that fall armyworms are present. Fall armyworm treatment in seedling soybean is warranted if the number of cut stems reduces the plant population below the recommended stand density.

In older soybean, the injury inflicted by the caterpillars discussed above and other leaf feeders (e.g., soybean looper, bean leaf beetle, and grasshoppers) is assessed accumulatively in terms of the proportion of leaf lost to defoliating pests (Chapter 36). The field scouting method to estimate average field defoliation rate is provided in Figure 36.4. Management action is recommended if defoliation reaches 40% in pre-bloom and 20% during bloom and pod-fill. Some of the pesticides labeled for these caterpillars are listed in Table 35.2 in Chapter 35 on soybean aphids.

References and additional information


Websites
www.highplainsipm.org
www.npipm.org
www.planthealth.info

Acknowledgements
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Determining Harvest Losses in Soybeans

Daniel Humburg (Daniel.Humburg@sdstate.edu)

Maximizing soybean profits involves minimizing harvest losses. Harvest losses can reduce your bottom line and may be the difference between making and losing money. The first step in minimizing harvest losses involves determining the amount and source of current losses. This chapter provides guidance on estimating soybean combining yield losses.

<table>
<thead>
<tr>
<th>Table 38.1. Key steps in determining harvest losses.</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Make a frame to count the number of lost beans on the ground. A square 1 ft(^2) frame is easy.</td>
</tr>
<tr>
<td>• Place the frame on the ground behind the combine and count the number of beans on the ground within the frame.</td>
</tr>
<tr>
<td>• Estimate the size of your soybeans. (You can measure this; see calculations below).</td>
</tr>
<tr>
<td>• For small soybeans, 5 soybeans/ft(^2) is approximately equal to 1 bu loss/acre, and for medium-sized soybeans, 4 soybean/ft(^2) is equivalent to 1 bu loss/acre.</td>
</tr>
<tr>
<td>• Estimate your percent loss (100 \times measured loss / yield). Losses &lt; 3% are generally acceptable. It should be possible to reduce losses if they are &gt; 3%.</td>
</tr>
</tbody>
</table>
Calculating soybean yield losses

Measuring soybean harvest yield losses involves determining the number of soybeans on a known area of the soil surface. Yield losses per unit area can be measured using rectangles or hoops. A circular hoop can be made from a piece of stiff wire. A length of 42.5 inches fashioned into a circle will enclose one square foot and will be about 13.5 inches in diameter (Fig. 38.1). This can easily be stored in the cab of the combine or hung on a post or hook where it is available. A circular hoop that encloses five square feet would require a length of wire 95 ⅛ inches in length fastened end to end, and would be 30.3 inches in diameter.

Another approach would be to make a frame of PVC pipe and 90 degree bends. Four pieces of pipe about 12 inches in length will enclose an area of one square foot with small adjustments needed depending upon the depth of the 90° corners used. A similar frame can be made to enclose five square feet if the inside dimensions of the square frame are 26.8 inches.

Rectangular frames of other sizes can also be constructed to be convenient to use or store. Inside length (inches) x inside width (inches) / 144 will give the area enclosed in square feet. The frame can be glued permanently or the end sections could be glued and the sides left loose to allow the frame to be broken down (Fig. 38.2). Two small bungee cords threaded through the two ends pieces and fixed with a knot will allow the frame to be broken down but kept as a unit so that it is always handy.

Make a device that is convenient and that you will use. Larger areas will make somewhat more accurate measurements of losses, but smaller areas are quicker to count.
Combine losses are estimated by tossing the frame onto the ground and counting the number of soybeans within the frame's boundaries. The soybean count is divided into the area enclosed by the frame in square feet. The loss is determined by converting the number of soybeans/ft² to bushels/acre. These calculations depend upon the size and weight of the beans. For these calculations the following information is needed:

- 1 acre contains 43,560 ft².
- 1 bushel of soybean at 13% moisture weighs 60 lbs.
- Soybeans generally range from 2500 beans/lb to 3500 beans/lb.
- Losses depend on soybean size and weight (Table 38.2).

Table 38.2. The relationship between soybean size and beans/ft². The # of beans per ft² that is equivalent to one bu/acre is determined by dividing the # of soybeans/bushel by 43,560.

<table>
<thead>
<tr>
<th></th>
<th>Weight/bushel</th>
<th>Bean/bushel</th>
<th>Beans/lb</th>
<th>Soybeans in beans/ft² equivalent to 1 bushel/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>@ 13% Moisture</td>
<td>60 lbs</td>
<td>218,000</td>
<td>3633</td>
<td>5</td>
</tr>
<tr>
<td>Small soybeans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ 13% Moisture</td>
<td>60 lbs</td>
<td>174,000</td>
<td>2900</td>
<td>4</td>
</tr>
<tr>
<td>Medium soybeans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ 13% Moisture</td>
<td>60 lbs</td>
<td>130,800</td>
<td>2180</td>
<td>3</td>
</tr>
<tr>
<td>Large soybeans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Determining the beans per bushel or bean per pound

Calculated soybean losses require an estimate of the bean size (Table 38.2) or the measured number of soybeans per bushel. If the conversion from beans/ft² to bushels/acre is known, then losses can be calculated as in the example below where 15 soybeans were found in each square foot.

For medium beans, \[
\frac{15 \text{ soybean}}{\text{ft}^2} \times \frac{1 \text{ bushel}}{4 \text{ soybeans}} \times \frac{4 \text{ soybeans}}{\text{ft}^2} = 3.8 \text{ bushels/acre}
\]

If you are uncertain about the size of your beans in these conversions, then you can measure the number of beans/bushel by weighting 200 soybeans from the combine on a scale. This weight is then converted to lbs/bushel using the following example where 200 beans weighed 0.80 ounces.

\[
\frac{\text{beans}}{\text{bushel}} = \left( \frac{200 \text{ beans}}{0.80 \text{ ounces}} \right) \times \frac{16 \text{ ounces}}{1 \text{ lb}} = \frac{240,000 \text{ beans}}{\text{bushel}}
\]

The bean counts (15 in this case) per ft² are then converted to bushel of loss/acre using the calculations below:

\[
\frac{\text{bushel}}{\text{acre}} = \left( \frac{15 \text{ beans}}{\text{ft}^2} \right) \times \frac{43,560 \text{ ft}^2}{\text{acre}} \times \frac{\text{bushel}}{240,000 \text{ beans}} = 2.72 \text{ bushels/acre}
\]

A quick initial test can be performed to determine if you need to do further measurements. Using your measurement frame or hoop, take several counts of beans in areas behind where the combine has passed when operating normally. Determine the number of soybeans/ft² in these areas. This will include losses from all sources. Use the calculations above to determine your loss per acre. Now divide the bushel per acre loss by...
the harvested yield in this area of the field and multiply by 100%. This will provide the % loss. If your losses are 3% or less of the harvested yield, your combine is doing a good job. Reducing losses below this level may be difficult. If the overall losses exceed 3%, you should do a more thorough examination of the losses to determine where they are occurring and if the losses can be reduced.

To calculate corn harvest losses an identical approach can be used. However, the corn kernels weighs/bushel are slightly different. Information for these calculations are provided in Table 38.3.

Table 38.3. The relationship between corn kernel size and kernels/ft².

<table>
<thead>
<tr>
<th>Weight/bushel</th>
<th>Kernels/bushel</th>
<th>Kernels/lb</th>
<th>Kernels/ft² Equivalent to 1 bushel/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>@ 15.5% Moisture</td>
<td></td>
<td>@ 15.5% Moisture</td>
<td></td>
</tr>
<tr>
<td>Large kernels</td>
<td>56 lbs</td>
<td>70,000</td>
<td>1250</td>
</tr>
<tr>
<td>Medium kernels</td>
<td>56 lbs</td>
<td>90,000</td>
<td>1607</td>
</tr>
<tr>
<td>Small kernels</td>
<td>56 lbs</td>
<td>110,000</td>
<td>1964</td>
</tr>
</tbody>
</table>

Reducing harvesting losses

Soybean losses occur primarily in the gathering process at the combine head. It is most common losses during threshing, separation, and cleaning to be very small, while losses at the head can be quite large. Losses can be categorized into the following categories:

- **Pre-harvest loss.**
  These are usually shatter losses and are visible as shelled beans or whole pods lying on the ground ahead of the combine.

- **Shatter loss.**
  These are additional beans lost onto the ground when pods open during the cutting and gathering process at the head.

- **Stubble loss.**
  This loss occurs when pods are attached to the plant stem below the height of the cutterbar and remain there after the passage of the machine.

- **Loose stem loss.**
  These losses are associated with pods attached to stems that are cut, but are not recovered by the head.

- **Lodging loss.**
  These losses are associated with stems that are uncut but lie on the ground, or are pushed to the ground by the head. Pods attached and the beans enclosed are lost.

- **Separator loss.**
  These losses occur when beans are not threshed, or are passed over the sieves and out the back of the combine with the chaff or straw.

- **Machine leakage loss.**
  These losses occur in some machines as wear or lose fitting parts allow beans to leak from holes or gaps in components. This type of loss is visible as an abnormal concentration of lost beans along a line under the machine.
Determining losses from different machine processes

Measurement of losses should be performed as an important component of the field work. Losses from different components can be determined by following different procedures.

**Step 1:** Operate the combine at your normal forward speed and settings, moving far enough into the crop to be at steady conditions and away from headlands. Stop the machine and shut down the separator. Back the machine away from the uncut crop about the length of the combine. For machines with very wide heads, it may not be necessary to back away as there are enough places to access behind the head.

**Step 2:** Begin with pre-harvest losses. In the standing crop ahead of the combine, place the measurement hoop on the ground such as in locations "A" in Figure 38.3. In this case, using a hoop that is smaller in size than the row spacing is advantageous. Larger hoops can dislodge or shatter pods in the process of placing the device on the ground. Count and record the number of beans + beans within pods found on the ground within the hoop. Perform this test in several places and calculate the average number of beans per square foot. Calculate losses using the examples above.

**Step 3:** Next, determine the shatter loss. Use the measurement hoop to perform counts of loose beans on the ground at several locations behind the combine header marked as “B” in Figure 38.3. If the combine has been backed away from the crop, these measurements can be made across the full swath width. If a wide head is used, this measurement can be performed to either side of the machine. Calculate the average number of loose beans per/ft². Subtract the average number of pre-harvest loose beans from this number. Calculate losses using the examples above.

**Step 4:** Stubble loss should be measured at each location where shatter loss is measured. Look for pods within the hoop still attached to the stubs of plants below the cut point. Shell these pods and determine the total number of beans contained within these pods. Repeat this at each measurement location and determine the average number of beans per square foot from stubble loss. Determine loss using the calculations above.

**Step 5:** Determine the loose stem loss. At each location “B,” also look for loose or cut stems within the sample area. Count the number of beans remaining within pods on loose stems. Average these numbers and determine the average number of beans on loose stems in each square foot. Calculate loss using the approach demonstrated above.

*Figure 38.3. Locations for determination of preharvest and machine losses in soybean harvest.* (Illustration by Daniel Humburg, SDSU)
Step 6: Determine the lodging loss. Within the sample locations “B,” look for stems that were not cut. Count the number of beans from the pods on these stems. Average these numbers for the sample locations and determine the average number of beans per square foot associated with lodged stems. Calculate loss using the approach demonstrated above.

Step 7: Check for separator loss. Use the measurement hoop to determine beans per square foot from several locations within the discharge swath marked “C” in Figure 38.3. If the number of loose beans plus beans from free pods exceeds the numbers counted from locations “B,” there is measureable separator loss. To identify the amount of separator loss, subtract the average number of loose beans per square foot at “B” from the number found at location “C.” This difference is the separator loss, but it is concentrated in the swath behind the combine. To adjust it to the full machine swath, multiply this beans-per-square-foot by the discharge pattern width and then divide by the full machine swath width. The result is the number of beans/ft² attributable to the separator. Calculate loss using the approach demonstrated above.

Step 8: Look for machine leakage loss. The combine should be backed away from the standing crop for this examination. Look for any pattern of crop lost under the combine or across the swath. Most combines will not exhibit this loss, but it is not unusual to have a leak. Any concentration of beans in a line along the direction of travel may indicate a leak from the machine. If such a strip is found, the machine should be examined to locate the source of the loss and the part repaired. To include this loss in the calculation of percentage losses, the number of beans in a one foot length of this strip must be divided by the combine swath width. For example, if a strip of beans is found that has 36 beans in each foot along the direction of travel and the header swath is 24 feet wide, the average loss would be 24/36 or 1½ beans/ft². Based on this value, calculate loss using the approach demonstrated above.

Step 9: Sum all of the bushel-per-acre losses to determine total losses in the crop. Determine the total per acre yield by adding the losses to the harvested yield. Now the percentage losses can be determined by dividing each individual type of loss by the yield and multiplying by 100%.

The page below (Table 38.4) is a calculator sheet that can be printed and used as a way of logging and calculating losses in soybeans. Some losses are inevitable. However, taking the time to count some beans in a few sample areas and quantifying the types of losses occurring will assist in making good decisions regarding which machine settings might reduce the losses. Even pre-harvest losses, although they cannot be prevented once they have occurred, are useful to measure as they may assist in making varietal selections in subsequent years.
### Soybean Harvest Loss Calculation Worksheet

#### Bean Counts by Sample Location and Loss Type

<table>
<thead>
<tr>
<th>Sample Location (See Figure)</th>
<th>#1 Bean Count</th>
<th>#2 Bean Count</th>
<th>#3 Bean Count</th>
<th>#4 Bean Count</th>
<th>Average Count</th>
<th>Average Beans/ft² (= Count Avg / ( \text{Sample Frame or Hoop Size} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;A&quot; Loose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;B&quot; Loose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;B&quot; On stubble</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;B&quot; On cut stems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;B&quot; On lodged stems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;C&quot; Loose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{Separator} = (\text{Sample Frame or Hoop Size} - \text{Sample Frame or Hoop Size}) \times \text{discharge pattern width} / \text{cut swath width} \]

\[ \text{Leakage} = \text{If present, bean count per 1 ft of travel} / \text{swath width (ft)} \]

Total Losses in bushels per acre = \( \frac{\sum \text{Bean Count}}{\text{Sample Frame or Hoop Size}} \)

Harvested Yield in bushels per acre

Actual Yield = (Harvested Yield + Total Losses)

Pre-Harvest Loss % = \( \frac{\text{Bean Count}}{\text{Sample Frame or Hoop Size}} \) \times 100%

Shatter Loss % at Head = \( \frac{\text{Bean Count}}{\text{Sample Frame or Hoop Size}} \) \times 100%

Stubble Loss % = \( \frac{\text{Bean Count}}{\text{Sample Frame or Hoop Size}} \) \times 100%

Loose Stem Loss % = \( \frac{\text{Bean Count}}{\text{Sample Frame or Hoop Size}} \) \times 100%

Lodged Stem Loss % = \( \frac{\text{Bean Count}}{\text{Sample Frame or Hoop Size}} \) \times 100%

Separator Loss % = \( \frac{\text{Bean Count}}{\text{Sample Frame or Hoop Size}} \) \times 100%

Leakage % = \( \frac{\text{Bean Count}}{\text{Sample Frame or Hoop Size}} \) \times 100%

Total % Loss = \( \frac{\text{Bean Count}}{\text{Sample Frame or Hoop Size}} \) \times 100%
An example using the loss calculator

An example can help show the value of the calculator (Table 38.5). In a 5-ft² area behind the combine, 67 loose beans are counted. Based on these values, the yield loss is 2.97 bu/acre (see below).

\[
\frac{67 \text{ beans}}{5 \text{ ft}^2} \times \frac{43,560 \text{ ft}^2}{\text{acre}} \times \frac{\text{bushel}}{196,000 \text{ beans}} = \frac{2.97 \text{ bushels}}{\text{acre}}
\]

If the yield is 45 bu/acre then the loss is 6.6% (100×2.97/45). This value exceeds 3% and therefore a closer look is needed. The calculator sheet in Table 38.5 is used to identify the sizes and origins of the losses that are occurring.

The 5 ft² frame was used to measure pre-harvest losses ahead of the combine in three places. Three additional places were sampled behind the combine head but ahead of the discharge pattern. The discharge pattern width was also sampled at three locations behind the combine. The bean counts from each of the loss categories were recorded on the calculator sheet. The bean counts are adjusted to beans/ft². The bushels per acre from each loss type are determined and the total yield determined from the harvested yield and the lost yield. Percentage losses for each type are calculated. In this case the shatter loss was 4.7% of the total yield, which may be excessive.

Once losses are measured and categorized, the combine can be adjusted. Suggestions for adjustment of machine operating parameters are given in Humburg (2012).
Table 38.5. Sample Soybean Harvest Loss Calculation Worksheet.

**Soybean Harvest Loss Calculation Worksheet**

Bean Counts by Sample Location and Loss Type

<table>
<thead>
<tr>
<th>Sample Location (See Figure)</th>
<th>#1 Bean Count</th>
<th>#2 Bean Count</th>
<th>#3 Bean Count</th>
<th>#4 Bean Count</th>
<th>Average Count</th>
<th>Average Beans/ft² (Count Avg / Θ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;A&quot; Loose</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2.67</td>
<td>54</td>
<td>10.8</td>
</tr>
<tr>
<td>&quot;B&quot; Loose</td>
<td>54</td>
<td>49</td>
<td>59</td>
<td>54</td>
<td>12.33</td>
<td>2.47</td>
</tr>
<tr>
<td>&quot;B&quot; On stubble</td>
<td>15</td>
<td>13</td>
<td>9</td>
<td>12.33</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&quot;B&quot; On cut stems</td>
<td>0</td>
<td>26</td>
<td>0</td>
<td>12.33</td>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td>&quot;B&quot; On lodged stems</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8.67</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&quot;C&quot; Loose</td>
<td>65</td>
<td>61</td>
<td>67</td>
<td>64.33</td>
<td>12.86</td>
<td>1.13</td>
</tr>
</tbody>
</table>

Separator

Separator Loss = \( \left( \Theta - \mathbb{E} \right) \times \text{discharge pattern width} / \text{cut swath width} \)

Leakage

Leakage Loss = \( \left( \mathbb{E} - \mathbb{O} \right) \times \text{bean count per 1 ft of travel} / \text{swath width (ft)} \)

Total Losses in bushels per acre = \( \left( \Theta - \mathbb{O} - \mathbb{O} - \mathbb{O} - \mathbb{O} - \mathbb{E} \right) \Theta \)

Yield in bushels per acre

Harvested Yield = \( 45 \)

Actual Yield = (Harvested Yield + Total Losses)

Pre-Harvest Loss % = \( \mathbb{E} \mathbb{O} / \Theta \times 100\% \)

Shatter Loss % at Head = \( \left( \mathbb{O} \mathbb{E} / \Theta \right) / \Theta \times 100\% \)

Stubble Loss % = \( \Theta / \Theta \times 100\% \)

Loose Stem Loss % = \( \Theta / \Theta \times 100\% \)

Lodged Stem Loss % = \( \Theta / \Theta \times 100\% \)

Separator Loss % = \( \Theta / \Theta \times 100\% \)

Leakage % = \( \Theta / \Theta \times 100\% \)

Total % Loss = \( \Theta \Theta \Theta \Theta \Theta \Theta \Theta \)

Harvested Yield in bushels per acre

Harvested Yield = \( 45 \)

Actual Yield = (Harvested Yield + Total Losses)

Pre-Harvest Loss % = \( \mathbb{E} \mathbb{O} / \Theta \times 100\% \)

Shatter Loss % at Head = \( \left( \mathbb{O} \mathbb{E} / \Theta \right) / \Theta \times 100\% \)

Stubble Loss % = \( \Theta / \Theta \times 100\% \)

Loose Stem Loss % = \( \Theta / \Theta \times 100\% \)

Lodged Stem Loss % = \( \Theta / \Theta \times 100\% \)

Separator Loss % = \( \Theta / \Theta \times 100\% \)

Leakage % = \( \Theta / \Theta \times 100\% \)

Total % Loss = \( \Theta \Theta \Theta \Theta \Theta \Theta \Theta \)
References and additional information

Acknowledgements
Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, SD Water Resources, USDA-AFRI, SD Drought Tolerance Center, and South Dakota 2010 research program.

Preventing Soybean Combine Fires

Daniel Humburg (Daniel.Humburg@sdstate.edu)

Combine fires are a serious threat that can cause millions of dollars in damage (Fig. 39.1). The purpose of this chapter is to provide information that can be used to reduce fires during soybean harvest. Fire risk can be reduced by checking and cleaning equipment. The risk is highest when wind speed is high and relative humidity and the soybean moisture percent is low. Additional key factors that can be used to reduce fires are below in Table 39.1.

![Figure 39.1. A typical combine fire. (Source: http://www.howardandsons.com)](http://www.howardandsons.com)
Warm and dry weather conditions can produce conditions that are highly conducive to fires. For example, in 2011 conditions existed that were conducive to combine fires. The highest fire risks were observed on days with high temperatures, low relative humidity, high winds, and low soybean moisture contents (Uilk, 2012). The combination of dry crops, warm temperatures, and high winds produced 100 combine fires in just 15 counties in northwest Iowa and southwestern Minnesota (Fig. 39.2). Similar conditions were also observed in South Dakota and northeast Nebraska. These data suggest that there are some conditions where it might be wiser to suspend harvesting and do something else. The benefit of an early or timely harvest may not outweigh the risk of the loss of the machine and the field surrounding it.

**Table 39.1. Keys to reducing or minimizing combine fire risks.**

- Park the combine during periods of high risk.
- Remember your safety comes first.
- Conduct a pre-harvest and daily cleaning.
- Fires require, fuel, an ignition source, and oxygen.

*Fire risks have increased because:*

- Many steel combine components have been replaced with combustible components.
- Combines are larger and process more biomass.
- Chain and belt drives have been converted to hydrostatic systems, which increase the risk of oil leaks and combustible hoses that can sustain a fire.
- The wide-scale use of powered sensors and controls systems which may provide the spark to ignite dust and chaff.

![Figure 39.2. The number of fires on equipment (first number) and field fires (second number) in Southern Minnesota and Northern Iowa.](image)

Pink counties are areas where fire data was obtained. Assessments were not conducted in orange or grey counties. (Source: Uilk, 2012)
Combine fires require a fuel and ignition source. The fuel source may be a plastic wiring harness, or other synthetic part. An arc from a short circuit in the wires within the wiring system can provide the spark that ignites the fire. These types of fires are rare. Producers can minimize this risk by maintaining the machine in its original configuration.

Any repair or replacement of parts should include examination of the electric and hydraulic systems adjacent to the repair to make sure that wires and hoses are routed or restrained such that they will not chafe or be cut by moving parts. Hydraulic systems frequently produce small leaks, or oily residues from repairs and replacement of parts. Hydraulic oil combined with crop dusts provides a ready fuel that will burn if ignited. It is very common for the fuel source to be crop residue or soybean dust. Soybean dust is fine fluffy material that finds its way to almost all machine parts. A combine that is not thoroughly cleaned following the corn harvest will have highly combustible dry corn silks tucked into numerous places.

Crop dusts or residue can be ignited by an multitude of sources. Some of these include:

1. exhaust manifold and turbocharger of the engine that produces exhaust gasses with temperatures that exceed 1000°F
2. a failing bearing can easily ignite crop residues
3. friction between plant parts
4. electrical shorts or arcs
5. possibly static electricity (Polin, 2012a, 2012b)

It is not clear whether static charges build sufficiently to ignite crop residue in soybean crop residue. Research is being conducted to evaluate this risk.
Preventing fires: removing the fuel and ignition sources

Preventing fires begins with minimizing fuel sources. The combine should be kept as clean as possible during harvest. Periodically cleaning the machine reduces the amount of accumulated residues that can be ignited. CaseIH recommends cleaning the machine after shut down at the end of the day (Case IH, 2011). We recommend that during periods of high fire risk consider cleaning the combine more frequently. Some producers use compressed air, while others use portable gas powered leaf blowers to blast dust, chaff, and leaves from the machine at regular intervals, or when there is downtime from harvest.

Cleaning should be thorough and focus on areas that are subject to heat or ignition sources. High risk ignition zones include: the engine and engine compartment, the hydraulic pumps and pump drives, gear boxes, batteries, and cables. When cleaning, scan for problems of any kind that may require maintenance.

The nature of soybean harvest makes it difficult to completely eliminate all fuel sources. There will be dust and chaff that accumulate on machine surfaces between maintenance events. The synthetic materials in current combine designs will burn if ignited. Hydraulic oil finds its way out of fittings and creates oily films that dust and chaff stick to.

Fire prevention starts before harvest and should include a pre-harvest inspection and cleaning. Corn husks, silks, chaff, and straw should be cleared from the machine. When cleaning, check for leaky hydraulic fittings. While it is not practical to prevent 100% of hydraulic leaks, any fittings that shows a pattern of leakage should be tightened, repaired, or replaced. The pre-harvest inspection should also include inspecting the combine's wiring harnesses.

The number of sensors, control valves, and electric actuators has increased on modern machines, and this complex system now reaches all parts of the combine. Look for places where wires are not adequately restrained, or where they might chafe from contact with moving parts. A short circuit of one or more of these wires can shut down the machine function when an ISOBUS message errors occur, but it can also provide ignition of the wire insulation and the crop material around it. Repair and secure any wires that show motion wear or chaffing.

Pre-harvest checkout of the combine and daily service generally includes lubricating any bearings that have grease fittings. Another pre-harvest check should include inspecting bearings, where friction can easily cause the bearing to heat and ignite fires. The availability of low-cost infrared thermometers with laser pointers makes it possible to identify bearings that could be problematic during harvest. The combine can be operated empty for a period of time in the farm yard as a part of the pre-harvest inspection.

Warm up all of the mechanisms. Following this warm-up period, an infrared thermometer can be used to quickly check the temperature of many bearings on the machine by simply pointing the laser to the bearing area and reading the measured temperature. Bearings that register substantially hotter than others may indicate wear that suggest that failure is not far off. Replacing a bearing prior to harvest may not only prevent down time during harvest, but could prevent a catastrophic fire. These IR devices can be purchased for less than $50 and can be kept in the combine cab.

Once harvest is underway, the relative temperature of bearings and mechanical parts can be checked when waiting for a truck or grain cart. The cost of this tool and the time taken to scan for hot spots are small compared to the costs that can result from a fire.

Figure 39.5. An example of an inexpensive infrared thermometer. These devices have a laser pointer and can quickly perform non-contact measurements of surface temperatures of bearings and mechanical components. (Source: www.harborfreight.co)
The engine exhaust system can also ignite crop residue. Temperatures of exhaust gases leaving the engine approach 1000°F. This means that the engine exhaust manifold and the turbocharger operate at temperatures that can ignite dusts. It is also possible for fine dusts that come very close to these hot components to ignite in the air. Sparks or embers landing on surfaces with combustible materials can ignite a fire.

Some producers are using aftermarket circuits or “chips” to bypass the factory programs that govern fueling rates of electronically controlled engines. This is done to increase the power output of the engine and capacity of the combine. However, this process inevitably increases the fueling rate and the engine temperature. Components that were a potential ignition source can now become a more severe hazard. Producers should think very carefully before overriding the engine factory settings. While the engine may be capable of producing more power, its life is typically reduced, while the fire hazard is increased.

**Putting out a fire**

If you detect burning crop residue and find that part of the machine is on fire, what should you do? If the fire is a smoldering in a dust layer or pile, you may be able to extinguish it. Current recommendations call for two 10 lb ABC dry chemical fire extinguishers on the machine. One is stored in or near the cab, and one where it can be reached from the ground.

Better yet, install a 20 lb ABC dry chemical extinguisher where it can be accessed from the ground. In use, the acronym PASS is used to remember the procedure for these devices.

- **P**ull the pin.
- **A**im the nozzle.
- **S**queeze the trigger.
- **S**weep across the base of the fire.

It is critical that these extinguishers be kept in good working order. They should be checked by a fire department or other agency qualified to determine that they are fully charged and ready. If an extinguisher is used, even briefly, it must be recharged. The dry chemicals passing through the valve are likely to prevent it from fully sealing and it may gradually lose pressure and effectiveness. Have it professionally serviced. Invert and shake the extinguisher canister once or twice during the harvest season to prevent machine vibration from consolidating the dry chemical at the bottom of the canister (Hanna, 2012).

Some producers prefer a water-charged extinguisher, a water jug, or even a water squirt bottle for smoldering fires in crop residue. The water is effective at putting these out without blasting loose smoldering residue to the surrounding areas. Water is not effective in controlling fires that have spread to hydraulic hoses or synthetic materials that are abundant on current model machines.

If the fire is more than a smolder, your first action should be to call for emergency assistance. If the fire has progressed beyond what can be controlled with the ABC extinguishers, get away from the machine and wait for help. The fire can progress very quickly and unpredictably. A half full poly fuel tank heated by a fire will not explode like a scene from an action film, but the empty portion of it will soften when exposed to a fire and it may burst with enough violence to rapidly spread the fire. Climbing onto a burning machine in an attempt to put it out is not worth the risk of the loss of your life.

During times of high fire risk, it may be wise to position a tractor with a tillage implement where it can be readily accessed if a machine fire should ignite the crop. High winds associated with combine fires can also spread the fire to the crop and potentially the neighboring crops with catastrophic losses. Tilling a soil break around the original fire can contain it and minimize the loss.

Good machine maintenance, preparation, and vigilance can minimize the incidence of fires while harvesting soybeans. However, fires will still occur when conditions become extreme and some part of the machine provides the trigger. In all cases, make your safety your first priority. The machine and the crop are replaceable.
References and additional information


Acknowledgements

Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

Soybean management decisions regarding field practices, timing of harvest, and operator settings of the combine can mean the difference between minimal losses of the crop and losses that can reach twenty bushels per acre. At current prices, these types of losses can dramatically influence profit or loss for the enterprise. The purpose of this chapter is to discuss combine harvest adjustments that minimize losses (Table 40.1).

Table 40.1. Keys for optimizing combine settings.

- Soybeans are most effectively harvested from a flat surface that is smooth.
- Harvest as soon as the crop reaches acceptable moisture level. A soybean crop that is drier than 13.5% moisture costs you money.
- Under normal conditions the reel-to-combine speed ratio is 1.25. If the soybean are lodged, a higher value will recover more crop.
- Keep the reel higher and farther forward in normal crop. In lodged soybeans, pull the reel closer to the cutter bar and lower it to lift the fallen stems.
- Learn the effects and interactions of combine adjustments. Use the dynamic simulator program, located at http://cell25.com/CaselH/htmls/global/course.html to test effects of different combine settings.
- Modern combines are capable of handling a variety of crop conditions. However, putting the highest possible percentage of the standing crop in the bin still requires that producers learn how to measure the machine performance, identify avoidable losses, and then make appropriate adjustments to machine settings and operating parameters.
**Plating impact on harvest efficiency**

Some decisions that impact harvest are made when the crop is planted. It is easiest for a combine harvester to harvest soybeans from a field that has a smooth, flat surface. Practices such as no-till, conventional tillage, ridge till, or field rolling impact how smooth a field is at harvest. Corn stubble and root balls can affect the harvest operation and soybean quality.

Evidence suggests that harvesting as soon as the crop reaches acceptable moisture levels provides for maximum yield recovery. If the crop is not harvested, rapid temperature and moisture changes can lead to shattering losses. These losses can be significant. For example, a study conducted at Pennsylvania State University showed that delaying harvest three weeks can reduce yields 12 to 20 bushels per acre (Voight, 2010). Additional losses occur when the crop moisture content is less than the market moisture content of 13.5%. Once the moisture % decreases below the market standard moisture content, the marketable yield decrease because the market does not compensate for moisture levels below 13.5%.

The following equation can be used to calculate potential yield of soybeans at market moisture from moisture contents below the market standard level. In the equation, $MC_{\text{harvest}}$ is the moisture content at the time the soybeans were harvested. $Y_{\text{harvestMC}}$ is the yield of the dry beans and $Y_{13.5}$ is the yield that could have been obtained at 13.5% moisture content.

\[
Y_{13.5\%} = 100 - 13.5 \times Y_{\text{harvestMC}}
\]

For example, a 45-bushel per acre yield harvested at 10% moisture content would equate to a 46.8-bushel per acre yield if it had been recovered at the market allowable moisture content of 13.5%. The result is a loss of 1.8 bushels per acre, which at a market price of $15/bushel represents $27/acre of reduced revenue. Table 40.2 shows the relationship between soybean selling price, grain moisture %, and lost $/bu. When the soybean are dried to 10% moisture, the amount of dry bean sold in a bushel (60 lbs) increases and the amount of water decreases.

**Table 40.2. The influence of soybean selling price on the cost of selling soybean at 10% moisture as opposed to 13.5 % moisture.** This occurs because a bushel of soybeans is assumed to weigh 60 lbs. A bushel at 13.5% moisture contains less dry soybeans than a bushel at 10% moisture.

<table>
<thead>
<tr>
<th>Soybean Selling Price</th>
<th>lbs/bu when sold</th>
<th>Moisture</th>
<th>Moisture</th>
<th>Lost $/bu from drying soybean to 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>13.5</td>
<td>10</td>
</tr>
<tr>
<td>$/bushel</td>
<td>Lbs water/bushel</td>
<td>Lbs water/bushel</td>
<td>Lbs dry beans/bu</td>
<td>Lbs dry beans/bu</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>6</td>
<td>7.8</td>
<td>54</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
<td>6</td>
<td>7.8</td>
<td>54</td>
</tr>
<tr>
<td>15</td>
<td>60</td>
<td>6</td>
<td>7.8</td>
<td>54</td>
</tr>
<tr>
<td>20</td>
<td>60</td>
<td>6</td>
<td>7.8</td>
<td>54</td>
</tr>
</tbody>
</table>

**Harvest Losses**

Details on measuring harvest losses are provide in Chapter 38. While delaying harvest may result in losses, rushing the harvest without determining machine losses will almost certainly result in avoidable losses as well. Most machine losses in soybeans occur at the combine head. Soybeans are a relatively easy crop to thresh and separate. Crop that enters the separator generally results in losses of less than 1%. However losses at the combine head can be many times this amount. Take the time to measure the performance of your machine and its settings.
**Pre-harvest losses**

These types of losses cannot be avoided by machine adjustment, but must be determined to be able to assess other losses. Typical losses due to pre-harvest shatter are 0.25%, but can be much larger in very dry crop, or if harvest is delayed.

**Header shatter losses**

Processes that take place at the head include gathering or guiding by the reel, cutting by the knife and sickle bar, and conveying by the cross auger or drapers. The greatest shatter losses occur in the process of gathering and cutting the plants by the reel and cutting system. Operator adjustments include the height of the reel, the forward separation of the reel from the cutter bar, the reel speed, and the forward vehicle speed. Shatter losses from all of these sources are aggravated by excessively dry drop conditions.

Shatter losses of 2% are generally considered acceptable, but average losses have been found to be 5% or more among different operators. It is recommended that you begin adjustments to reduce machine losses by reviewing the recommendations of the combine manufacturer in the owner's manual. The suggested settings for different crops and conditions are specific to your model machine. However, the following are general guidelines to reduce machine losses.

The height of the reel should be adjusted no lower than needed to guide the plants across the cutter bar. In lodged crop, it may be necessary to lower the reel to recover plant stems that are close to the ground, but in standing crop it is more desirable to stay in the top ⅓ of plants.

The centerline of the reel is positioned 6 to 12 inches ahead of the cutter bar. This produces a motion where the reel fingers are lifting out of the crop just as it is cut. For a lodged crop, the reel should be moved rearward so that the crop is guided farther onto the head before the reel fingers lift out. By lowering the reel and moving it rearward, the lodged stems can be lifted up and back across the cutter bar and recovered. Some increase in shatter of pods may occur in this process. However, the increased recovery of whole lodged stems with multiple pods can more than offset the shatter loss. If you move into a field that does not have lodged stems, do not forget to reset the reel height and forward position to the recommended positions for standing crop.

The speed of the reel at its lowest point should be rearward at about 125% of the forward speed of the harvester. This ratio is called the reel index. A reel index of 125% means that the fingers of the reel are guiding the crop backward at a speed that is about ¼ of the machine speed. This results in a gentle guiding of the stems, such that they tip backward as they are cut and fall onto the grain platform or drapers.

Current model machines may automatically slave the reel speed to the forward vehicle speed so that if you increase the harvester speed, the reel speed will increase to keep this ratio constant. In this case, you will have control over the reel index as an adjustment within the electronic settings of the machine. The operator's manual will provide the details of how to adjust the ratio. For normal crop conditions, an index of about 1.25 is recommended. When harvesting lodged soybeans, a reel index closer to 1.5, or 150%, may provide better crop recovery. Again, if you move from a field with lodged stems to one with a clean standing crop, do not forget to readjust the reel speed, or the reel index to the recommended setting for this crop condition.
The cutting system should be examined and maintained to keep it in optimum working condition. The knife sections must be kept sharp and in good repair. A damaged section will result in incomplete cutting of stems and will result in increased shatter loss, stubble loss, and lodged stem loss along the path of that knife section. Hold-down clips should position the knife to within 1/32” of the guards. Wear plates should be adjusted to make light contact with the back of the knife. In most cases the oscillation speed of the knife will be sufficient to provide complete cutting of the crop stems. However, the cutting action is determined by the knife reciprocation rate and the forward speed of the machine. Check the recommended speeds of operation in the owner’s manual for your combine and stay within those recommendations.

Figure 40.2. Knife and guard maintenance is critical. At left a guard section has broken. At right a knife or sickle section has broken off at the knife bar. Both conditions will produce losses when stems encounter this part of the head. (Photos courtesy of D. Humbug, SDSU)

A flexible head can keep the cutting system in the closest possible contact with the ground to recover low pods. The use of a rolling implement (Chapter 12) while the crop is small can flatten the soil surface and press rocks, clods, and other debris into the soil surface. This provides a smooth, flat surface at the time of harvest for the cutter to follow and leaves fewer rocks and other materials protruding to damage the knife or be taken into the combine. Rolling can improve the quality of harvested beans for seed producers as less dirt and foreign matter are picked up from the flattened surface than from an uneven soil surface. Protocols for determining yield benefits from rolling are provided in Chapter 12.

Alternate gathering systems

Alternate gathering systems include draper heads and air assist reels. Draper heads transport the cut stalks to the center of the head after they are propelled onto the drapers by the reel. The process is gentler to the crop than the conventional cross augers. The stems maintain a consistent orientation as they are transported. That “head first” orientation is maintained as the stems enter the feeder house and eventually the threshing system. This approach should produce less shatter on the head and fewer split soybeans and higher quality.
Figure 40.3. Draper head used in soybean harvest. The drapers transport crop to the feederhouse in a consistent orientation and with less disturbance to the pods. Draper heads are available both in rigid and flexible types. (Source: www.macdon.com)

An air assist reel uses directed jets of air to help propel the crop across the cutter bar and onto the grain platform or drapers. It may also be able to reduce shatter losses at the head when conditions are dry and the crop is fragile.

Figure 40.4. An air assist reel. Air jets help to propel the crop across the cutter bar onto the grain platform. (Source: http://www.mascus.com/agriculture/used-combine-harvester-accessories/crary-wind-system-crary-wind-system/do7i7men.html)

Separator losses

Although soybeans are not generally difficult to thresh and separate when compared to other crops, it is important to pay attention to the settings of these systems. The measurement procedures to determine losses at the threshing system or at the separator are provided in Chapter 38. Follow the recommendations of the combine manufacturer with regard to initial settings of the rotor speed, concave gaps, and sieve and fan settings to adjust for losses in the threshing, separating, and cleaning sections of the combine.

A software application developed by CaseIH can be useful for gaining a general understanding of the interaction of machine settings and operator controls on the combine performance. Figure 40.5 shows an
image of the rotor, shoe, fan, of an axial flow combine. The program animates the components showing relative motion and the flow of material. At the top of the diagram, graph bars indicate performance measures such as losses, grain damage, and engine load. Ideal performance is shown. The user can increase or decrease any of these settings or inputs.

The software will indicate the likely impact of the change in setting on the six performance measures. In this way, it is possible to see which performance measures are impacted by a setting change. The tool is a quick way to consider the impact of a change to the machine or operating point. It may also help identify the unintended consequences of operating at an extreme of one machine setting. The Case IH course on combine theory and settings, along with the dynamic simulator program can be accessed at http://cell25.com/CaseIH/htmls/global/course.html.

Figure 40.5. CaseIH combine simulator illustration. Changing one or more of the operator adjustments at the bottom is reflected by corresponding changes in performance. (Source: http://cell25.com/CaseIH/htmls/global/course.html)

Soybeans produced for seed and for some specialty markets are particularly sensitive to quality measures. Producers for these markets will want to pay particular attention to adjustments that impact crop quality. Foreign matter and split seeds will detract from the seed quality and can lower premiums or lose the opportunity for sale as seed.

Follow the manufacturer’s recommendations with regard to rotor speeds. In general lower rotor speeds will produce fewer split seeds so in fragile crop, move to the lower end of the recommended range. Keeping the threshing and separating systems consistently loaded results in less damage to seed as the crop stems act as a cushion between seed and moving parts. A lightly loaded rotor and concave will result in greater impacts from the rotor tines or rasp bars on the seeds and more breakage. Larger concave spacing will in general produce less damage.
The combine simulator can be a tool in addition to the operator’s manual to understand how separator adjustments will affect damage and foreign material in the harvested crop. Sharp metal edges in contact with soybeans will produce more split seeds. If quality is critical to the market, it can pay to relieve sharp edges on the cross auger, feeder house chain flighting, and rotor parts. Maintain clearance between the cross auger and the underlying platform of ⅜ inch or 15 mm, or the clearance recommended in the operator’s manual to avoid splitting seeds.

References and additional information
Staton, M. 2012. Pay close attention to reducing soybean harvest losses this fall. Michigan State University Extension news item. Available at http://msue.anr.msu.edu/news/pay_close_attention_to_reducing_soybean_harvest_losses_this_fall

Acknowledgements
Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

In many years, soybean drying is required to insure that the crop will be available to sell in the following year. Prior to storing soybean, the bin should be cleaned and potential pest problems controlled (Chapter 43). This chapter discusses soil moisture calculations, drying rules of thumb (Table 41.1), and yield estimates.

### Table 41.1. Soybean drying rules of thumb.

- The equilibrium soybean moisture content is a function of air temperature and relative humidity.
- Because of the high oil content in soybeans, beans should be stored at 2-3 moisture percentage points below what is the acceptable moisture content for storing corn.
- For short-term winter storage, 12-13 percent moisture content is usually acceptable.
- In both the field and elevator, soybeans generally dry faster than corn.
- As a general rule, do not exceed a plenum temperature of 130°F for commercial beans and do not exceed a plenum temperature of 100°F for seed beans.
- It is suggest that for maximum efficiency of drying and minimum damage to the beans, a 20 degree increase in plenum temperature should be the goal when drying beans.
**Harvest moisture content**

To understand soybean drying, a basic understanding of grain moisture content is needed. Soybeans are sold on a wet basis using the calculations shown below.

\[
\text{Water content} = \frac{\text{Water weight}}{\text{Water weight} + \text{Dry soybean weight}} \times 100%
\]

\[
\text{Water weight} = \left(\frac{\text{Percent moisture}}{100} \times \text{Dry soybean weight}\right) \frac{100}{1-\text{Percent moisture}}
\]

Other critical information to know about soybean moisture content is that at 13.5% moisture, a bushel of soybeans weighs 60 lbs. This 60 lbs/bushel weight consists of 52.2 lbs of dry beans and 7.8 lbs of water. Many elevators assume that a bushel of soybeans weighs 60 lbs regardless of the moisture content. This means that if you sell soybeans at 10% moisture, it’s assumed that they contain 13.5% moisture. Sixty lbs of beans at 10% moisture contain more dry beans than 60 lbs of beans at 13.5% moisture. This assumption means that by letting soybeans dry to 10% moisture, it costs you money. Examples of grain moisture calculations are available in Clay et al. (2012) and Chapter 53.

As a rule of thumb, the optimum soybean harvest moisture content is between 13% and 15%. If the soybeans are drier than 11% moisture, significant shattering losses can occur. In many combines, significant crushing and damage problems can occur when the soybean moisture content exceeds 15 to 18%. Typically in South Dakota, the moisture content of soybeans will be 13% in middle to late October. However, if beans are not dry by mid October, the atmosphere’s natural drying potential is greatly diminished. Harvesting wet soybeans may be the only alternative, since it is also clear that significant pre-harvest losses occur when soybeans are left in the field.

**Storage**

Because of the high oil content of soybeans, they should be stored at 2-3 moisture percentage points below what is the acceptable for corn (Table 41.2). For short-term winter storage, 12-13% moisture is usually acceptable. If you are planning on storing soybeans over the summer, they should be dried down to 11% moisture. If there are green beans present, lower the moisture percentage an additional 2 points. When in storage, soybeans should be monitored weekly.
**Drying**

Table 41.2 shows that soybean moisture content is a function of air temperature and relative humidity. Soybeans, being round, have about 25% less airflow resistance than corn. Therefore, when placing soybeans in a drying system designed for corn, the beans will dry more rapidly than corn. For this reason, soybeans are easier to dry than corn. However, there have been years that were so humid and cold that soybeans could not dry to an acceptable level. In those years, drying may be the preferred alternative to leaving the beans in the field.

**Table 41.2. The influence of relative humidity and temperature on the soybean moisture content.**
(Modified from ASAE D245.4)

<table>
<thead>
<tr>
<th>Relative Humidity</th>
<th>Soybean Equilibrium Moisture Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35°F</td>
</tr>
<tr>
<td>% RH</td>
<td>% moisture content</td>
</tr>
<tr>
<td>30%</td>
<td>6.6%</td>
</tr>
<tr>
<td>45%</td>
<td>9.1%</td>
</tr>
<tr>
<td>60%</td>
<td>11.7%</td>
</tr>
<tr>
<td>75%</td>
<td>14.8%</td>
</tr>
</tbody>
</table>

To understand soybean drying, Table 41.2 is critical. Table 41.2 shows that at an air temperature of 65°F and an air moisture content of 60% relative humidity, soybeans can dry no further than to 10.8% MC. This means that if relative humidity is >75%, it is not possible to dry the soybean to below 13 to 14% moisture. Soybeans can be dried in conventional corn drying facilities, but extreme caution must be exercised. Soybeans are more fragile than most cereal grains.

*As a general rule do not exceed a plenum temperature of 130°F for commercial beans and do not exceed a plenum temperature of 100°F for seed beans.*

As a crude rule of thumb, heating air 20°F will lower the relative humidity of air to ½ the initial relative humidity. It is suggest that for maximum efficiency the oven temperature should be 20 degrees higher than air temperature.

As with corn, air-only drying can be effective. If beans are put in the bin at 18% to 20% moisture content, use the suggested air flow of about 1-1.25cfm/bu (minimum 0.5 cfm/bu), (for a 20-25 ft deep bin). For this flow rate, approximately 1 hp/1000 bu is required. With natural air drying, it will typically take about 70 days to decrease the moisture content from 20% to 13%. If the air temperature falls below freezing before drying has been completed, cool the beans to about 30°F. Resume drying in the spring when the air temperature rises above 40°F. If beans are at less than 15%, 0.1 to 0.2 cfm/bu should provide sufficient airflow to finish drying.

**Green beans**

In some years and with some varieties of soybeans, an early frost may result in your harvest containing many immature green beans. Natural-air or low-temperature drying at a minimum of 0.5 cfm/bu can help to limit the amount of bean damage from drying. For the long exposure times, limit the heat added to 20°F above the ambient temperature. High-temperature systems may leave higher amounts of green beans, which translates into higher dockage at the elevator. If there are significant numbers of green beans, there is some evidence to indicate that for long-term storage, the moisture should be lowered an additional two points.
Yield estimates

Yield estimates can be used to guide management and marketing decisions. For soybean yield estimates, information on the number plants/acre, the number of seeds/pod, and the number of seeds/pound are needed. As the season progresses, the number of assumptions associated with these critical values decrease, which in turn increases accuracy. An additional purpose of this chapter is to provide guidance on soybean yield estimates at three different growth stages.

Most northern soybean varieties have an indeterminate growth habit (Chapter 3). Indeterminate growth means that plants develop leaves and flowers simultaneously during the reproductive growth stages. Yields in plants with indeterminate growth are limited by season length. Early season yield estimates are based on average growing season lengths which can vary substantially from season to season. As the season progresses, yield estimates generally improve.

Early season yield estimates

Early in the season we can develop our first yield approximation (a scientific guess) by counting the plant population and assuming the beans/plant and soybeans/bu. We recommend the 1/1000 of an acre method for estimating the plant population. You need to first measure the row spacing. You will then use Table 40.3 to determine the distance that constitutes 1/1000 of an acre. For example, the length of row for 1/1000 of an acre when the row spacing is 20 inches is 26 feet and 1.6 inches. To estimate the plant population, you count the number of plants contained in 1/1000 of an acre at 10 locations and then multiply the average population by 1000. The length of row to produce 1/1000 of an acre is directly related to the row spacing (Table 41.3).

Table 41.3. Distance as a function of row spacing that is required to constitute an area of 1/1000 of an acre.
(Data from C.G. Carlson and K. Gustafson, SDSU)

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
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<tbody>
<tr>
<td>3</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>feet</td>
<td>67</td>
<td>74</td>
<td>65</td>
<td>52</td>
<td>37</td>
<td>34</td>
<td>25</td>
<td>24</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>inches</td>
<td>1.4</td>
<td>8.1</td>
<td>4.1</td>
<td>3.3</td>
<td>4.0</td>
<td>10.2</td>
<td>1.6</td>
<td>10.7</td>
<td>8.0</td>
<td>5.1</td>
</tr>
</tbody>
</table>

For early season estimates, assume that a plant contains 60 beans and that there are 215,000 beans per bushel (60 lbs/bushel). For South Dakota, these are reasonable assumptions. It should be noted that there is much error inherent in these assumptions. If in a 20-inch row bean field we count 140 bean plants in a 26-foot and 1.6-inch row, the estimated yield is 39.1 bu/acre. This calculation is shown below,

\[
\frac{140,000 \text{ plants}}{\text{acre}} \times \frac{60 \text{ beans}}{\text{plant}} \times \frac{1 \text{ bushel beans}}{215,000 \text{ beans}} = \frac{39.1 \text{ bushel}}{\text{acre}}
\]

Later in the season estimates

During the reproductive stages, the number of pods per plant can be counted. Based on this value, yield estimates are improved. However, it is important to point out that soybean plants will continue to produce pods as the growing season progresses. Yields at this growth stage are estimated by determining the plant population and the number of pods per plant. In a particular area, select at least 10 plants to determine the
average number of pods/plant. If the row spacing is 20 inches and there are 140 plants in 26-foot and 1.6-inch of row and if there are 26 pods/plant, then the yield estimate is 42.3 bushel acre. The calculation for this estimate is below.

\[
\frac{140,000 \text{ plants}}{\text{acre}} \times \frac{26 \text{ pods}}{\text{plant}} \times \frac{2.5 \text{ beans}}{\text{pod}} \times \frac{1 \text{ bushel beans}}{215,000 \text{ beans}} = 42.3 \text{ bushel acre}
\]

![Figure 41.4. Average soybean sizes and the conversion of the number of soybean per ft² to bu/acre. (Photo courtesy of Brent Turnipseed, SDSU Seed Lab)](image)

### Yield estimates as harvest approaches

As harvest approaches, the number of soybean per pod can be counted. For this measurement, the number of beans per pod should be counted in 10 plants. At this time, count the beans found on each plant, determine the average bean count/plant, and estimate a bean size (small, medium, or large) (Table 41.4).

Seed sizes can be measured with a micrometer. The number of seed per lb decrease with increasing seed size. The relationship between seed diameter and seeds per bushel is below (Table 41.4).

For example, 1) if the row width is 20 inches, 2) if there are 140 plants in a row length of 26 ft plus 1.6 inches, 3) if there are on average 67 beans/plant, and 4) if the bean size is medium to large (237,000 beans/bu), then the yield estimate is 39.6 bushels/acre.

### References and additional information


### Acknowledgements

Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

Monitoring and managing grain pests doesn’t stop until the grain has been sold, delivered, and accepted. Problems can be minimized by cooling the grain as quickly as possible. The feeding by insects, rodents, and other animals on stored grain can significantly impact its quantity and quality. Insect pests that attack field crops are not the same ones that threaten stored grain. Roosting birds or other animals may not directly feed on the stored grain, but can contaminate it with their waste products. For example, fecal dropping can promote the presence of molds that degrade the quality and condition of the grain. Therefore, sanitation and preventative actions are critical.

A regular pest monitoring program should be continued right up to when the crop leaves the farm. The purpose of this chapter is to discuss grain maintenance, structural management, and treatment options for stored grain. Key grain storage components are provided in Table 42.1.
Storage considerations

Environmentally-sound pest management is essential to maintain the quantity and the condition of stored grain (Table 42.1). Storage conditions play an important role in controlling storage pests and a pest monitoring program should be established for their grain bins. Schedules will vary depending on stored product, pest history, environmental conditions, control options used, length of storage and other factors. There is no one schedule to fit all needs. Insuring a pest-free environment should be the first step in preventative management. This is true whether a new or previously used storage bin is involved. In cases where used bins were infested with pests, use a residual insecticide treatment in bin cleanup. As always follow labeled directions. Maintenance should include treating: 1) all bin surfaces including removable doors, 2) around partitions, and 3) under floors with an appropriate insecticide two weeks before reusing the bin.

After grain is placed in the bin it should be checked routinely (Table 42.2). A good monitoring schedule would be a minimum of once a month during the winter (November through April) and at least two times a month during the rest of the year.

<table>
<thead>
<tr>
<th>Table 42.1. Key components to consider when storing grain.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural</strong></td>
</tr>
<tr>
<td>• Insure that the storage bin facilities are weather tight and rodent proof.</td>
</tr>
<tr>
<td>• Screen ventilation openings to prevent entry of rodents and birds.</td>
</tr>
<tr>
<td>• Build the bins on moisture-proof base.</td>
</tr>
<tr>
<td>• When the bin is filled, seal any holes.</td>
</tr>
<tr>
<td>• Check the roof for leaks.</td>
</tr>
<tr>
<td>• Do not seal roof aeration exhaust of inlet vents except during fumigation.</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
</tr>
<tr>
<td>• Sanitation is very important.</td>
</tr>
<tr>
<td>• Do not mix new and old grain.</td>
</tr>
<tr>
<td>• Clean up spills outside the bin.</td>
</tr>
<tr>
<td>• Keep the area (10 feet) from around the bin free of vegetation and trash.</td>
</tr>
<tr>
<td>• Clean the bin wall, ceiling, ledges, floors, sills prior to filling with new grain.</td>
</tr>
<tr>
<td>• Insure proper aeration management.</td>
</tr>
<tr>
<td><strong>Pesticides</strong></td>
</tr>
<tr>
<td>• Consider an insecticide treatment after cleanup and two weeks prior to filling.</td>
</tr>
<tr>
<td>• Insure insecticidal treatments are targeted to susceptible stages of the pest.</td>
</tr>
<tr>
<td>• Use preventative applications where of a history of problem exists.</td>
</tr>
<tr>
<td>• Try to choose options that promote applicator safety and pose the least environmental risk.</td>
</tr>
<tr>
<td>• Following labeled instructions is critical when using rodent baiting stations outside the bin.</td>
</tr>
</tbody>
</table>
Table 42.2. Steps to follow when monitoring grain.

1. Climb up the grain bin, open the door, and smell exhaust air as someone turns the fan on. If the air smells musty, there may be a problem.
2. Check the temperature at several locations on the top of the grain. If the temperatures are different, collect a sample and have it tested for moisture and inspected for pests.
3. Run the unloading auger. Check the grain for moisture and inspect for pests.
4. Periodically monitor the grain mass. Monitoring can be conducted through the side access panel. This is conducted using plastic tube traps, probe traps, and sticky pheromone traps. These traps are inserted for a period of time and then retrieved.
5. Collect and inspect grain samples for temperature and pests. Equipment needed for grain sampling includes a deep bin compartment probe, deepcup probe, vials, and temperature probe. The deepcup grain probe is a brass or plastic cup about 8 to 12 inches long. A handle and extension rod allows for the probe to be pushed into the grain. This is accomplished by standing on the grain surface and pushing the probe into the grain mass at a slight angle. Collect samples from representative areas in the bin. Check the temperature of the sample and inspect the sample for insects. It may be necessary to use a magnifying glass to see small insects. For assistance contact an expert at http://igrow.org/about/our-experts/ When inside the bin, follow safety protocols (Table 42.3).

Figure 42.1. Grain bins need to be inspected regularly for pests.

Table 42.3. Follow safety protocols.

It is important to be aware of the potential hazards of sampling inside a grain bin. Suffocation can occur in grain bins, and sampling should be done with caution. Bridged grain, resulting in a cave-in and subsequent worker suffocation, is a serious problem. Bridged grain is caused when grain mats together forming a false floor. Where possible:

1. Break up crusted grain with a long pole.
2. Wear a harness attached to properly secured rope when entering a grain bin.
3. Stay near the outer wall of the bin and keep walking if the grain starts to flow. Get to the bin ladder as quickly as possible.
4. Have another person outside the bin in case there is a problem.
For fall harvested grain it should be safe until May or June without insecticide treatment. If you plan to store the grain after May or June a labeled grain protectant treatment is recommended. Grain protectants kill insects as they crawl on or feed on grain and grain fragments. These products generally are applied as the grain is being augured into the bin. The moisture of the grain is critical in preventing stored grain problems. A rule of thumb is that for long-term storage the moisture content should be less than 12% moisture.

Maintaining aeration

Proper aeration of the grain will help to maintain uniform temperatures and will prevent moisture buildup and mold growth. Mold will affect grain quality and can serve as an alternative food source for some grain insect pests. Be sure to level off the grain in the bin once it has been filled. This will improve air movement by preventing air flow along the bin walls. If the grain is not level, grain in the peak can become moist, moldy and heated, providing a good area for insect outbreaks to occur.

Chemical management

Applicator safety should be a primary consideration when considering pesticide treatment options (Table 42.4). It is very important to remember that pesticides are poisonous. Be sure to read and follow label directions. Handle all pesticides carefully and store in original labeled containers out of the reach of children, pets, and livestock. Dispose of empty containers right away following recommended procedures.

If bin fumigation is required, remember these products are highly toxic and restricted use. Extensive technical knowledge and special applicator certification is required for their legal use. Never fumigate alone. Always have at least two trained people when using fumigates. Follow all safety regulations and precautions for fumigating application. Chemical treatment options are provided below (Tables 42.5, 42.6, 42.7).
Table 42.5. Insecticides labeled for empty grain bin treatments intended to be applied four to six weeks before grain enters storage.

<table>
<thead>
<tr>
<th>Insecticide*</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tempo® SC Ultra</td>
<td>May not fully protect grain against weevils.</td>
</tr>
<tr>
<td>(beta-cyfluthrin)</td>
<td></td>
</tr>
<tr>
<td>Storcide® II</td>
<td>Bin and warehouse applications should only be applied from outside with a downward spray. All openings, except for the point of application must be closed during applications. This product may only be applied to empty grain bins using automated spray equipment.</td>
</tr>
<tr>
<td>(deltamethrin + chlormethylfos)</td>
<td></td>
</tr>
<tr>
<td>Suspend® SC</td>
<td>Do not allow dripping or run-off to occur.</td>
</tr>
<tr>
<td>(deltamethrin)</td>
<td></td>
</tr>
<tr>
<td>6% Malathion dust, Malathion 5EC or 57EC, others exist</td>
<td>Select a product specifically labeled for treating grain storage facilities.</td>
</tr>
<tr>
<td>Diacon-D® and Diacon II® (S-methoprene)</td>
<td>Insect growth regulator that only affects immature life stages.</td>
</tr>
<tr>
<td>Dryacide® and Insecto (silicon dioxide)</td>
<td>Select a product specifically labeled for treating grain storage facilities.</td>
</tr>
</tbody>
</table>

*Mention of a trade name neither constitutes endorsement of the products mentioned nor criticism of similar ones not used or mentioned.

Table 42.6. Common protectants applied to grain stored longer than 12 months; applications should be made to clean, dry grain.

<table>
<thead>
<tr>
<th>Insecticide* (active ingredient)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipel® DF or ES (Bacillus thuringiensis kurstaki)</td>
<td>Labeled for all crops. Will only control moth larvae, such as the Indian meal moth. Slow to kill existing infestations. Some Indian meal moth populations may be resistant to Dipel®.</td>
</tr>
<tr>
<td>Storcide® II (deltamethrin + chlormethylfos)</td>
<td>Labeled crops include wheat, barley, oats, sorghum and rice. Product effective against a broad spectrum of insects.</td>
</tr>
<tr>
<td>Diacon-D® and Diacon II® (S-methoprene)</td>
<td>Labeled crops include barley, corn, grain sorghum, oats, peanuts, and wheat. Insect growth regulator that only affects immature life stages. Dilute DIACON II® with water or FDA-approved food grade oils and apply to the moving grain stream as a coarse spray.</td>
</tr>
<tr>
<td>Dryacide® and Insecto (silicon dioxide)</td>
<td>Labeled for all crops.</td>
</tr>
</tbody>
</table>

*Mention of a trade name neither constitutes endorsement of the products mentioned nor criticism of similar ones not used or mentioned.
Table 42.7. Top dressing insecticides for stored grain pests.

<table>
<thead>
<tr>
<th>Insecticide* (active ingredient)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipel®DF or ES (Bacillus thuringiensis kurstaki)</td>
<td>Labeled for all crops, including soybeans. Mix into the top four inches of grain surface. Will only control moth larvae, such as the Indian meal moth. Slow to kill existing infestations. Some Indian meal moth populations may be resistant to Dipel®.</td>
</tr>
<tr>
<td>Diacon-D® and Diacon II® (S-methoprene)</td>
<td>Labeled crops include barley, corn, grain sorghum, oats, peanuts, rice and wheat. Insect growth regulator that only affects immature life stages.</td>
</tr>
<tr>
<td>Dryacide® and Insecto (silicon dioxide)</td>
<td>Labeled for all crops. Some products carry instructions on use as top dressing treatments either alone or in combination with treatment of rest of the grain mass.</td>
</tr>
</tbody>
</table>

*Mention of a trade name neither constitutes endorsement of the products mentioned nor criticism of similar ones not used or mentioned.

Fumigation

A rescue treatment may be required to effectively control or eliminate some insect pests and to safeguard grain quality. In these instances, fumigation should be conducted by trained, experienced, registered pesticide applicators using the required safety gear. When insects are higher than the suggested thresholds, fumigation is suggested. The toxic gases will penetrate into cracks, crevices, grain in the bin. The goal is to maintain a toxic concentration of gas long enough to kill the insect population. Fumigants do not provide residual protection. There are several types and formulations of fumigates available. The common products include methyl bromide and phosphine producing materials such as magnesium phosphide and aluminum phosphide. Always remember to read and follow all label instructions.

Common stored grain insects

There are a variety of insects that can be found in stored grain. These can include the Indian meal moth, red flour beetle, confused flour beetle, flat grain beetle, sawtoothed grain beetle, lesser grain borer, rice weevil, granary weevil, and meal worm. Of these, one of the most common pests is the Indian meal moth (Figs. 42.2 and 42.3).

Left: Figure 42.2. Indian meal moth adult. (Photo courtesy of Mark Dreiling, Bugwood.org)
Right: Figure 42.3. Indian meal moth larva. (Photo courtesy of Whitney Cranshaw, Colorado State University, Bugwood.org)
Indian meal moth adults can be distinguished from other stored grain moths by the reddish-brown color and copper luster on the outer two-thirds of their wings. The remainder of the wing is whitish-gray and will have a wing span of about ¾ inch. The fully grown larvae are about ½ inch long and have a dirty white color. However, these moths can have a greenish to pinkish tint depending on diet. Young larvae are difficult to detect. Heavy infestations can completely web over the grain surface, which protects the young larvae and can make insecticide applications difficult.

The most favorable temperature for Indian meal moths is about 80°F, but they can become active when the grain or air temperature reaches 60°F. Check insecticide labels for the types of grain products treatments can be used. Soybeans are only approved on a few product labels. Malathion is no longer effective against most populations of Indian meal moth. Using dichlorvos resin strips can be affective for the control of adult moths. We recommend that one strip be suspended over the grain per 1,000 ft² of overhead bin space. To protect against Indian meal moth infestations, rake in applications of Bt on the grain surface. Diatomaceous earth would be an example of an approved treatment for organic production. These applications can also be done as the bin is filled and the grain is leveled, or apply by May of the following year.

References and additional information

Peairs, F.B. Rev. 2010. Insect damage to farm-stored grain. Factsheet No. 5.545. Colorado State University Extension, Fort Collins, CO. Available at http://www.ext.colostate.edu


Acknowledgements
Support was provided by USDA through the NIFA/IPM program.

Effective soybean marketing begins with understanding the fundamentals of the world and local soybean market complex. Being familiar with demand-users and sources of supply from both a world and local level can better enable a producer to anticipate changes in futures and local cash market prices. The value of a commodity is based upon its value to the end-user at a specific time and place and of certain quality.

This chapter is broken down into a discussion on world and local soybean supply/demand and logistics, United States grading, South Dakota historical price indexes, various marketing strategies to provide background for developing a marketing plan, and concludes with discussing the steps of developing a marketing plan. Table 43.1 provides a list of successful tips for marketing soybeans.
Historical Supply & Demand (World, United States, and South Dakota)

Major world suppliers of soybeans include the United States, Brazil, and Argentina. In the United States, the top soybean producing states have included Iowa, Illinois, and Minnesota (2008-2012, NASS). From 2008-2011, South Dakota has ranked 8th in the top producing states in the United States, while in 2012 South Dakota production is expected to be ranked 10th. The major importer of world soybeans is China.

**Historical supply**

World soybean production averaged 8.8 billion bushels in 2007-2012 (WASDE). The average distribution in the share of soybean production in the world can be seen in Figure 43.1. The major soybean producers of the world are the United States, Brazil, and Argentina comprising 82% of the average soybean production supply over the last five years. They have also accounted for 89% of the world exports, while Paraguay, Canada, and Uruguay collectively comprise 10% of world exports in the last five years.

**Table 43.1. Keys to successful soybean marketing.**

1. Understand your local and international markets.
   a. Produce soybeans that meet these markets.
   b. Understand transport costs to these markets.
2. Calculate net returns that include dockage.
3. Sell your soybeans at an appropriate time.
   a. Selling soybeans that are non-insurance covered soybeans contains risk.
   b. It is very difficult to time markets.
4. Develop a market plan.
   a. Calculate insurance covered soybeans.
   b. Estimate your yield.
   c. Calculate your cost of production and cash flow needs.
   d. Estimate selling price expected ranges.
   e. Develop a selling plan based on production costs and expected selling prices.

**Figure 43.1. World soybean production (2007-2011).** (Data Source: USDA, FAS. Production, Supply and Distribution, http://www.fas.usda.gov/esrquery/esrq.aspx)
United States soybean production has averaged 3.1 billion bushels in the last five years (USDA-WASDE, 2012). South Dakota has contributed approximately 5% of the total U.S. production (NASS; WASDE). Figure 43.2 shows where the soybean production is concentrated in South Dakota. In the last five years, South Dakota has averaged 4.2 million acres of harvested soybeans compared to an average of 4.7 million acres of harvested corn. Over the last five years, South Dakota averaged a soybean yield of 36 bushels per acre, while the U.S. soybean yield averaged 41 bushels per acre.

![Figure 43.2. South Dakota regional soybean production (2007-2011). (Source: USDA-NASS)](image)

**Historical demand**

In 2011-2012, China comprised 64% of the total world imports (USDA-WASDE, 2012). During this time, the EU-27 made up 12% of the world imports, followed by Mexico and Japan, comprising 3% and 4% respectively. Together China, EU-27, Japan, and Mexico comprised 83% of total world imports. U.S. soybeans are predominately exported (57%) to China (FAS, Export sales query). Collectively, Mexico, EU-27, Japan, Indonesia, Taiwan, and Egypt import 33% of U.S. soybeans (Fig. 43.3).

![U.S. Soybean Exports (2008-2012 Average)](image)

**Figure 43.3. U.S. soybean exports (2008-2012). (Data Source- USDA, FAS. Export Sales Query [http://www.fas.usda.gov/esrquery/esrq.aspx])**
In 2006, according to Qasmi et al. (2010), 77% of South Dakota soybeans were handled by elevators (Fig. 43.4) and 88% of the elevator soybeans were sold to terminals and processors. Most of the soybeans sold to elevators are shipped out of the state, with 47% being shipped to the Pacific Northwest (Fig. 43.5). Foreign buyers, feed mills, Minneapolis markets, and others make up the remaining 12%.

![South Dakota Elevator Buyer Types (2006)](image)

**Figure 43.4. South Dakota soybean buyers (2006).** (Source: Qasmi et al., 2010)

According to the survey results, the majority of soybeans handled by elevators are sold for export, with 47% going to the Pacific Northwest (PNW), while 35% are sold in the South Dakota area. South Dakota elevators sell 8% of their soybeans to the Minneapolis area.

![South Dakota Elevator Soybean Shipments (2005)](image)

**Figure 43.5. South Dakota elevator soybean shipments (2005).** (Modified from Qasmi et al., 2010)

**Soybean utilization**

USDA World Agricultural Supply and Demand Estimate (USDA-WASDE, 2012) Reports over the past five years (2007-2011) estimated 54% of the U.S. total usage has been comprised of crushing soybeans, while exports comprised 43% of usage. Feed-to-total-usage averaged 4%. Comparing five-year averages to ten-year averages, crushing-to-total-usage decreased by 2% and feed to usage decreased by 1%, while exports increased by 4%.
Soybeans are primarily processed to produce crude soy oil and soybean meal. The soybean is comprised of about 18% oil and 35% protein. Soybean oil is used in foods and for industrial purposes, including biodiesel. Soybean meal is used in animal feeding of livestock, poultry, and dairy.

The structure of the soybean industry is shown in Figure 43.6. From 2007-2010, soybean oil domestic usage averaged 85% of production, while export usage averaged 15%. Biodiesel comprised 12% of total domestic usage (USDA-ERS, 2011a, 2011b, 2012a, 2012b). Soybean crude oil price at Decatur averaged 41 cents per pound from 2005-2010, a 37% increase from a ten year average. From 2006-2010, soybean meal domestic usage averaged 77% of production, while export usage averaged 23%. Soybean meal (48% protein) price at Decatur averaged 306 cents per ton from 2006-2010, a 23% increase from a ten-year average. Local soybean processors are provided in Table 43.2.

Figure 43.6. Structure of the U.S. soybean industry. (Source: USDA-WASDE, 2012; U.S. Census Bureau, 2010)
Table 43.2. Regional soybean processors.

<table>
<thead>
<tr>
<th>Process or Name</th>
<th>Location</th>
<th>Website/Email Address</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>South Dakota</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Soybean Discount Schedule- <a href="http://www.sdsbp.com/documents/DISCOUNT_SCHEDULE.pdf">http://www.sdsbp.com/documents/DISCOUNT_SCHEDULE.pdf</a> Email- <a href="mailto:postmaster@sdsbp.com">postmaster@sdsbp.com</a></td>
</tr>
<tr>
<td><strong>Minnesota</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(320) 769-4396</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Box 100 Brewster, MN 56119</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(888) 842-6677 or (507) 842-6677</td>
<td></td>
</tr>
<tr>
<td><strong>Iowa</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2753 Port Neal Rd, Sergeant Bluff, IA51054 (712) 943-4291</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sheldon, IA (65 mi. from Sioux Falls)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>804 2nd Sheldon, IA 51201</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(712) 324-2531</td>
<td></td>
</tr>
<tr>
<td></td>
<td>980 Clark Street Sioux City, IA51101</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(712) 279-1200 or 800-428-8527</td>
<td></td>
</tr>
<tr>
<td><strong>Nebraska</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coleridge Grain</td>
<td>Coleridge, NE (53 mi. from N. Sioux City)</td>
<td>Website- <a href="http://www.soybest.com/about/">http://www.soybest.com/about/</a></td>
</tr>
<tr>
<td></td>
<td>101 E Cedar Street Coleridge, NE 68727</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(402) 283-4247</td>
<td></td>
</tr>
<tr>
<td>Grain States Soya, Inc.</td>
<td>West Point, NE (68 mi. from N. Sioux City)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>400 Johnson Road, P.O. Box 157</td>
<td></td>
</tr>
<tr>
<td></td>
<td>West Point, NE 68788 (402) 372-2429 or (800) 422-4697</td>
<td></td>
</tr>
</tbody>
</table>
Logistics and transportation costs

Besides local processing and by-product demand, export demand is a critical component in the soybean selling price. For South Dakota to be competitive in the world market the cost of importing soybeans must be competitively priced. Differences between South Dakota and Brazil are also related to different production timelines and shipping costs. Harvest in Brazil typically occurs in March while harvest in South Dakota occurs in October. South Dakota soybeans can be shipped from the state to an export terminal by truck, rail, and river.

The costs of shipping soybean from various locations in North Dakota, South Dakota, Iowa, and Minnesota to China are examined below (Fig. 43.7). The U.S. location will be compared with exporting soybeans from Mato Grosso though the Port Santos and from Goiás through the Port Paranaguá (Fig. 43.8).

In Figure 43.8, Mato Grosso is identified by a yellow circle around “MT” with the associated Port de Santos shown with a yellow dot. Goiás is shown by a red circle around “GO” with the associated Port de Paranaguá shown with a red dot. Comparing U.S. destinations, soybeans exported through the PNW have a higher transportation cost than soybeans exported through the Gulf.

Comparing U.S. to Brazil originated soybeans, Brazil’s higher transportations costs is due to higher trucking costs to get soybeans to the port and an ocean freight costs to transport the soybeans to China (Fig. 43.7).

For these locations, the lowest cost soybeans for China would be the Goiás-South Brazil, followed respectively by Iowa (Gulf), North Dakota (PNW), Minnesota (Gulf), South Dakota (PNW), and Mato Grosso-Brazil North. On average, U.S. soybean producers receive approximately 14% more value at the farm gate than South American producers. U.S. producers whose soybeans are exported through the Gulf of Mexico receive about 2% more than producers whose soybeans are exported through the Pacific Northwest (PNW).
The changes in U.S. and Brazil soybean costs to Shanghai, China, from 2011 to 2012 are shown in Figure 43.9. Many factors influence the overall cost of soybean transport to China. These factors include the farm value and collective transportation costs to the final destination. Transportation costs vary over time and are a function of fuel, labor, rail car and barge availability, and port fees. Transportation costs also change due to infrastructure investments.

Figure 43.9 shows the change in overall costs to China in green. The overall change in cost to China can be segregated into the changes in farm value (shown in blue) and transportation costs (shown in red). Transportation costs of U.S. soybeans exported through the Gulf have decreased 10%, mainly due to lower costs of using the river barge system. Transportation costs remain nearly unchanged for U.S. soybeans exported through the PNW. This is due to the decrease in ocean freight costs that has been nearly offset from an increase in rail and trucking costs. The lower transportation costs for Brazil from 2011 to 2012 are attributed to reduced trucking costs.
Delivery

The Grain Inspection, Packer & Stockyard Administration of the USDA develops the quality standards for soybean grades. These standards include minimum test weight and maximum percentage limits of damaged grains and maximum percentage limits of foreign matter. The USDA soybean grading standards can be seen in Table 43.3.

Figure 43.9. Changes in soybean transportation costs to China. (Source: USDA-AMS, 2012)
Quality standards include moisture, test weight, heat damage, total damage, and foreign material. By knowing the quality levels, producers can compare the processor and elevator discounts and premium schedules. First, the cash bids of the various outlets can be compared and the discounts/premiums can be calculated. It is important to understand that buyers have different discount schedules for different quality standards. For example, some buyers have higher discount rates for moisture levels while another buyer may have higher dockages for heat damage. If producers are producing higher protein and oil content soybeans, they should investigate if a premium schedule for quality is available.

Consider this: the highest cash bid minus any transportation/labor costs may not always provide the highest net price available. The example shown in Problem 43.1 shows how Buyer A has a cash bid of $15.00, while Buyer B has a cash bid of $14.80. This example assumes that transportation costs to both Buyer A and Buyer B would be equal. Without taking into account the buyers’ discount schedule, Buyer A looks like the best option; however, further examination shows that based on quality discounts, Buyer B has the highest net price.
Delivery contract specifications – Chicago Mercantile Exchange (CME)

On soybean futures, the CME provides specification in contract size and deliverable grade. The contract size is 5,000 bushels and the deliverable grade is #2 Yellow at contract price, #1 Yellow at 6 cent/bushel premium, and #3 Yellow at a 6 cent/bushel discount. The CME Globex (Electronic Platform) is open 5:00 p.m. through 2:00 p.m. from Sunday through Friday (Central Standard Time). Open outcry (trading floor) is open from 9:30 a.m. to 2:00 p.m. Monday through Friday. However, for major USDA crop reports, such as the WASDE, open outcry starts at 7:20 a.m. Currently, soybean daily price limits are at $0.70 per bushel, but can be expandable if the market closes at the limit bid or offer.

Historical and Forecasted Prices

South Dakota historical prices

Figure 43.10 provides monthly prices received by South Dakota producers from January 1997 through October 2012. Price peaks were seen in May 1997 ($8.13/bu), May 2004 ($9.61/bu), June 2008 ($12.90/bu), May/June 2011 ($12.90/bu), and August 2012 ($16.00/bu). Lows between these price peaks were observed in July 2000 ($3.95/bu), September 2006 ($4.95/bu), March 2009 ($8.90/bu), and December 2011 ($11.10/bu).
Table 43.4 shows that soybean prices have large seasonal variability. Seasonality is related to the production cycle of a commodity, which influences the supply and demand levels. Typically, it would be expected that prices would be lowest during the harvest months (September and October) when usable supplies become abundant. Prices would be expected to increase as supplies are drawn down (November through January) and producer selling slows. Then prices would increase at a slower rate or level off during (February through June) as southern hemisphere harvest begins (e.g., Brazil and Argentina) and export demand shifts to the more available supplies in the southern hemisphere.

It is expected that prices would increase once again when inventories are at the lowest levels, before new crop supplies are realized (July and August). The last two columns of Table 43.4 shows the 10-year and 5-year average seasonal prices. The ten-year average shows the lowest price in September and October and increases each month after until a decrease is shown from July to August. The five-year average shows the lowest prices in September and October and increases each month after.

**Table 43.4. South Dakota seasonal average soybean prices, 2002-2011.**
(Source: USDA-NASS, 2012)

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Sep</td>
<td>5.12</td>
<td>5.83</td>
<td>5.73</td>
<td>5.51</td>
<td>4.95</td>
<td>7.70</td>
<td>10.50</td>
<td>9.16</td>
<td>9.64</td>
<td>11.50</td>
<td>7.56</td>
<td>9.70</td>
</tr>
<tr>
<td>Nov</td>
<td>5.18</td>
<td>6.95</td>
<td>5.21</td>
<td>5.40</td>
<td>5.79</td>
<td>8.74</td>
<td>9.14</td>
<td>9.22</td>
<td>10.60</td>
<td>11.50</td>
<td>7.77</td>
<td>9.84</td>
</tr>
<tr>
<td>Dec</td>
<td>5.31</td>
<td>7.04</td>
<td>5.28</td>
<td>5.51</td>
<td>5.98</td>
<td>9.73</td>
<td>8.87</td>
<td>9.46</td>
<td>11.10</td>
<td>11.10</td>
<td>7.94</td>
<td>10.05</td>
</tr>
<tr>
<td>Jan</td>
<td>5.33</td>
<td>7.37</td>
<td>5.34</td>
<td>5.50</td>
<td>6.12</td>
<td>9.48</td>
<td>9.60</td>
<td>9.15</td>
<td>11.30</td>
<td>11.60</td>
<td>8.08</td>
<td>10.23</td>
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<tr>
<td>Feb</td>
<td>5.41</td>
<td>8.08</td>
<td>5.44</td>
<td>5.36</td>
<td>6.57</td>
<td>10.60</td>
<td>9.37</td>
<td>9.22</td>
<td>12.60</td>
<td>12.00</td>
<td>8.47</td>
<td>10.76</td>
</tr>
<tr>
<td>Mar</td>
<td>5.48</td>
<td>9.14</td>
<td>5.83</td>
<td>5.29</td>
<td>6.57</td>
<td>11.20</td>
<td>8.90</td>
<td>9.00</td>
<td>12.50</td>
<td>12.80</td>
<td>8.67</td>
<td>10.88</td>
</tr>
<tr>
<td>Apr</td>
<td>5.66</td>
<td>9.54</td>
<td>6.00</td>
<td>5.26</td>
<td>6.69</td>
<td>11.70</td>
<td>9.37</td>
<td>9.18</td>
<td>12.70</td>
<td>13.70</td>
<td>8.98</td>
<td>11.33</td>
</tr>
<tr>
<td>Jun</td>
<td>5.95</td>
<td>9.12</td>
<td>6.47</td>
<td>5.38</td>
<td>7.09</td>
<td>12.50</td>
<td>10.50</td>
<td>9.03</td>
<td>12.90</td>
<td>13.50</td>
<td>9.24</td>
<td>11.69</td>
</tr>
<tr>
<td>Aug</td>
<td>5.40</td>
<td>6.35</td>
<td>5.87</td>
<td>5.04</td>
<td>7.30</td>
<td>12.60</td>
<td>10.30</td>
<td>9.59</td>
<td>13.00</td>
<td>16.00</td>
<td>9.15</td>
<td>12.30</td>
</tr>
<tr>
<td>Avg.</td>
<td>5.45</td>
<td>7.80</td>
<td>5.75</td>
<td>5.38</td>
<td>6.34</td>
<td>10.61</td>
<td>9.77</td>
<td>9.21</td>
<td>11.83</td>
<td>12.78</td>
<td>8.49</td>
<td>10.84</td>
</tr>
<tr>
<td>Low</td>
<td>5.02</td>
<td>5.83</td>
<td>5.21</td>
<td>5.04</td>
<td>4.95</td>
<td>7.70</td>
<td>8.87</td>
<td>9.00</td>
<td>9.64</td>
<td>11.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>5.95</td>
<td>9.61</td>
<td>6.47</td>
<td>5.51</td>
<td>7.30</td>
<td>12.90</td>
<td>10.50</td>
<td>9.59</td>
<td>13.00</td>
<td>16.00</td>
<td></td>
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</tr>
</tbody>
</table>

Seasonal price indexes the movement of monthly prices around the average annual price. The average annual prices were given an index value of 100, while monthly indices where a percentage of the annual averages. Monthly index values were calculated for each year, and then averaged over a ten- and five-year period. Table 43.4 shows a ten-year (2002-2011) and five-year (2007-2011) seasonal index.
The ten-year and five-year price indices show a similar pattern for South Dakota from September through June, with October being the seasonal low and increasing through June. The five-year average index (2007-2011) deviates from the ten-year average (2002-2011), by increasing from June through August; while, the ten-year average index shows a decrease in prices. This deviation could be due to ending stocks in the five-year average being 28% less than the ten-year average, resulting in tighter supplies until the new crop supplies start to be realized. The five-year index shows that highs are generally observed in August, while the ten-year index shows the seasonal highs generally occur in July. Both indices show that seasonal lows generally occur in September.

Figure 43.11 shows the standard deviation around the ten-year average (2002-2011) seasonal index. The standard deviation shows the consistency in the seasonal pattern. The outer lines in Figure 43.12 show one standard deviation above (blue) and below (green) the seasonal index values. This range indicates where prices are expected in two out of three years. The greatest uncertainty in price in relationship to the ten-year average occurs in August, September, and October when total production is determined by weather and production information from USDA-WASDE and USDA-NASS. December, January and February is when there is historically less price uncertainty, since supply and demand fundamentals in the U.S. are fairly well known. Understanding the seasonal trends and price risk associated with certain months can be used to help develop a marketing plan.
Forecasted prices

Prices are based on three values: demand, supply, and carry over. Estimated world supply and demand are provided monthly by the USDA-World Agricultural Outlook Board (WASDE). To see current and historical WASDE reports, visit the WASDE website at http://www.usda.gov/oce/commodity/wasde/.

Many firms try to project future prices, including marketing firms and university institutions. One example of a university institution that forecasts commodity prices is the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri. In early March, FAPRI releases their baseline projections for the marketing year. The FAPRI U.S. Baseline Briefing Book includes a ten-year baseline projection for U.S. agricultural commodities. The baseline projection is developed by considering 500 alternative outcomes based on different assumptions about weather, oil, GDP growth, and other crucial factors that influence supply and demand and price for commodities. It is important to understand that actual market prices can vary from the projected average prices.

The USDA-Economic Research Service (ERS) also publishes agricultural prices projections through 2021. USDA-ERS developed its projections by making specific assumptions regarding the macroeconomic indicators, agricultural policy, weather, and international factors. This is a different procedure than FAPRI. USDA-ERS and FAPRI can produce very different price projections (Table 43.5). These price estimates are released at different times, with FAPRI being released in August, while ERS projections being released in February.

Table 43.5. FAPRI and USDA-ERS projected U.S. soybean prices 2012-2018. (Data Source: FAPRI & USDA, ERS Projections)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>FAPRI</td>
<td>16.27</td>
<td>11.28</td>
<td>11.05</td>
<td>11.26</td>
<td>11.41</td>
<td>11.57</td>
</tr>
<tr>
<td>USDA-ERS</td>
<td>11.00</td>
<td>10.30</td>
<td>10.55</td>
<td>10.70</td>
<td>10.80</td>
<td>10.90</td>
</tr>
</tbody>
</table>

Developing a Marketing Plan

Step 1: Estimate the quantity of crop to be produced.

The grain marketing plan starts with the crop production plan. Estimate the acres and yield of soybeans to be produced. Consider purchasing crop insurance. The crop insurance reduces the financial risk of selling your crop ahead of harvest. You will want to take into account the level of coverage that you will have on your crop. Use the production plan and crop insurance plan to determine insurance covered bushels and uncovered bushels. Further information on insuring soybeans can be found in Chapter 46.
Problem 43.2. Determine the amount of covered vs. uncovered soybeans for a revenue protection plan (RP).

- 1,000 acres of soybeans
- Expected yield: 50 bushels per acre
  - Based on estimated yields (Chapter 41)
  - Total projected production: 50,000 bushels
- Actual Production History (APH) = 40 bushels per acre
- APH bushels: 40,000 bushels
- Insurance coverage level 75% Revenue Protection (RP)

Crop insurance covered bushels:

\[
1,000 \text{ acres} \times 40 \text{ bushels per acre} \times 75\% \text{ RP} = 30,000 \text{ bushels}
\]

At a $10/bu selling price

\[
30,000 \text{ bushels} \times \$10/\text{bushels} = \$300,000
\]

If you harvest 20,000 bushels then,

- $200,000 is provided by the market and $100,000 is provided by insurance
- Coverage allows covered bushels may be more aggressively priced than uncovered soybeans.

Uncovered bushels:

\[
50,000 - 30,000 = 20,000 \text{ bushels}
\]

Marketing these bushels prior to harvest contains risks because soybeans are not covered.

Step 2: Estimate cost of production and cash flow needs.

Develop a new crop budget for your soybean crop. Use total cost of production including overhead allocated to the soybean crop (Chapter 56). The cost of production estimate may be used to establish prices required to meet your target profit or return on investment goals.

The cash flow requirements are different than profit. The farm’s cash flow needs may be greater or less than the total costs of production depending on the financial and ownership position of the farm. Establish prices needed to meet cash flow needs.

Step 3: Evaluate expected average price range.

Use FAPRI, USDA-WASDE, or a private marketing service to arrive at the price outlook for the marketing year. Futures contract price charts may be used to establish price ranges. Soybean futures prices can be seen at the Chicago Mercantile Exchange (CME) website.

http://www.cmegroup.com/trading/agricultural/

When developing an expected price range, historical seasonal and basis patterns should be incorporated. South Dakota basis information can be found on the igrow.org website. The information at igrow.org provides basis information for regions of South Dakota that includes current basis levels, along with past year levels, and a five-year average. This information is updated weekly on igrow.org.

http://igrow.org/agronomy/profit-tips/

To monitor day-to-day basis changes in a local area, private websites, such as Agweb, list basis below the current futures prices on the front page of the website. You can obtain the past day’s cash bids for a local area according to the zip code entered. Throughout the year as supply and demand fundamentals change, you should adjust their expected price objective.

http://www.agweb.com/
The National Agricultural Statistics Service (NASS) of the USDA releases reports throughout the year that include: Acreage, Crop Production, Grain Stocks, and Crop Progress & Condition. The reports can be found at the NASS website. In addition, NASS has reports covering the livestock sector. Also, export figures can be monitored by accessing the Foreign Agricultural Service (FAS) of the USDA's website.
http://www.nass.usda.gov/Publications/
http://www.fas.usda.gov/data.asp

Step 4: Create a price protection and selling plan.

Using the cost of production (Chapter 56) the cash flow needs, and price outlook can be estimated. In this planning use realistic objective measures (achievable with good likelihood) to write your selling plan (price, amount of production to be sold, time of execution (i.e., November, March, May) and determine return on investment goals. By setting price and target date objectives some of the emotion can be removed from the crop selling process. Once you have determined the necessary cash needs and return on investment goals, determine where your future marketing risk exists and how much risk you’re willing to bear. To determine the future marketing risk, make notes of your own and other forecasters’ estimates for price projections (averages and ranges) from Step 3. Extrapolate what you believe the price risks will be in the future given current market prices, and determine how confident you are in your projections.

1. Do you believe futures price is likely to increase, decrease, or remain in the same range?
2. Do you believe basis will narrow, widen, or remain average to futures price?
3. Determine the amount of risk you’re willing to bear to meet your return on investment goal. For example, does the current market price meet your return on investment goals (Y/N)? If not, how likely is it that prices will reach a level that would?
4. If the current price meets your goal, do you want to eliminate all risks or carry some upside risk in the event that prices do increase?
5. Once you have established your potential risk and what risk you’re willing to bear, then you can choose the optimal pricing tool and marketing strategy.

There are numerous combinations that can be employed to manage risk. Identifying the optimal strategy or tool is determine your risk. It is important to note that doing nothing is also a strategy, typically assuming higher risk. Lowering your risk is removing adverse movements in the value of the product that you have in inventory or that you are or will be producing in the future. Table 43.6 outlines possible market forecasts for futures and basis levels, willingness to bear risk (risk-taker vs. risk adverse), and possible marketing strategies and tools. Table 43.6 does not represent an exhaustive list, just an illustration that all possible market scenarios have a corresponding marketing strategy and tools given a producer's willingness to bear risk in managing return on investment.

Multiple marketing tools exist to remove risk. Examples include: cash sales, minimum price contracts, forward hedging, basis contracts, option strategies (puts and calls, straddles, strangles, delta spreading), hedge to arrive contracts (HTA), price later contracting, etc. A cash sale, or spot market contracting, is maintaining ownership in the product until a transfer is made at the prevailing market price of that specific day minus storage fees if the product was stored in commercial or rented facilities. Minimum price contracts are contracts that lock in a basis bid for a specific quantity, delivery period, and minimum price that can be achieved at that time. Minimum price contracting is essentially the same as locking in basis and buying a put option.

Hedge-to-arrive (HTA) contracts, or hedging, is selling a futures contract in a specific month of delivery for a specific quantity and price, basis is not determined until at delivery however. A forward
contract is the same as an HTA, but you also lock in basis. Price later contracting is giving the rights to ownership of the grain to the buyer, but reserving the right to determine amount of payment or price at a later date. This allows commercial storage facilities to move the product and eliminate storage costs to the seller; however the seller's rights would resemble more of a loan to the buyer. Depending on the financial soundness of the buyer to pay the loan, price later contracts may create added financial risk.

**Put options** are contracts that stipulate the owner of the option has the right to sell at a specific price (strike price) in a specific delivery period. **Call options** are contracts that stipulate the owner of the option has a right to buy at a specific price (strike price) in a specific delivery period. Owners of options (buy a call or buy a put) can choose if they want to exercise the option or allow it to expire at the specified date of expiration (Option expiration day). If the prevailing market futures price offers a more beneficial outcome for the owner of the option, then they can choose not to execute the option. If the option is more beneficial than the prevailing futures market price, then the option owner can execute the option or sell the option to someone who would use it.

As options approach the specified expiration date they lose their extrinsic value and approach the intrinsic value (time-decay). **Extrinsic value** is the premium or added cost to having an option to execute or not, over the prevailing market price (intrinsic value). **Near-the-money** or **in-the-money** are options that would likely be exercised given prevailing current futures market prices (have value on expiration date). **Out-of-the-money options would not** be exercised given current futures market prices (valueless if current prices remain the same on option expiration day). Most marketing contracts have some costs of implementing or marketing fees. Trading on your own account or through a broker will require additional money to maintain margin calls, etc.

Options can be used in a number of strategies to enhance returns on investment and remove risk. For example, producers can purchase a put option that gives them the right to sell at a specific strike price during a specific delivery period. Typically, out-of-the-money puts are purchased to reduce the risk of a decreasing futures market at a later period—meaning the current futures price exceeds the strike price of the deferred put option.

Depending on what strike price one elects, the prevailing futures market price of the day, how much volatility and uncertainty there is, and how far out the option contract is, the cost to purchase can vary. If the futures market price increases, then the put option loses value or becomes cheaper to purchase, particularly as the option reaches the date of expiration. However, if the futures market price decreases then the put options gains value. If the futures market is higher than the put option strike price on expiration date then it will retain the value of the difference between the strike price and the futures price.

More sophisticated options strategies can be utilized by producers to remove a position on a commodity in possession, but to enhance returns if the price of the commodity changes substantially, or doesn't change substantially. An example would be producers trying to capitalize on historical volatility in August through October by hedging their production (selling futures) and buying a call and buying a put at equivalent strike prices (long straddle) to enhance returns on wide (volatile) movements in price when unknown supply information is determined and incorporated in the market price.

This type of strategy allows the producer to remove all risk to the change in the price of commodity, and limit risk to the costs of the options. But using this strategy the producer can still enhance returns on investment if the futures market increases or decreases substantially from the option strike prices. In this case, the producer has taken no position on the underlying commodity, but has taken a position on volatility of that commodity.
Table 43.6. Market forecasts: futures, basis, willingness to bear risk, and marketing strategies. (Source: L. Elliott, SDSU)

<table>
<thead>
<tr>
<th>Futures Price</th>
<th>Basis Level</th>
<th>Willingness to Bear Risk</th>
<th>Marketing Tool/ Marketing Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing</td>
<td>Narrowing</td>
<td>High (Risk-Taker)</td>
<td>Store and wait for better Cash Prices</td>
</tr>
<tr>
<td>Increasing</td>
<td>Narrowing</td>
<td>Low (Risk Adverse)</td>
<td>Buy Put Options or Minimum Price Contracting</td>
</tr>
<tr>
<td>Increasing</td>
<td>Widening</td>
<td>High</td>
<td>Basis Contract or sell cash and buy a call</td>
</tr>
<tr>
<td>Increasing</td>
<td>Widening</td>
<td>Low</td>
<td>Basis Contract and buy puts</td>
</tr>
<tr>
<td>Neutral</td>
<td>Average</td>
<td>High</td>
<td>Store and wait for cash prices on high end of range, sell near the money calls (Covered Calls)</td>
</tr>
<tr>
<td>Neutral</td>
<td>Average</td>
<td>Low</td>
<td>Store and wait for cash prices on high end of range, sell out of the money calls</td>
</tr>
<tr>
<td>Decreasing</td>
<td>Narrowing</td>
<td>High</td>
<td>Store and sell near the money calls</td>
</tr>
<tr>
<td>Decreasing</td>
<td>Narrowing</td>
<td>Low</td>
<td>Store and buy puts or hedge to arrive (HTA)</td>
</tr>
<tr>
<td>Decreasing</td>
<td>Widening</td>
<td>High</td>
<td>Buy puts and do basis contract, minimum price contracting</td>
</tr>
<tr>
<td>Decreasing</td>
<td>Widening</td>
<td>Low</td>
<td>Hedge futures and basis, forward contracting, sell cash</td>
</tr>
<tr>
<td>Unknown but volatile</td>
<td>Narrowing</td>
<td>Low</td>
<td>Hedge futures, use Option Straddles and Strangles to gain a return on volatility, and store grain to capture improving cash basis</td>
</tr>
<tr>
<td>Unknown but stable</td>
<td>Narrowing</td>
<td>Low</td>
<td>Hedge futures, use Delta spreads to achieve a return on price stability, and store grain and capture improving cash basis</td>
</tr>
</tbody>
</table>

**U.S. soybean producers – usage of marketing contracts**

The percent of U.S. soybean producers that utilize some form of contracting that incorporate some of the previous discussed strategies was 34%, in 2008, according to the ERS publication by MacDonald and Korb. Contracting is defined as operations that reach agreements prior to harvest on outlet and pricing mechanism. The producers who used contracting in this context would on average contract 54% of their soybeans. However, this implies that 66% of operations did not use contracting (agreements prior to harvest).

The usage of different marketing strategies among producers who use contracts and those who do not are shown in Table 43.7. The marketing strategies of those who used contracting included using on-farm storage, farmer-owned cooperative, futures, and options strategies. About 29% of producers who use contracts use the futures exchange, while 14% use the options markets. 53% of the producers who did not use contracting (agreements prior to harvest) used the spot markets as their only marketing strategy and are not using options, future, or farmer-owned cooperatives.

<table>
<thead>
<tr>
<th></th>
<th>Options</th>
<th>Futures</th>
<th>On-farm Storage</th>
<th>Farmer-owned Cooperative</th>
<th>Spot Markets Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contract</td>
<td>13.8</td>
<td>28.5</td>
<td>63.2</td>
<td>54.8</td>
<td>0</td>
</tr>
<tr>
<td>Noncontract</td>
<td>7.1</td>
<td>9.1</td>
<td>51.1</td>
<td>43.1</td>
<td>52.6</td>
</tr>
</tbody>
</table>

*Note:* “Spot markets only” is defined as farms that do not use marketing contracts, options, futures, or farmer-owned cooperatives.

Table 43.8 shows the soybean prices received and quantities marketed through contracting. In 2008, the average contract price received for soybeans was $10.85 per bushel, while USDA/NASS mean equaled $9.97. It needs to be noted that this data only includes information for one marketing year. In addition, the NASS data is monthly, while the ARMS data is annual. The two surveys cover different grades and qualities and respondent sample differences may exist. The average amount contracted (prior harvest) was 6,580 bushels.

Table 43.8. Soybean prices and quantities in marketing contracts, 2008. (Source: USDA, ERS. Agricultural Contracting Update, Table 15)

<table>
<thead>
<tr>
<th>Item</th>
<th>Price received per unit ($/bu.)</th>
<th>Quantity marketed through contract (Bushels)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>USDA/NASS mean, all sales</td>
<td>Median</td>
</tr>
<tr>
<td></td>
<td>9.97</td>
<td>3,000</td>
</tr>
<tr>
<td></td>
<td>Contract mean</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>10.85</td>
<td>6,580</td>
</tr>
<tr>
<td></td>
<td>Contract 25th percentile</td>
<td>25th percentile</td>
</tr>
<tr>
<td></td>
<td>9.62</td>
<td>1,200</td>
</tr>
<tr>
<td></td>
<td>Contract 75th percentile</td>
<td>75th percentile</td>
</tr>
<tr>
<td></td>
<td>12.00</td>
<td>7,000</td>
</tr>
</tbody>
</table>

Use caution when comparing NASS and contract prices for the reasons described previously. As described in the ERS publication by MacDonald and Korb, Figure 43.13 shows that:

“contract prices remain above NASS prices when NASS prices are stable or falling, and they fall below them when NASS prices are rising. As NASS prices rose sharply in 2007, they also rose above contract prices; but contract prices received a premium in 2008 as NASS prices fell late in the year.” (page 28)
This may suggest that higher prices may be achieved through using marketing contracts (prior harvest) when prices are expected to decrease over a period, while non-contracting may result in higher prices received when prices are expected to increase over time. However, using a non-contracting strategy also results in producers bearing more price risk.

**Step 5: Monitor and evaluate the plan.**

The marketing plan should be monitored and evaluated through the marketing year and adjusted appropriately in accordance to changes in production, cash flow needs, and price outlook.

**Conclusion**

Successful soybean marketing involves considerable labor and analytical input.

First, know supply and demand fundamentals in both the world and local soybean market complex. You should understand your own, local, state, and national competitive advantage in the soybean market complex as it relates to export demand and domestic consumption. Also, know how the value that can be achieved at the farm gate is dependent on logistical costs and capacity.

Second, know the historical tendencies of futures prices and basis during seasonal periods and how they deviate due to changes in supply and demand fundamentals. Once these factors are better understood, a marketing plan should be developed that assesses production, quality of production, cash flow needs, ability to store, interest rates, and required labor. You should combine your own understanding of supply and demand fundamentals with other forecasters, or market participants, to determine likely average prices and ranges in the marketing year.

Third, determine what risk you are willing to bear and what marketing tools best optimizes their return on investment given their market forecast and willingness to bear risk.

Finally, marketing plans should constantly be updated and evaluated to determine if market forecasts were correct, or if there is more risk than you are willing to bear. The speed in assessing and altering a plan that was incorrect is as important as implementing the initial plan. It should be recognized producers appear to be able to reduce their risk and achieve higher returns by implementing a sounder marketing plan.
References and additional information


Acknowledgements
Support was provided by USDA and South Dakota State University.

Every year new specialty markets become available to producers. However, prior to growing soybeans for these markets, we recommend that arrangements be developed. The purpose of this chapter is to provide an overview of alternative markets and to provide contact information. Keys for identifying new soybean markets are provided in Table 44.1.

Table 44.1. Keys for alternative markets.

1. The majority of South Dakota soybeans are categorized as “commodity beans” that are primarily used for edible oil and animal feed.

2. During the crushing process, about 80% of commodity soybeans become soymeal for animal feed and 20% become soy oil.

3. Currently, food-grade soybeans are one of the most desired specialty soybeans in the U.S. 

   a. Specialty soybeans require specific shapes, protein content, oil and sugar concentrations, and other characteristics that are required for human consumption.

   b. Soybeans raised for tofu production often require higher protein (40% or higher) and lower oil concentration.

4. South Dakota soybean growers who are interested in exploring specialty soybean markets are encouraged to contact nearby processors or companies for contract opportunities.
**Soybean production and current markets**

Starting in the late 1960s, the U.S. experienced widespread, rapid soybean production growth. Today, soybeans have become one of the most important commodity crops grown in the United States. Farmers in the Midwest often rotate the cultivation of corn and soybeans to reduce pest pressure and reduce N fertilizer requirements. Soybean production has been so substantial that the U.S. is currently the world leader of soybean production. The profit generated by exporting soybeans represents a substantial income source for U.S. producers and contributes to reducing our trade balance.

The key outlets in the international market for U.S.-produced soybean products (oilseeds, oilseed meal, and soil oil) are China, the European Union (EU), Japan, Mexico, and Taiwan (USDA ERS, 2012). Although China was the first country to export soybeans, at the beginning of the 20th century, it is now one of the largest importers of soybean (World Bank, 2002). This market has continued to grow (World Watch Institute, 2012).

The majority of soybeans grown in South Dakota are categorized as “commodity beans” and are primarily used for edible oil and animal feed. During the crushing process, about 80% of commodity soybeans become soymeal for animal feed and the remaining 20% become soy oil. Even though demand for soymeal in the U.S. domestic market and the international market is growing, U.S. soymeal producers face competition from substitutes such as cornmeal, sorghum, and fishmeal—both in market share and price. In addition, other soybean exporting countries (such as Brazil and Argentina) have gradually taken a market share from U.S. soybean producers. Adding to this pressure is the fact that the U.S. market share for soy oil has weakened in recent years. Approximately 97% of soy oil after the crushing process (from the previously mentioned 20%) is used for human food consumption.

While the world demand for vegetable oil (human consumption) has increased, the profits of U.S. soy oil production are hurt by competition from other vegetable oils (palm, canola, and sunflower) and animal-based oil such as fish oil. Finally, the market share and profit potential for non-human consumption soy oil usages (from the rest of 3% soy oil after the crushing process) are promising, but relatively small.

Besides facing current domestic and international market competition, soybean producers have to consider the impact of U.S. government farm policies on profitability. Under the pressure from agreements made by the World Trade Organization (WTO), the U.S. government and its trade partners have gradually retired farmers’ protections (i.e., subsidies, price support, barriers to entry, etc.). Consequently, a number of soybean producers have explored the option of producing specialty soybeans.

**Food-grade soybeans**

Soybeans have long been recognized as a rich source of nutrition for direct human consumption in Eastern and Southeast Asia. Compared to other food sources, soybeans contain a higher percentage of protein and a more complete range of essential amino acids. In China, soybean (originally domesticated around 4,000 B.C.) was the major food (staple) for more than 2000 years (Clay, 2004). Tofu (bean curd), a popular Eastern and Southern Asian food made by coagulating soy juice, was invented in China approximately 2,000 years ago. Tofu later entered the Japan and Korea around 700 A.D. (Tengnas and Nilsson, 2002).

Currently food-grade soybeans are one of the most desired specialty soybeans in the U.S. The wide range of quality and varieties of food-grade soybeans offers soy producers opportunities to find potential niche markets. However, early efforts by the United States Department of Agriculture (USDA) in the 1960s to promote the cultivation of food-grade specialty soybeans failed to encourage more production (Lee and Herbek, 2004). On the contrary, the recent increasing demand for soybean-based food in the U.S. domestic and exporting markets has created market incentive to encourage specialty soybeans production.

The continuous improvements in breeding techniques also provide producers with numerous new varieties. In general, specialty soybeans require specific shapes, protein content, oil, sugar concentration, and other characteristics to satisfy the quality and nutrition requirements for human consumption. Although the
established varieties such as "Hawkeye", "Kanrich", and "Beeson" are good options, many private companies and public universities are constantly developing new varieties to improve soybean quality. For example, specialty soybean growers in Ohio have widely adopted varieties with high resistance to Phytophthora such as Beeson 801 and Vinton 811. Recently, Dr. Guo-Liang Jiang and others at South Dakota State University developed and released new high-protein soybean varieties such as SD-05 240, a new seed that contains 39-43% protein, 21% oil, and resistance to Phytophthora root rot.

As previously mentioned, food-grade soybeans have specific requirements for protein content, saturated fats, bean shape, sugar concentration, and size—unlike commodity soybeans where few requirements exist. For instance, soybeans raised for tofu production often require higher protein (40% or higher) and lower oil concentration. In addition, these soybean seeds usually have clear hila and a larger size (Chapter 45). Another example are soybeans used for Natto, a traditional Japanese food often served with rice (Fig. 44.1). These soybeans require a smaller size, clear hila, and higher levels of starch and sugar concentration for the sweet, sticky flavor.

Edamame soybeans, a variety of soybeans purchased and consumed by humans directly while they are still green, have large seeds, thin coats, clear hila, high sugar concentration, and (preferably) low/zero amounts of amino acids. These specialty soybeans are usually sold on contract between producers and buyers, which provide price premiums and secure markets (Lee and Herbek, 2004). A specific contract example is GMO specialty soybeans commanding a $0.50/bu price premium over commodity soybeans (Conley and Gasaka, 2008).

Figure 44.1. The soybean cultivar Natto. This cultivar is often served with rice. (Source: Japan Centre, http://www.japancentre.com/)

Figure 44.2: The soybean cultivar Edamame. This soybean is consumed by humans directly. (Source: Tofu for Two, http://tofufortwo.net/wp-content/uploads/2008/02/frozen_edamame.jpg)

United States soy-based food markets

Since the 1980s, soy-based food markets have experienced remarkable growth. The early soybean food companies were mostly small, family-run businesses that sold tofu or soymilk on a store-to-store basis (Soyfoods Association of North America, 2012). One of the first soybean food companies was Vitasoy, a Hong-Kong soymilk company. Vitasoy entered the U.S. market in 1979 (Vitasoy USA, 2012). Over time they have expanded their market for soybean products. Most U.S. consumers who are interested in soy-based food are also familiar with tofu and other soy-based food sold by Vitasoy under other brand names such as Nasoya and Azumaya.

During the same time when Vitasoy USA entered the California market, a Minnesota company, Sunrich Food Group, started to explore the specialty soybean market in the Midwest (Soyfoods Association of North
They also have expanded their market (Sunrich Nature, 2012). Today, Sunrich and SunOpta together provide a successful business model for specialty soybean producers, with Sunrich focusing on food markets and SunOpta concentrating on "behind the scene" services, such as grain handling, processing, ingredient control, and helping local farmers select and contract the production of specialty soybeans, grains and oilseeds.

Since the mid-1990s, the Silk company has been introducing soymilk products to mainstream American families through larger supermarkets. Today, Silk® Soymilk is one of the most successful soymilk products. The Silk® Soymilk brand was originally owned by White Wave Co. and is now owned by Dean Foods. They have access to 94% of supermarkets nationwide (Soyfoods Association of North America, 2012).

The significant increase in demand for soy-based food from U.S. domestic consumers has encouraged companies to explore other food items such as vegetarian alternatives (for example, by Lightlife Food), vegetarian burgers (Boca Food, a subsidiary of Kraft), and soy flour (Cargill). Many companies have also started to work with soybean growers to improve soybean characteristics such as protein concentration and isolates. For example, Cargill Health & Food Technologies has developed new products providing soy protein isolates with isoflavones (e.g., Prolisse® soy protein isolate). Archer Daniels Midland Company has introduced its Specialty Ingredients Division to provide soy isolates, soy concentrates, soy flour, and soy grits (ADM, 2012).

Soy foods sales and market contacts

An increasing health concern among U.S. consumers in recent years has contributed to the increased demand for soy-based food. Between 1996 and 2011, total U.S. soy-based food sales have increased from $1 billion to $5.2 billion. In 2010:

1. 37% of Americans consumed soy-based food or soy-based beverages, and
2. 31% of U.S. consumers would specifically seek out products containing soy-related ingredients (Soyfoods Association of North American, 2012).

Table 44.2 shows the total sales of selected soy-based foods from 2008 to 2011 (Soytech, Inc, 2012); however, not all categories shared the same levels of growth. Sales of energy bars have become the number one category of soy food sales. Meat alternatives also showed an increase in sales of $55 million between 2008 and 2011, with frozen meat alternatives sales growing at a faster rate (2.6%) than other meat alternatives. On the other hand, sales of well-known products such as tofu and soymilk showed a relatively stable trend. Accordingly to the Soytech, Inc report (2012), non-dairy refrigerated soymilk products were still the dominant soymilk product, accounting for 70% of the market. Finally, Table 44.2 also indicates that sales of “all other products” over the past five years were approximately $2,000 million.

<table>
<thead>
<tr>
<th>Category</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tofu</td>
<td>$255</td>
<td>$252</td>
<td>$247</td>
<td>$255</td>
</tr>
<tr>
<td>Soymilk</td>
<td>$1,156</td>
<td>$1,081</td>
<td>$1,043</td>
<td>$1,033</td>
</tr>
<tr>
<td>Meat Alternatives</td>
<td>$607</td>
<td>$622</td>
<td>$649</td>
<td>$662</td>
</tr>
<tr>
<td>Energy Bars</td>
<td>$792</td>
<td>$806</td>
<td>$952</td>
<td>$1,092</td>
</tr>
<tr>
<td>Soy Cheese, Cultured Soy (Soy Yogurt) and Frozen Soy Desserts</td>
<td>$221</td>
<td>$203</td>
<td>$186</td>
<td>$174</td>
</tr>
<tr>
<td>All Other Products</td>
<td>$2,094</td>
<td>$2,053</td>
<td>$2,039</td>
<td>$1,956</td>
</tr>
<tr>
<td>Total Sales</td>
<td>$5,128</td>
<td>$5,020</td>
<td>$5,116</td>
<td>$5,172</td>
</tr>
</tbody>
</table>
Opportunities for South Dakota producers

South Dakota Soybean growers who are interested in exploring specialty soybean markets are encouraged to contact nearby processors or companies (Table 44.3). Although most of the companies are not located in South Dakota, these companies have extended their business and programs to nearby states, including South Dakota.

Producers can also visit the Soy Food Association of North America website (http://www.soyfoods.org/) to find rich information pertaining to specialty soybeans marketing, nutrition, buyer information, and event notices. Finally, soybean producers who are interested in finding specialty soybeans programs can also visit the following websites to discover information on buyers and premium programs:

- Soybean Premium.org  http://www.soyfoods.org/
- Vistive https://www.vistive.com
- Pioneer http://pioneer.com
- Soyatech: http://www.soyatech.com/
Table 44.3. Contact information for premium and specialty soybean markets.

<table>
<thead>
<tr>
<th>Company Name</th>
<th>Mailing Address</th>
<th>Phone</th>
<th>Website/Email Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag Processing, Inc.</td>
<td>12700 West Dodge Road PO Box 2047 Omaha, NE 68103</td>
<td>402-498-2210</td>
<td><a href="http://www.agp.com">http://www.agp.com</a></td>
</tr>
<tr>
<td>CHS</td>
<td>5500 Cenex Drive Inver Grove Heights, MN 55077</td>
<td>651-355-6000</td>
<td><a href="http://chsinc.com">http://chsinc.com</a></td>
</tr>
<tr>
<td>Clarkson Grain Company</td>
<td>Box 80 320 East South Street Cerro Gordo, IL 61818</td>
<td>217-763-2861</td>
<td><a href="http://www.clarksongrain.com">http://www.clarksongrain.com</a></td>
</tr>
<tr>
<td>Crawford Grain International</td>
<td>29330 South Elevator Road Manhattan, IL 60442</td>
<td>815-478-4962</td>
<td>N/A</td>
</tr>
<tr>
<td>The De Long Co.</td>
<td>601 DeLco Drive PO Box 552 Clinton, WI 53525</td>
<td>608-676-2255</td>
<td><a href="http://www.delongcompany.com">http://www.delongcompany.com</a></td>
</tr>
<tr>
<td>Gavilon Group, LLC</td>
<td>300 Osage Street Creston, IA 50801</td>
<td>877-274-2676</td>
<td><a href="http://www.gavilon.com">http://www.gavilon.com</a></td>
</tr>
<tr>
<td>Grain Miller Specialty Products</td>
<td>10400 Viking Drive Suite 301 Eden Prairie, MN 55344</td>
<td>952-983-1289</td>
<td><a href="http://www.grainmillers.com">http://www.grainmillers.com</a></td>
</tr>
<tr>
<td>Knewtson Soy Products LLP</td>
<td>17303 State Highway 22 Good Thunder, MN 56037</td>
<td>507-278-4087</td>
<td><a href="mailto:wk@adrsoy.com">wk@adrsoy.com</a></td>
</tr>
<tr>
<td>Microsoy Corporation</td>
<td>300 E. Micorsoy Drive Jefferson, IA 50129</td>
<td>515-386-2100</td>
<td><a href="http://www.microsoylakes.com">http://www.microsoylakes.com</a></td>
</tr>
<tr>
<td>Midwestern Soybeans International</td>
<td>PO Box 289 500 3rd Street Mason City, IA 50402</td>
<td>515-424-5669</td>
<td>N/A</td>
</tr>
<tr>
<td>North Country Seed LLC</td>
<td>501 Main Street PO Box 548 Ormsby, Minnesota 56162</td>
<td>507-736-2004</td>
<td><a href="http://www.northcountryseed.com/">http://www.northcountryseed.com/</a></td>
</tr>
<tr>
<td>Pattison Brothers</td>
<td>PO Box 670 701 King Street Fayette, IA 52142</td>
<td>563-425-3361</td>
<td>N/A</td>
</tr>
<tr>
<td>Richland Organics</td>
<td>100 10th Street, N. Breckenridge, MN 56520</td>
<td>218-643-1797</td>
<td><a href="http://www.richlandorganics.com">http://www.richlandorganics.com</a></td>
</tr>
<tr>
<td>The Scoular Company</td>
<td>2027 Dodge Street Omaha, NE 68102</td>
<td>402-342-3500</td>
<td><a href="mailto:IPGrain@scoular.com">IPGrain@scoular.com</a></td>
</tr>
<tr>
<td>South Dakota Soybean Processor</td>
<td>100 Caspian Ave. Volga, SD 57071</td>
<td>605-627-9240</td>
<td><a href="http://www.sdsbp.com">www.sdsbp.com</a></td>
</tr>
<tr>
<td>The Seed Company</td>
<td>504 Center Street Lynnville, IA 50153</td>
<td>641-527-2775</td>
<td><a href="http://supremesoys.com">http://supremesoys.com</a></td>
</tr>
<tr>
<td>Sinner Brothers &amp; Bresnahan</td>
<td>PO Box 549 Casselton, ND 58102</td>
<td>701-347-4900</td>
<td><a href="http://www.sb-b.com">http://www.sb-b.com</a></td>
</tr>
<tr>
<td>SK Food International</td>
<td>4666 Amber Valley Parkway Fargo, ND 58104</td>
<td>701-356-4106</td>
<td><a href="http://www.skfood.com">http://www.skfood.com</a></td>
</tr>
<tr>
<td>Specialty Grains, Inc.</td>
<td>231 N. Sangamon Ave. Gibson City, IL 60936</td>
<td>217-784-4400</td>
<td><a href="http://www.sgigrain.com">http://www.sgigrain.com</a></td>
</tr>
<tr>
<td>The Scoular Company</td>
<td>250 Marquette Ave. Suite 1050 Minneapolis, MN 55415</td>
<td>612-335-8205</td>
<td><a href="http://www.scoular.com/markets">http://www.scoular.com/markets</a></td>
</tr>
<tr>
<td>Unity Seed Company</td>
<td>3510 154th Ave. SE PO Box 567 Casselton, ND 58017</td>
<td>701-347-5355</td>
<td><a href="http://www.unityseed.com">http://www.unityseed.com</a></td>
</tr>
</tbody>
</table>
Other specialty soybeans

In addition to food-grade soybeans, other marketing alternatives include biodiesel, ink solvent, lubricants, soy wax (i.e., candles), cleaners, pants/coatings, soy-based forms, and high-quality seeds. For example, Low linolenic soybeans usually generate a $0.50/bu to $1.25/bu price premium. These types of beans contain less than 3% linolenic acid, while conventional soybean varieties contain about 7% (Pedersen, 2012). Mainstream national food companies such as KFC and Kellogg’s have already adopted food oil made by low linolenic soybeans specifically for the linolenic acid and low saturated fat content.

South Dakota growers who plan to cultivate non-food specialty soybeans should be aware of the limited market outlets and delivery points. For example, although Cargill and a few other companies have established facilities in Iowa, Nebraska, and Oklahoma to produce biodiesel, the bio-energy production in South Dakota is dominated by corn-based ethanol production. The only biodiesel plant, Midwest Biodiesel Producers, is currently not in operation due to the lack of economic profits. The productions and profit margins of other soy-based, non-food products (for example, soy candles, cleaners, soy-based forms, etc.) are also trivial at this time.

Before growing soybeans for specialty markets, we recommend that soybean producers thoroughly research their contracting opportunities. It is important to choose the varieties designed for the growing environment similar to the natural resource inputs in South Dakota. Growers should also be aware of responsibility and premium rules when signing contracts with buyers.

References and additional information

Acknowledgements
The authors would like to express their gratitude to Japan Centre and hosts of Tofu for Two for granting the rights to use the pictures. We would also like to thank Dr. Lisa Elliott, Dr. Evert VanDer Sluis, Dr. Bashir Qasmi, and Soyfoods Association of North America for their inputs.

Food Product Innovations Using Soy Ingredients

Padmanaban Krishnan (Padmanaban.Krishnan@sdstate.edu)
Julie Darly-Kindelspire (Julie.Kindelspire@sdstate.edu)

Consumers demand a whole host of qualities in their foods that includes convenience, low cost, nutrition, health, wholesomeness, and above all, taste. The challenge for product innovation involves the introduction of new ingredients that improve food functionality and nutrition while retaining the familiarity of conventional foods. Soybean produces many different products, some of which are shown in Figure 45.1. The purpose of this chapter is to present key aspects of soy utilization in foods, provide some practical considerations relating to taste and consumer acceptance, and discuss SDSU’s investment in overcoming these limitations.

Figure 45.1. Processing flow diagram showing production of various soy products. (Source: U.S. Soybean Export Council. 2008. Soy protein concentrate technical bulletin)
**Human food opportunities**

The increasing awareness of ethnic cuisines and the growing sophistication of U.S. taste buds, provides opportunities for soybean products (Fig. 45.1) to lead food innovation while simultaneously improving human nutrition. Opportunities exist because soybean can be a vital source of vegetable oil and proteins in the human diet. In terms of nutritional composition, soybeans are made up of 38% protein, 18% oil, 35% carbohydrates, and 5% minerals (Kim et al., 2003). The carbohydrates consist of sackrides, namely, sucrose (2.5-8.2%), raffinose (0.1-1.0%) and stachyose (1.4-4.1%). In addition, they contain many essential amino acids (Table 45.1).

Table 45.1. Amino acids composition of soy/corn blends with increasing proportions of soy protein concentrates (SPC). (Source: Kaipesh Parmar Thesis, 2012)

<table>
<thead>
<tr>
<th></th>
<th>Raw soybean</th>
<th>Soybean concentrate</th>
<th>Distillers dried grains (DDG)</th>
<th>Food grade DDG</th>
<th>Blend -1 (30 SPC + 70 DDG)</th>
<th>Blend -2 (50% SPC + 70 DDG)</th>
<th>Blend -3 (70 SPC + 30 DDG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td><strong>Crude Protein</strong></td>
<td>47.8</td>
<td>68.9</td>
<td>34.8</td>
<td>35.1</td>
<td>41.7</td>
<td>45.8</td>
<td>45</td>
</tr>
<tr>
<td><strong>Alanine - Total</strong></td>
<td>2</td>
<td>2.99</td>
<td>2.46</td>
<td>2.4</td>
<td>2.42</td>
<td>2.32</td>
<td>2.34</td>
</tr>
<tr>
<td><strong>Ammonia - Total</strong></td>
<td>1.1</td>
<td>1.84</td>
<td>0.77</td>
<td>0.73</td>
<td>0.81</td>
<td>0.78</td>
<td>0.92</td>
</tr>
<tr>
<td><strong>Arginine - Total</strong></td>
<td>3.54</td>
<td>5.28</td>
<td>1.8</td>
<td>1.88</td>
<td>2.59</td>
<td>2.85</td>
<td>3.71</td>
</tr>
<tr>
<td><strong>Aspartic Acid-Total</strong></td>
<td>4.9</td>
<td>7.47</td>
<td>1.96</td>
<td>1.84</td>
<td>3.25</td>
<td>3.67</td>
<td>4.25</td>
</tr>
<tr>
<td><strong>Cystine - Total</strong></td>
<td>1.18</td>
<td>1.67</td>
<td>1.14</td>
<td>1.24</td>
<td>1.5</td>
<td>1.64</td>
<td>1.46</td>
</tr>
<tr>
<td><strong>Glutamic Acid-Total</strong></td>
<td>8.06</td>
<td>12.1</td>
<td>5.6</td>
<td>5.31</td>
<td>7.02</td>
<td>7.24</td>
<td>8.23</td>
</tr>
<tr>
<td><strong>Glycine - Total</strong></td>
<td>1.9</td>
<td>2.95</td>
<td>1.38</td>
<td>1.45</td>
<td>1.75</td>
<td>1.8</td>
<td>2.14</td>
</tr>
<tr>
<td><strong>Histidine - Total</strong></td>
<td>1.18</td>
<td>1.75</td>
<td>0.99</td>
<td>1.07</td>
<td>1.17</td>
<td>1.1</td>
<td>1.36</td>
</tr>
<tr>
<td><strong>Isoleucine - Total</strong></td>
<td>1.86</td>
<td>3.07</td>
<td>1.18</td>
<td>1.19</td>
<td>1.62</td>
<td>1.44</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Leucine - Total</strong></td>
<td>3.53</td>
<td>5.32</td>
<td>4.28</td>
<td>4.46</td>
<td>4.56</td>
<td>4.05</td>
<td>4.37</td>
</tr>
<tr>
<td><strong>Lysine - Total</strong></td>
<td>2.76</td>
<td>4.3</td>
<td>0.97</td>
<td>0.92</td>
<td>1.65</td>
<td>1.8</td>
<td>2.36</td>
</tr>
<tr>
<td><strong>Methionine - Total</strong></td>
<td>0.67</td>
<td>1.41</td>
<td>0.93</td>
<td>1.01</td>
<td>0.92</td>
<td>0.81</td>
<td>0.82</td>
</tr>
<tr>
<td><strong>Phenylalanine-Total</strong></td>
<td>2.26</td>
<td>3.41</td>
<td>1.9</td>
<td>2.1</td>
<td>2.31</td>
<td>2.14</td>
<td>2.66</td>
</tr>
<tr>
<td><strong>Proline - Total</strong></td>
<td>2.32</td>
<td>3.5</td>
<td>2.94</td>
<td>2.97</td>
<td>2.92</td>
<td>2.76</td>
<td>2.85</td>
</tr>
<tr>
<td><strong>Serine - Total</strong></td>
<td>2.62</td>
<td>3.68</td>
<td>1.98</td>
<td>2.14</td>
<td>2.44</td>
<td>2.59</td>
<td>2.78</td>
</tr>
<tr>
<td><strong>Threonine - Total</strong></td>
<td>1.94</td>
<td>2.8</td>
<td>1.5</td>
<td>1.57</td>
<td>1.76</td>
<td>1.84</td>
<td>2.15</td>
</tr>
<tr>
<td><strong>Valine - Total</strong></td>
<td>1.89</td>
<td>3.14</td>
<td>1.54</td>
<td>1.57</td>
<td>1.91</td>
<td>1.63</td>
<td>2.37</td>
</tr>
</tbody>
</table>

South Dakota State University has been conducting research designed to increase the amount of soybean used in human food. A Test Kitchen (Fig. 45.8) was developed in the Health and Nutritional Sciences Department in 1990 at the behest of the South Dakota Soybean Research and Promotion Council (SDSRPC). The Test-Kitchen employs undergraduate nutrition and dietetics students for the development soy-based food products. It is a training ground for future nutrition practitioners who learn about culinary and scientific aspects of soy substitutions for the purpose of fat reduction and flavor enhancement in conventional baked foods. The outcomes from the Test Kitchen are featured in a gourmet soy cookbook, *Favorites from the Heartland*, published by the SDSRPC.
New food product development is both a scientific and a creative exercise. Food innovations materialize in subtle ways as stealth ingredients that do not reveal their presence in food formulations, are used to improve functionality. Soybeans are critical in food experimentation because soybean protein has unique chemical and physical properties that make them particularly suited for improving food texture, appearance, nutrition, and processing ability.

However, soy ingredients present unique opportunities in new food formulations. A bland flavor allows for incorporation into a wide range of products. While use of the unprocessed bean presents several problems for American taste buds, refined ingredients such as protein concentrates and protein isolates hold prospects for use in conventional foods.

Unprocessed soybean has inherent flavor problems owing to chemical changes in the fat content and the occurrence of non-digestible oligosaccharides. Widespread acceptability has been slowed by abdominal discomfort caused by consumption of oligosaccharides. In addition, low protein digestibility is seen in humans as evidenced by a low Biological Value of 74 for protein isolates compared to 83 for egg white (Hoffman et al., 2005). It is difficult to avoid the occurrence of the green-beany flavor of soybean in untoasted full-fat or defatted soybean flour. A beany flavor is an undesirable trait that limits its use.

Soybean also contains the oligosaccharides stachyose and raffinose. These sugars are indigestible and can cause flatulence and abdominal discomfort in humans and animals. These undigested oligosaccharides are broken down in the gut by microbes producing gases such as carbon dioxide, hydrogen, nitrogen, methane, etc. Different processing techniques are used to minimize these problems. Generally, heat treatment is used for inactivation of lipoygenase enzymes and trypsin inhibitors. Aqueous alcohol washing is used to remove oligosaccharides.

Soy proteins are composed of four major groups, 2S, 7S, 11S, and 15S globulins. The 7S and 11S globulins, known as glycinin and β-conglycinin, are the two major storage proteins and make up approximately two-thirds of the total proteins. These proteins have properties that impact solubility, foaming, emulsification, oil absorption capacity, and hydration. Emulsification and foaming properties are closely associated with solubility. Water absorption, water holding, water hydration, and water-binding capacity are terms used interchangeably. Hydration properties are important in baked goods, cheeses, and meat products. Emulsifying properties of soy proteins are particularly suited for use in coffee whiteners, comminuted meats and, mayonnaise. Foaming capacity is important in cakes, whipped toppings, and frozen desserts.

**Soy protein concentrate**

Soy protein concentrates (SPC) were developed as flavor improvers and for increasing the protein content of foods. Soy protein concentrate has a protein content of at least 65% (H.Wang et al., 2004). SPC preparation involves retaining the soybean globulin proteins while selectively removing the soluble sugar carbohydrates. This increases the protein content in the final product. Preparation of soybean protein isolates (SPI) involves the extraction of the protein followed by precipitation and centrifugation. These products provide high quality protein and are comparable to animal protein, but consisting of no cholesterol and little or no fats. The FDA has allowed a claim that “A daily diet of 25 g of soybean protein which is low in cholesterol and unsaturated fat can reduce total LDL cholesterol moderately” (FDA, 1999).

**Producing protein concentrates**

Soybean concentrates can be produced using a number of different approaches. These approaches include:

- Aqueous alcohol and heat treatment/water extraction processes.
- Aqueous acid leaching.
The extraction technique influences its properties. Soybean protein concentrate is produced by the aqueous alcohol and heat treatment/water extraction processes. In contrast, the products made by aqueous acid leaching have high solubility if neutralized prior to drying. These concentrates may vary in particle size, water and fat absorption properties, and flavor. They all have improved flavor characteristics and they also provide functional characteristics such as fat-micelle stabilization, water and fat absorption, viscosity control, and texture control in forming fat emulsions in food systems. Many of these characteristics are interrelated in a stable food system. Both pH and temperature affect the emulsifying properties of soybean concentrate, which absorbs a significant amount of water.

Processing conditions can vary the amount of water that can be absorbed. In fact, these conditions can be varied to influence how tightly the water is bound by the protein in the finished food product. Processing techniques such as the acid leaching, steam injection, and jet cooking can result in a product with higher dispersibility. These concentrate are more desirable for functional properties in emulsion-type applications. Soy protein concentrate, regardless of the production process used, has certain oil and water-holding characteristics as well.

Effects of soy, corn, and wheat protein concentrates on food texture properties

Table 45.1 shows the nutritional advantages of combining protein sources from soy and corn processing in yielding nutritionally advanced high protein fractions or blends. Increased soy protein concentrate inclusions in soy/corn distillers dried grains (DDG) blends improved the amino acids composition of the resulting blends (30:70, 50:50, and 70:30). The use of such protein blends in various applications is currently under investigation. Improved protein content, amino acid profiles and dietary fiber content in soy/corn DDG have obvious positive implications for the food ingredient market. Incorporation of such blends in wheat flour substitution can also improve dough functionality and introduce food functional properties not traditionally seen in the conventional flour blends.

Tables 45.2 and 45.3 provide data on changes that occur in food systems owing to the addition of high-protein ingredients such as soy protein concentrates or corn protein concentrates in wheat-based formulations. The farinograph output (Fig. 45.2) in general shows increased dough extensibility largely due to gluten dilution and increased water requirements for dough formation.

Protein and fiber constituents in food adjuncts change the water-holding abilities of dough owing to the competition for water in the food system. Such trade-offs are manifested as reduced dough volume, decreased dough stability, changes in machinability and also reduced eating quality. There is a need to balance the formulation to retain the desirable traits of taste and texture. Advanced instruments such as the Farinograph®, Mixolab®, and Texture Analyzer® remove the guesswork in estimation of optimal water content, mixing requirements while providing explanations for starch-protein interactions and other changes in the functional nature of the food constituents.

Advanced instrumentation for product development

The Farinograph® is a dough-recording mixer (Fig. 45.2). The output of a Farinograph test is a mixing curve. Different types of information can be obtained from the mixing curve. The flour water absorption is the amount of water needed to produce a dough of “perfect” consistency. It is an important parameter in the baking industry. This test also determines the:

- Dough mixing time (or dough development time) which corresponds to the amount of time required to obtain a dough with the proper consistency.
- Dough mixing stability, how long the dough can be mixed before it starts breaking down. Dough mixing tolerance index (MTI). Dough eventually sustains break down when mixed; the MTI is a measure of the dough resistance to over-mixing.
High water absorption, high mixing stability, and low MTIs are indicators of good dough quality. Dough extensibility tests are another popular quality test. In this test, a dough piece is stretched upwards or downwards in one direction. This test is used to measure dough strength, the amount of force required to break to dough, and the dough extensibility (a measure of how much the dough can be stretched before it starts to break).

The substitution of flour by 5% SPC increased the blend protein content by approximately 2.5% while the addition of 5% food grade DDG increased the protein content by 1%. The addition of the SPC-DDG blends also significantly increased the blend’s protein content. Both the SPC and the DDG had similar effects on the water absorption of the blend. The water absorption increased by 3% when 5% of SPC or DDG were added to the flour; 8% and 4.5% when 10% of SPC and DDG were added respectively; and 19% when the flour was substituted with 15 % SPC or DDG (Table 45.1 and 45.2).
The water absorption increased as the substitution level with the SPC-DDG blends increased. This is due to the added protein and fiber; these constituents have a high water-holding capacity, therefore more water is required to hydrate the blend. The substitution affected the dough characteristics; adding 15% of Blend 1 (25% SPC – 75% DDG) resulted in a significant increase in the dough development time. Blend 2 (50% SPC – 50% DDG) and Blend 3 (70% SPC – 30% DGG) had similar effects on the dough development; substituting at the 5% level resulted in an increase in the dough development time. The flour blends with a level of substitution of 10 and 15% had longer development times in comparison to the 5% blends; however, there was no significant difference between the 10% and 15% blend.

The effect of SPC and DDG fortification on the dough development time were assessed separately. The addition of up to 15% SPC did not significantly affect the dough development time. However, the addition of 15% DDG significantly increased the dough development time. Dough formation in flour dough occurs when the flour proteins (glutenins and gliadins) are hydrated and form a cohesive mass, which is a protein composite commonly referred to as gluten (Fig. 45.4).
The SPC-DDG blend consists of constituents with a high water holding capacity. When part of the flour is substituted with the SPC-DDG blend, the constituents from the SPC-DDG blend compete with the flour proteins for water which in turn results in a delay to reach the target consistency. Therefore, flours fortified with the SPC-DDG blend will have longer development times.

The mixing stability was also affected by the addition of the SPC-DDG blend, the substitution of flour by the different SPC-DDG blends resulted in an increase in dough stability. Adding 5 or 10% of SPC to flour increased the dough mixing stability, but the substitution at the 15% level significantly decreased the mixing stability. On the other hand, the addition of DDG did not significantly affect the mixing stability.

When the SPC-DDG blends were used in flour, the mixing tolerance index increased with increasing substitution. Substitution with SPC at the 15% level decreased the dough mixing tolerance while the addition of DDG did not impact MTI. The addition of the SPC-DDG blends up to the 15% level did not impact dough strength, however increasing the level of substitution reduced extensibility. Adding the SPC-DDG blend altered the dough stretchability and color (Fig. 45.5).

Figure 45.4. Wheat protein (gluten) and corn protein (Zein) showing potential foam and film production food applications, respectively. (Photos courtesy of Dr. Padu Krishnan, SDSU)

Figure 45.5. L, a, b color space and color changes in DDG during processing. Higher brightness values L and lower redness (a) are achieved with processed DDG using solvent extraction. (Graphics and photo, P. Krishnan, SDSU)
**SDSU investments in food quality and crop quality efforts**

The Food Science program in the Health and Nutritional Sciences Department, South Dakota State University, has devoted over 2000 ft$^2$ of space for research and innovation in the area of food and nutrition. Analytical instrumentation acquired with the support of the South Dakota Soybean Research and Promotion Council (SDSRPC) include a combustion protein analyzer, a liquid chromatography mass spectrometer, gas chromatography mass spectrometer, solvent extractor, and a host of food preparation equipment (Fig. 45.6). A texture analyzer was acquired with federal, state, and SDSRPC support. A Vita Cow® (aka Soy Cow) was also acquired for the processing of soymilk and related soy products. A test kitchen equipped with stainless steel counters, food grade equipment, and a sensory evaluation facility allows for the product development and evaluation efforts (Fig. 45.7).

The development of a Crop Quality Laboratory (CQL) in the Seed Technology Laboratory adds additional research space (1300 ft$^2$) for grains and oilseeds. Images of the new laboratories are provided in Figure 45.8. The CQL features wheat, flour and dough quality measurement equipment for routine evaluation of South Dakota crops. In addition, capabilities exist for experimental baking and tortilla and noodle processing.

Basic and applied research in the area of cereal grains and oilseeds is supported through a variety of commodity, industry, and federal agencies. Fundamental properties of locally grown varieties of wheat, oat, and soybeans are studied for the nutritional, health, and food functional traits. The economic value of cash crops is enhanced by their end-use properties. High value and economical sources of protein from corn and soybeans are useful in feeding livestock and in aquaculture, while wheat proteins are used directly in the food industry. The latter are then transformed into high quality and cost effective protein in human nutrition through the food we eat.

More recently, a 2012 award of a $500,000 grant from the South Dakota Board of Regents Productivity Improvement Program has made possible the acquisition of a pilot scale extruder. This versatile cooker-extruder will be centrally located in SDSU and used in research and development efforts in the area of food, aquaculture, and biomaterials. A well-equipped, state-of-the-art food laboratory can be used to develop new products that can be locally manufactured.

Research into foods for healthy living include new oat varieties with enhanced soluble fiber and anti-oxidative properties, new blends of soy and corn proteins in bread formulations, high temperature processing of flat breads, high fiber pizza crusts and Asian noodles, high-selenium gluten, and anti-tumor canola meal constituents. The program engages the national food industry for support in several proprietary research projects. Basic research into dough rheology and breeding techniques also employ food science research knowledge. These areas provide excellent training grounds for master of science and Ph.D. students interested in science careers in academia and the food industry.
Figure 45.6. Equipment contained within the food laboratory. The equipment shown is a texture analyzer used to measure extensibility and force needed to shear food products, a protein analyzer, a gas chromatograph mass spectrometer, and a pilot-scale food extruder. (Photos courtesy of Food Science Lab, SDSU)

Figure 45.7. Tofu fudge cookie developed by the SDSU Test Kitchen (left) and texture analysis of tofu cookie (right). (Photos, P. Krishnan, SDSU)
Crop Quality Lab and Baking Room

Sensory Analysis Booth

Soyfoods Cookbook and Test Kitchen

Soy milk Production Unit “soy cow” and Faye Tyler Wade Lab

Figure 45.8. Facilities available for food product development activities. (Photos, P. Krishnan, SDSU)
References and additional information


Websites


Acknowledgements

The authors thank the South Dakota Soybean Research and Promotion Council, Omnitech International, United Soybean Board, South Dakota Corn Utilization Council, South Dakota Wheat Commission and the South Dakota Agricultural Experiment Station for support for their programs.

Insuring Soybeans in South Dakota

Matthew Diersen (Matthew.Diersen@sdstate.edu)

Insurance is an important part of managing South Dakota soybean crops. Programs and needs are constantly changing; therefore, it is recommended that coverage be reviewed annually by the March 15 sales closing date. South Dakota producers insured 4.5 million acres of soybeans in 2012, second only to the record of 4.9 million acres that were insured in 2009. The purpose of this chapter is to highlight common features of soybean insurance. An example is provided and if you have questions contact your agent. Once understood, producers can make better decisions related to choices of insurance policy type and coverage levels.

Figure 46.1. Soybean counties in South Dakota.
(Additional information at http://www.rma.usda.gov/fields/mt_rso/2013/sdinsurable.pdf)
Where and when coverage is available

Information about crop insurance can be obtained from many sources including a crop insurance agent, a lender, the university, and the USDA-Risk Management Agency (www.rma.usda.gov). Each of these information sources provide a slightly different perspective that will help you make your decision. Soybean coverage details as discussed here are outlined in the "Common Crop Insurance Policy," the "Coarse Grains Crop Provisions," and the "Commodity Exchange Price Provisions" (CEPP). Copies are available from crop insurance agents and on the Risk Management Agency (RMA) website (www.rma.usda.gov). Standard coverage for soybeans is available in eastern South Dakota counties (Fig. 46.1). In other counties, soybeans may be covered by written agreements from insurance companies.

Several dates are critical to assure the proper coverage is chosen and in place when needed. For soybeans, the insurance must be purchased or changed by March 15 and the earliest planting date is April 26. The final planting date is June 10. After the final planting date, there is a 25-day late planting period with reduced coverage levels. In the event of a loss, producers typically have 72 hours to notify their insurance agent of a potential claim. The latest this coverage lasts is December 10.

Policy dates match up fairly well with South Dakota cropping and marketing patterns as reported by the National Agricultural Statistics Service (NASS). The range of common planting dates for soybeans is from May 10 through June 30. The range of common harvest dates is from September 20 through November 10. Historically, the percentage of soybeans marketed peaks after harvest, commonly in October. Additional higher monthly marketings are also common in January.

Policy type and coverage level specifics

While dates and details are important, producers struggle with the overriding issues of policy type and yield coverage level. The main policy types are:

- **Revenue Protection (RP)**
- **Yield Protection (YP)**
- **Revenue Protection with the Harvest Price Exclusion (RP-HPE)**
- **Catastrophic Risk Protection (CAT)** (Table 46.1)

Each policy type has different benefits (Table 46.1) and coverage level generally refers to the yield coverage level or percent of the producer’s actual production history insured.

Revenue insurance products have dominated the coverage type choice in recent years. Relatively high prices have encouraged producers to forward price soybeans and use revenue insurance. Statewide, 95% of insured soybean acres in 2012 were covered by RP. Another 3% of acres were covered by YP. The remaining acres were covered by RP-HPE and CAT.

With YP, a producer receives an indemnity payment at the fixed per bushel price if the resulting yield falls below the yield coverage level. With RP, there is a fixed guarantee level and either lower yields and/or lower prices may trigger an indemnity payment. RP is designed to cover price increases and is ideal when producers forward price the crop. Producers with RP can select the harvest price exclusion (RP-HPE), which is limited to downside revenue protection at a slightly higher cost than YP. RP-HPE costs less than RP and may be preferred if little forward pricing is expected.

Once a policy type has been selected, the coverage levels need to be chosen. With RP and RP-HPE there is no price election option; one must use 100% of the projected price (Table 46.1). For YP, a producer can select less than 100% of the projected price. To minimize the insurance premium expense, a producer could use a price election that closely aligns the insured price with the expected cash price. For example, if expected basis implies a cash price below an RMA projected price, a price election of less than 100% may match well and reduce the cost of protection accordingly.
Across policy types the yield coverage level must be chosen. The elections range from 50% to 85% coverage. Soybean producers in South Dakota used 75% and 70% yield coverage levels most often in 2012. The optimal level depends on a producer's willingness and ability to self-insure the deductible amount and on the cost of different coverage levels. The best choice is a farm-specific decision and is also influenced by any forward pricing or protection strategies employed.

The pre-harvest statewide level of liability coverage in 2012 was $1.5 billion on soybeans. That averages out to about $350 per insured acre in liability protection. Producers paid about $12.50 per acre in premiums for the coverage. The liability coverage protects the cost of crop production that a producer may seek to insure. Depending on the farm's financial situation and the insurance cost, many producers try to obtain coverage for seed, chemicals, fuel, and perhaps land rent. Producers may also try to obtain coverage for the fixed cost of machinery or profits.

The premium outlay reflects the cost of insurance products. The premium is a positive function of the prevailing soybean price when the insurance is purchased. For revenue insurance, the premium is also a positive function of the prevailing soybean price volatility. The cost of policy types increases when moving from yield to revenue protection. Within policy types, costs increase with the coverage level. The premium cost also depends on the crop, the county, and a producer's yield history.

Information on determining proven yields are available at http://www.extension.iastate.edu/agdm/crops/html/a1-55.html.

Table 46.1. The details of insurance types.

<table>
<thead>
<tr>
<th>Insurance Option</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue Protection (RP)</td>
<td>• Price election level fixed at 100%.</td>
</tr>
<tr>
<td></td>
<td>• Most expensive, but may be best choice if forward pricing.</td>
</tr>
<tr>
<td></td>
<td>• Capped upside protection to offset potential hedging losses when yield risk is possible.</td>
</tr>
<tr>
<td>Yield Protection (YP)</td>
<td>• Price election level can be adjusted to below 100%.</td>
</tr>
<tr>
<td></td>
<td>• Inexpensive option but no downside price protection.</td>
</tr>
<tr>
<td></td>
<td>• May be of interest if no forward pricing is likely.</td>
</tr>
<tr>
<td>Revenue Protection with Harvest Price Exclusion (RP-HPE)</td>
<td>• Price election level fixed at 100%.</td>
</tr>
<tr>
<td></td>
<td>• Slightly higher cost than YP, but provides downside price protection.</td>
</tr>
<tr>
<td></td>
<td>• May be of interest if little forward pricing is likely.</td>
</tr>
<tr>
<td>Catastrophic Risk Protection (CAT)</td>
<td>• Price election level fixed at 50%.</td>
</tr>
<tr>
<td></td>
<td>• Yield election level fixed at 50%.</td>
</tr>
<tr>
<td></td>
<td>• Least expensive option.</td>
</tr>
<tr>
<td></td>
<td>• Suitable when self-insuring.</td>
</tr>
</tbody>
</table>

Managing yield and revenue risks

Conceptually, producers make crop insurance choices based on their risk tolerance and marketing considerations. Insurance only covers downside yield and some price risks. Insurance does not eliminate the need for sound marketing strategies. Producers also need to account for any government programs (such as loan deficiency payments) that would provide income protection under certain circumstances. Producers may consider what level and under what conditions to prudently hedge some production. Producers may also consider what risks remain once insurance is in place.
By aligning policy type and coverage level with a marketing strategy, producers can implement a comprehensive risk management plan in a cost-effective manner. Insurance factors, many specific to RP, may need to be accommodated in the marketing plan. The RMA price discovery periods use the CBOT November Soybean futures contract. The average of the futures closes during the discovery periods sets the respective prices. The projected price discovery period is February 1 to February 28. The Projected Price is used in YP to determine the price level at which indemnities are paid. The Projected Price sets the minimum coverage level for RP and RP-HPE.

The harvest price discovery period is October 1 to October 31. The Harvest Price is combined with the actual yield to determine harvest revenue in RP-HPE. The Harvest Price is also used in RP to determine whether higher coverage is relevant at harvest. The unbiased nature of futures prices is evident based on the past ten years (Table 46.2). The average change has been $0.28 per bushel with six years of increases and four years of decreases. Extreme moves are also evident as the price increased $2.84 in 2012 and decreased $4.14 in 2008.

<table>
<thead>
<tr>
<th>Table 46.2. Soybean insurance and marketing factors from 2003 to 2012. (Sources: USDA-RMA and USDA-NASS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Price ($/bushel)</td>
</tr>
<tr>
<td>2003 5.26</td>
</tr>
<tr>
<td>2004 6.72</td>
</tr>
<tr>
<td>2005 5.53</td>
</tr>
<tr>
<td>2006 6.18</td>
</tr>
<tr>
<td>2007 8.09</td>
</tr>
<tr>
<td>2008 13.36</td>
</tr>
<tr>
<td>2009 8.80</td>
</tr>
<tr>
<td>2010 9.23</td>
</tr>
<tr>
<td>2011 13.49</td>
</tr>
<tr>
<td>2012 13.55</td>
</tr>
</tbody>
</table>

RP and RP-HPE insurance premiums are a direct function of the soybean price volatility. The volatility factor, measured late in the projected price discovery period, was at a historically low level in 2012 (Table 46.2). Producers responded by purchasing high yield coverage levels. When the volatility was relatively high in 2008 and 2009, the premium levels were also high, limiting coverage.

Basis, defined as the difference between a cash price and a futures price, reveals a disparity between insurance coverage and local conditions. Basis is not factored into the projected nor harvest prices for crop insurance. As such, the RMA prices likely exceed the expected and actual local cash prices. The insurance settles to a fixed or static month that may not always line up with harvest or crop sales.

October is typically the month with the greatest percent of soybeans marketed in South Dakota. For reference, the statewide price received by farmers (from NASS) is shown for October along with the basis relative to the harvest price (Table 46.2). Basis variability is evident, ranging from $0.49 per bushel in 2008 to -$1.75 per bushel in 2010. For planning purposes, a five-year moving average of historical basis seems reasonable.
Examples for comparing coverage levels for YP, RP and RP-HPE are available in Problem 46.1. Consider a projected price of $13.00 per bushel, an approved yield of 40 bushels per acre, and a yield election coverage of 75%. The coverage level implies a Trigger yield of 30 bushels and a liability level of $390 per acre across major coverage types. The premium costs were projected for 2013 for Brookings County with a volatility level of 20% using the RMA Cost Estimator. Combinations of actual yields and harvest prices result in different net proceeds across coverage types.

### Problem 46.1. Potential indemnity payments across coverage types.

<table>
<thead>
<tr>
<th>Harvest Price: $14.00, Actual Yield: 40 Bu.</th>
<th>YP</th>
<th>RP</th>
<th>RP-HPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated Revenue</td>
<td>$560</td>
<td>$560</td>
<td>$560</td>
</tr>
<tr>
<td>Indemnity Payment</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Premium Cost</td>
<td>$15</td>
<td>$20</td>
<td>$16</td>
</tr>
<tr>
<td>Net Proceeds</td>
<td>$545</td>
<td>$540</td>
<td>$544</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Harvest Price: $12.00, Actual Yield: 25 Bu.</th>
<th>YP</th>
<th>RP</th>
<th>RP-HPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated Revenue</td>
<td>$300</td>
<td>$300</td>
<td>$300</td>
</tr>
<tr>
<td>Indemnity Payment</td>
<td>$65</td>
<td>$90</td>
<td>$90</td>
</tr>
<tr>
<td>Premium Cost</td>
<td>$15</td>
<td>$20</td>
<td>$16</td>
</tr>
<tr>
<td>Net Proceeds</td>
<td>$350</td>
<td>$370</td>
<td>$374</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Harvest Price: $12.00, Actual Yield: 30 Bu.</th>
<th>YP</th>
<th>RP</th>
<th>RP-HPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated Revenue</td>
<td>$360</td>
<td>$360</td>
<td>$360</td>
</tr>
<tr>
<td>Indemnity Payment</td>
<td>$0</td>
<td>$30</td>
<td>$30</td>
</tr>
<tr>
<td>Premium Cost</td>
<td>$15</td>
<td>$20</td>
<td>$16</td>
</tr>
<tr>
<td>Net Proceeds</td>
<td>$345</td>
<td>$370</td>
<td>$374</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Harvest Price: $14.00, Actual Yield: 25 Bu.</th>
<th>YP</th>
<th>RP</th>
<th>RP-HPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated Revenue</td>
<td>$350</td>
<td>$350</td>
<td>$350</td>
</tr>
<tr>
<td>Indemnity Payment</td>
<td>$65</td>
<td>$70</td>
<td>$40</td>
</tr>
<tr>
<td>Premium Cost</td>
<td>$15</td>
<td>$20</td>
<td>$16</td>
</tr>
<tr>
<td>Net Proceeds</td>
<td>$400</td>
<td>$400</td>
<td>$374</td>
</tr>
</tbody>
</table>

*Note: Following the method and notation of Woodard, Sherrick and Schnitkey (2010) for earlier insurance products, the respective indemnity calculations are as follows:

- \( YP \text{ Indem} = \max(0, \text{Projected price} \times (\text{Trigger yield} - \text{Actual yield})) \)
- \( RP \text{ Indem} = \max(0, (\text{Trigger yield} \times \max(\text{Projected price, Harvest price})) - (\text{Harvest price} \times \text{Actual yield})) \)
- \( RP - HPE \text{ Indem} = \max(0, (\text{Projected price} \times \text{Trigger yield}) - (\text{Harvest price} \times \text{Actual yield})) \)*

RP coverage will increase should the harvest price be higher than the projected price. However, a 200% limit on the price change by harvest is in effect. As stated in the CEPP, “The harvest price will not be greater than the projected price multiplied by 2.00.” If a producer hedges aggressively, suffers a large yield loss, and the market price increases beyond 200% of the projected price, then hedge losses may exceed indemnity payments. Covered sales seem like the best way to mitigate this low probability event. Forward contract sales or short futures hedges are covered by buying call options on the same number of bushels at a strike price below 200% of the projected price.

There is a continuum of insurance and marketing choices (Fig. 46.2). Some coverage or use of insurance is expected because of the premium subsidy. The subsidy is large enough that minimal insurance will pay for itself over time regardless of the risk tolerance of the producer. The historic loss ratio also favors purchasing the insurance; it has been high enough that indemnity payments have consistently exceeded the producer premiums paid at the aggregate or statewide level. Minimal coverage, typically CAT, is still available, but has not been widely used for soybeans.
Relatively high prices reflected in futures prices suggest RP-HPE would be intermediate coverage. It is difficult to justify purchasing YP when RP-HPE is nearly the same cost and provides downside price protection. For those forward pricing, standard RP will likely be optimal. The upside protection of RP is often necessary to offset potential hedging losses when yield risk is possible. Given the upside cap on RP, covered sales should be considered if hedging aggressively.

At the far extreme are very high coverage levels and full hedging or risk protection. This can be overdone. The subsidy declines as the coverage level increases. In essence, a producer would approach the point where one pre-pays the cost of routine yield variability. Over-hedging is another concern as potential hedge losses (usually from extreme price increases) can exceed insurance indemnity levels. Thus, some optimal insurance coverage exists.

**Final thoughts**

Insurance is an important part of managing soybean production in South Dakota. Programs and needs are constantly changing; therefore, it is recommended that coverage be reviewed annually. For example, Group Risk types of coverage were not discussed here. Current production conditions leave a high amount of intra-county yield variability, limiting the attractiveness of group coverage. Producers may want to visit with their agent about how units are treated, prevented planting rules, insuring specialty soybeans and necessary production records. If you are planning on planting a cover crop, you need to check with your agent about your insurance eligibility. Producers may also want to visit with their commodity broker about matching marketing to the product type, limiting hedging based on the coverage level, and making covered sales.

**References and additional information**

CME Group. Available at www.cmegroup.com


Risk Management Agency. Available at www.rma.usda.gov


**Acknowledgements**

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Managing High Water Tables and Saline Seeps in Soybean Production

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Jeppe Kjaersgaard (Jeppe.Kjaersgaard@sdsstate.edu)
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Poorly drained areas frequently require drainage to optimize crop growth. In these areas, high water contents can drown crops, delay seeding, increase the loss of N fertilizer, increase crop diseases, and slow seed germination. These areas may be small depressional areas in relatively large flat fields or lower elevation areas in rolling fields. Based on a field's topography, individualized drainage systems need to be developed. In addition to having high water contents, many poorly drained fields have high salt concentrations. This chapter will address the management of high water tables and the basic reclamation principles for saline seeps.

Figure 47.1. Water flowing from the outlet of a subsurface drain. (Photo courtesy of Lynn Betts, USDA Natural Resources Conservation Service)
Lowering high water tables with subsurface drainage

Subsurface (tile) drainage is used to remove excess soil water and salts using drainage pipes or tiles installed below the soil surface (Fig. 47.1). Since the 1970s, perforated polyethylene tubing has become the most popular material for drainage pipes. Historically, cylindrical clay or concrete sections, or “tiles,” were used, so the customary terms “tiling” and “tile drainage” are still used to describe subsurface drainage. Drains are typically installed just below the root zone at depths of 2.5 to 4 feet. The outlets for the drain lines are generally streams or open ditches.

Subsurface drainage is used to enable timelier planting, harvesting, and other field operations and to increase crop yields. Many South Dakota soils have poor natural drainage, and without artificial drainage they would remain waterlogged from excess precipitation for extended periods.

Approximately 25% of the farmable acres in the U.S. have some form of artificial drainage. By removing excess water from the root zone (Fig. 47.2), salts are flushed from the root zone, and the risk of soil compaction from field operations is reduced. Since soils with subsurface drainage will dry out and warm up faster in the spring than undrained soils, subsurface drainage can enhance the ability to implement no-till and minimum tillage.

Figure 47.2. Subsurface drainage removes excess water from the root zone via pipes or “tile” buried beneath the soil surface. (Illustration courtesy of Gary Sands, University of Minnesota)

Along with improved yields, subsurface drainage tends to reduce surface runoff and peak flows by encouraging increased infiltration of water into the soil. Zucker and Brown (1998) reported that subsurface drainage reduces surface runoff by 29 to 65%, peak flows are reduced by 15 to 30%, and total outflows (surface runoff plus subsurface drainage) are similar. Other studies have shown modest increases (5 to 10%) in total outflows from the addition of subsurface drainage.

The impacts of subsurface drainage on water quality can be both positive and negative. Because subsurface drainage reduces surface runoff, sediment and nutrient losses from surface runoff are also reduced. Sediment loss reductions range from 16 to 65%, and losses of phosphorous may be reduced up to 45% (Zucker and Brown, 1998). However, subsurface drainage can increase nitrate export. Nitrate losses from subsurface drainage vary widely, but concentrations of nitrate in drainage water frequently exceed the drinking water standard and may lead to local or regional water quality problems.

Conservation drainage constitutes a set of established and new designs and practices designed to maintain the benefits of drainage, while reducing negative environmental impacts. This is an active area
of research, and a number of conservation drainage demonstration projects are being implemented in the Midwest. These practices include:

1. **Drainage water management (controlled drainage).**
   Water control structures are used to raise or lower the outlet elevation to manage the water table depth. By restricting the water movement in the drains at times when drainage is not needed, the overall volume of water flow is reduced, more soil moisture is available for the growing crop when it can be used, and nitrate export is reduced.

2. **Denitrifying bioreactors.**
   Outflow from the drainline is intercepted near the outlet and the water is routed through a trench filled with wood chips or other carbon-rich media. Bacteria growing on the chips remove nitrate from the water by converting it to harmless nitrogen gas. A bypass pipe ensures that the capacity of the drainage system is not reduced. Bioreactors are typically located near field edges so little or no land needs to be taken out of production and the wood chips may last 10 to 20 years with little maintenance.

3. **Constructed wetlands.**
   Drain water is discharged into a wetland constructed near the field edge. Within the wetland, nitrate is removed from the drain water, water movement is slowed, and biomass can be produced for other uses. Depending on local conditions, the wetland may take up production ground.

4. **Saturated buffers.**
   Drain water is distributed with a subsurface manifold parallel to the receiving waterway. Nitrate is removed from the water as it flows through the soil/wetland system to the waterway.

5. **Shallow drainage.**
   Drain lines are installed shallower than standard drainage systems. The shallower drains intercept and remove less water than deeper drains. Shallower drains may have to be installed with closer spacing to gain adequate crop benefits.

South Dakota drainage law delegates regulatory authority of drainage to the county level. So, an important first step in planning any drainage project is to consult with the county drainage board (in many counties, the board of county commissioners is also the drainage board). Other states have different governing authorities for regulating drainage activities. In addition to county regulations, the Swampbuster provisions introduced in the 1985 Food Security Act (Farm Bill) discourage the drainage of wetlands for agricultural use. Therefore, local USDA Farm Service Agency and Natural Resources Conservation Service offices must be consulted about drainage plans. Draining wetlands can result in the loss of farm program benefits.

When preparing a drainage plan, it is useful to gather background information from county soil surveys, topographic maps, aerial photos, climate data, local water management authorities, and drainage guides from neighboring states (e.g., Minnesota and Iowa). Obtaining detailed data (topographic surveys and soils characterizations) for areas to be drained is also useful.

**Economics**

A primary goal of subsurface drainage is increased profit for the producer. Because installing a subsurface drainage system involves a significant investment, an economic feasibility study should be conducted before installation. Factors that should be considered are expected yield response, impact on equipment and material costs, and costs of the drainage system over the life of the drainage system. Although
the actual lifetime of a well designed drainage system may be 50 to 100 years, the economic lifetime of the drainage system is often assumed to be 20 to 30 years.

Estimating values to use in the economic analysis, particularly yield response, is difficult. Comparisons of combine yield monitor data from poorly drained and adequately drained areas of a field may give some indications of potential yield response when drainage improvements are made. Other potential sources of information include neighboring producers who have installed drainage systems and drainage contractors. As examples of yield increases following drainage, results from an 11-year study in Ohio indicated that subsurface drainage increased soybean yields by 7 to 14 bushels per acre (Zucker and Brown, 1998), and data based on 20 years of yield records from Ontario showed yield increases of 8 bushels per acre (26% increase) for soybeans (Irwin, 1998).

Additional information is available in Hofstrand (2010) and online calculators.

Prinsco at http://www.prinsco.com/article.cfm?ID=96

Drainage outlet
Subsurface drainage systems perform only as well as the outlet, so good drainage design should begin by ensuring there is a suitable outlet. Typically, the drainage outlet is the lowest point in the drainage system. At the outlet, water is delivered to a natural or manmade open channel that is deep enough so that the bottom of the outlet is at least 1 foot above the normal low-water level in the waterway. Proper maintenance is needed to prevent drainage ditches from becoming clogged by sediment and/or by vegetation growth. Consequently, erosion and weed control are essential to ensure that these systems continue to function effectively.

Any existing drainage outlet should be checked to see if it can handle additional water, and if it is deep enough to allow the planned additional field drains to be placed at the desired depth. Pumped outlets may be considered where there is an otherwise adequate outlet that is not deep enough to allow for gravity drainage. The outlet should be protected from rodents or other small animals, washout, and erosion.

In addition to the physical requirements for an outlet described above, the outlet must also meet all legal and regulatory requirements for drainage outlets. In general, the drainage should occur through a natural or established watercourse and should not substantially alter the flow such that it causes unreasonable harm downstream. In many cases, downstream notification or approval may be required as part of the regulatory process. Regardless, drainage problems are often not limited to a single property, so working with neighbors to address drainage problems can result in more effective solutions and less potential for disputes.

Surface intakes
Surface intakes can be used to remove ponded water from closed depressions or potholes through the subsurface drainage system. If surface intakes are added to a subsurface drainage system, the system should be sized to accommodate the concentrated flow entering from the surface. Surface intakes can be a source of weakness in the drainage system, so offsetting them on a short lateral will help protect the main line.

By providing a direct connection to water at the surface, these intakes can serve as a shortcut for sediment, nutrients, or other pollutants to travel to downstream surface water bodies. Open intakes that are flush with the surface, in particular, should be avoided for this reason. Slotted or perforated risers allow for some settling of sediments before water enters the intake. A permanent grass buffer should be provided around the riser to trap sediment and other pollutants before they reach the intake. Rock or “blind” inlets are another option that eliminates the need for a riser by filtering out sediment before it enters the drain.
Drainage coefficient

The drainage system should be designed to remove excess water from the active root zone to prevent crop damage within 24 to 48 hours of excess precipitation. The rate at which the drainage system can remove water from the soil is commonly called the drainage coefficient, and it is a measure of the system capacity. The drainage coefficient is typically expressed as the depth of water removed in a 24-hour period (inch/day). Because drain spacing and sizing will be determined by the drainage coefficient, the choice of a drainage coefficient is an economic as well as an agronomic decision.

If surface inlets will be used to directly drain water from the surface through the drain pipes, a larger drainage coefficient should be used to account for the additional water coming from the surface. Typical drainage coefficients for humid regions are shown in Table 47.1. Choice of an appropriate drainage coefficient should be made based on local conditions, experience, and judgment. Because South Dakota is in a transition zone from humid to semiarid regions, a smaller drainage coefficient of $\frac{1}{4}$ inch per day may be an appropriate choice.

Table 47.1. Typical drainage coefficients for humid areas. (ASAE EP480 standard)

<table>
<thead>
<tr>
<th></th>
<th>No Surface Inlets (inch/day)</th>
<th>Blind Surface Inlets (inch/day)</th>
<th>Open Surface Inlets (inch/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mineral Soils</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field crops</td>
<td>$\frac{3}{8} - \frac{1}{2}$</td>
<td>$\frac{1}{2} - \frac{3}{4}$</td>
<td>$\frac{1}{2} - 1$</td>
</tr>
<tr>
<td>High value crops</td>
<td>$\frac{1}{2} - \frac{3}{4}$</td>
<td>$\frac{3}{4} - 1$</td>
<td>$1 - 1 \frac{1}{2}$</td>
</tr>
<tr>
<td><strong>Organic Soils</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field crops</td>
<td>$\frac{1}{2} - \frac{3}{4}$</td>
<td>$\frac{3}{4} - 1$</td>
<td>$1 - 1 \frac{1}{2}$</td>
</tr>
<tr>
<td>High value crops</td>
<td>$\frac{3}{4} - 1 \frac{1}{2}$</td>
<td>$1 \frac{1}{2} - 2$</td>
<td>$2 - 4$</td>
</tr>
</tbody>
</table>

Drain depth and spacing

The depth and spacing of parallel drains necessary to achieve a certain drainage coefficient are determined in large part by the hydraulic conductivity (permeability) of the soil and the depth to a low permeability barrier. For single targeted drains, the hydraulic conductivity and depth to the barrier will determine the effective distance from the drain that will be adequately drained given the depth of the drain. Depth and spacing should be considered simultaneously when trying to achieve a desired drainage coefficient.

As shown in Figure 47.2, the water table will be highest midway between two parallel drains and lowest at the drains themselves. The depth and spacing are chosen to maintain a minimum depth to the water table midway between the drains. The height that the water table will reach above the drains will be less for drains spaced more closely together. Therefore, deeper drains can be spaced further apart, whereas shallower drains need to be closer together to achieve the same drainage coefficient. Table 47.2 lists general drain depth and spacing recommendations based on soil type. More specific depth and spacing recommendations should be based on measured soil properties or drainage experience with similar soils and conditions. The SDSU Drain Spacing Calculator can help with drain spacing decisions.

http://climate.sdstate.edu/water/DrainSpacingCal.html
Drains are typically placed 3 to 4 feet deep. If possible, drains should be placed above shallow, low permeability layers. The minimum depths to avoid damage from heavy equipment are 2 feet for laterals (3 to 6 inch diameter pipes) and 2.5 feet for mains (8 inches or greater diameter pipes). Ideally drainage systems would have uniform depth, but field topography and the layout design will determine actual drain depths.

**System layout**

The layout of the drainage system, along with the design decisions made above, will determine the uniformity of drainage for the field or area. Drainage system layout is chosen to best match field topography, outlet location, and drainage needs of the field. Topography will dictate what layout options are practical.

There are several layout options available for drainage systems (Fig. 47.3). The layout may be complex or as simple as a single drain line from a wet spot in the field. Parallel drainage systems are used to drain large areas or entire fields of regular shape and uniform soils. Herringbone systems are typically used in relatively narrow depressions such as those along shallow drainageways. Double main systems are used where a larger or deeper drainageway divides the field. Targeted drainage systems are used where there are isolated wet areas that require drainage. Mains are run through natural low areas toward the outlet, and laterals may be added to provide drainage for larger wet areas.

For any layout pattern, a general guideline to follow when laying out the system is to align laterals along the field contours to the extent possible. This allows the laterals to act as interceptors of water as it moves down the slope. Collectors or mains are then placed on steeper grades or in swales to allow for a more uniform lateral gradeline.

**Drain grades and envelopes**

Drainage systems should be designed such that both minimum and maximum grade recommendations are followed. This is to ensure that flow velocities are within an acceptable range. The grade should be sufficient to prevent sediments from accumulating in the drains and shallow enough to prevent excessive pressure that

---

**Table 47.2. Typical drain spacing and depths for parallel drains for various soils. (Wright and Sands, 2001)**

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Permeability</th>
<th>Drain Spacing (ft) for:</th>
<th>Drain Depth (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fair Drainage (¼ inch/day)</td>
<td>Good Drainage (½ inch/day)</td>
</tr>
<tr>
<td>Clay loam</td>
<td>Very low</td>
<td>70</td>
<td>50</td>
</tr>
<tr>
<td>Silty clay loam</td>
<td>Low</td>
<td>95</td>
<td>65</td>
</tr>
<tr>
<td>Silt loam</td>
<td>Moderately low</td>
<td>130</td>
<td>90</td>
</tr>
<tr>
<td>Loam</td>
<td>Moderate</td>
<td>200</td>
<td>140</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>Moderately high</td>
<td>300</td>
<td>210</td>
</tr>
</tbody>
</table>

Figure 47.3. Typical drainage system layout options for lowering a water table.
could result in erosion of soil around the drain. Drains in stable soils (clay content greater than 25 to 30%) can be placed on shallower grades. Soils lower in clay with more fine sands and silt require steeper grades.

Table 47.3 lists the minimum recommended grades for various pipe sizes depending on whether fine sands and silts are likely to be a problem. In addition to minimum grades, the use of drain envelopes should be considered for soils high in fine sands and silts, particularly if shallower grades must be used. Materials used for drain envelopes include gravel, synthetic fiber membranes, and pre-wrapped geotextiles (or “socks”).

To prevent problems with excessive pressures and velocities, mains should not be placed on grades greater than 2% where practical. When steeper grades must be used, additional precautions should be taken, which may include the use of pressure relief wells. Large changes in grade, particularly steep-to-flat, should be avoided to prevent the risk of blowouts. Reversals in grade must always be avoided.

Table 47.3. Minimum recommended grades (% or ft/100 ft) for drainage pipes where CPE is corrugated polyethylene plastic pipe and smooth refers to smooth wall plastic pipe or concrete or clay tile. (ASAE EP480 standard)

<table>
<thead>
<tr>
<th>Inside diameter of drain (inch)</th>
<th>Drains not subjected to fine sand or silt (min. velocity of 0.5 ft/s)</th>
<th>Drains subjected to fine sand or silt (min. velocity of 1.4 ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CPE</td>
<td>Smooth</td>
</tr>
<tr>
<td>3</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>4</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>5</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>6</td>
<td>0.04</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**Drain pipe sizing**

The recommended size of drainage pipe depends on the area to be drained, the chosen drainage coefficient, the grade on which the pipe is laid, and the pipe materials (corrugated plastic or smooth-wall, plastic or concrete, pipe). To determine the required flow that the pipe must handle the following equation can be used:

\[
Q \text{ (cfs)} = \frac{\text{Area (acres) } \times \text{DC (inches/day)}}{23.8}
\]

Where Q is the required flow rate (capacity) in cubic feet per second (cfs), the area to be drained is in acres, and the drainage coefficient (DC) is in inches per day. For example, the flow capacity needed to drain 40 acres with a ½ inch drainage coefficient is: 40 acres x 0.375 inch/day ÷ 23.8 = 0.63 cfs.

To size the outlet, the total area to be drained by that outlet should be used. For sizing individual laterals, only the area drained by the lateral is used. If future expansion of the drainage system is likely, the outlet should be sized to accommodate that expansion. Once the required flow is calculated, the pipe size (diameter) necessary to carry that flow can be determined based on the grade and the pipe material. Figure 47.4 can be used to determine necessary pipe size for corrugated plastic pipe. Other sources for determining necessary pipe size include:

- Manufacturer’s literature.
- Slide calculators from drain pipe manufacturers (e.g., Prinsco, Hancor, and ADS).
- Web-based calculators:
  - [http://www.extension.umn.edu/AgDrainage/online calculator.html](http://www.extension.umn.edu/AgDrainage/online calculator.html)
- Drainage contractors and engineers.
Installation considerations

In addition to a good design, the quality of installation is also important in determining how well a drainage system will perform. Once a drainage system is installed, correcting any problems is difficult and expensive. It is, therefore, important to make sure that drainage installation is done on grade and is of high quality. An experienced and reliable contractor can be an asset in achieving a quality installation. The equipment used for installation can also influence the quality of installation. Tractor mounted and pull-type plows can perform well, but good grade control can be more difficult to manage.

Shallow or flat grades, in particular, have a smaller margin for error, so accurate grade control is especially important under those conditions. As-built plans showing the dimensions and locations of all drains should be prepared following or during (such as those created by GPS systems) installation and kept as part of the farm records. These plans will facilitate any future expansion or required maintenance of the

**Figure 47.4. Chart for determining the required diameter of corrugated plastic pipe based on the pipe grade (in percent) and the design drain discharge (in cubic feet per second).**

The solid black lines represent the discharge of a pipe of the size indicated that is flowing full based on the drain grade. The space between the solid black lines represents the range of pipe capacity for the pipe size indicated between the solid lines.

For drain grade and discharge combinations that do not fall directly on one of the solid lines, the next larger commercial pipe size would be chosen. For example, the required drain size for a drain grade of 0.07% and a design discharge of 0.15 cfs would be an 8-inch pipe (dashed black lines).

(Adapted from ASAE EP480 standard)
drainage system. Problems to watch for following installation include wet spots in the field where drains were installed, sedimentation at the outlet, blockages of the outlet, and erosion damage around the outlet.

**Saline seeps**

Another problem caused by excess water is the saline seep. A saline seep is the discharge location for shallow groundwater. The water also carries any soluble salts or nutrients that it encountered in the soil. Over time, the seep area becomes too wet and too saline, either reducing crop performance or preventing crop growth. Additional information on the management of saline soils is available in Chapter 53.

Saline seeps start when water from rain or snowmelt enters the soil in a recharge area. This recharge area is often located some distance from the seep and must be higher in the landscape (Fig. 47.5). If the water is not used by a crop in the recharge area, it eventually drains downward and leaves the root zone. If the water draining downward reaches a layer of high lateral permeability, then the water can move laterally in that layer. If the topography is such that the zone of high lateral permeability intersects or approaches the soil surface, the water will re-emerge on the soil surface as a saline seep.

![Figure 47.5. A diagram showing saline seep hydrology.](image)

As the water moves through the soil, it dissolves salts and soluble nutrients. If and when the water reappears on the soil surface, those salts and nutrients arrive with the water and are deposited on the soil surface. Magnesium and sodium salts are often found in seep areas. Seep areas with high sodium salts must be managed carefully (Chapter 53). Saline seeps can also have high nitrate-nitrogen concentrations.

The excess water in the seep can prevent access by equipment and reduce the plant root effectiveness. The salts interfere with water uptake and reduce or even prevent plant growth. Sodium salts can cause problems with the soil itself, reducing infiltration rates. Nitrate-nitrogen is a vital crop nutrient and can be used by growing plants. High nitrate concentration in these areas generally is not a concern unless it gains entry to a drinking water supply and causes nitrate-nitrogen concentrations in excess of the maximum contaminant level of 10 mg/L (ppm).

Control of a saline seep starts in the recharge area. The precipitation that falls on the recharge area must be prevented from leaving the root zone. That is, the crop (vegetation) water use must be increased in the recharge area so water is used up before it can drain out the bottom of the root zone. Crop water use can be increased with greater cropping intensity. One strategy for increasing the cropping intensity is annual cropping instead of fallow.
Another strategy is planting alfalfa in the recharge area. This is a good option because alfalfa has a high water use each growing season, and alfalfa has deep roots, using water and nutrients deeper in the soil profile, when compared to small grain crops. Planting alfalfa may not be required for the entire recharge area. In the central Great Plains, planting one-third of the recharge area to alfalfa has been shown to reduce water movement to a seep by one-half or more.

Any crop rotation that decreases the amount of time the recharge area is fallow will help reduce or eliminate the active mechanism supporting a saline seep. When the increased cropping intensity in the recharge area has effectively controlled the water, the seep area will respond in one or two years, depending on the weather. More rainfall will cause greater leaching in the seep, reducing the time until the area is fit again for crop production.

When the water is effectively controlled in the recharge area, some management practices in the seep area can hasten reclamation. Straw mulch has been shown to be effective at increasing the rate of salt removal from the seep area. Other practices that conserve soil water in the seep area will increase the rate of salt removal by increasing the water drainage and leaching.

Interceptor drains have been tried to reclaim saline seeps. However, the intercepted saline water poses a disposal problem. In addition, the interceptor drainage strategies have been shown to be less successful at reducing water and salt flow to the seep.

Irrigation has been used to impose downward water movement in the seep itself, moving water and salts downward and out of the root zone. This can be effective in moving salts out of the root zone, especially if accompanied by artificial drainage within the seep area. However, the drain water disposal issue is still a problem, and resalinization can occur during the non-growing (and non-irrigating) season.

In summary, saline seeps are caused by excess water coming from a location higher in the landscape. Reduction or reclamation of the saline seep starts with intensified cropping in the recharge area.

References and additional information
CHAPTER 47: Managing High Water Tables and Saline Seeps in Soybean Production


Acknowledgements
Thanks to Gary Sands, University of Minnesota, for providing illustrations and helpful comments. Funding provided by the SD Water Resources Institute, South Dakota Corn Utilization Council, USDA-NRCS, and USGS.

The purpose of this chapter is to discuss the hazards associated with salt-affected soils and to present guidelines for reducing the impacts of salts on soybeans production. South Dakota has many soils that are impacted by either high sodium (sodic) or high salts (saline), or by both high sodium and salts.

Salt problems are often discovered in low elevation areas. In the spring as the soil dries these zones may appear white. For sodic soils, extreme care must be used. High sodium has the added problem in that it can greatly reduce water infiltration. If a sodium problem is suspected, a soil sample should be collected and a water extract from that soil analyzed for Na, Ca, and Mg. Based on this value, the sodium adsorption ration (SAR) should be calculated. If the SAR is greater than 5, the long-term goal should be to prevent further degradation.

Correct identification of the problem is critical for improving profitability and long-term sustainability. Selected guidelines are provided in Table 48.1.
Salt problems, natural or man-made

Saline soils are those that contain high concentrations of soluble cations and anions (Ca$^{2+}$, Mg$^{2+}$, Na$^{+}$, K$^{+}$, SO$_4^{2-}$, NO$_3^{-}$, Cl$^{-}$), while sodic (Na$^{+}$) soils are those that contain high concentrations of sodium. High salt concentrations can result from weathering of soil minerals or an unintended byproduct of agricultural management. Minerals that may contribute to high salt concentrations include table salt (NaCl), baking soda (NaHCO$_3$), gypsum (CaSO$_4$), and calcite (CaCO$_3$). In saline soils, seed germination or plant growth can be reduced, while in sodic soils water infiltration can be reduced and emergence of seedlings can be impaired. Saline (high salts) and sodic soils require different management practices. Salt accumulation in South Dakota soils can result from interactions among management practices that impact local hydrologic cycles and natural processes.

Soils with salt problems can result from the weathering of soil and geologic parent materials, management, or a combination of both. A generalized saline risk map is provided in Figure 48.1. However, salt problems are not limited to high risk areas on the map. Within a field, salt has the potential to accumulate in some areas and not others. Generally poorly drained areas have a higher potential to have higher salts than well drained areas. The lack of subsoil drainage and periods of above normal precipitation (or management that conserves water, such as summer fallowing and no tilling) often contribute to rising water tables.

When water tables rise to within several feet of the surface, ground water, through capillary rise, may be transported to the soil surface where it evaporates or is transpired. When this happens, pure water is evaporated and/or transpired leaving the salts behind. These conditions will result in elevated salt concentrations. High salt concentrations can reduce seed germination and yields. In many South Dakota fields, salt accumulation is not a problem. This is especially true if irrigation water is not applied and/or if the water table is deeper than six feet.

Saline (salts) and sodic problems can also result from irrigating with low quality (high salt content) irrigation water. When irrigation water is applied to soils, the water is used by the plants leaving the salts behind. Over a period of time these salts accumulate. These salts can reduce seed germination, plant growth, and yields. Before developing a remediation program it is important to determine if the problem is the result of high salts (saline) or high sodium (sodic soil).
Using a saline remediation program on a saline soil or vise versa produces adverse consequences:

*In saline soils (high salts)* salts can be removed from the soil by: 1) installing tile drainage; and 2) using irrigation water in excess of the plant requirement, to leach salts from the soil surface.

*In a sodium soil,* a remediation program might consist of: 1) installing tile drainage, 2) applying gypsum to the soil surface, and 3) using high quality water (low salts and sodium) to leach Na from the soil surface.

![Figure 48.1](http://www.soilsci.ndsu.nodak.edu/DeSutter/TomDeSutter.html)

**Figure 48.1.** A map of the Northern Great Plains soils with a high risk potential for excessive soil salinity. Soils with EC > 4 dS/m constitute the high risk areas. (Source: [http://www.soilsci.ndsu.nodak.edu/DeSutter/TomDeSutter.html](http://www.soilsci.ndsu.nodak.edu/DeSutter/TomDeSutter.html))

![Figure 48.2](http://www.sdnotill.com/Newsletters/2003_Salt_Soils.pdf)

**Figure 48.2.** The percentage of sodic soils in South Dakota. In this map yellow is 10-20%, blue is 5-10%, green is 1-5%, and red is 20-30% sodium-affected soils. (Modified from Millar, 2003, [http://www.sdnotill.com/Newsletters/2003_Salt_Soils.pdf](http://www.sdnotill.com/Newsletters/2003_Salt_Soils.pdf))

### Measurement

Many different approaches are used to measure salinity (salts). Salinity can be measured in the field with an EM meter (Geonics) or with a Veris Soil EC Mapping System. Both of the systems measure apparent EC (EC$_a$). Because both systems measure EC in the field, their measurements are influenced by soil water and bulk density. As the soil dries, EC$_a$ decreases. In addition, soils with very high bulk densities or compacted layers can have very high EC$_a$ values.

In the laboratory, EC is typically measured on water using a saturated paste extraction or a 1:1 soil/water solution. Most saline soil remediation protocols, including South Dakota, are based on saturated paste values, while most soil testing laboratories conduct a 1:1 soil/water test. A saturated paste is made by adding water
to soil until it glistens and flows slightly when jarred. After allowing the mixture to equilibrate, the soil water solution is extracted by suction filtration. The electrical conductivity (dS/m) of the water is then measured.

Using a 1:1 test on saturated pasted recommendations can result in serious errors. For example, the EC of a soil sample determined by a local soil testing laboratory is 2 dS/m. Based on this value, you determine that raspberries (sensitive plant, Table 48.3) will have a minimal yield reduction. Based on this assessment you recommend that the producer plants 10 acres of pick-your-own raspberries. Two years later the producer comments to you that the raspberries died and that he (or she) planted the field with organic wheat, which did well.

The error in this assessment was that 1:1 soil test value was not converted to a saturated paste value. When converted, the 2 dS/m is converted to value ranging from 5 to 6 dS/m (Table 48.2). This example shows that prior to making recommendations, 1:1 EC values must be converted to saturated paste values (Table 48.2). According to Franzen (2007), the equations relating EC using a 1:1 soil to water extraction ratio are different for coarse (sands), medium (loams), and fine (clay) textured soils.

The equations for these soils are:

Coarse soil: \[ EC_{\text{saturated paste}} = 3.01 \times EC_{1:1} - 0.06 \]
Medium: \[ EC_{\text{saturated paste}} = 3.01 \times EC_{1:1} - 0.77 \]
Fine: \[ EC_{\text{saturated paste}} = 2.96 \times EC_{1:1} - 0.95 \]

<table>
<thead>
<tr>
<th>EC 1:1 dS/m</th>
<th>Saturated Paste EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse (sand)</td>
<td>Medium (silt loam)</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
</tr>
</tbody>
</table>

**Table 48.2. The relationship between EC measured using the 1:1 and saturated paste techniques.** (Modified from Franzen, 2007)

**Impact on plants**

Different plants have different tolerances to saline conditions (Fig. 48.3). A detailed list of plant salt tolerances is available at [http://www.fao.org/DOCREP/005/Y4263E/y4263e0e.htm](http://www.fao.org/DOCREP/005/Y4263E/y4263e0e.htm). A shortened list is provided in Table 48.3. Soybean is considered a moderately tolerant plant and has an EC saturated paste threshold value of 5.0 dS/m (Fig. 48.3; Maas, 1984). For moderately tolerant plants such as soybeans, each 1 dS/m increase above 5 dS/m results in a 20% yield loss. In addition to restricting plant growth, saline soils can restrict seed germination. Many plants have different tolerances for seed germination than for growth. For example, alfalfa has a low tolerance for seed emergence and moderate tolerance for plant growth.
Mapping soil salinity within a field

Several approaches can be used to assess the extent of salt problem. The first approach is targeted soils sampling. Areas that appear white as they dry often have high salt concentrations. An alternative approach is to map a field with either a Veris Technologies EC cart (http://www.veristech.com/products/soilec.aspx) or a Geonics EM 38 (http://www.geonics.com/html/em38.html) meter. These systems measure apparent EC because the readings are sensitive to many factors including salt concentration, bulk density, and soil water content.

Salinity management: Drainage

High salinity is often a symptom of a high water table. Drainage can be used to reduce salinity risks. On average, the soil EC value will decrease 0.5 dS/m for every six inches of water that percolates through the soil.

For tile drainage to be effective, a suitable outlet for the drainage water must be available. There are many places in South Dakota where surface drainage outlets are not available. In addition, there are drainage laws that require producers to work with local authorities and USDA-NRCS. Details about tile drainage are provided in Chapter 47.

### Table 48.3. A list of salt tolerances of selected plants

(Modified from Franzen, 2007)

<table>
<thead>
<tr>
<th>Salt Tolerance</th>
<th>Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitive</td>
<td>Beans, Carrot,</td>
</tr>
<tr>
<td></td>
<td>Raspberry</td>
</tr>
<tr>
<td>Moderately</td>
<td>Alfalfa, Corn,</td>
</tr>
<tr>
<td>sensitive</td>
<td>Flax, Cucumber</td>
</tr>
<tr>
<td>Moderately</td>
<td>Oats, Sorghum,</td>
</tr>
<tr>
<td>tolerant</td>
<td>Soybean, Sunflower</td>
</tr>
<tr>
<td>Tolerant</td>
<td>Barley, Canola,</td>
</tr>
<tr>
<td></td>
<td>Sugar beets, Durum wheat</td>
</tr>
</tbody>
</table>

![Figure 48.3. Relative crop yield potential as a function of soil salinity. (Developed from data by E.V. Mass, 1984)](http://www.veristech.com/products/soilec.aspx)
Salinity management: Cover and deep-rooted plants

In some situations, perennial deep-rooted crops, such as alfalfa, can also be used to lower the water table and reduce salinity problems. Alfalfa may not germinate in the saline area, but seeding in strips several hundred feet wide in non-saline areas just above the saline spot may be effective in reducing the water table. Seeding a salt-tolerant crop such as Tall Wheat grass or barley within a salinity pocket may also be effective in lowering the water table. Cover crops seeded in the fall may be used to reduce the water table. Lowering the water table reduces capillary rise and provides the opportunity for salts to leach.

Tillage in saline areas

In South Dakota there is a significant opportunity for salt leaching from fall, winter, and spring precipitation, assuming the water table is not close to the soil surface. Deep tillage or ripping should be used with caution because it has produced inconsistent impacts on salt concentrations. Spring tillage has the potential to reduce seed germination by moving salts leached during the fall and spring to the soil surface. For many fields with adequate natural and tile drainage, techniques that reduce surface soil evaporation, such as no-till and minimum till, have been used successfully.

Soil amendments for saline areas

A saline soil has a high concentration of total salt. The application of materials such as gypsum (calcium sulfate) will not resolve the salt issue. In fact, gypsum is a salt and therefore its addition may make the problem worse.

Sodium-affected soil

Sodium (Na) is a salt that requires special attention (Figs. 48.2 and 48.4). High concentrations of sodium on the soil exchange complex when combined with low salt concentrations in the soil water solution can destroy the soil structure. Soils with high Na concentrations will be cloddy with poor infiltration. Drainage of high Na soils without adding an appropriate surface treatment (CaCl₂, CaSO₄, or elemental S) is very risky. Many tile-drained fields fall into this category. If drainage through tile lines appears to be slowing with time, you may be at risk. It is important to point out that an analysis of the tile-drained water does not provide an accurate assessment of the Na risk in the surface soil.

The sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) are two calculations used to estimate Na risk. Both calculations provide estimates of the relative amount of Na contained in the soil. Due to cost, most recommendations are based on the SAR value. If a Na problem is suspected, a soils specialist should be contacted for advice. In dryland agriculture, the drainage of soils with sodium adsorption ratios greater than 5, without the addition of Ca or lowering the pH, can result in soil dispersion. Sample calculations to determine the soils SAR are shown in Problem 48.1.
Problem 48.1. Sample calculations for determining SAR values.

A soil sample is sent off to a laboratory for analysis. In this analysis a saturated paste (approximately 100 g soil + 60 ml water) is made and equilibrated for 24 hours. The water is extracted by vacuum and the Na, Ca, and Mg determined. The water analysis of a soil/water saturated paste is 2136 ppm Na, 2181 ppm Mg, and 3198 ppm Ca. SAR is calculated below.

A list of laboratories that could conduct the analysis is provided in Chapter 18.

Answer to Problem 48.1.

Note: When doing this calculation, it is important to know that Na has a valance of +1, Ca has a valance of +2, and Mg has a valance of +2. The valances are used to convert mmol to mmolc.

Step 1. Convert ppm to mmolc/L. For this conversion 1 ppm = 1 mg/L

\[
\frac{\text{Na mmol}_c}{\text{L}} = \frac{2136 \text{ mg Na}}{23 \text{ mg Na}} \times \frac{\text{mmol Na}}{1 \text{ mmol Na}} = 92.9 \text{ mmol}_c/\text{L} \\
\frac{\text{Mg mmol}_c}{\text{L}} = \frac{2180 \text{ mg Mg}}{24.3 \text{ mg Na}} \times \frac{\text{mmol Mg}}{2 \text{ mmol Na}} = 179.3 \text{ mmol}_c/\text{L} \\
\frac{\text{Ca mmol}_c}{\text{L}} = \frac{3198 \text{ mg Na}}{40 \text{ mg Na}} \times \frac{\text{mmol Ca}}{2 \text{ mmol Na}} = 159.9 \text{ mmol}_c/\text{L}
\]

Step 2. Calculate SAR

\[
\text{SAR} = \frac{\left(\frac{\text{mmol}_c \text{ Na}}{\text{L}}\right)^{0.5}}{\left(\frac{(\text{mmol}_c \text{ Ca} \div \text{L} + \text{mmol}_c \text{ Mg}}{2}\right)^{0.5}} = \frac{92.9}{\left(\frac{(179 + 160)}{2}\right)^{0.5}} = 7.1
\]

Reclamation of sodium-affected soils

As a rule of thumb, South Dakota soils should not exceed a sodium adsorption ratio (SAR) (~exchangeable sodium percent, ESP) values of 5. The reclamation of sodium soil is slow because it can take a long time to rebuild the structure. One relatively inexpensive approach to improve the soil structure is to apply low Na containing manure or to apply crop residues to these areas. The organic matter in these materials can help stabilize and improve soil structure. It must be pointed out that not all manures have low Na concentrations.

Manure from animals that have high concentrations of NaCl in their rations may not be desirable. For example, 1) distillers grains from ethanol plants may be treated with sodium chloride; and 2) swine, poultry, and beef that are often supplemented with NaCl. Many animals have diets supplemented with NaCl because the plant materials do not provide enough Cl or Na to meet the animals’ nutritional requirement.

A second approach is to replace the Na on the soil exchange site with calcium. For this treatment, CaCl_2 is often the most effective materials. However it also is very expensive. A less expensive Ca source is gypsum (CaSO_4 \cdot 2H_2O). For a typical South Dakota soil with a cation exchange capacity (CEC) of 25 cmol / kg and a SAR value of 12, a one-ton application of gypsum per acre would be needed to lower the SAR value of the surface 6 inches to 8. To lower the SAR value to 4, about 2 ton/acre of gypsum are needed. For this calculation, the CEC can be estimated from the organic matter and clay contents of the soil (Fig. 48.6).
Sample calculations are below:

**Figure 48.6.** A soil contains 3\% organic matter and 20\% smectite clay. What is its estimated cation exchange capacity (Clay et al., 2011)?

<table>
<thead>
<tr>
<th>Soil component</th>
<th>CEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic matter</td>
<td>200 cmol_c k_soil</td>
</tr>
<tr>
<td>Smectite clay</td>
<td>100 cmol_c k_soil</td>
</tr>
</tbody>
</table>

\[
\text{Cation Exchange Capacity} = \frac{\% \text{ clay}}{100} \times CEC_{\text{clay}} + \frac{\% \text{ Organic matter}}{100} \times CEC_{\text{organic matter}}
\]

\[
\text{Cation Exchange Capacity} = \frac{20\%}{100} \times \frac{100 \text{ cmol\_c}}{\text{kg}} + \frac{3\%}{100} \times \frac{200 \text{ cmol\_c}}{\text{kg}} = \frac{26 \text{ cmol\_c}}{\text{kg}} = \frac{26 \text{ mmol\_c}}{100 \text{g}}
\]

Calcium can also be released by lowering the pH. The soil pH can be lowered by adding elemental sulfur. To increase the effectiveness of elemental S it should be mixed into the soil. The amount of S that needs to be applied can be calculated from data provided in Table 48.4. To displace the Na from the soil exchange site, good quality water must be added.

**Table 48.4.** Relative amount of different soil amendments needed to reduce Na on the exchange site.
Rates for alternative substances determined by taking recommended amount of Gypsum times base amount of alternate substance.

<table>
<thead>
<tr>
<th>Recommended Amount of Gypsum tons/acre</th>
<th>Amount of CaCl_2 tons/acre instead of Gypsum</th>
<th>Amount of Elemental S tons/acre instead of Gypsum</th>
<th>Amount of Aluminum sulfate tons/acre instead of Gypsum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0.85 (base)</td>
<td>0.19 (base)</td>
<td>1.29 (base)</td>
</tr>
<tr>
<td>1.5</td>
<td>1.28</td>
<td>0.29</td>
<td>1.94</td>
</tr>
<tr>
<td>2.0</td>
<td>1.7</td>
<td>0.38</td>
<td>2.58</td>
</tr>
</tbody>
</table>

**Summary**

Saline (high total salts) and sodic (high sodium) must be managed differently. In managing saline and sodic soils care must be used to prevent further degradation.

**In saline soils**, recommended practices include:

- Collect soil and water samples to identify the scope and magnitude of the problem.
- Analyze the soil samples for both EC and SAR.
- Convert 1:1 EC values to saturated paste values (Table 48.2).
- Track changes in EC and SAR over time.
- Seed salt tolerant plants.
- Treat soil with crop residues to increase water infiltration.
- Eliminate sources of new salt.
- Use practices that reduce surface evaporation.
- Provide subsurface drainage.
In sodic soils, recommended practices include:

- Collect soil and water samples to identify the scope and magnitude of the problem.
- Analyze the soil samples for EC and SAR.
- Track changes in EC and SAR over time.
- Seed full season, deep-rooted plants.
- Eliminate sources of new Na.
- Use practices that reduce surface evaporation.
- Minimize the use of tillage which brings Na to the soil surface and reduces residue cover.
- Eliminate fallow.
- Apply crop residues to increase infiltration.
- Provide subsurface drainage and treat with a Ca source such as gypsum.

Salt problems are often discovered in low elevation areas. In the spring as the soil dries, these zones may appear white. In these areas, water and the salts dissolved in the water rise through capillary movement from the water table to the surface. As the water evaporates at the soil surface it is replaced by more water from the water table. The net result is an accumulation of salts. This net gain of salts can be reduced by installing tile drainage; planting full season, deep-rooted plants; and eliminate fallow. The most important management consideration for these areas is to maximize transpiration and minimize evaporation (Franzen, 2007).

For sodic soils, extreme care must be used. High sodium has the added problem in that it can greatly reduce water infiltration. If a sodium problem is suspected, a soil sample should be collected and a water extract from that soil analyzed for Na, Ca, and Mg. Based on this value, the SAR should be calculated. If sodium is a problem, the SAR is greater than 5-8, then a long-term goal should be to prevent further degradation. This can be accomplished by tracking changes in the EC and SAR values of the soil, installing tile drainage, adding low Na manure or gypsum, or lowering the pH (if the soil pH is high) with elemental S. If drainage and soil amendments are not possible, consider placing the field into pasture and planting it with salt-tolerant grasses.

References and additional information
USDA. 1954. Diagnosis and improvement of saline and alkali soils. Agric. Handbook. No. 60. United States Salinity Laboratory, Riverside, CA. Available at http://www.ars.usda.gov/sp2UserFiles/Place/53102000/hb60_pdf/hb60complete.pdf

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Soybean Irrigation

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Corn and soybeans require different irrigation management practices. These differences are the result of physiological differences between the plants. For soybeans, the most critical period is between R2 to R6 growth stages (Chapter 3). This chapter discusses when and how much irrigation water to apply and how to manage the salts contained in the water.

Irrigating soybeans

Irrigation or high rainfall that occurs during vegetative growth stages may not increase yields unless the soil water contents are extremely low. In many moderate- to fine-textured soils, early season irrigation can actually stimulate vegetative growth without increasing soybean yields (Kranz and Specht, 2012). Due to little available water in sandy soils, early season irrigations maybe required to germinate the seed and encourage growth. For soybeans, water stress between R2 to R6 (Chapter 3) can greatly reduce yields. Irrigation during this period of time typically increases the number of seeds per plant and yield per acre. However, it may also increase the disease potential. A good approach for irrigating soybeans is to match irrigation water with the most sensitive growth stages of plants.

Climatic conditions

In South Dakota, average annual precipitation ranges from less than 13 inches to nearly 30 inches, generally increasing from west to east (Fig. 49.1). However, all regions of South Dakota can experience drought. Irrigation can reduce a crop's dependence on natural rainfall and improve yields. If you are planning a new system or expanding an existing system, equipment and management options should be discussed with your local irrigation equipment dealer or Extension specialist. All irrigation systems in South Dakota using more water than 18 gpm require a water right permit pursuant to procedures in SDCL Chapter 46.2A. For permit requirements, contact the South Dakota Department of Environment and Natural Resources (http://denr.sd.gov/des/wr/watrightsapps.aspx).
Soil-water-plant relations

The amount of water retained and available for plant growth from the soil is dependent on the soil texture and organic matter content. Soil serves as a water storage reservoir for the plant, though not all soil water is available to the plant (Fig. 49.2).

Figure 49.2. Soil water availability related to saturation, field capacity, and wilting point. The allowable depletion can vary based on growth stage and management considerations and is usually 50% or 70% of the available water. (Image courtesy of Gary Sands, University of Minnesota; and Chris Hay, SDSU)
The water-holding properties of soil are similar to a sponge. When a sponge is placed in a bucket of water, all the pores in the sponge are filled to the saturation point with water. When the saturated sponge is removed from the bucket, some of the water freely drains out of the sponge. When soil is at its maximum water-holding capacity, soil is referred to as saturated. After water has drained freely from the soil for a couple of days, the soil water content reaches field capacity (Fig. 49.2). Water content can continue to decrease until permanent wilting point is reached. Water held by the soil between field capacity and permanent wilting point is called available water and varies by soil texture (Table 49.1).

### Table 49.1. Ranges of available water for different soil textures. (Werner, 1993)

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Available Water, inch/foot of soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine sands</td>
<td>0.7 – 1.0</td>
</tr>
<tr>
<td>Loamy sands</td>
<td>0.9 – 1.5</td>
</tr>
<tr>
<td>Sandy loams</td>
<td>1.3 – 1.8</td>
</tr>
<tr>
<td>Loams</td>
<td>1.8 – 2.5</td>
</tr>
<tr>
<td>Silt loams</td>
<td>1.8 – 2.6</td>
</tr>
<tr>
<td>Clay loams</td>
<td>1.8 – 2.5</td>
</tr>
<tr>
<td>Clays</td>
<td>1.8 – 2.4</td>
</tr>
</tbody>
</table>

As soil dries and approaches permanent wilting point, the remaining water becomes more difficult for the plant roots to extract. Soybean yield response to water stress will vary according to the growth stage of the plant.

To be most effective, water must be stored in the soil zone containing a majority of the soybean roots. Early in the growing season, the roots may be concentrated in the surface twelve inches. As the season progresses, roots can extend down to five feet. But irrigations should be scheduled to manage the water in the surface three feet unless local knowledge or experience suggests otherwise.

The relative amount of water lost from the soil to transpiration (water lost through the leaves to the air) and evaporation (water lost from the soil to the air) changes during the year. At planting, evaporation is the most important water-loss mechanism; however, when the crop canopy has fully developed, the major water-loss mechanism is transpiration.

**Irrigation scheduling**

Irrigation scheduling is the process of matching plant requirements to your ability to provide the water. The amount and timing of the irrigation is dependent on plant requirements as well as the irrigator preference, the amount of water contained in the soil, the soil characteristics, the water availability, the equipment capacity, and amount of water used since the most recent irrigation.

When scheduling irrigation, it is important to realize that heavy irrigations (saturating at least the top two feet of soil) are typically more effective and may take less time than several light irrigations. Wetting the soil to deeper depths also promotes deeper root development; light irrigations promote shallow rooting, which may lead to nutrient deficiency or lodging problems later in the season.

The most widely used approach for irrigation scheduling is called the Checkbook Approach (Werner, 1993). Whether using the checkbook approach or another method, soil water content should occasionally be measured.
The Checkbook Approach for irrigation scheduling

The Checkbook Approach is often called the Water Balance method. This method adds water received from rainfall and irrigation to the water balance and subtracts crop evapotranspiration (ET). To maximize productivity, the field should be irrigated before readily available water has been depleted. Detailed information for this approach is available at http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC897.pdf. There are many software implementations of the water balance method. Some of them are listed at http://irrigation.wsu.edu/Content/Resources/Irrigation-Scheduling-Aids-Tools.php.

The checkbook approach utilizes the following tools:
- a rain gauge to measure rainfall and irrigation
- estimated ET\(_c\) values
- soil water balance worksheets
- soil water content measurements (to validate balances)

Evapotranspiration (ET), which is the loss of water from both evaporation and transpiration, is calculated using weather data (i.e., temperature, wind, and relative humidity) and crop information. Values of ET\(_c\) vary by climate across South Dakota (Fig. 49.3 and Table 49.2). Daily values of soybean ET\(_c\) are published on the South Dakota State Climatologist's website (http://climate.sdstate.edu/awdn/et/et.asp). If you are located close to a weather station, these are the most accurate estimates of ET. If a weather station is not located near your farm, ET can be estimated by measuring evaporation with an instrument such as an atmometer (Irmak et al., 2005). If neither method is available, long-term averages can be used (Werner, 1993).

Figure 49.3. Evapotranspiration (ET) regions of South Dakota.

For irrigation planning, South Dakota can be divided into regions: West, Central, and East (Fig. 49.3). Daily water-use estimates are used to calculate water use over the season and are also used to estimate water use between irrigations for scheduling (Table 49.3). For example, to estimate seasonal irrigation requirements, daily water-use values (Table 49.2) are summed and compared with your field's expected rainfall estimates. The difference between daily water use and expected rainfall is the irrigation potential.
Table 49.2 Estimated soybean water use per day in South Dakota. (Werner, 1993)

<table>
<thead>
<tr>
<th>Weeks After Emergence</th>
<th>Central Region</th>
<th>East Region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum Temperature, °F</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50-59</td>
<td>70-79</td>
</tr>
<tr>
<td>Inches of water used/day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>3</td>
<td>0.02</td>
<td>0.05</td>
</tr>
<tr>
<td>5</td>
<td>0.04</td>
<td>0.08</td>
</tr>
<tr>
<td>7</td>
<td>0.07</td>
<td>0.14</td>
</tr>
<tr>
<td>9</td>
<td>0.10</td>
<td>0.19</td>
</tr>
<tr>
<td>11</td>
<td>0.10</td>
<td>0.21</td>
</tr>
<tr>
<td>13</td>
<td>0.09</td>
<td>0.19</td>
</tr>
<tr>
<td>15</td>
<td>0.06</td>
<td>0.11</td>
</tr>
<tr>
<td>17</td>
<td>0.03</td>
<td>0.06</td>
</tr>
</tbody>
</table>

For the Checkbook Approach, rainfall should be measured at your location. The total (gross) rainfall should not be entered into the checkbook irrigation schedule. Instead, use effective rainfall, which is the amount of rain that actually soaked into the soil and is available to the crop. Effective precipitation can be estimated by measuring the gross rainfall and subtracting an estimate of how much of the rain ran on or off the field. The effective rainfall is usually less than the measured rainfall because more runoff leaves the field rather than running onto the field from a neighboring field.

One approach to estimating effective precipitation is to include all rainfall up to 0.2 inch then include 80% of any rainfall greater than 0.2 inch. If the crop is at full cover, a small amount (up to 0.05 inch for soybean or corn) may be subtracted for water intercepted and retained by the leaves. Additional details for estimating effective precipitation can be found at Cahoon et al. (1992).

Table 49.3. Irrigation scheduling example: Keeping the soil profile full.

This irrigated soybean field is near Beresford, SD. The rainfall and crop evapotranspiration (ETc) data were retrieved from http://climate.sdstate.edu. The field is irrigated with a center pivot. The soil in the field is a uniform silt loam with available water of 2.2 inches per foot. The irrigator manages the center pivot by setting the speed to make the full circle once every 4 days and apply 1 inch (gross irrigation) during that revolution. The application efficiency of the irrigation system is 85% so the net irrigation is 0.85 inch for the gross irrigation of 1 inch.

The center pivot was started on July 31, 2011, and completely refilled the soil profile. That is, the soil water deficit was 0 after the center pivot passed over. The crop looks good and the irrigator wishes to keep the soil profile as close to field capacity (full) as possible. After the center pivot completes its circle on August 3, what should the irrigator do on August 4? All values are in inches.

<table>
<thead>
<tr>
<th>Date</th>
<th>ETc</th>
<th>Eff Rain</th>
<th>Gross Irr</th>
<th>Net Irrig</th>
<th>Depletion</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 31, 2011</td>
<td>0.42</td>
<td>0</td>
<td>1</td>
<td>0.85</td>
<td>0</td>
</tr>
<tr>
<td>Aug. 1, 2011</td>
<td>0.32</td>
<td>0</td>
<td>1</td>
<td>0.85</td>
<td>0.42</td>
</tr>
<tr>
<td>Aug. 2, 2011</td>
<td>0.23</td>
<td>0</td>
<td>1</td>
<td>0.85</td>
<td>0.74</td>
</tr>
<tr>
<td>Aug. 3, 2011</td>
<td>0.23</td>
<td>0</td>
<td>1</td>
<td>0.85</td>
<td>0.97</td>
</tr>
<tr>
<td>Aug. 4, 2011</td>
<td>0.24</td>
<td>0</td>
<td>1</td>
<td>0.85</td>
<td>0.36</td>
</tr>
</tbody>
</table>

The crop has used enough water so the depletion is great enough to hold another entire irrigation. The irrigator can keep the center pivot running on August 4 without losing water to excessive runoff or drainage.
Soil water measurement

Checkbook balances should be periodically checked against measured soil water content. Soil water status can be 1) estimated by the “hand-feel” method, 2) measured from soil samples by calculating the gravimetric water content, or 3) monitored with sensors.

1. The hand-feel method is fast and inexpensive (NRCS, 1998).
   This method involves “feeling” a soil of known water content and comparing that to a soil with unknown water content; available water is estimated by how the soil “feels” in your hand. Note that a “same” amount of available water for different soil textures will “feel” different, so you need to “calibrate” your feel to the different soil textures that are found in your fields. Obviously, hand-feeling is the least accurate method, but it can be effective with some practice.

Samples should be collected from areas of the field with soil types that represent a majority of the field. Enough samples should be tested to get a consistent sense of the average conditions in the field. If the soil and water content are consistent, two or three samples may be adequate. Samples should be collected from enough depths to adequately represent the root zone. Use a hand soil probe or trenching spade to collect samples deeper than the top few inches.

2. Gravimetric water content is measured by collecting samples and calculating the weight difference between wet and oven-dried samples.
   The problem with oven drying samples is that drying may take several days. This problem can be overcome by using a microwave oven to dry the samples (Schneekloth et al., 2007). Drying with a microwave oven is much quicker than drying with a conventional oven and can provide water percentage estimates within an hour of collecting the sample. Samples should be collected from areas with representative soil types, similar to sampling with the hand-feel method. The depths of sampling should reflect the root zone of the soybean (as deep as three feet). The percent water is calculated with the following equation:

\[
\% \text{ water} = \left( \frac{\text{wet weight of soil} - \text{dry weight of soil}}{\text{dry weight of soil}} \right) \times 100\%
\]

3. Soil water content or status can also be measured with sensors placed in the soil.
   Three commonly used sensors are gypsum blocks (Werner, 2002), granular matrix blocks (e.g., WaterMark®, Irmak et al., 2006), or tensiometers (Kranz et al., 1989). Gypsum or granular matric blocks measure soil water content or provide readings that are correlated to soil water content. Tensiometers provide readings of soil water potential, or energy with which the water is held to the soil particles.

For irrigation scheduling, sensors should be placed at multiple depths (6”, 18”, and 30”) at both the start and endpoint of the irrigation system. That requires a minimum of two locations in a pivot-irrigated field. It is preferable to have more locations to average out some of the soil variability. Additional sensors might be required to monitor soil water in an area of different soil types (e.g., a sandy area) if the area with the different soil type is large. When placing a soil water sensor, push a soil probe into the soil to the desired depth. With soil from that depth, make a thin slurry with soil and water, insert the sensor into the hole, and pour the slurry into the hole. The slurry helps ensure good contact between the soil and the sensor.
Another way to describe soil water is to consider soil water depletion. Soil water depletion is the amount of water required to bring the root zone back to field capacity. When the soil is at field capacity, depletion is zero. Optimal irrigation efficiency is realized when irrigation water is applied in the amount equal to depletion. Runoff and deep drainage can result when water is applied in excess of depletion. Excess irrigation water application not only diminishes irrigation efficiency, but also can result in soil, nutrient, and pesticide losses from runoff and leaching.

**Critical plant growth stages**

Adequate soil water is needed for germination; therefore, if the soil is dry, irrigation may be needed to improve germination and seedling vigor. As the crop develops, moist soil is needed for root development. Check your fields by probing to discover if there are any layers of dry soil in the profile. Irrigation may be needed earlier than expected to wet deeper soil layers. Most irrigation systems cannot keep up with crop water demands during the later critical growth periods when the weather is often warmer and drier (Werner, 1993); therefore, some planning with estimated water use values (Table 49.2) can be beneficial.
Soybean is most sensitive to water stress from the beginning of flowering all the way through pod filling. Soil water depletion should not be allowed to exceed 50% after flowering begins. Soybean is less susceptible to water stress during the early stages of growth and development, prior to flowering. Soil water depletion up to 70% is allowable during vegetative growth prior to flowering.

At the end of the growing season, it is wise to deplete as much water as possible from the root zone. Depleting soil water at the end of the season minimizes the risk of nutrient leaching, allows you to take advantage of any off-season precipitation, and allows for surface-soil drying prior to harvest.

Monitoring soil water content can provide valuable information related to when to terminate irrigations. Rather than terminating irrigation at a given date, you should monitor weather forecasts, crop development, and soil water content to estimate how much water will be required to get the crop to maturity. Terminating irrigation early does not promote early maturing and dry-down of the grain (Werner, 1993).

**Irrigation systems**

Surface irrigation systems have been used for millennia. Surface irrigation uses the soil surface for water conveyance and the soil profile for water storage (http://waterquality.colostate.edu/CornBook/64Irrigation.pdf). Water is available to infiltrate into the soil longer at the top of the field, so more water is stored in the soil profile in that area.

The uniformity of water distribution can be improved by minimizing the length of run. Short runs that reduce the difference of infiltration time between the top and bottom of the field can improve water-distribution uniformity. An alternative is to optimize the uniformity by increasing the water inflow rate to a maximum, without causing excessive soil erosion at the top of the field. This advances the water as quickly as possible across the field and reduces the difference in infiltration time. Other methods for increasing uniformity include surge irrigation, cutback irrigation, furrow packing (usually for the first irrigation), and the use of polyacrylamide (PAM) soil amendments.

Sprinkler systems, including center pivots, are the most popular irrigation systems in South Dakota. Center pivot systems can reduce labor requirements (compared to surface irrigation), increase distribution uniformity and irrigation efficiency (potentially, for the latter), and allow the effective application of fertilizer

---

**Table 49.5. Irrigation scheduling during wetter, cooler weather.**

During 2010, rain was more plentiful. The same irrigated field near Beresford received a 2-inch rain that refilled the soil profile on July 30. When should the producer irrigate again to keep the soil profile full but not waste water? All values are in inches.

<table>
<thead>
<tr>
<th>Date</th>
<th>$\text{ET}_c$</th>
<th>Eff Rain</th>
<th>Gross Irrig</th>
<th>Net Irrig</th>
<th>Depletion</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 30, 2010</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>July 31, 2010</td>
<td>0.21</td>
<td></td>
<td></td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>Aug. 1, 2010</td>
<td>0.28</td>
<td></td>
<td></td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Aug. 2, 2010</td>
<td>0.12</td>
<td>0.45</td>
<td></td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>Aug. 3, 2010</td>
<td>0.12</td>
<td>0.20</td>
<td></td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Aug. 4, 2010</td>
<td>0.23</td>
<td></td>
<td></td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>Aug. 5, 2010</td>
<td>0.21</td>
<td></td>
<td></td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Aug. 6, 2010</td>
<td>0.23</td>
<td></td>
<td></td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>Aug. 7, 2010</td>
<td>0.28</td>
<td></td>
<td></td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>Aug. 8, 2010</td>
<td>0.21</td>
<td>0.70</td>
<td></td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>Aug. 9, 2010</td>
<td>0.14</td>
<td></td>
<td></td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Aug. 10, 2010</td>
<td>0.20</td>
<td>0.25</td>
<td></td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>Aug. 11, 2010</td>
<td>0.25</td>
<td></td>
<td></td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>Aug. 12, 2010</td>
<td>0.26</td>
<td></td>
<td></td>
<td>1.12</td>
<td></td>
</tr>
</tbody>
</table>

The small rainfall amounts on August 2 and 3, coupled with the lower values of $\text{ET}_c$ because of the cooler weather, resulted in depletions of less than an inch until August 7. The irrigator might have started the pivot on or about August 7. Given the cool, wet weather, the irrigator might have waited until August 12 or later.
or pesticides with the irrigation water. With center-pivot systems, nozzles can be placed either on the pipe or near the soybean canopy.

Historically, sprinkler irrigation systems had high operating pressures, wide sprinkler spacings, and sprinklers that were mounted well above the crop canopy. These systems generally had low application rates. To reduce energy costs, many high pressure systems have been replaced with low pressure systems. Low pressure systems have closer nozzle spacings that often are nearer to the ground.

In many fields, drop hoses or pipes can be used to lower the nozzles to just above or even into the crop canopy. Where water supplies are greatly diminished and irrigation systems have limited capacity, nozzles have been installed as low as two feet above the soil surface. In some cases the pipe has been covered with a sock that drags on the ground so that water is applied directly to the soil surface.

Placing the nozzles near to the soil surface reduces the amount of water that might be lost to wind drift or evaporation. The danger of this approach is that runoff can be increased. If you are considering installing nozzles near the soil surface, be sure that your soils have high infiltration rates (>0.25"/hr). In addition, nozzles must be spaced more closely together (approximately five feet apart).

Many irrigated fields will be in a corn-soybean crop rotation. Installing nozzles near the top of a mature corn canopy (approximately seven feet) is a good compromise in those situations. This allows for a wider spread of water from the nozzles while still reducing wind drift and droplet evaporation.

Subsurface drip irrigation (SDI) is a type of microirrigation system. SDI systems have high water-use efficiency and have been used to irrigate many different crops in the central and southern high plains of the United States. A disadvantage with these systems is that they are expensive to install. They are not commonly used in South Dakota, but may be an option for areas poorly suited to center-pivot irrigation (e.g., some field shapes, small field sizes, and so on) and for high value crops.

Managing salinity and sodium problems

Salts most often interfere with crop water uptake and can reduce yields and crop quality. To prevent salt accumulation in irrigated systems, monitor the salinity (i.e., total salt content—measured as electrical conductivity) and sodium content of water and soil. Salt accumulation can be hastened when several small irrigations are applied rather than fewer, deeper irrigations. Yield impacts from salts (salinity) vary greatly with management, soil type, and weather conditions. If salinity or sodium problems are suspected, consult with a crop consultant or an Extension specialist.

When preparing to irrigate, a water sample should be collected and analyzed for salts (electrical conductivity) and sodium (Na) content. A good lab should be used to analyze the salinity of the water sample, address the compatibility of the water and soils for irrigation, and provide recommendations to manage the salinity.

Salt problems often occur in soils with poor internal drainage. Layers of low permeability restrict the flow of water "out the bottom" more slowly than evapotranspiration removes water from the upper profile. To avoid the accumulation of salts in irrigated situations, the soil must have adequate drainage capacity, even if your water quality is relatively good. Water must move freely through the soil, leave the root zone, and carry with it some salts. Without adequate drainage capacity, salts will build up over time and cause problems with soil nutrient holding capacity and stunted crop growth. In poorly drained situations, select salt-tolerant crops and/or install artificial drainage to remove excess water and salts from permeable soils. County, district, federal, or state drainage laws may apply to artificial drainage systems.

Salt accumulation in the soil profile can also be managed by applying extra water to leach the salts from the soil profile. The amount of water needed is referred to as the leaching requirement (LR).

\[
LR = \frac{\text{irrigation water EC (dS/m)}}{\text{acceptable deep drainage EC (dS/m)}}
\]
Leaching can occur naturally when the soil is wet enough for water to move downward, driven by gravity. This happens most often during spring snow melt and thaw. It can also happen during the growing season if a large rainfall occurs when the soil water content is already high.

Soybean is considered moderately tolerant to salinity, but the tolerance can vary widely among varieties. A deep drainage EC threshold of 5 dS/m has been reported for soybean, above which yield loss occurs. For each 1 dS/m increase of deep drainage EC, approximately 20% of the yield will be lost.

<table>
<thead>
<tr>
<th>Table 49.6. Example of calculating the leaching requirement.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A water sample is collected and analyzed by a reputable lab. They report the EC of the irrigation water as 2 dS/m. You know that the deep drainage EC threshold for yield loss for soybean is 5 dS/m. Thus, the leaching requirement (LR) for your situation is 2 dS/m divided by 5 dS/m, or 0.4. That is, the water application amount should be 40% greater than the crop water needs to help leach salts out the bottom of the root zone. If the soil salinity increases enough so that the deep drainage EC is greater than 5 dS/m, soybean yield will be decreased.</td>
</tr>
</tbody>
</table>

Extreme care must be used in soils with high sodium (Na) contents or when the irrigation water has high sodium concentration. Sodium destroys soils by dispersing soil colloids and destroying soil structure. In addition, high sodium concentrations reduce water infiltration rates and permeability. Irrigating with water that had high sodium concentrations has rendered some land in South Dakota useless. Sodium-affected soils often have very poor drainage, and sodium-sensitive plants experience reduced growth. Nutrient-deficiency symptoms (resulting from high pH) and poor soil physical conditions are often observed in high-sodium situations.

More information for managing saline soils and information about acceptable deep drainage EC values are provided in Bischoff and Werner (1999). For further information related to salinity and sodium, see Chapter 48.

Chemigation

One advantage of irrigation is the ability to apply fertilizers or pesticides through the irrigation system. This practice is commonly referred to as chemigation. Fertilizer applied through an irrigation system must remain soluble in the irrigation water because nozzles, emitters, and fittings can become clogged by precipitates from fertilizers. After fertilizer application, a short irrigation may be used to wash the fertilizer off the plant and lessen the possibility of fertilizer burn. If applying pesticides, the pesticide must be labeled both for use in soybean and for application with the irrigation system.

When chemigating you must also protect the water supply. Backflow into a well or other water supply can have serious consequences for other users and make the water unusable for their applications. State law requires the use of an anti-backflow device when chemigating; examples of anti-backflow devices include such things as check valves and low-pressure relief valves (SDCL §34A-2A-3). Always read and follow the instructions on the product label and take precautions to protect yourself and others from exposure to chemicals.

When using chemigation, to apply liquid nitrogen or other chemicals, you may not need water at the time you want to apply the chemicals. Apply the chemicals in a timely fashion, but use the least amount of water possible. High-capacity injection equipment, along with an irrigation system that can cover the field in the shortest period of time, is desirable for chemigation.
References and additional information


Acknowledgements
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Seasonal Hazards

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Weather and climate is an everchanging element in soybean production, and is rarely the same from year to year. The impacts of weather and climate-related hazards vary, depending on the growth stage. For example, hail that defoliates a crop at the V3 growth stage will have a different impact than hail that defoliates the crop at R3. The purpose of this chapter is to discuss flooding, drought, frost, and hail impacts on soybean growth. Table 50.1 provides rules of thumb when considering how to manage seasonal hazards. If damage is serious, we recommend that you contact your insurance agent (Chapter 46).

Table 50.1. Rules of thumb for managing seasonal hazards.

- Understand your climate risks.
- Keep your head.
- Document the problem.
- Contact your insurance agent.
- Collect images and note where and when.
- Carefully consider your management options.

Flooding

Yield losses from flooding can range from total crop failure to minimal. The extent of flooding loss depends on the amount of water movement, the duration, air temperature, and the growth stage of the plant.

Flooding of standing soybeans

Soybean plants are tolerant of flooding for up to two to four days under ideal conditions with virtually no impact on yield. If flooding lasts four to six days, some reduction in stands, vigor, and yield may occur. This duration may also delay plant growth and cause plants to be shorter with fewer nodes. After seven or more
consecutive days of flooding, there is likely to be a significant yield loss or loss of the entire crop. This is due to decreased oxygen concentration, increased CO₂ concentrations, and sediment deposition.

Soil oxygen is necessary for maximum productivity. When a field is flooded, it reduces the amount of oxygen available to the plant, because the oxygen content of water is less than soil. Without oxygen, the plant cannot properly respire. If there is little water movement, research has shown that oxygen concentration can approach zero within 24 hours in a flooded field. In addition to the lack of oxygen, flooded fields often have higher levels of toxins and carbon dioxide. Some research from Minnesota has shown that the increased carbon dioxide levels are more dangerous to the plant health than the low oxygen levels (Coulter et al., 2008). This build-up can amount to 50 times higher than in non-flooded soils.

Air temperature can also play a role in the success of soybean in a flooded field. Higher temperatures cause soybean plants to use its energy stores more quickly. If oxygen levels are reduced in the soil, the plant can become stressed. High temperatures can also affect carbon dioxide levels, because of increased respiration by the plants and soil microbes. Generally, a submerged soybean plant fares better under cool cloudy conditions than warm sunny conditions.

Water movement has an effect on soybean plant health as well. If stream flooding was the cause, oftentimes water is moving across or through a field. This is common during flash flooding situations, and could arrive and recede quickly. The resulting damage to the soybean plants may include plant scouring or sand and/or silt deposition on the plants. Rainfall can help clean these leaves.

In lowland flooding, water is retained in depressed areas of fields, and may remain for several days. Although silt or soil deposition is less of an issue, waterlogged or saturated soils may be a prolonged problem after the surface water has receded. Soils in these types of areas tend to be heavier, such as clay. These types of soils do not drain as well, and yield reductions are often higher on clay than on silt loam soils, even when flooded for the same length of time.

The rate of drying will impact yield (Sullivan et al., 2001). Research has shown that for each day of flooding at V4 stage, yield loss is about 1.8 bu/(acre×day) on clay soil and 0.8 bu/(acre×day) on silt loam soil (Scott et al., 1989). In the reproductive stages, yield loss is even higher. At R1 growth stage, clay soil yield loss is 2.8 bu/(acre×day) and silt loam soil yield loss is 1.5 bu/(acre×day). Larger yield losses would be expected at R3 to R5.

Flooding can also result in surface crusting, which has the potential to reduce seedling emergence. If crusting is an issue, light tillage with a rotary hoe, coulter cart, or even the planter or seed drill can help with emergence. Note, however, this may cause 10% loss of emerged beans. If there is an adequate stand present, “crust busting” may not be necessary, as the tillage would not improve recovery or yield.

Post-flood concerns

When the plants are recovering from a flood, avoid management practices that will further place the plant under stress. For example, postpone the use of pesticides and consider cultivation to improve aeration. Flooding may also have killed the soil bacteria responsible for N₂ fixation and may have produced an environment favorable for many diseases. If the plants are killed and reseeding is an option, check with your insurance agent and estimate your yield potential (Chapter 51). Before reseeding, make sure that soil is dry enough to support heavy machinery. Some yield potential is already lost due to the later planting date, and ensuring a good seedbed is the best way to get your crop off to a good start.
End-of-season flooding

When flooding occurs at harvest time, it is a challenge to determine the proper action to take when heavy equipment cannot enter the field. Yield losses are difficult to estimate at this stage. There are several concerns when flooding occurs at the end of the growing season:

1. **Sprouting in the pod.**
2. **Shattering of beans as they dry out.**
   If the soybeans were mature and dried before flooding, they may shatter as they dry out. It is tempting to harvest these as soon as they are dry enough for combining, but this risk should be balanced against other concerns listed here.
3. **Saprophytic fungi on the seed.**
   If the crop is not affected and the soybean seeds are mature, it is ideal to harvest as soon as possible. If there is some infection, the decision to harvest should be weighed with other concerns listed here.
4. **Lodging of plants in wet soils.**
   Some seed will be lost to the ground, and the remainder will be difficult to harvest. If they are in contact with the soil, there will be reduced seed quality and harvest will be very slow. Yield losses will be very likely.
5. **Silt and mud deposits.**
   Silt coating on the leaves can delay drying out of soybean plants, and will create dusty harvest conditions. If the plants are still standing, harvest should be postponed. The silt and dust will create extra wear and tear on the combine, so it is best to keep the equipment clean until it is necessary to harvest the silted and dusty field.
6. **Grain quality.**
   Flooded fields will likely have lower seed quality than non-flooded fields. Monitor each field for grain quality prior to harvest. If damage is extensive, there may be a dockage at the elevator, or the seed may not be accepted.
7. **Soybeans not progressing to maturity.**
   If soybeans were flooded for more than 24 hours and were not quite at R7 stage, they will have some yield loss. If the plants had green foliage (R5 to early R6), then there is likely to be a reduction in seed quality. In these cases, seed may be green and off-color, shriveled, and/or small in size.

There are a number of ways that a late-season flood can be managed to minimize losses and maintain the best quality grain possible. Scout your fields to determine the extent of flood damage and harvest order. Each farmer will have to make his or her own decisions, as no two flooding events are the same, nor do any two fields recover the same from flooding.

1. For fields that have extensive damage, consult your crop insurance advisor for advice.
2. Separate the soybeans harvested from flooded fields apart from the non-flooded fields, as seed quality may be reduced in the flooded fields. If they are mixed, that may reduce the overall quality of the load of soybeans.
3. If multiple fields are ready to harvest at the same time, consider harvesting the dry fields before the wet ones. Yields will likely be reduced in the flooded fields, whereas the dry fields will have reached maximum yield and will also harvest faster.
4. If shattering is a real threat, it may be advised to harvest those areas first. But, if there is dust or silt deposited, it may be advised to move that area down in the harvest order.
5. If a field has fungi, the level of severity could be considered as well. Keep in mind that harvesting a field that has been flooded will take longer than a dry one.
Drought

Drought can be defined as a shortage of available water when plants need it, but oftentimes dryness and warmer than average temperatures occur together in South Dakota. In combination, dryness and heat can provide a “double whammy,” and can negatively impact soybean production if these climatic conditions occur at the reproductive stages or last over a significant portion of the growing season.

Dry soil conditions can affect soybean at two primary growth stages, at planting and at reproductive stages (from bloom through pod fill). During the vegetative stages, drought stress does not greatly impact yield.

At germination, a soybean seed absorbs water equal to about 50% of its weight. This is the first critical stage, where some soil moisture is needed to get the germination process started. During the vegetative stages, drought or water stress does not typically impact yield. Early signs of water stress are difficult to see from the road. A walk through the field will give the best indication of stress response. Shorter plants and smaller leaf size may be visible indicators. This usually takes a few weeks to develop, and will be noticed if the plants do not appear to be growing.

A second indicator of drought stress is leaf flipping, where the leaves literally turn over to the silver-green underside. The lighter color will reflect more light and conserve water by absorbing less sunlight and reducing photosynthetic processes.

Third, severely drought-stressed soybeans will clamp their leaves, similar to leaf rolling in drought-stressed corn. By doing this, the plant is trying to reduce its exposed leaf area to sunlight to conserve water. Leaf flipping and clamping may occur throughout the growth of the plants from emergence to seed fill.

As the soybean transitions to the reproductive stages, soil moisture availability becomes a determining factor in yield, although soybean is somewhat more resilient to water stress than corn. At the R1 stage, extreme heat can reduce growth, flowering, and pod development. If it is water stressed at the same time, flowers may be aborted. Between the R1 and R3 stages, water and heat stress can be overcome if the stress is relieved. At this point, there are several opportunities for soybean to continue to flower if a prolonged stressful period occurs.

Indeterminate soybean varieties will bloom for four to six weeks. As the plant progresses through the reproductive stages, the opportunity to recover is reduced and potential yield loss is increased. Soybean’s initial response to stress will be to increase the number of seeds per pod and increase seed size to compensate for aborted flowers and young pods. If severe stress is present (water and/or heat stress) during these early reproductive stages, the bloom period could be shortened. If no pods are set after the normal blooming period, it is possible that the crop will not set many pods at all, or seed yield will be reduced.

By the time the soybean reaches R4, a decision may need to be made if drought has impacted enough of the potential yield to cut for hay. Soybeans that have 50 to 90% leaves and a good number of pods at this stage will have a decent chance of producing a good crop. This is particularly true if favorable conditions return. However, if the crop has set very few pods the yield will be low.

At R5, the demand for water and nutrients is at its maximum during the rapid seed filling period. A shortage of available water will reduce N fixation and N availability. Water and heat stress at the R5-R6 stage generally results in fewer pods per plant and fewer beans per pod, and sometimes smaller seed size. If weather and climate conditions have been favorable up to this point, there may be some reduction in seed size and yield, but not as much as would have occurred due to pod and seed abortion in the earlier reproductive stages. Late rains can help fill out seeds, but increasing seed size cannot fully compensate for the reduction in seed number.

The best way to reduce vulnerability to drought stress is to manage the land to maintain favorable soil moisture. Without soil moisture, roots will not be able to take in nutrients or grow in the upper soil areas where the soil dries. Soil and tillage practices affect the temperature and moisture of the soil, which can impact the entire growing season.
Irrigation can help reduce drought stress in soybeans as well. Irrigation scheduling and planning for the growth period with the most water demand can help alleviate drought and temperature stress. Refer to Chapter 54 in this book for more information on irrigation.

**Frost**

Frost is a concern both in the spring and the fall seasons (Figs. 50.1, 50.2, 50.3, 50.4). Researchers at North Dakota State University generally advise that it is better to plant early and risk a spring freeze than plant late and risk a fall freeze (Halvorson et al., 1995). After a spring freeze, replanting is often an option, whereas few options are available after an early killing fall freeze. As a result, in general, it is better to try to maximize your growing season than risk a fall freeze. Information on replant options is available in Chapter 51.

Soybean can be affected by temperatures in the 28°F to 32°F range early in the growing season. This largely depends on the length of time that temperatures hold at these low levels. Plants in the VE to VC stage can tolerate short periods of 29°F to 30°F, and can be hardened after repeated short exposures so that they may tolerate temperatures down to 28°F. Once true leaves emerge, soybean plants are more susceptible to any extended period below 32°F.

![Median Last Spring 32 °F Day Occurrence](http://climate.sdstate.edu/w_info/frost/frost.asp)

![Median Last Spring 28 °F Day Occurrence](http://climate.sdstate.edu/w_info/frost/frost.asp)
If a fall season hard freeze (28°F or lower) occurs after the R7 stage, then yields are not impacted (Figs. 50.3, 50.4). If there is an early killing frost in the fall when leaves are light green or yellow, let those frost-damaged soybeans dry down in the field to reach mature color whenever possible. Keep in mind that leaves may not fall from frost-damaged plants. This dry-down period will help green seeds turn yellow and minimize the need for forced drying. Beans that are still green will soften and shrivel. If the frost occurred after R6, it is unlikely that oil and protein content of the harvested seed will be reduced. Generally, the most serious potential impact will be on quality for seed purposes.

If you have experienced some frost or freeze damage, it is best to wait for about three to five days before making a damage assessment. For more information on how to estimate yield loss after a frost or freeze event, or to determine if replanting is economical, refer to Chapter 51.
Hail

Hail can occur at any time during the growing season. Damage can range from slight leaf damage to total loss. It is advised to complete a damage assessment three to five days after the hail event to get the most accurate estimate. Yield loss predictions are generally made on the basis of two factors:

- The growth stage at the time of damage.
- The degree of plant damage.

Plant damage can be classified as leaf defoliation, stand reduction, stem damage and pod damage.

Oftentimes, a widespread event with small, soft hail may cause less damage than large, icy hailstones. Small, soft hail will impact the plants and leaves with less force than large stones. In addition, they are more likely to fall between plants, roll off of leaves, and melt faster. Plants in the early growth stages are most susceptible to small hail damage, as the growing point is most exposed and vulnerable at the VE and VC stages.

Large, icy hailstones will impale the plants with more force, and thus could cause more stem breakage. Damage may be very localized, but severe, with large stones. As a general rule, the larger the hail is, the fewer stones per area. For more details on how to assess hail damage, consult Chapter 51.

References and additional information


Websites


Acknowledgements
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Assessing Spring Frost and Hail Damage

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Robert Hall (Robert.Hall@sdstate.edu)
Kyle Gustafson (Kyle.Gustafson@sdstate.edu)

Spring frost and hail (Fig. 51.1) can result in partial to total destruction of a soybean crop early in the growing season. Agronomists, producers, and insurance agents need accurate estimates of these spring damages to make good recommendations on the decision to replant. The purpose of this chapter is to provide information and general rules of thumb (Table 51.1) for managing spring frost injury and hail damage.
When to scout and assess damage

All crop producers agree that assessing crop damage is a very emotional experience. If you assess damage too soon after a spring frost or hail event, you run the risk of under- or over-estimating damage. Damage to soybean plants should be assessed three to five days after the event to minimize rash decisions to replant, allow time for potential crop recovery, and schedule a field visit with your insurance agent. However, it is appropriate to scout fields after a spring frost or hail event in your area to generate a list of fields to revisit in three to five days.

Assessing spring frost injury

Soybean fields should be scouted for potential spring frost damage when temperatures are near 32°F and below for several hours since temperatures across the landscape are uneven. Low-lying areas may have experienced cooler temperatures than neighboring areas of higher elevation. In general, a 28°F air temperature or below for several hours is considered a severe low temperature event causing significant damage in soybean. The growing point(s) or bud(s) are above the ground in soybean, unlike corn early in the season. For this reason, assessing aboveground growth in soybean is a good indicator of potential recovery. Generally, after a moderate frost, new buds could appear in about three to five days if temperatures increase enough to spur growth. If the seedlings are totally black below the cotyledons, the frost most likely killed the plant and there is no chance for recovery. If cool temperatures persist then you have two choices. First, you can go ahead and make a pre-mature decision that may or may not be to your advantage; or second, you can wait until temperatures rise to the point that plants will begin to recover (new growth or no growth). Remember, you are relying on the plants to show you that they have the potential to recover from injury.

Often the most vivid symptoms of freeze injury in soybean immediately following the frost or a few days later are the appearance of the leaves. Generally, water-soaked areas will appear on the leaves. These spots will turn brown in a few days if the frost event was moderate. In cases where the leaves appear black and/or are disintegrating, then the frost was severe. Even though the appearance of the leaves following a spring frost or freezing event may result in leaf defoliation, defoliation itself is not the most important factor. The primary goal in the assessment is to determine the number of plants with new buds that can recover. To make this assessment:

- Determine if a live plant has bud(s) available for regrowth.
- Determine the amount of live soybean plants per acre using guidelines in “Determining plant population after spring frost or hail.”

<table>
<thead>
<tr>
<th>Table 51.1. Rules of thumb for managing spring frost and hail damage.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Contact your insurance agent and follow directions to maintain insurance coverage on your soybean field.</td>
</tr>
<tr>
<td>2. Assess damage three to five days after the event</td>
</tr>
<tr>
<td>3. Determine economic ramification of the event.</td>
</tr>
<tr>
<td>4. Determine if the field should be replanted or left alone.</td>
</tr>
<tr>
<td>a. Yields can decrease from ¼ to ½ bushel per acre per day from planting May 28 to June 14, respectively in South Dakota.</td>
</tr>
<tr>
<td>b. A thin and uneven soybean stand in May and June has a great potential to compensate, resulting in little yield loss.</td>
</tr>
<tr>
<td>c. If the average surviving soybean plant population is 75,000 or more after June 10, leave it alone even if one-foot gaps exist in the row.</td>
</tr>
</tbody>
</table>
The terminal growing point or bud (apical meristem) is a region of actively dividing cells located at the tip of the main stem (see Chapter 3). The terminal bud along with the axillary buds located in the axil between the main stem and each leaf stem all have the potential for regrowth if they are intact. The two cotyledons, the two unifoliolate leaves, and all the trifoliolate leaves have an axillary bud.

If the seedling was at the V1 stage (one trifoliolate leaf), the seedling would have a terminal bud plus axillary buds at the cotyledons, unifoliolate leaves, and the one trifoliolate leaf for a total of one terminal bud; and five axillary buds for a grand total of six buds available for regrowth (Chapter 3). Growing points are critical because they create all of the plant's leaves, buds and stems, and terminates in the uppermost trifoliolate leaf and its associated buds and pods. Therefore, if there is no terminal or any axillary buds, the plant has no means of recovering. Only one bud (terminal or axillary) is needed for regrowth and recovery.

Assessing spring hail damage

Hail damage can occur almost anytime during the growing season. However, hail damage in May and June needs to be critically evaluated to determine if replanting is an economically viable option. Hail causes defoliation and stem bruising/breakage. The amount of yield loss is dependent on growth stage, amount of damage, and surviving plant population.

The ability of soybean to recover from hail is similar to its ability to recover following frost injury. Again, when assessing damage, use the guidelines listed under spring frost injury. In many cases, the leaves may be stripped from the plant and recovery is possible if buds exist. Plants cut off below the cotyledons have no means of regrowth. If damaged plants are completely defoliated but have a stem, you still must look for axillary buds. Look for scars where the leaf stems were attached before the hail. If you can find the scars where the cotyledons were attached, you should find an axillary bud immediately above each of the two scars where the cotyledons were attached. If they are present, the plant has the potential to recover.

Determining plant population after spring frost or hail

Two ways to determine plant populations are 1) row width method (easier with 15-inch or wider rows) and, 2) the Hula Hoop® method (easier in drilled rows).

In the row width method, count the number of live plants (based on the discussion above on assessing frost injury and hail damage) in an area equivalent to 1/1000th of an acre in at least five locations and determine the average. It is always best to randomly select locations to get a good average. This length of row is dependent on the row spacing (Table 51.2). The population is the number of plants within that distance times 1,000. If the rows spacing is not listed, use the equation: Row length = (43,560 ÷ Row width in feet ÷ 1000).

<table>
<thead>
<tr>
<th>Row Width (inches)</th>
<th>Row Length Needed to represent 1/1000th of an acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>17 feet, 5 inches</td>
</tr>
<tr>
<td>20</td>
<td>26 feet, 2 inches</td>
</tr>
<tr>
<td>15</td>
<td>34 feet, 10 inches</td>
</tr>
</tbody>
</table>

Table 51.2. Row width method. When using this method, determine the plant population by counting the number of live plants in 1/1000 of an acre. The row length is dependent on the row width.
Plant populations can also be determined using the Hula Hoop® method. To use this method:

1. Randomly toss the hoop (any circular object similar to a Hula Hoop®) in at least five locations.
2. Count the plants within each of the five hoop counts, total them, and divide by five to obtain an average count.
3. Multiply the average hoop count by the multiplier factor listed in Table 51.3. For example, if the inside hoop diameter is 36 inches, multiply your average hoop count by 6,165 to obtain your estimate.
4. If the inside diameter of your hoop is not listed, use the equation:
   \[ \text{Multiplier factor} = \frac{43,560}{(0.785 \times \text{diameter} \times \text{diameter} \div 144)} \]
   The plants/acre is the counted number of plants in a hoop times the multiplier factor.
   Small hoop diameters is less preferred (less than 18 inches).

<table>
<thead>
<tr>
<th>Diameter of Hoop (inches)</th>
<th>Multiplier Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>24,662</td>
</tr>
<tr>
<td>24</td>
<td>13,872</td>
</tr>
<tr>
<td>30</td>
<td>8,878</td>
</tr>
<tr>
<td>36</td>
<td>6,165</td>
</tr>
</tbody>
</table>

Managing poor soybean stands with offset or patch planting

In most situations, the soybean plant has a large capacity to fill in low to moderate damage (Pepper, 1997; Whigham et al., 2000). Random loss of soybean plants across a field from hail damage is less worrisome if more than 75,000 live plants per acre still exist. Research in Minnesota showed no yield decrease even if one-foot gaps existed in the row with a soybean stand of 75,000 plants per acre compared to a full stand (150,000 plants/acre) prior to the V4 growth stage (Hicks et al., 1990).

Hick et al. (1990) found that even two-foot gaps in the row with a stand of 75,000 plants per acres decreased yield by only four bushels/acre prior to the V4 growth stage. However, frost damage may have impacted low-lying areas within a field, where a decision to replant these portions is clear. Unfortunately the decision to replant a soybean field is not always very clear. Before replanting, consider the size and extent of the damage. Information on replanting options are provided in Table 51.4.

In some situations, yield losses resulting from poor plant stands can be reduced by offset seeding or patching the problem areas. Patching the problem areas might involve seeding an additional row next to the emerged row. To conduct offset planting, the planter must be shifted from its normal position. One problem with this approach is that original and offset rows will be at different growth stages. Other problems to be considered in offset seeding include different soybean stages and offset rows during chemical application as well as variable stands and grain moisture levels at harvest. Yield advantages are higher when the original row has a gapped pattern rather than a uniform pattern (Pepper, 1987).
Table 51.4. Information to consider when assessing replanting.

1. Count the surviving plants (new buds or growth) and determine the population per acre.
2. Estimate the yield without replanting. (Hicks et al. 1990, Klein and Shapiro, 2011; Robertson and Conley, 2007)
   a. A “surviving seedling” should contain one or more buds (terminal or axillary) that will enable the seedling to recover, resume growth, and produce a yield. In addition, a surviving seedling should also be able to be bent over until it touches the soil surface without breaking. If it breaks, it would most likely not have the strength to support the plant during pod filling.
   b. Soybeans have a large capacity to compensate for thin and uneven stands, especially when damage occurs during the vegetative growth stages in May and June. If the average surviving soybean plant population is 75,000 or more after June 10, leave it alone even if one-foot gaps exist in the row.
3. Estimate the yield with replanting.
   a. Yields can decrease from ¼ to ½ bushel per acre per day from May 28 to June 14, respectively in South Dakota or a total of eight bushels per acre average decrease in yield from planting on May 12 compared to June 14. (Data from 1986-2002 in Beresford, SD; Berg et al., 2002).
4. Consider reducing the maturity group of the soybean planted by 0.5 in mid-June to as much as 1.0 by early-July compared to a full-season variety adapted to your area (Fig. 6.1 in Chapter 6). Data in Table 51.5 can be used to assess the change in the number of days to reach maturity with a change in planting date and maturity group.
5. Consider using narrow rows when seeding late in the season.

Table 51.5. The influence of a change in soybean maturity group rating and reseeding date on the number of days required to reach maturity. (Modified from Syngenta, 2011)

<table>
<thead>
<tr>
<th>Days Between Planting Dates</th>
<th>Change in the Maturity Rating of the Planted Variety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
</tr>
<tr>
<td>Change in Days Needed to Reach Maturity</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>30</td>
<td>12</td>
</tr>
<tr>
<td>35</td>
<td>14</td>
</tr>
<tr>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>45</td>
<td>18</td>
</tr>
<tr>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>55</td>
<td>22</td>
</tr>
<tr>
<td>60</td>
<td>24</td>
</tr>
</tbody>
</table>
**Final planting dates**

The final planting date for full insurance coverage is June 10 in South Dakota with delayed planting coverage until July 5 (Chapter 46). Consider reducing the maturity rating by 0.5 from normal if replanting occurs in mid-June and at most by 1.0 if replanting in early July to minimize the risk of frost damage during seed fill. When considering late planting or replanting, it is important to check the level of insurance coverage available with your agent. Numerous factors must be considered when considering replanting including the cost of additional operations/field passes, labor, and decrease in yield potential with later planting dates. In general, soybeans have a large capacity to compensate for thin and uneven stands.

**References and additional information**


**Acknowledgements**

Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA- AFRI, and South Dakota 2010 research program.

In most years, South Dakota crops are never more than two weeks away from a drought. Planning for a drought is a continuous process and involves planting at an appropriate date, careful management of your soil nutrients, managing pests, and using a tillage system that reduces evaporation (Table 52.1 and Fig. 52.1). In drought planning, it is imperative to select the correct maturity group for your area and select genetics that include stress tolerance traits (e.g., iron chlorosis, root knot nematode). The purpose of this chapter is to discuss techniques that can be used to reduce your drought risk. Selected tips for pre-plant management of water stress are available in Table 52.1.
Table 52.1. Tips for increasing drought tolerance resistance.

1. There is no-magic bullet that overcomes drought.
2. Use rotations and tillage systems that increase water storage and increase soil organic matter, which helps conserve water.
3. Do not harvest crop residues.
4. Apply sufficient rates of P and K fertilizer.
5. Control pests.
6. Optimize the planting date that minimizes the chance of early frost damage, but maximizes season length.
7. Use a realistic yield goal to match seeding rates and fields.
8. Select the cultivar with the proper maturity, for your area, that has drought tolerance and pest resistance.
9. In dry soil, consider seeding deeper.
10. Consider using an innovative seeding strategy.

Figure 52.1. Drought affected soybean crop. (http://corn.osu.edu/newsletters/2012/2012-21/symptoms-and-effects-of-water-stress-on-soybean-production, Ohio State Extension)

Water stress impact on crop growth

In many South Dakota fields, the most limiting factor for plant growth and high yields is water. Understanding water stress impacts on crop growth and development is the first step toward creating a resilient system. Plants have predictable responses to water stress, and when soybean plants are stressed they slow growth and abort flowers and pods. Under extreme drought, the plant will drop leaves to save water.

Under drought conditions, less water is available for the plants to use, which causes the plant to close its stomata and wilt. When the stomata are closed, atmospheric CO$_2$, which is needed for photosynthesis, no longer enters the plant. This first limits, and then finally stops, the plant's ability to convert CO$_2$ into stored chemical energy.

Research conducted over the past several years in corn shows that in response to water stress corn plants up-regulate their genes associated with managing water stress, and down-regulate their genes associated nutrient uptake and disease and insect management. Soybean plants likely have similar responses. These results suggest that under water-stressed conditions, management of soil nutrients and pests is crucial.
Saving soil water through reduced tillage

The amount of water available for the plant depends on the soil depth, soil quality, the amount of plant-available water in the soil, and management. Over the past 25 years, many producers have changed from the moldboard plow to the no-tillage system. No-tillage, when compared to a moldboard plow system, increases snow catch and water infiltration, and reduces runoff and evaporation from the soil surface (Triplett and Dick, 2008). In addition, no-till reduces erosion and reduces the risk of detached soil particles forming impermeable crusts or seals, and decrease erosion.

Soil moisture leaves the soil profile through evaporation, transpiration, and leaching. Transpiration represents the water that is used by the plant. Evaporation is water lost from the soil surface (not through the plant). Water lost through evaporation does not contribute to higher yields. Water-use efficiency (grain produced/inch water) can be increased by reducing evaporation, thus increasing the amount of water available for transpiration. This can be accomplished by reducing the tillage intensity and leaving residue on the soil surface. For example, Hatfield et al. (2000) reported that evaporation following cultivation in Iowa was four to five inches over a three-day period, while evaporative water losses in no-tillage was less than one inch.

Reduced evaporation is attributed to crop residues that remain on the soil surface (Klocke et al., 2009) and increased reflection of the sun's energy back into the atmosphere. The resulting impact on plant available water and yields can be significant. One inch of stored (saved) water can increase corn yield 8 to 14 bushels.

http://www.ag.ndsu.edu/pubs/plantsci/rowcrops/a1130-8.htm

Soil water-holding capacity

Not all water contained in soil is available to the plant. A portion of the soil water is bound to the soil particles and will never be available to plants. As the soil moisture content increases, pores are filled with water. A portion of this water is available to the growing plant. Based on the amount of energy required to extract the water it can be categorized into three categories: gravitational water, plant-available water, and non-available water.

Gravitational water is the amount of water lost between the point when all of the pores are filled with water (saturated conditions) and the water content when free drainage stops (between -0.1 and -1/3 bars). When free drainage stops, the soil is at field capacity. Plant-available water is the difference in the water contained in the soil at field capacity and the point when the plant permanently wilts (-15 bars). Gravitational water can be removed through tile drainage, while plant-available water is not removed by tile drainage.

The ability of soil to store plant-available water is related to its soil organic matter content and texture. Generally, available water increases with soil organic matter content and amount of silt contained in the soil. Silt loam soils have more available water than sandy soils (Table 52.2). The amount of soil organic matter contained in the soil is related to tillage intensity and amount of crop residue returned to the soil annually. Reducing the tillage intensity reduces the rate that organic matter is lost through microbial breakdown (mineralized).

Over the past 25 years, decreases in tillage intensity and increases in crop yields have contributed to a 24% increase in the South Dakota soils organic matter content (Clay et al., 2012). Leaving crop residues on the soil surface can increase soil organic matter content and reduce evaporation. The bottom line is that building the soil organic matter content improves drought resilience.
Following winter and spring rains, many South Dakota soils are at or near field capacity, i.e., the soil water content after free drainage. If the soil is below field capacity at planting, consider reducing your yield potential. Yield potentials, which is a function of available water, can be used to estimate the seeding populations (Chapter 10). For corn, Carlson et al. (2011) determined the relationship between a practical corn yield goal and seeding rate. This relationship is:

Population (seeds/acre) = 16,900 seeds/acre +74.2×(corn yield goal in bu/acre)

Based on this relationship, a corn yield goal of 180 bu/acre should have a seeding rate of 30,300 seeds/acre, whereas a yield goal of 120 bu/acre should have a seeding rate of 25,800 seeds/acre. This analysis indicates that the corn seeding rate should be decreased with increasing expected water stress. Similar analysis needs to be conducted in soybeans.

The amount of stored soil moisture is dependent on the amount of available water contained in the soil. For example, a four-foot deep profile that is a silt loam with 2.5 inches of available water per foot contains 10 inches of water in the entire profile, whereas a sandy loam soil with 1.5 inches of available water per foot contains six inches of available water in the entire profile.

### Water stress and crop growth

In soil, water moves from wet to dry areas and roots cannot grow through dry soil to reach wet soil. Planting a crop early is key toward providing an opportunity for creating an effective root system that can use water stored deep in the profile. Row crops grown in South Dakota (corn, soybean, and wheat) are moderate to deep rooted and can produce root systems that can penetrate to four feet or more.

In many situations, water and heat stress can combine to reduce crop growth. In soybeans, the combined impact of water and heat stress can cause leaf wilting (or if severe enough, leaf drop), reduced growth, reduced N fixation, and yield reductions. Corn, soybeans, and wheat are very sensitive to water stress during pollination and grain filling. In soybeans, water stress reduces the number of pods, the number of beans per pod, and the size of the beans.

Under extreme water stress conditions, soybeans and corn crops can be harvested for hay or silage. If you decide to harvest the crop for forage or produce silage, you should communicate with your crop insurance agent and you must read and follow the pesticide label instructions about using the crop as a feedstock. For example, soybeans treated with Poast® (Sethoxydim)/Poast Plus® (used to control many grasses in soybean) can be harvested for hay, but not for silage. [http://www.cdms.net/ldat/ld00F009.pdf](http://www.cdms.net/ldat/ld00F009.pdf)

When deciding on how much and which crop residues can be used for livestock feed, it is important to consider the livestock nutritional requirements and the nutrient content of the plant. Drought-affected plants may have very high protein contents and other chemicals, such as nitrate, that may cause problems in livestock. Evans and Foweld (1921) suggest that soybeans should be considered a high protein hay crop. A good approach for determining the nutrient content of drought-affected crops is to collect a plant sample and send it to a laboratory for analysis.

---

**Table 52.2. Soil texture impact on plant-available water.**

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Available Water (inch water per foot soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy loam</td>
<td>1.3-1.8</td>
</tr>
<tr>
<td>Loam and silt loam</td>
<td>2.0-2.8</td>
</tr>
<tr>
<td>Silty clay and clay</td>
<td>1.6-2.2</td>
</tr>
</tbody>
</table>

[www.iGrow.org](http://www.iGrow.org)
Drainage

Drainage is being installed in many South Dakota fields. Many details about drainage are provided in Chapter 52. When installing drainage, it is important to consider that drainage may remove water that could be used by your crop. Controlled drainage is a tool that can be used to reduce water lost after the crop has been planted. Information about control drainage systems is available at http://admcoalition.com/latest-research/.

Design an appropriate nutrient package

Providing an appropriate nutrient package is critical for increasing the plants ability to withstand water stress. For example, starter fertilizer stimulates early-season growth, P fertilizers stimulate root development, and N promotes above ground growth. When using starter fertilizers, care should be followed to insure that seed germination is not reduced. Details on starter fertilizer are provided in Chapter 21.

Skip-row seeding

Skip-row planting has been used to increase corn and sorghum yields and water-use efficiency. http://www.ianrpubs.unl.edu/epublic/pages/publicationD.jsp?publicationId=1226

In skip-row planting, rows are skipped, while the plant population per acre remains the same. This configuration results in very high populations within the seeded rows. Three approaches tested in Nebraska are:

1. plant 2 and skip 2;
2. plant 1 and skip 1, and
3. plant 2 and skip 1.

Skip-row seeding works best: 1) in low rainfall environments where there are frequent stresses during reproductive stages; 2) in deep soils with high plant-available water; and 3) in fields that use a good pest control strategy and 4) use realistic yield goals. For this approach to be effective, good weed control is essential since the “between” rows are not covered and vulnerable to weed emergence and growth. Research conducted in Nebraska suggests that if your corn yields are less than 100 bu/acre, then you may benefit from skip-row seeding. http://www.tsln.com/article/20090602/TSLN01/906029923

Twin-row seeding

Twin-row seeding has been used to increase soybean yields in the Southern states. In the research conducted in Mississippi, twin-row soybean seeding (10-inch rows spaced 40 inches apart) out yielded (5% increase) conventional seeding (rows 40 inches apart) (Bruns, 2011). Twin-row seeding provides the opportunity to take advantage of narrow rows without the requirement to purchase specialized equipment. Benefits from twin-row seeding are dependent on the characteristics of the cultivar. http://www.lewishybrids.com/files/File/Lewis%20University%20Issues/MON%20Tech%20Development%20-%20Twin%20Row%20Summary%20Final.pdf

Use cultivars with drought tolerance

Many current cultivars contain drought tolerance. In many situations, seeding plants with a genetic capacity to reduce the impacts of water stress on yield makes sense. However, care should be used to select varieties that do not reduce yields under a high yield environment. Information on selecting varieties is available in Chapter 10.

Crop rotations

In many areas of South Dakota, yields are influenced by the moisture left behind by the previous crop. Early maturing, shallow root crops like field peas leave more moisture than deep rooted full season crops like sunflowers.
Table 52.3. Rules of thumb for rotations.

1. Do not follow like-with-like. For example, “good” results have been observed when soybeans follow corn or vice versa, and winter wheat follows peas. When like-following-like, pathogens may be more prevalent and other problems may occur.

2. Cropping intensity should match available water. If a field consistently has too much water, then the intensity should be increased. If a field is consistently dry, then the intensity should be decreased. Guidelines for determining the rotational intensity are available at http://www.dakotalakes.com/Publications/Div_Int_FS2pg5.PDF.

3. Crop rotations are very effective at reducing pest and weed problems. By reducing pest pressures, the plant is better able to withstand water stress. http://www.ag.ndsu.edu/pubs/plantsci/crops/eb48-1.htm

4. Water-use efficiency can be increased by accounting for differences in plant rooting depth. For example, small grains may deplete soil water to a depth of three to four feet deep, while sunflower, safflower, and corn may deplete soil water to depths of five to six feet. Following sunflowers after wheat provides an opportunity to utilize water that was positionally unavailable to wheat.

References and additional information


Acknowledgements
Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

There are many calculations that are conducted that impact economic returns and costs. The purpose of this chapter is to discuss and provide examples of agronomic calculations routinely determined. Additional problems are available in Clay et al. (2011).

Table 53.1. Equations and other information typically used in calculations.

<table>
<thead>
<tr>
<th>Soybean plant</th>
<th>Information</th>
<th>Fertilizer grades</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 bu = 32 dry qt = 35.238 l</td>
<td>DAP 18-46-0</td>
<td>Chapter 21</td>
<td></td>
</tr>
<tr>
<td>1 bu = 1.24456ft³</td>
<td>Map 11-52-0</td>
<td>Chapter 21</td>
<td></td>
</tr>
<tr>
<td>1 bu beans at 13% moisture typically = 60 lbs</td>
<td>KCl 0-0-60</td>
<td>Chapter 21</td>
<td></td>
</tr>
<tr>
<td>1 bu beans at 0% moisture typically = 52.2 lbs</td>
<td>Nutrient Removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,500-3,000 soybean seeds/lb</td>
<td>0.84 lb P₂O₅/bu soybeans</td>
<td>Chapter 25</td>
<td></td>
</tr>
<tr>
<td>Seeding rate, 30-45 lbs/acre</td>
<td>1.3 lb K₂O/bu soybeans</td>
<td>Chapter 26</td>
<td></td>
</tr>
<tr>
<td>Volumes and areas</td>
<td>soybean stover, 6.8 lbs P₂O₅/ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyramid volume=1/3base × width × height</td>
<td>soybean stover 37 lbs K₂O/ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectangle area = base × width</td>
<td>soybean stover 6.2 lbs S/ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area of a circle = pi × r²</td>
<td>Areas and lengths</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circle circumference = 2 × r × pi</td>
<td>1 acre = 43560 ft²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of a sphere = (4/3) × pi × r³</td>
<td>1 section - 640 acres</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of a cone = (1/3) × pi × r² × height</td>
<td>1 chain = 66 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of a cylinder = pi × r² × h</td>
<td>1 link = 0.66 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of a bushel= 1.244 ft³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Densities liquid fertilizer</td>
<td>1 acre = 10 chain²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density 0-60-0 14.4 lbs/gal</td>
<td>Chapter 21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density 10-34-0 11.64 lbs/gal</td>
<td>1 section = 6400 chain²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density 0-60-0 14.4 lbs/gal</td>
<td>1 acre = 208.7 ft by 208.7 ft</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Soil temperatures, seeding rate, fertilizers, and salt-affected soils

Problem 53.1. The surface soil (~1 to 2 inches) temperatures are 45°F at 7:00 AM and 55°F at 3:00 PM. Is the temperature warm enough to plant soybean seeds?

**Answer:** The temperature average is 50°F. This is below the minimum temperature of 55°F. However, it is equal to the minimum temperature for corn of 50°F.

Problem 53.2. Calculate the seeding rate if the germination rate is 98%, purity is 96%, and seeding vigor is 90%. The desired live population is 135,000 plants/a.

\[
\frac{135,000 \text{ plants at V2}}{\text{acre}} = \left(\frac{\text{seeding rate}}{\text{acre}}\right) \times \frac{0.98 \text{ germination rate}}{\text{seed}} \times \frac{0.96 \text{ pure seeds}}{\text{seed}} \times \frac{0.90 \text{ emergence}}{\text{seed}}
\]

\[
= \frac{159,500 \text{ seeds}}{\text{acre}}
\]

Problem 53.3. Determine the P₂O₅ recommendation for a soil with a Bray-1 soil test value of 10 ppm and a soybean yield goal of 60 bu/acre and a corn yield goal of 210 bu/acre. The fertilizer grade is 18-46-0. In using equations from page 5 of SDSU EC750 one gets:

Use the soil test value (10) and yield goal (60 bu soybeans and 210 bu corn) to determine the two-year P rate, as shown below.

\[
\text{Soybean lbs P₂O₅/acre} = (1.55 - 0.14 \times 10) \times 60 = 9 \text{ lbs P₂O₅/acre}
\]

\[
\text{Corn lbs P₂O₅/acre} = (0.70 - 0.044 \times 10) \times 210 = 54.6 \text{ lbs P₂O₅/acre}
\]

Based on these calculations, the P recommendation total is 63.6 lbs P₂O₅/acre

How much DAP (18-46-0) should be applied?

\[
\text{DAP acre} = \frac{63.6 \text{ lbs P₂O₅}}{46 \text{ lbs P₂O₅}} \times \frac{100 \text{ lbs DAP}}{1 \text{ lb DAP product}} = 138 \text{ lbs DAP acre}
\]

Problem 53.4. How much P will it take to increase a soil test P value from 3 to 11? The fertilizer grade DAP is 18-46-0.

As a general rule, it takes from 10 to 30 lbs of P₂O₅ to increase soil test (Olsen or Bray) one soil test point. Using a median of 20 lb P₂O₅/point of soil test, to change a soil test from 3 to 11 (Olsen P) will require the addition of (11-3)*20 = 160 lb P₂O₅.

\[
160 \text{ lb actual P₂O₅} \times \frac{1 \text{ lb DAP product}}{0.46 \text{ lb actual P₂O₅}} = 348 \text{ lb DAP}
\]

Problem 53.5. You are planning on applying 10lbs/a of N to a field. If the fertilizer source is 28-0-0 (which has a density of 10.9 lbs/gal), how much 28% should be applied?

\[
\frac{10 \text{ lb actual N}}{\text{acre}} \times \frac{1 \text{ lb UAN}}{0.28 \text{ lb actual N}} \times \frac{1 \text{ gal UAN}}{10.9 \text{ lb UAN}} = 3.3 \text{ gal/acre}
\]
Problem 53.6. How much fertilizer should you apply in the following problem?

In South Dakota, the nutrient that most often limits soybean yields is P. However, many South Dakota fertilizer retailers sell phosphorous as diammonium phosphate (DAP 18-46-0) or as mono-ammonium phosphate (MAP 11-52-0). Because each contains nitrogen, to effectively use the nitrogen, many producers who rotate between corn and soybeans put their DAP or MAP on the corn. Determining the P removal rates for a two-year rotation is shown below. Calculations showing how to determine the P rate based on a soil sample is provided in Problem 53.3 earlier in this chapter.

1. Calculate the P removal rate for a soybean and corn crop. These calculations assume that 1 bu of corn removes 0.38 lb of P₂O₅ and 1 bu of soybeans removes 0.84 lb of P₂O₅. Example is for 175 bu of corn and 55 bu of beans.

   \[
   \frac{175 \text{ bu corn}}{\text{acre}} \cdot \frac{0.38 \text{ lb} \ P_2O_5}{\text{bu corn}} + \frac{55 \text{ bu beans}}{\text{acre}} \cdot \frac{0.84 \text{ lb} \ P_2O_5}{\text{bu beans}} = 112.7 \text{ lb} \ P_2O_5
   \]

2. Calculate the amount of DAP (18-46-0) needed to replace this P.

   \[
   \frac{112.7 \text{ lb} \ P_2O_5}{\text{acre}} \cdot \frac{100 \text{ lb DAP}}{46 \text{ lb} \ P_2O_5} = 245 \text{ lb DAP}
   \]

3. Calculate the amount of N from the DAP that is available for the corn.

   \[
   \frac{245 \text{ lb DAP}}{\text{acre}} \cdot \frac{18 \text{ lb N}}{100 \text{ lb DAP}} = 44 \text{ lb N}
   \]

4. Subtract the N in the DAP from the overall N recommendation (assume soil test N recommendation is 150 lbs N/acre).

   \[
   \text{N rec.} = 150 \text{ lbs N/acre} - 44 \text{ lbs from DAP}
   \]

Problem 53.7. How much gypsum should be applied to the following soil?

The soil has a cation exchange capacity of 30 mmole/100 gm of soil. The laboratory analysis indicates that the exchangeable sodium percentage, ESP, is 10%. We want to treat the top 6 inches with gypsum so that the final ESP is about 5%. How much gypsum needs to be applied? Note that the atomic weight of Gypsum (CaSO₄ · H₂O) is 172 gm/mole which equals 86*10⁻³gm/mmole. We know that:

\[
\text{ESP} = \frac{\text{mmole}_e \text{ Na}/100 \text{ gm soil}}{\text{CEC} \left( \text{mmole}_e \text{ cations}/100 \text{ gm soil} \right) }, \text{ so at an ESP of 5% and 10% respectively}
\]

(0.05=Na/30 then Na = 1.5 mmole_e Na/100 gm soil)

(0.1=Na/30 then Na = 3 mmole_e Na/100 gm soil) and since 3-1.5 =1.5

We need to exchange

\[
\frac{1.5 \text{ mmole}_e \text{ Na}}{100 \text{ gm soil}} \cdot \frac{86 \cdot 10^{-3} \text{ gm gypsum}}{\text{mmole}_e \text{ Ca}} \cdot \frac{2 \cdot 10^6 \text{ lb soil}}{\text{acre 6 inch soil}} = \frac{2580 \text{ lb gypsum}}{\text{acre 6 inch soil}}
\]

Since there will be inefficient exchange of the Ca for Na, there needs to be an additional amount of gypsum, so 1.5 ton (3000 lb) of gypsum is recommended.
Problem 53.8. Convert 2 dS/m EC measured using a 1:1 to saturated paste EC. The soil is sand.

The conversion equations are:
A sandy soil has a coarse soil texture and therefore, the conversion factor for coarse textures should be used.

Coarse soil (sand): \( \text{EC}_{\text{saturated paste}} = 3.01 \times \text{EC}_{1:1} - 0.06 \)
Medium (silt loam): \( \text{EC}_{\text{saturated paste}} = 3.01 \times \text{EC}_{1:1} - 0.77 \)
Fine (clay): \( \text{EC}_{\text{saturated paste}} = 2.96 \times \text{EC}_{1:1} - 0.95 \)

\( \text{EC} = 3.01 \times 2.01 - 0.06 = 5.96 \text{ dS/m} \)

Problem 53.9. A soil sample is sent off to a laboratory for analysis. In this analysis, a saturated paste (approximately 100 g soil + 60 ml water) is made and equilibrated for 24 hours. The water is extracted by vacuum and the Na, Ca, and Mg is determined. The water analysis of a soil/water saturated paste is 2136 ppm Na, 2181 ppm Mg, and 3198 ppm Ca. What is its SAR?

When doing this calculation, it is important to know that Na has a valance of +1, Ca has a valance of +2, and Mg has a valance of +2. The valances are used to convert mmol to mmolc.

Step 1. Convert ppm to mmolc/L. For this conversion 1 ppm = 1 mg/L

\[
\begin{align*}
\text{Na mmolc/L} &= \frac{2136 \text{ mg Na}}{23 \text{ mg Na/mmolc}} \times \frac{1 \text{ mmolc Na}}{1 \text{ mmol Na}} = 92.9 \text{ mmolc Na/L} \\
\text{Mg mmolc/L} &= \frac{2181 \text{ mg Mg}}{24.3 \text{ mg Mg/mmolc}} \times \frac{2 \text{ mmolc Mg}}{1 \text{ mmol Mg}} = 179.3 \text{ mmolc Mg/L} \\
\text{Ca mmolc/L} &= \frac{3198 \text{ mg Ca}}{40 \text{ mg Ca/mmolc}} \times \frac{2 \text{ mmolc Ca}}{1 \text{ mmol Ca}} = 159.9 \text{ mmolc Ca/L}
\end{align*}
\]

Step 2. Calculate SAR

\[
\text{SAR} = \left( \frac{\text{mmolc Na}}{\frac{\text{mmolc Ca/L} + \text{mmolc Mg}}{2}} \right)^{0.5} = \left( \frac{92.9}{\frac{179.3 + 159.9}{2}} \right)^{0.5} = 7.1
\]

You need to monitor Na inputs (see Chapter 48).
Controlling weeds

Herbicides

Problem 53.10. Calculate the active ingredient when spraying herbicides (lbs active ingredient over 160 a at 20gal/a):

The manufacturer’s recommended rate of a product is 2 lb active ingredient(AI)/acre. A gallon of the product contains 6 lb AI. How many gallon/acre should be applied?

\[
\frac{2 \text{ lb AI}}{\text{acre}} \times \frac{1 \text{ gal product}}{6 \text{ lb AI}} = \frac{0.33 \text{ gal product}}{\text{acre}}
\]

If the calibration of your sprayer indicates that you are applying 11.5 gal/acre, how many gallons of product and gallons of water should you load into a 300-gallon spray tank?

\[
\frac{0.33 \text{ gal product}}{11.5 \text{ gal mix}} \times \frac{300}{300} = \frac{8.7 \text{ gal product}}{300 \text{ gal mix}}
\]

And there will be 300 – 8.7 = 291.3 gal water.

Problem 53.11. What is the output of a sprayer that has a nozzle output of 28 fluid oz in 29 seconds? The number of nozzles on the boom are 100 and they are spaced at 20 inches.

\[
\text{Sprayer output/nozzle} = \left( \frac{28 \text{ oz}}{29 \text{ sec.}} \right) \times \left( \frac{1 \text{ gal}}{128 \text{ oz}} \right) \times \left( \frac{60 \text{ sec}}{1 \text{ min}} \right) = \frac{0.453 \text{ gal}}{\text{min}/\text{nozzle}}
\]

Sprayer output = 50 nozzles×0.453gal/(min)/(nozzle) =22.6 gal/min
Plant Population and Emergence

To determine the plant population, the number of plants contained within an area is determined. For drilled soybeans, we recommend shortly after emergence, measure the row spacing, measure off 5 feet of row, and count all seedlings in the 5 feet of row. Do this at approximately 10 places in the field. The example below shows the calculations.

For broadcast seeding, we recommend that shortly after emergence, producers use a PVC counting frame that measures (inside diameter) 1 foot × 1 foot. The frame is randomly placed on the ground and all plants within the frame are counted. The average of about 10 random counts is used.

For planted beans, measure the row spacing and then measure off 20 feet of row, and count the seedlings per 20 feet of row. If the row spacing is 30 inches, the plant population is calculated as: (counted plants/(row spacing × length of row measured)).

Problem 53.12:

If an average of 93 plants were counted in 5 ft of row in a field where the drill row width was 7.5 inches, then the plant population is \( \frac{93 \text{ plants}}{5 \text{ ft} \times 7.5 \text{ inches}} \). To convert this population to plants/acre, the ft × inch area must be converted to acres. An example is shown below:

\[
\frac{9.3 \text{ plants}}{5 \text{ ft} \times 7.5 \text{ inches}} \times \frac{12 \text{ inches}}{1 \text{ ft}} \times \frac{43560 \text{ ft}^2}{1 \text{ acre}} = 130,000 \text{ plants/acre}
\]

Example broadcast:

If an average of 2.9 soybeans plants are counted per ft\(^2\), then the population of the field is \( \frac{2.9 \text{ plants}}{\text{ft}^2} \). To convert this population to plants/acre, the ft\(^2\) area must be converted to acres. An example is shown below:

\[
\frac{2.9 \text{ plants}}{\text{ft}^2} \times \frac{43560 \text{ ft}^2}{1 \text{ acre}} = 126,000 \text{ plants/acre}
\]

Problem 53.13. Calculate the % emergence—if the % germination is 96%, percent pure seed is 99%, the seeding rate was 150,000 seed/acre, and measured population was 125,000 plants (at V2)/acre.

\[
\text{Seeding rate} = \frac{\text{Desired plant population}}{\frac{\% \text{ germ} \times \% \text{ pure seed} \times \% \text{ emergence}}{100 \times 100 \times 100}}
\]

\[
150,000/\text{acre} = \frac{125,000/\text{acre}}{0.96 \times 0.99 \times \% \text{ emergence}}
\]

\[
\% \text{ emergence} = \frac{125,000/\text{acre}}{0.96 \times 0.99 \times 150,000/\text{acre}} = 67.7\% \text{ emergence}
\]

The apparent emergence was 80% \( [100 \times (1 - (150,000 - 125,000)/150,000)] \). The emergence and apparent emergence values are very different and can lead to different interpretations. Low emergence can result from poor seed viability, soil crusting, or a number of other factors.
Problem 53.14. Assuming a standard bushel of 13% moisture content soybeans weighs 60 lb, what will this standard bushel weigh when dried to 10% moisture?

When the grain is delivered to an elevator, often the payment is calculated based on the number of bushels of grain delivered. Different grains have different conversion factors. Because the moisture percentage is based on wet weight, the calculations are not straightforward and require several steps. Examples and needed equations are below.

\[
\text{% Grain moisture} = \frac{\text{Water Weight}}{\text{Water Weight + Dry soybean weight}} \times 100\%
\]

\[
\text{water weight} = \frac{\text{water weight}}{1 - \frac{\%\text{moisture}}{100}}
\]

1 bushel soybean at 13% moisture weighs 60 lbs
1 bushel soybean at 0% moisture weights 52.2 lbs

To solve this equation, water weight + dry soybeans = 60 lbs is needed. The dry grain weight is now determined by solving both equations simultaneously. This is accomplished by replacing Water Weight + Dry Soybeans with 60 lbs and rearranging the equation. After this is done, the water weight is calculated to be 7.8 lbs, from which the dry weight can be determined (60 lbs - 7.8 lbs = 52.2 lbs).

To determine the weight of a bushel of soybeans that has been dried down to 10% moisture, we use the same equation. These calculations are below.

\[
\text{10% Moisture} = \frac{\text{Water Weight}}{\text{Water Weight + Dry Soybeans}} \times 100\%
\]

Rearrange and substitute 52.2 lbs of dry soybeans for Dry Soybeans, which results in the equation:

\[
0.10(\text{Water Weight + 52.2lbs}) = \text{(Water Weight)}
\]

\[
\text{Water Weight} = \frac{0.1 \times 52.2\text{lbs}}{1 - 0.1}
\]

Based on these calculations, the water weight is determined (5.8 lbs/bu). This value is added to the dry corn weight to determine the weight of a bu of soybeans that has been dried to 10% moisture content. The bushel of 13% soybeans, dried to 10% moisture content now weighs 58 lbs (58 lb = 52.2 + 5.8 lbs).
Problem 53.15. What is the estimated yield if the plant population is 140,000 plants/acre, there are 72 beans per plant, and there are 3600 seeds per lb?

\[
\frac{140,000 \text{ plants}}{\text{acre}} \times \frac{72 \text{ beans}}{\text{plant}} \times \frac{1 \text{ lb beans}}{3600 \text{ kernels}} \times \frac{1 \text{ bushel beans}}{60 \text{ lb beans}} = 46.7 \text{ bu/acre}
\]

Crop yield estimates are very useful for marketing and planning purposes. Since plant population has been determined at plant emergence, the next step is to determine the average number of pods per plant and then determine the average number of beans per pod. Using this information we are able to calculate the number of beans per acre. Data from the seed testing laboratory at SDSU indicated that soybeans should fall between 2,800 and 4,400 beans/lb. The calculation is based on 1 lb of soybeans containing 3,600 seeds.

Problem 53.16. If you have 21 soybeans/ft behind the combine, what was your yield loss during combining?

To estimate combine yield losses, it is assumed that there will be about 3,600 beans per pound (for small and large beans use 4,400 beans/lb and 2,800 beans/lb, respectively). Yield loss can be measured by randomly placing a 1-foot square on the ground after combining and then counting the kernels contained within the square. To obtain a good estimate, this should be done at numerous locations. Once the beans are counted, the count/ft² are converted to bu/acre by using the appropriate conversion factors. For example, if 21 beans/ft² are found behind the combine, the yield loss is 4.2 bu/acre. The calculations are below.

\[
\text{Yield Loss} = \left( \frac{21 \text{ beans}}{\text{ft}^2} \right) \left( \frac{4356 \text{ ft}^2}{\text{acre}} \right) \left( \frac{1 \text{ lb}}{3,600 \text{ beans}} \right) \left( \frac{1 \text{ bu}}{60 \text{ lb}} \right) = 4.2 \text{ bu/acre}
\]

Note that \( \frac{21 \text{ beans}}{\text{ft}^2} \times \frac{1 \text{ bu}}{5 \text{ beans/ft}^2} = 4.2 \text{ bu/acre} \).

In many years in South Dakota, there are pods close to the ground. If the header cuts the stem above the pod, we refer to the pods left behind as in-row loss. To determine the magnitude of this loss (in 30-inch rows), count the beans in 4 foot of row. This will be beans/(4 feet by 30 inches) or beans/(10 ft²). Again use 5 beans/ft² = 1 bu/acre. It may be possible to reduce the loss of pods close to the ground by rolling the field (Chapter 16).

As a rule of thumb, assume that 5 beans/ft² = 1 bu/acre.
As a rule of thumb 50 beans left after cutting on stems in 30 inch rows is 1 bu/acre.
53.17. **Calculate the speed of the reel in the combine based on the following information.**

The reel on the combine header should be traveling at 10% to 25% faster speed than the ground speed of the combine. The speed of the reel can be measured by following the following procedure.

1. Measure the diameter of the reel, outside to outside. Our reel is 4 foot, 9 inches in diameter (4.75 ft).
2. With the combine running at normal field rpm, count the revolutions the reel makes in a minute. We put a red flag on one of the bars to make our counting easier. We counted 24.25 revolutions in a minute.
3. Calculate the velocity of travel at the tip of the reel in (mph) miles per hour. (Note: The circumference of a circle is calculated as \( \pi \times \text{diameter} \) or \( 3.14159 \times 4.75 \).)

\[
\frac{24.25 \text{ rev}}{\text{minute}} \times \frac{4.75 \text{ ft}}{\text{rev}} \times \frac{60 \text{ minutes}}{\text{hour}} \times \frac{1 \text{ mile}}{5280 \text{ ft}} = 4.11 \text{ mph}
\]

4. Since we typically combine at 3.5 mph, we need the end of the reel to be traveling somewhere 10% to 25% faster speed then the ground speed of the combine, so \( (3.5 + 3.5 \times 0.1 \) and \( 3.5 + 3.5 \times 0.25 \) is 3.85 to 4.37 mph. Our reel is traveling at 4.11 mph so the reel meets the criteria.

**Soybean Storage in a Cylinder**

To determine how much soybean can be stored in a cylinder, the volume of the bin must be determined. Many grain storage systems are cylinder in shape and the volume is determined using the equation for a cylinder and the volume of a bushel (Table 53.1).

The volume for a cylinder is \( v = \pi r^2 h \); volume of a bushel is 1.244 ft\(^3\). \( \pi \) is approximately equal to 3.14159 and \( r \) is the radius (2 \( \times \) r = diameter).

**Problem 53.18. How many bushels of soybeans can be stored in a cylinder that has a diameter of 26 feet and height of 24 feet?**

The amount of grain stored in cylinder-shaped bin is calculated by dividing the volume of the bin by the volume of a bushel. The volume for a bushel is 1.244 ft\(^3\). By substituting a value for the radius (half the diameter) into the cylinder equation, the storage capacity per bin is determined.

\[
\frac{\pi \times 13^2 \times 24}{2 \times \text{1 bu}} = \frac{3.14159 \times 13^2 \times 24}{1.244 \text{ ft}^3} = \frac{10,243 \text{ bu}}{\text{bin}}
\]

**Hint:** When doing these calculations, check the units.
References and additional information

Acknowledgements
Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

To combine data sets from different farms, common protocols must be followed. To develop on-farm protocols several conventions should be followed (Table 54.1). The purpose of this chapter is to discuss those conventions and develops guidelines for developing new protocols.

Table 54.1. Guidelines for developing on-farm research protocols.

1. The learning community identifies a critical need.
2. Based on current recommendations, identify the critical value that should be measured.
3. All collaborators should read, review, and agree to the stated protocols.
   a. Collaborators need to agree to share data.
4. Identify fields where differences are likely.
5. Collect archived yield monitor data from the field.
6. Conduct the experiments.
7. Conduct a field day where the experiments are reviewed by the different collaborators.
8. Calibrate the yield monitor on the combine.
9. Collect and analyze the yield responses and determine economic optimum algorithms.
10. Develop optimized input recommendation algorithms and distribute results.
Case Study One

Critical need: Profitability and energy efficiency can be improved by using variable rate seeding. Typical planting population recommendations of approximately 150,000 seeds per acre were developed from experiments conducted on uniform topography.

Experiment: Plant Different Populations Across the Field

1. Select fields for the study. In the analysis, historical yield maps (actually the yield monitor data is needed) will improve the calculations. There should be five years of yield monitor data for the selected field.
2. Place strips perpendicular to the landscape topography (i.e., running uphill and downhill).
3. Apply at least one complete set of a minimum of four rates, the length of the field. Document cultural practices such as planting date, hybrid, condition of seedbed, etc.
   A grower with a variable rate planter will plant ½ mile strips (of width greater than the combine header) at 80,000, 130,000, 180,000, and 230,000 thousand seeds/acre.
4. Collect soil samples (0-6 and 6-24 inches) to document soil fertility. Consolidate onto a single memory device all historical yield monitor data taken from the field on which the experiment is to be accomplished.
5. Vary only the planting population. Uniformly apply all other inputs in the field.
6. Accurately record the GPS coordinates of the experiment. If rows are not straight (not planted on an A-B line with an auto steer), an agronomy professional will walk the strip centers with a recording GPS receiver.
7. Measure stand counts and planter uniformity.
8. The trial must be harvested with a data recording, GPS-equipped combine. The yield monitor must have been recently calibrated for the variety of beans in the trial. Harvest the entire trial area on the same day. Combine direction of travel should be the same for all strips within a set. GPS yield data should be submitted within 30 days of harvest or no later than December 1, as raw yield from the memory card.
9. Measure post harvest losses both on the ground and on stems.
10. Allow SDSU to analyze and use data collected from the study sites for research, educational, and informational purposes.
11. Measure rainfall and scout the field regularly. Document as much auxiliary information as is possible (precipitation, weed, insect, disease problems, soil test analysis, etc.)

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Case Study 2

Critical issue: Profitability can be improved by using variable rate P applications. This information is needed to address increasing costs of phosphorous fertilizer. Our current P recommendations were developed from studies conducted on uniform soil types. This approach may lead to incorrect rates on certain soils.

Experiment Option 1: Apply Different P Rates Across the Field

1. Select fields for the study. In the analysis, prior yield records will improve the calculations. The availability of five years of data should be checked before selecting the field.
   a. Soil test P level should be in the medium to low range.
   b. No recent history of manure applications.
2. Consolidate onto a single memory devise all historical yield monitor data taken from the field on which the experiment is to be accomplished. Submit this data with strip trial yield monitor data.

3. Place treatment strips perpendicular to the landscape topography (i.e., running uphill and downhill) variability.

4. Apply at least one complete set of alternating strips of four rates, the length of the field. Document cultural practices such as planting date, hybrid, condition of seedbed, etc.
   a. 500 lb of actual \( P_2O_5 \) /Acre
      (If DAP is applied, 18-46-0; this will be 1087 lb DAP/acre—after application soil test will increase ~25 points)
   b. 300 lb of actual \( P_2O_5 \) /Acre
      (652 lb DAP/acre—after application soil test will increase ~15 points)
   c. 100 lb of actual \( P_2O_5 \) /Acre
      (217 lb DAP—after application soil test will increase ~5 points)
   d. 0 lb of actual \( P_2O_5 \) /Acre

5. Collect soil sample (0-6 and 6-24 inches) to document soil fertility.
   a. Both depths should be analyzed for either Olsen or Bray P.
   b. Before fertilizer application 15 soil sample cores (cores to be composited for each depth) will be taken on a spacing of approximately every 400-foot on the \( \frac{1}{2} \) mile center of the strips transect. Across \( \frac{1}{2} \) mile, there will be about six sites from which samples are taken. Sites can be adjusted so that samples are taken to adequately represent every topographic feature of the transect. (hill top, side hill, foot slope, bottom ground). A GPS receiver will be used to document the location of each sampling location. A year after treatment and every two years after, the same sampling protocol will be accomplished for each treatment strip. If there are four treatments and six sites, there will be 24 sites at which samples will be taken.
   c. Use the same laboratory to do the soil analysis.

6. Within a strip, P should be uniformly applied.

7. Record in a experimental notebook the GPS coordinates of the various treatments. If rows are not straight (not planted on an A-B line with an auto steer), an agronomy professional will walk the strip centers with a recording GPS receiver.

8. Measure stand counts and planter uniformity.
9. Measure yield losses. The trial must be harvested with a data recording, GPS-equipped combine. The yield monitor must have been recently calibrated for the variety of beans in the trial. Harvest the entire trial area on the same day. Combine direction of travel should be the same for all strips within a set. GPS yield data should be submitted within 30 days of harvest or no later than December 1, as raw yield from the memory card.

10. Allow SDSU to analyze and use data collected from the study sites for research, educational, and informational purposes.

11. Measure rainfall and scout the field regularly. Document as much auxiliary information as is possible (precipitation, weed, insect, disease problems, soil test analysis, etc.)

**Experiment Option 2: Apply One P Rate Across Field**

1. Spread heavy rates of P or K perpendicular to the rows. The width of the spreader swath is typically greater than 90 ft.

2. The P rate for the strip should be designed to increase the soil test P value to greater than 16 ppm (very high soil P level). Typically it takes around 20 lbs of $\text{P}_2\text{O}_5$/acre to increase the soil test value 1 ppm (1 pt of Olsen P). (Fig. 54.2)

3. Harvest going in the same direction as the rows and evaluate yield monitor data. An increase in yield indicates that there is fertilizer response.

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One of the first steps in improving field profitability is to identify portions of fields making and losing money. The purpose of this chapter is to demonstrate a cookbook approach for developing a soybean profitability map.

**Estimating production costs**

Field profitability maps can be used to identify where and when not to invest your limited resources. To develop a field profitability map, the production costs and returns must be calculated. For many fields, the input costs are not variable (the cost for spraying an acre is the same everywhere in the field) and can be assigned equally for every acre in a field. The production input costs can be itemized into:

<table>
<thead>
<tr>
<th>Annual input costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Known variable expenses</td>
</tr>
<tr>
<td>a. Seed</td>
</tr>
<tr>
<td>b. Fertilizer</td>
</tr>
<tr>
<td>c. Pesticide</td>
</tr>
<tr>
<td>d. Insurance</td>
</tr>
<tr>
<td>e. Crop consulting</td>
</tr>
<tr>
<td>2. Allocated expenses</td>
</tr>
<tr>
<td>a. Repairs</td>
</tr>
<tr>
<td>b. Fuel</td>
</tr>
<tr>
<td>3. Capital Expenses</td>
</tr>
<tr>
<td>a. Machinery ($/acre, interest + depreciation to annualized, and allocated by acre)</td>
</tr>
<tr>
<td>b. Land ($/acre, known market value for your area)</td>
</tr>
<tr>
<td>4. Labor ($/acre)</td>
</tr>
<tr>
<td>5. Interest and depreciation</td>
</tr>
</tbody>
</table>
**Input costs detailed**

The annual input costs are calculated from your records. The sample data set shown in Table 55.1 was estimated from students attending Plant Science Agronomy courses at South Dakota State University. For these calculations, the farm size is 778 acres. The annualized per acre machinery cost assumes 6% interest and 7% depreciation for a total annualized cost of 13% of the total machinery value. Divide the annualized cost by the number of acres covered to get annualized per acre cost. This data suggests that soybean inputs costs are $372.75/acre.

The production costs do not consider returns on the investment. For example, the soil sampling cost of $2.50/acre provides the basis for the fertilizer recommendations and provides critical information for where to apply the fertilizer inputs.

### Table 55.1. Estimated soybean input costs for a typical South Dakota soybean grower. The farm size is 778 acres.

<table>
<thead>
<tr>
<th>Known Variable Expenses</th>
<th>Amount</th>
<th>Rate</th>
<th>Cost ($/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed</td>
<td>1 bag of seed/acre</td>
<td>$52/bag</td>
<td>$52</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>51 lbs P₂O₅/acre</td>
<td>$0.41/lb</td>
<td>$21</td>
</tr>
<tr>
<td>Herbicide (Roundup®)</td>
<td>2 Roundup® applications/acre</td>
<td>$10/application</td>
<td>$20</td>
</tr>
<tr>
<td>Insecticide (Warrior®, aphids)</td>
<td>1 application of Warrior®</td>
<td>$22/application</td>
<td>$22</td>
</tr>
<tr>
<td>Crop Consulting</td>
<td></td>
<td>$4.50/acre</td>
<td>$4.50</td>
</tr>
<tr>
<td>Soil Sampling</td>
<td></td>
<td>$2.50/acre</td>
<td>$2.50</td>
</tr>
<tr>
<td>Insurance</td>
<td></td>
<td>$19/acre</td>
<td>$19</td>
</tr>
<tr>
<td>Interest</td>
<td></td>
<td>$4.25/acre</td>
<td>$4.25</td>
</tr>
</tbody>
</table>

| Allocated Expenses               |                         |              |            |
| Fuel and Lub (average = 5 gal diesel and lub per acre, i.e., 5110 gal used on 1040 acres) | 5 gal diesel and lub | $16.50/acre | $16.50     |
| Repairs and parts                |                         | $6/acre      | $6         |

| Capital Expenses                 |                         |              |            |
| Machinery ($227,000 to val, int + dep = 13% over 778 acre. If owned, this will be a cost to the crop but income to separate machinery ownership enterprise.) | $29,510/(farm year) | $38        |
| Land rent (If owned, use known value for similar soil type in area. Will be a cost to raising crop but income to a separate land ownership enterprise.) | $135/acre | $135        |

| Labor                            |                         |              |            |
| 70% to crops and 30% to part time job | $35,000/year on 778 acres, 70% to crop | $32        |

**Total Costs**                     |                         |              | $372.75    |

1. The Roundup Ready® seed was tested and found to contain 2800 seeds/lb. The 50 lb bag cost $52 and contained 140,000 seeds. The field was planted at a rate of 140,000 seeds/acre.
   a. Increasing the seeding rate to 160,000/acre would increase the seeding cost to $59.43/acre, reducing the seeding rate to 120,000 seeds/acre would reduce the costs to $44.57/acre. This cost is likely to increase in the future.

2. When DAP was applied (to the corn prior to the beans) the yield goal was 60 bu/acre. The recommendation was based upon removal of 0.84 lb P₂O₅/bu. (P₂O₅ cost $0.41/lb).

\[
\frac{21}{acre} \left( \frac{60bu}{a} \right) \left( \frac{0.84lbP₂O₅}{bu} \right) \left( \frac{0.41}{lbP₂O₅} \right)
\]
3. The local Coop applied two applications of generic glyphosate at a billed rate of $10/acre.

4. The local Coop applied one application of Warrior® at a billed rate of $22/acre.

5. The producer hires a crop consultant on an annual basis to make recommendations and to weekly scout his or her fields for $4.50/acre.

6. The crop consultant zone samples the field for $2.50/acre.
   - 160-acre field, where 10 composite samples are collected.
   - Total cost per field is $400 (160a x $2.5/a), for a cost of $40/sample which is collected from a 16-acre area.

7. The producer's crop insurance was $19/acre.

8. Crop inputs were prepaid with money borrowed from the local bank. The bank loan is at an interest rate of 6%, but the money was borrowed for six months so ½ year of interest was charged.

9. The total bill for all diesel and lubricant from the local BP fuel dealer was $12,840. Since there was no other user of the fuel and lubricants other than the 778 acres of crop land, the bill was divided out evenly across all acres. ($12,840 / 778 = $16.50)

10. All repairs and parts were purchased from the local John Deere dealer. The John Deere dealer’s year end summary bill indicated what he spent for parts and repairs ($4670), so $4670 / 778=$6.00.

11. An inventory of the producer’s machinery that is used only on the 778 acres indicates that it is valued at $227,000. Assume that the farmer’s machinery is depreciating at a rate of 7% per year. Assume that the money to buy the machinery was borrowed at 6% per year, then interest and depreciation costs are 13% per year (7% + 6%). The annual cost for owning the machinery is (0.13*$227,000 = $29,510) and since this farmer uses this machinery to only farm the 778 acres, (no livestock or custom work) this cost is evenly divided across the 778 acres. The annualized machinery cost per acre is ($29,510/778 = $37.93~$38/acre). If owned, this will be a cost to raising the crop, but as income to a separate machinery ownership enterprise.

12. The field in question is rented and the farmer’s rent for the field is $135/acre. If owned, use known value for similar soil type in local area. Will be a cost to raising the crop but income to separate land ownership enterprise.

13. The farmer does all of the work himself. He has a part time job that he assumes accounts for 30% of his time. The rest of his time (70%) is devoted to farming. He feels he could make $35,000/year if he took a job other than farming so ($35,000 * 0.7 / 778 acres) = $31.50/acre (~$32/acre.)

14. Add together each expense to get the total of $372.75/acre.

**Estimated return and profitability**

The estimated return is calculated by multiplying the soybean selling price times the yield. In this example, the soybean selling price was $9.50/bushel and the yield was 55 bushels/acre. Based on these values, the profit for the entire field was $149.75/acre (522.50-372.75=$149.75/acre).

**Developing a profitability map**

A soybean profitability map is developed using Ag Leader SMS Advanced® Software with detailed map shots provided below. To do this analysis a yield monitor data file is needed.
Open the SMS Advanced program and select a soybean yield file (Fig 55.1). Start first by cleaning the data. A basic data filter can be set for the yield data by high-lighting the yield data product under Grain Harvest, then right clicking with the mouse button. Select "Reprocess Data."

Next set the filter settings for a minimum and maximum yield. Press "Next."

Note: A more advanced filtering of the data can be conducted using the USDA Agricultural Research Service “Yield Editor” software program. The exporting and importing of the yield data will be required between the SMS and Yield Editor programs.

Website: https://www.ars.usda.gov/services/software/download.htm?softwareid=370 - downloadForm
Once the dataset has been filtered, a profitability map can be developed. First, open a soybean map in Ag Leader SMS™ Advanced version 12.0 software (Fig. 55.3). Developing the profitability map involves a number of steps that are explained below. Different commercial mapping programs will use different steps, but the purpose in this chapter is to highlight the process of developing a map. The profitability map is very useful for identifying problem areas. For example:

1. Should I install a tile drain?
2. Should I enroll my land in CRP?
3. Should I try precision farming?
4. Should I increase or decrease my cash rent?

Answers to these questions are determined by identifying if there are areas that routinely make or lose money. If they lose money, you can use the approach described below to develop approaches that will make money. In some situations, it may be most profitable to install tile drainage or put the land into pasture or graze the land.

Figure 55.3. Filtered soybean yield data shown in the mapping area.
Select Analysis Wizard (Fig. 55.4).

Select Equation Based Analysis: Press “Add.”
Figure 55.6. Enter Equation Name.

Enter a name for the Equation Based Analysis. Press “Next.”

Figure 55.7. Creating an Analysis (Step 1).

Step 1: Press “Add” under Analysis Result 1.
Step 2: Enter: Result Name (Soybean Profit Map): Attribute Group (Profit/Loss): Units ($/ac).

Step 3: Set Result Operation (select Analysis Results).
Figure 55.10. Define Temporary Result variable 1 (Soybean Sell Price).

Step 4. Press Add under Temporary Results: Enter Result Name (Soybean Sell Price): Set Data Type to (Decimal Number): Checkmark (Prompt for Value When Analysis is Run): Press “OK.”
Step 5. Enter a second Temporary Result variable: Enter Result Name (Soybean Cost/Acre): Set Data Type to (Decimal Number): Checkmark (Prompt for Value When Analysis is Run): Press “OK.”

Figure 55.12. Analysis Result page with information entered.
Step 6. Press “Next.”
Step 7. Press “Add Dataset.”

Step 8. Select an appropriate soybean yield dataset from the Management Tree.
Figure 55.15. Dataset Grid Settings main screen.


Figure 55.16. Dataset Grid settings.

Step 10. Enter appropriate grid settings for your dataset.
Step 11. Press “Ok.”

Step 12. Press “Next.”
Figure 55.19. Management Item Inputs screen.

Step 13. Press “Next.”

Figure 55.20. Define Result Equation Screen.

Step 15. Select the Input Dataset (Grain Harvest): Attribute (Estimated Volume (Dry)): Attribute Statistic (Grid Value): Units (bu/ac): Press “Add”: Set the Alias name to Soybean_Yield: Press “OK.”
Figure 55.22. Result Equation is defined as shown.

Step 16. To enter equation:
Press “Result =”
Press “(”
Press “Soybean_Yield”
Press “*”
Press “Soybean Sell $/bu”
Press “)”
Press “-”
Press “Soybean Cost Acre”

Enter the shown equation using Equation Functions, Constant Values and Variable Spatial Functions. Note: “Result=” is the soybean profitability result at each grid area. Press “Finish.”
Step 17. The “Soybean Profitability” Analysis Function is now available for running on desired fields. Press “Single Field.”
Figure 55.24. Soybean Profitability analysis is started with selection of yield data.

Step 18. The Default yield map appears for profitability analysis. This can be changed to desired field. Press “Next.”
Step 19a. Analysis begins on the desired field. Enter the selling price for the soybean crop.

Step 19b. Enter the cost analysis for the soybean crop.
Figure 55.27. Preview window of Soybean Profitability Analysis.

Step 20. The soybean profitability map appears. Press “Save.”

Figure 55.28. Profitability Map appears after selecting Profit/Loss in the Legend area.

Figure 55.29. Profitability Map shown with legend set at profitability levels.

Step 22. Set the Legend to your desired settings. This process has converted a yield map into a map that accounts for financial inputs and outputs. Based on this map you can identify areas that make and lose money. As you travel from right to left across the map, the profitability decreases. In many fields, large portions of the field lose money. Maps such as these can be used to assess profitability across years. If areas consistently lose money, the management practices need to be modified so that they make money. Approaches that should be considered include: installing tile drainage, converting to CRP, increasing or decreasing the seeding or fertilizer rate, and converting to a pasture.

References and additional information
SMS Certified training manual. 2012. SMS Advanced version 12.0. Ag Leader Technology Inc.

Acknowledgements
Funding for developing this chapter was provided by the South Dakota Soybean Research and Promotion Council, USDA-AFRI, and South Dakota 2010 research program.

Understanding soybean production costs is the first step in optimizing your soybean management system. An interactive tool, the “2012 Risk Calculator,” is available at http://www.sdstate.edu/econ/extension/index.cfm. It will assist you in calculating your total costs and net returns. This chapter is focused on the analysis of South Dakota soybean production costs and changes in these costs over time. The analyses are based on county producers workshops conducted between 2009 and 2012 and may be different from actual budgets.

**Soybean gross returns and total costs**

Financial budgets are important to understand before committing resources to implementing a new plan. Each crop grown can be considered as an enterprise, and a budget can be realized to provide an estimate of the potential revenue, expenses, and profit. The base unit is typically one acre for crops. Budgets help identify the most profitable crop to be included in the whole farm plan. Table 56.1 is used to discuss the content and components of a crop budget. In the following discussion, the soybean production budget is separated into several categories that include gross returns, total direct costs, total costs, and returns to management and labor.

- **Gross returns** or revenue are the long term average return assumed to be earned before deducting management fees and other expenses. It is the total revenues from grain or hay sales, insurance indemnities, and government payments.

- **Total direct costs** are all the variable costs associated with production; seeds, fuel, fertilizers, chemicals, and so forth. Total costs are total direct costs plus land charge and machinery ownership costs.
**Returns to management and labor** or profit are the net returns after deducting all expenses from the gross returns. Everyone is interested by this last value, and therefore it is important to interpret it correctly. The first step in constructing a crop financial budget is to determine agronomic practices, type and level of inputs, etc. All of the agronomic, technical, and production decisions have to be made before realizing the crop budget.

**Gross returns** include all cash and non-cash revenue from the crop. Some crops have several sources of revenue, and therefore all should be included. For example, both corn grain and stover can be harvested. Both revenue streams should be included in the budget. The accuracy of the estimated profit highly depends on the accuracy of this section. Yields and prices estimates should be as accurate as possible.

**Projected yields** are based on historical yields or yields trends from the concerned state or the county.

**The appropriate selling price** depends if the budget is only for the next year planning or for long term purposes. Historical prices levels, price trends, and futures markets prices adjusted for local basis are often used.

**The direct costs** are the costs that are induced only if the crop is produced. Table 56.2 shows the details of the production inputs for soybean and corn in 2011.

- The costs of **seed, fertilizers, and pesticides** are easy to calculate, once the level of input has been decided.
- The **crop insurance** is found depending on the kind of insurance a producer will choose, either yield insurance or revenue insurance.
- **Machinery costs** (operating) are difficult to estimate. A method must be chosen to estimate the amount of repair expenses relative to the type of machinery, and the amount of use. Some tools exist to help farmers estimate these costs; the Iowa Custom rate is one example and can be found for a given year at https://www.extension.iastate.edu/agdm/crops/html/a3-10.html. The cost of fuel and lubricants should not be forgotten in those estimates.
- The **cost of labor** should also be included. It depends on the crop production and on the size of the machinery used and the number of machinery operations. The opportunity cost of farm operator is normally used to value labor.
- The **operating interest** is the last direct cost included in the budget. For soybeans or corn, it is generally less than a year from the time of the expenses until harvest when income is received. Interest is charged for a period of less than one year. Even if no capital is borrowed, there is an opportunity cost on the farm operator’s capital. A weighted average of the interest rate on borrowed money and the opportunity cost of the farmers operating capital are used to estimate the operating interest.

All of these costs are summed and described as total **direct costs** per acre. Return over direct costs is the value of total direct costs subtracted from the gross returns. The last part of the budget is the **total costs**. It includes direct costs in producing a crop and the other costs that exist even if the crop is not grown. Land charge and machinery ownership costs are added to the direct costs. Land charge can be calculated several ways: the cost to cash rent similar land, the cost of a share rent lease for this crop on similar land, or the opportunity cost of the capital invested in the owned land. The estimated **net returns** are found by subtracting total costs from gross returns.

Soybeans are often grown in rotation with corn. In this case, budgets should be developed for each crop and the ownership costs divided between the two crops. Storage, marketing, and transportation are not included in this budget because they are not considered as a production decision, but rather a marketing decision. Crop enterprise budgets can be used to determine:
• The **cost of production** is the average cost of producing one unit of the commodity. It is determined by dividing the total cost by the estimated yield. In Table 56.1, the estimated soybean costs in 2012 was $10.38/bushel. This cost changes annually. A profit is realized when the crop is sold at higher price than the cost of production.

• The **breakeven yield or prices**. The breakeven yield is calculated by dividing total cost by the selling price. The breakeven yield is the yield necessary to cover the cost of production. For example, in 2012 the cost of production was $415.06/acre and the expected selling price was $12.6/bu. Based on these values, the breakeven yield was 33 bushels/acre.

Table 56.1. Estimated South Dakota soybean production costs and return to labor and management from 2009 to 2012. This calculator is available at [http://www.sdstate.edu/econ/extension/index.cfm](http://www.sdstate.edu/econ/extension/index.cfm).

<table>
<thead>
<tr>
<th>Gross returns</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated yield (bu)</td>
<td>40.00</td>
<td>40.00</td>
<td>40.00</td>
<td>40.00</td>
</tr>
<tr>
<td>Estimated selling price ($/bu)</td>
<td>8.02</td>
<td>8.28</td>
<td>12.90</td>
<td>12.60</td>
</tr>
<tr>
<td>Value/acre</td>
<td>328.00</td>
<td>331.20</td>
<td>516.00</td>
<td>504.00</td>
</tr>
<tr>
<td>Other income/acre</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross return ($/acre)</td>
<td>328.00</td>
<td>331.20</td>
<td>516.00</td>
<td>504.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Direct costs ($)/acre</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed ($) (a)</td>
<td>52.50</td>
<td>52.50</td>
<td>52.50</td>
<td>56.00</td>
</tr>
<tr>
<td>Fertilizer ($) (a)</td>
<td>33.55</td>
<td>18.11</td>
<td>30.27</td>
<td>48.12</td>
</tr>
<tr>
<td>Herbicide ($) (a)</td>
<td>20.39</td>
<td>15.28</td>
<td>15.28</td>
<td>17.88</td>
</tr>
<tr>
<td>Insecticide ($) (a)</td>
<td>3.81</td>
<td>3.81</td>
<td></td>
<td>4.20</td>
</tr>
<tr>
<td>Fungicide</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop insurance ($) (a)</td>
<td>25.00</td>
<td>25.00</td>
<td>25.00</td>
<td>17.25</td>
</tr>
<tr>
<td>Machinery ($) (a)</td>
<td>43.00</td>
<td>28.00</td>
<td>38.00</td>
<td>50.00</td>
</tr>
<tr>
<td>Drying</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating interest ($) (a)</td>
<td>10.47</td>
<td>8.56</td>
<td>9.48</td>
<td>11.61</td>
</tr>
<tr>
<td>Other costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total direct costs ($) (a)</td>
<td>184.91</td>
<td>151.26</td>
<td>174.34</td>
<td>205.06</td>
</tr>
</tbody>
</table>

| Return over direct costs ($) (a) | 143.09   | 179.94   | 341.66   | 298.94   |
| Total direct costs/bushel ($) (a) | 4.62     | 3.78     | 4.36     | 5.13     |
| Machinery ownership costs ($) (a) | 45.00    | 45.00    | 51.00    | 60.00    |
| Land charges ($) (a)  | 102.00    | 102.00   | 110.00   | 150.00   |

| Total costs/acre ($) (a) | 331.91   | 298.26   | 335.34   | 415.06   |
| Breakeven value ($) (bu) | 8.30      | 7.46     | 8.38     | 10.38    |
| Return to management ($) (a) | -3.91    | 32.94    | 180.66   | 88.94    |
| Breakeven yield (bu/acre) | 40.00    | 36.00    | 26.00    | 33.00    |
Table 56.2. Costs estimates for crop budgeting in 2011. Left: Production inputs for soybeans. Right: Production inputs for corn. (Source: SDSU Extension)

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Price</th>
<th>Unit</th>
<th>Cost/ ac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed</td>
<td>150.0</td>
<td>0.35</td>
<td>1,000</td>
<td>$52.50</td>
</tr>
<tr>
<td>Fertilizer (lbs)</td>
<td>25.0</td>
<td>3.07</td>
<td>1,000</td>
<td>$76.75</td>
</tr>
<tr>
<td>N</td>
<td>11.0</td>
<td>0.48</td>
<td>lbs</td>
<td>$30.27</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td></td>
<td>lbs</td>
<td>$118.90</td>
</tr>
<tr>
<td>P</td>
<td>52.0</td>
<td>0.48</td>
<td>lbs</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>0.38</td>
<td></td>
<td>lbs</td>
<td></td>
</tr>
<tr>
<td>Herbicide</td>
<td>4.0</td>
<td>1.29</td>
<td>oz</td>
<td>$15.28</td>
</tr>
<tr>
<td>Select</td>
<td>44.0</td>
<td>0.23</td>
<td>oz</td>
<td></td>
</tr>
<tr>
<td>Insecticide</td>
<td>2.8</td>
<td>1.36</td>
<td>oz</td>
<td>$3.81</td>
</tr>
<tr>
<td>Baythroid</td>
<td></td>
<td></td>
<td>oz</td>
<td></td>
</tr>
<tr>
<td>Fungicide</td>
<td></td>
<td></td>
<td>oz</td>
<td>$ -</td>
</tr>
</tbody>
</table>

South Dakota soybean production costs

By tracking changes in costs and net returns farm investment options can be explored. A tool for conducting this analysis is available at http://www.sdstate.edu/econ/extension/index.cfm. This analysis showed that:

1. On average from 2009 to 2012, soybean production costs increased from $331.91 to $415.06 per acre. This increase was attributed to many factors including higher costs for fertilizer, land, and machinery (Table 56.1).
2. The major annual production costs were for seed, fertilizer, and chemicals which increased from $106.44 in 2009 to $126.20 in 2012. Most of the remaining costs were for machinery operations, machinery ownership, and land costs (Table 56.1).
3. In soybean production most of the fertilizer cost was associated with purchasing P fertilizer, herbicides were Select® and Roundup®, while insecticides were baythroid (Table 56.2).
4. In corn production, fertilizer costs were associated with N, P, and zinc, and herbicide costs were associated with harness extra and roundup (Table 56.2).

To further assess production cost changes across different localities, Mr. Donald Guthmiller, SDSU Extension, conducted a production survey in 2011 and 2012 (Fig. 56.1) in 13 different counties. Most participants were located in eastern South Dakota. Several differences can be seen across counties (Fig. 56.1):

1. In 2011, the lowest soybean total cost per acre ($304.48/acre) were in Clark County, and in 2012 the highest costs per acre ($403.40/acre) were in Deuel County.
2. Large variation in county yields, which ranged from 35 to 48 bushels /acre, affected net returns.
3. In 2012, projected return to management and labor varied from near $0 in Grant County to over $150/acre in Minnehaha County.
The details of the soybean production costs across counties are shown in Figure 56.2. This analysis shows that in 2012: 1) seed costs were relatively stable across counties; 2) fertilizer prices varied from $23.4/acre to $37.12/acre; and 3) land rental costs varied from $60/acre in Hughes County to $155/acre in Brookings and Day counties.
The amount of gross returns, direct costs, total costs, and returns for labor and management were influenced by the location (Fig. 56.3). In 2011, the highest return to management and labor was in Brown County and the lowest return was in Clark County. Slightly different results were observed in 2012 where the highest returns were in Minnehaha County and the lowest returns were in Grant County.

Yields of corn, similar to soybeans, vary a lot depending on the county, from 130bu/acre in Hughes County to 180bu/acre in Kingsbury, Hamlin, and Brookings counties; therefore the gross return for corn production is also really different from $936/acre in Hamlin County to $627/acre in Roberts County.

Seed costs were stable across counties, while fertilizers costs ranged from $123/acre to $160/acre. The other main factor of variation across counties is the land charge. The variation is much higher than for soybean, from $60/acre in Hughes County to $250/acre in Minnehaha County which is more than four times higher. This difference in land charge across counties explains most of the difference in total cost and therefore in net returns.

**Changes in soybean production costs from 1980 to 2012**

From 1980 to present, soybeans have become a major South Dakota crop. In 1980, soybeans were harvested from 770,000 acres and production value was $144 million. In 2011, South Dakota farmers harvested 4.1 million acres of soybeans and production value was $1.716 billion, second only to corn acres and production value. From 1980 to 2011, South Dakota farmers harvested nearly 3.33 million more soybean acres and production value had increased by 12-fold (USDA-NASS). Factors that contributed to increased soybean production include strong soybean prices, low production costs, and that soybeans fit into the production system.
The widespread adoption of herbicide-tolerant varieties and low-till production practices helped keep soybean production costs low. This part presents the costs of producing soybeans in South Dakota and examines how these costs varied from 1980 to 2012, a 32-year period. The budgets reported in Table 56.3 and Figure 56.4 were from crop planning budgets used by SDSU Extension Economists in the respective years. The planning budgets were usually developed in January using projected yields, prices, and production costs for the upcoming crop year.

Table 56.3. Summary of January soybean budgets for South Dakota from 1980 to 2012.  
(Source: SDSU Extension)

<table>
<thead>
<tr>
<th>Year</th>
<th>Yield (bu/a)</th>
<th>State-wide Yield (bu/a)</th>
<th>Selling Price ($/bu)</th>
<th>Total Revenue ($/a)</th>
<th>Production Costs ($/a)</th>
<th>Land Charges ($/a)</th>
<th>Total Cost ($/a)</th>
<th>Breakeven Price ($/a)</th>
<th>Breakeven Yield (bu/a)</th>
<th>Net Income ($/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>18.5</td>
<td>26.0</td>
<td>6.50</td>
<td>120.25</td>
<td>81.85</td>
<td>28.50</td>
<td>110.35</td>
<td>5.96</td>
<td>17.0</td>
<td>9.90</td>
</tr>
<tr>
<td>1983</td>
<td>30.0</td>
<td>26.5</td>
<td>5.10</td>
<td>153.00</td>
<td>122.60</td>
<td>37.40</td>
<td>160.00</td>
<td>5.33</td>
<td>31.4</td>
<td>3.00</td>
</tr>
<tr>
<td>1985</td>
<td>28.0</td>
<td>32.0</td>
<td>5.50</td>
<td>154.00</td>
<td>117.50</td>
<td>32.25</td>
<td>149.75</td>
<td>5.35</td>
<td>27.2</td>
<td>4.25</td>
</tr>
<tr>
<td>1989</td>
<td>28.0</td>
<td>26.0</td>
<td>6.50</td>
<td>182.00</td>
<td>104.87</td>
<td>33.75</td>
<td>138.62</td>
<td>4.95</td>
<td>21.3</td>
<td>43.38</td>
</tr>
<tr>
<td>1993</td>
<td>29.0</td>
<td>22.0</td>
<td>6.03</td>
<td>174.04</td>
<td>116.31</td>
<td>41.25</td>
<td>153.62</td>
<td>5.46</td>
<td>26.1</td>
<td>16.48</td>
</tr>
<tr>
<td>1997</td>
<td>31.0</td>
<td>35.0</td>
<td>6.35</td>
<td>199.43</td>
<td>108.22</td>
<td>56.22</td>
<td>157.56</td>
<td>5.24</td>
<td>25.9</td>
<td>34.99</td>
</tr>
<tr>
<td>2000</td>
<td>36.0</td>
<td>35.0</td>
<td>4.95</td>
<td>178.20</td>
<td>95.80</td>
<td>56.00</td>
<td>164.44</td>
<td>4.22</td>
<td>30.7</td>
<td>0.59</td>
</tr>
<tr>
<td>2002</td>
<td>36.0</td>
<td>31.0</td>
<td>5.15</td>
<td>185.40</td>
<td>103.40</td>
<td>57.00</td>
<td>151.80</td>
<td>4.56</td>
<td>31.2</td>
<td>31.49</td>
</tr>
<tr>
<td>2005</td>
<td>40.0</td>
<td>38.0</td>
<td>5.00</td>
<td>200.00</td>
<td>108.56</td>
<td>65.00</td>
<td>160.40</td>
<td>3.96</td>
<td>31.7</td>
<td>26.41</td>
</tr>
<tr>
<td>2010</td>
<td>40.0</td>
<td>30.0</td>
<td>8.28</td>
<td>331.20</td>
<td>196.26</td>
<td>102.00</td>
<td>298.26</td>
<td>7.46</td>
<td>36.0</td>
<td>32.94</td>
</tr>
<tr>
<td>2012</td>
<td>40.0</td>
<td>12.0</td>
<td>12.60</td>
<td>504.00</td>
<td>265.06</td>
<td>150.00</td>
<td>415.06</td>
<td>10.38</td>
<td>32.9</td>
<td>88.94</td>
</tr>
</tbody>
</table>

Figure 56.4. Changes over time in net income and costs of producing soybeans from 1980 to 2012.  
(Source: Data is from Table 56.3, SDSU Extension)
Over the last 32 years several changes were noticeable. First, over time, gross income (total revenue) and total cost per acre have generally increased. Between years, however, this is not necessarily the case. For example, between 1980 and 1989 gross income increased, whereas from 1989 to 2005 gross income remained relatively stable. During the same period, total costs per acre peaked in 1983 and were relatively stable until 2005. Yields were trending upward, so total costs per bushel were generally declining. From 2005 to 2012, total costs and gross income have increased rapidly. The two major reasons for temporal budget changes were the release of Roundup Ready® soybean cultivars, and the increasing demand for agricultural products.

**The 1980 to 2012 time period (32 years)**

From 1980 to 2012, soybean yields doubled from 18.5 bushels to 40 bushels (Table 56.4). Prices have followed the same trend and also nearly doubled from $6.50/bu. in 1980 to $12.60/bu. in 2012. Based on these changes, gross income increased by 319% in 32 years, while total costs increased by 276%, and net income over all costs increased nearly eight-fold. Much of the increase in total costs is attributed to land costs that increased from $28.50/acre in 1980 to $150/ac in 2012.

During this time period, production costs increased at a slower rate than land costs. The percentage change in the rate of inflation is included in the table below to compare the soybean costs figures to general price inflation that occurred in the economy. Between 1980 and 2012, inflation has increased by a total of 148%.

**Table 56.4. Analysis of soybean production budget variation between 1980 and 2012.**
(Data source from Table 56.3, SDSU Extension)

<table>
<thead>
<tr>
<th></th>
<th>Difference</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td>Bu. 21.5</td>
<td>116%</td>
</tr>
<tr>
<td>Selling Price</td>
<td>$ 6.10</td>
<td>94%</td>
</tr>
<tr>
<td><strong>Gross Income</strong></td>
<td>$ 383.75</td>
<td>319%</td>
</tr>
<tr>
<td>Production costs ($/ac., excluding land)</td>
<td>$ 183.21</td>
<td>224%</td>
</tr>
<tr>
<td>Land charges ($/ac.)</td>
<td>$ 121.50</td>
<td>426%</td>
</tr>
<tr>
<td><strong>Total Cost ($/ac.)</strong></td>
<td>$ 304.71</td>
<td>276%</td>
</tr>
<tr>
<td><strong>Breakeven Price ($/bu)</strong></td>
<td>$ 4.41</td>
<td>74%</td>
</tr>
<tr>
<td><strong>Breakeven Yield (bu/ac.)</strong></td>
<td>Bu. 16.0</td>
<td>94%</td>
</tr>
<tr>
<td><strong>Net Income over all costs ($/acre)</strong></td>
<td>$ 79.04</td>
<td>798%</td>
</tr>
<tr>
<td><strong>Inflation (from 1980 to 2012)</strong></td>
<td></td>
<td>148%</td>
</tr>
</tbody>
</table>
The 1989 to 2012 time period (23 years)

From 1989 to 2012 land costs increased 344%, non-land production costs increased by 153%, while yields increased by 43%. Over this time period, gross income increased from $182/acre in 1989 to $504/acre in 2012. Net income over all costs increased from $43 to $89 per acre. During this time period, inflation has increased by a total of 67%.

Table 56.5. Analysis of soybean production budget variation between 1989 and 2012.
(Data source from Table 56.3, SDSU Extension)

<table>
<thead>
<tr>
<th></th>
<th>Difference</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td>Bu. 12</td>
<td>43%</td>
</tr>
<tr>
<td>Selling Price</td>
<td>$ 6.10</td>
<td>94%</td>
</tr>
<tr>
<td><strong>Gross Income</strong></td>
<td>$ 322.00</td>
<td>177%</td>
</tr>
<tr>
<td>Production costs ($/ac., excluding land)</td>
<td>$ 160.19</td>
<td>153%</td>
</tr>
<tr>
<td>Land charges ($/ac.)</td>
<td>$ 116.25</td>
<td>344%</td>
</tr>
<tr>
<td><strong>Total Cost ($/ac.)</strong></td>
<td>$ 276.44</td>
<td>199%</td>
</tr>
<tr>
<td>Breakeven Price ($/bu)</td>
<td>$ 5.43</td>
<td>110%</td>
</tr>
<tr>
<td>Breakeven Yield (bu/ac.)</td>
<td>Bu. 11.6</td>
<td>54%</td>
</tr>
<tr>
<td><strong>Net Income over all Costs ($/acre)</strong></td>
<td>$ 45.56</td>
<td>105%</td>
</tr>
<tr>
<td><em>Inflation (from 1989 to 2012)</em></td>
<td></td>
<td>67%</td>
</tr>
</tbody>
</table>

The 2002 to 2012 time period (10 years)

Over the last 10 years production costs, gross income, and profits (net income) increased in most years (Table 56.6). Over this time period, soybean selling prices increased by 145% and projected yields increased 11%, which resulted in gross income increasing by 172%. During these last 10 years, land charges and non-land production costs increased at similar rates (163% vs. 156%). Total costs per acre increased by 159%, while inflation only increased by 25%.

Soybean gross income and costs relative to inflation

During all three time periods examined, soybean gross income greatly exceeded the rate of inflation, primarily due to yield increases from the early 1980s to 2000 and from soybean price increases after 2005. Land charges were well above the inflation rate (except from 1983 to 1989). All other soybean production costs were lower than the inflation rate from 1980 to 2012, similar to the inflation rate from 1989 to 2012, and substantially above the inflation rate from 2002 to 2012.
Corn yields and returns from 1980 to 2010

Corn yields and selling prices have increased rapidly over these last 30 years. Corn yields went from 53 bu/acre in 1980 to 135 bu/acre in 2010. Selling prices increased from $2.84/bu in 1980 to $5.09/bu in 2010 (Fig. 56.5). Recent increases in the corn selling price are linked to ethanol production.

Table 56.6. Analysis of soybean production budget variation between 2002 and 2012.
(Data source from Table 56.3, SDSU Extension)

<table>
<thead>
<tr>
<th></th>
<th>Difference</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td>Bu. 4</td>
<td>11.1%</td>
</tr>
<tr>
<td>Selling Price</td>
<td>$7.45</td>
<td>144.7%</td>
</tr>
<tr>
<td><strong>Gross Income ($/ac.)</strong></td>
<td>$318.60</td>
<td>171.8%</td>
</tr>
<tr>
<td>Production costs ($/ac., excluding land)</td>
<td>$161.66</td>
<td>156.3%</td>
</tr>
<tr>
<td>Land charges ($/ac.)</td>
<td>$93.00</td>
<td>163.2%</td>
</tr>
<tr>
<td><strong>Total Cost ($/ac.)</strong></td>
<td>$254.66</td>
<td>158.8%</td>
</tr>
<tr>
<td>Breakeven Price ($/bu)</td>
<td>$5.92</td>
<td>132.9%</td>
</tr>
<tr>
<td>Breakeven Yield (bu/ac.)</td>
<td>Bu. 1.8</td>
<td>5.8%</td>
</tr>
<tr>
<td><strong>Net Income over all costs ($/acre)</strong></td>
<td>$63.94</td>
<td>255.8%</td>
</tr>
</tbody>
</table>

*Inflation (from 2002 to 2012)*

25%

Figure 56.5. Changes from 1980 to 2010 in corn grain yields and selling price. (Source: NASS)
Historical data of cost and return estimates for corn, soybeans, wheat, cotton, grain sorghum, rice, peanuts, oats, barley, milk, hogs, and cow-calf are available at http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx. These cost and return estimates are reported for major production regions and for the United States, but not for individual states. South Dakota is included in the Great Plains production region. Costs of production forecasts are also available.

References and additional information
South Dakota State University, SDSU Extension. http://www.sdstate.edu/econ/extension/index.cfm

Acknowledgements
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Soybean Cyst Nematode

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Soybean cyst nematode (SCN) was first identified in the United States in 1954. In South Dakota, SCN was first detected in Union County in 1995 and is currently found in 27 counties. Beadle County was recently added in mid-2012 (Fig. 57.1). In annual surveys of scientists working with soybean throughout the country, soybean cyst nematode was ranked as the top yield-limiting disease in the country. The latest estimate indicated that soybean cyst nematode robbed over 134,000 ton of soybean yield per year in South Dakota. This chapter provides information on signs and symptoms, life cycle, and SCN management.

**Causal organism**

Soybean cyst nematode, Heterodera glycines, is a microscopic roundworm (the adult is about ½ inch long) that attacks the roots of soybean; several other leguminous crops, such as cowpea, dry beans, and crimson clover; and a number of weeds (Table 57.1).
Table 57.1. Examples of host and non-host plants of soybean cyst nematode.

<table>
<thead>
<tr>
<th>Host Crops</th>
<th>Weed Hosts</th>
<th>Non-hosts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birdsfoot trefoil</td>
<td>Common chickweed</td>
<td>Alfalfa</td>
</tr>
<tr>
<td>Edible beans</td>
<td>Common mullen</td>
<td>Canola</td>
</tr>
<tr>
<td>Clover (Aliske, Crimson, Sweet)</td>
<td>Field pennycress</td>
<td>Clover (Red, White, Ladino)</td>
</tr>
<tr>
<td>Cowpea</td>
<td>Henbit</td>
<td>Corn</td>
</tr>
<tr>
<td>Lespedezas</td>
<td>Pokeweed</td>
<td>Forage grasses</td>
</tr>
<tr>
<td>Lupine (White, Yellow)</td>
<td>Purslane</td>
<td>Small grains (barley, oats, rye, wheat)</td>
</tr>
<tr>
<td>Soybeans</td>
<td>Sericea lespedeza</td>
<td>Sorghum (grain and forage)</td>
</tr>
<tr>
<td>Vetch (Common, Crown, Hairy)</td>
<td>Wild mustard</td>
<td>Sugar beets</td>
</tr>
</tbody>
</table>

Genetic variability occurs within the SCN populations in the United States. This genetic variability allows different SCN populations to overcome different sources of resistance in soybean. In the past, a scheme classifying the SCN population into different races based on the population's response towards four known sources of resistance was used (PI 88788, PI 90763, Pickett and Peking).

The race designation was relatively close-ended and could not take into account newer sources of resistance. Thus, a new classification scheme that is open-ended to include newer sources of resistance was proposed in 2002. This new classification scheme has been widely used. In this new scheme, a population of SCN is inoculated to several indicator lines associated with different sources of resistance (Table 57.2) and a susceptible check. The population is then classified to different HG (*Heterodera glycines*)-types based on its observed virulence on various indicator lines.

Table 57.2. Indicator lines for HG-Type classification of SCN.

<table>
<thead>
<tr>
<th>Number</th>
<th>Indicator Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PI 548402 (Peking)</td>
</tr>
<tr>
<td>2</td>
<td>PI 88788</td>
</tr>
<tr>
<td>3</td>
<td>PI 90763</td>
</tr>
<tr>
<td>4</td>
<td>PI 437654</td>
</tr>
<tr>
<td>5</td>
<td>PI 209332</td>
</tr>
<tr>
<td>6</td>
<td>PI 89772</td>
</tr>
<tr>
<td>7</td>
<td>PI 548316 (Cloud)</td>
</tr>
</tbody>
</table>

Virulence is measured with a Female Index (FI), calculated as the percentage of the number of females found on a particular indicator line compared to the number of females found on the susceptible control. If the average Female Index on an indicator line is greater than 10, the population is considered virulent for the respective line.

In the HG-type scheme, more indicator lines can be added as new sources of resistance are developed, thus it is considered “open-ended.” Furthermore, a designation of a population HG-type does not have to take into account all possible indicator lines. The “-” following some of the HG-type designations in Table 57.3 indicates that the test did not take into account all possible indicator lines.

In practice, HG-typing helps assessing whether a resistant soybean variety derived from a particular resistance source will be effective against a certain SCN population. For example, a grower notices that
the performance of an SCN-resistant soybean variety has been declining periodically. HG-typing the SCN population found in the field may help pinpoint the problem by ascertaining whether the population is able to overcome the particular source of resistance used in the variety.

An example of HG-type classification of some SCN populations is illustrated in Table 57.3. Of the three samples assayed in Table 57.3, sample numbers 14 and 59 are classified as HG-type 2. In this case, SCN in these samples will be able to reproduce in soybean varieties with PI 88788 as their resistance source. This is valuable information when choosing resistant varieties in the face of perennial SCN problems.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Female Indices on PI 548402</th>
<th>Female Indices on PI 88788</th>
<th>Female Indices on PI 437654</th>
<th>HG Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>#14</td>
<td>7</td>
<td>32</td>
<td>0</td>
<td>2-</td>
</tr>
<tr>
<td>#57</td>
<td>7</td>
<td>8</td>
<td>0</td>
<td>0-</td>
</tr>
<tr>
<td>#59</td>
<td>19</td>
<td>13</td>
<td>0</td>
<td>1,2-</td>
</tr>
</tbody>
</table>

**Symptoms and signs**

Above-ground symptoms of SCN infection are not always visible. A soybean crop may lose as much as 30% of yield due to SCN without showing above-ground symptoms. Consequently, it is quite common to have an infestation of SCN in a field for several years before the presence of the worm is suspected or detected. Areas that have yields that are below expectations may indicate the presence of SCN. Yield maps can be very helpful in identifying areas for intensive scouting of SCN.

When symptoms are present, they are first manifested as a slight variation in height of otherwise healthy-looking, dark-green plants, sometimes described as “rollercoaster-ing” of soybean rows. High SCN levels may induce leaf yellowing, plant stunting (Fig. 57.2), and plant death. These symptoms are easily confused with potassium deficiency, nitrogen deficiency, iron chlorosis, herbicide injury, soil compaction, and several soybean diseases. Fields with high SCN population densities may have elliptic, circular, or elongated areas with severe above-ground symptoms. Sometimes the areas of plants showing clear above-ground symptoms follow the tillage patterns.

Diagnostic signs of SCN infection can be found by digging roots from the soil and searching for females or cysts on the root surface. Female SCN appears as pearly white or yellow lemon-shaped bodies on the root surface, visible to the unaided eye (Fig. 57.3). The cysts, being a dead body of the females encapsulating viable eggs, are of a similar shape with the females, but brownish in color. It takes several weeks from planting to actually observe these diagnostic signs on infected roots. Swollen females are common on smaller roots and much less common on the tap root. The females and cysts are readily lost when digging plants in very dry soil as the smaller roots that are most commonly infested may be left behind when digging the plants.
Life cycle and epidemiology

Soybean cyst nematodes undergo several phases in their life cycle. The eggs serve as the survival means for SCN, a portion of which are retained within the cyst. The cyst acts as an extra protective layer to these eggs. The juveniles hatching from these eggs move freely and actively enter the roots of soybean plants. Within the roots, the nematodes induce the development of a specialized feeding site.

Soybean cyst nematode infection of soybean roots stunts roots and reduces the number of nitrogen-fixing nodules which results in the disruption of water and soil nutrient intake. Soybean cyst nematode feeds directly on the root. Infected plants develop fewer pods and produce lower yields. Feeding damage by SCN also predisposes the plants to infection by other root-infecting pathogens, especially fungal pathogens causing sudden death syndrome and brown stem rot.

The nematodes grow in size and develop into adult males or females. The SCN females eventually become large enough that they rupture out of the roots and are visible on the root surface (Fig. 57.3). The SCN males retain a vermiform (worm-like) shape in its adulthood (Fig. 57.4), move out of the roots, and mate with the females. The mated SCN females lay some of their eggs in gelatinous masses deposited on the rear of the body. The females also retain some of the eggs within their bodies. The female SCNs eventually die with the viable eggs still stored within their body cavities. The dead nematodes’ body walls form cysts that protect the eggs inside (Figs. 57.5 and 57.6).
Under a constant temperature of $77^\circ$F ($25^\circ$C), the life cycle of SCN can be completed in 21 days. In the field, temperatures and soil moisture levels conducive for soybean growth are also optimal for SCN population development. The SCN population density in the beginning of a soybean season is a critical factor determining yield loss. Thus, management strategies for SCN should be developed and implemented as soon as the presence of SCN within a field is confirmed.
Management approaches

Effective SCN management includes using an effective rotation that includes non-host plants (corn, wheat, and grain sorghum), cleaning equipment between fields, confirming SCN by soil sampling, and planting SCN-resistant cultivars. In making these decisions, it is important to ascertain whether a field is infested with SCN. Since above-ground symptoms of SCN infection are not always apparent, field soil testing for the presence of SCN in areas with SCN history is crucial.

Scouting

To confirm an SCN problem, soil samples can be collected systematically and tested for SCN cysts and eggs. Divide the field into 10- to 20-acre sections and sample each section separately. Within a section, walk a zig-zag or an M pattern path and collect 10-20 soil core samples (6-8 inches or 15-20 cm deep). Use a cylindrical soil probe to collect the soil core samples from around the root area. Specifically include soil samples from high-risk areas where nematodes may have been introduced to the field, such as field entrances, fence lines, areas with occasional flooding, and areas with unexplained low yield. Bulk the core samples from a section and mix it thoroughly in a bucket.

Place 1 pint (0.55 L) of mixed soil in a plastic bag, label the bag with the field information and date of collection, and keep it in a cool and dark environment until shipping.

Send the soil samples to:
SDSU Plant Diagnostic Clinic
Box 2108
SPSB 153
Plant Science Building
Brookings, SD 57007

(As of the writing of this chapter [August 2012], SCN testing at the SDSU Plant Diagnostic Clinic is provided free of charge to residents of South Dakota. This free service is made possible through funding provided by the South Dakota Soybean Research and Promotion Council.)

Soil samples can be collected at any time, but the optimal time to sample for SCN is as close to soybean harvest as possible. The presence of SCN in a field may also be confirmed by carefully digging plants in late July or August and examining roots for white females (Figure 57.3). The SDSU Plant Diagnostic Clinic does not conduct HG-type assay. SCN detection at the SDSU plant clinic simply ascertains whether the samples taken from the field contain SCN. If the results show that SCN is present in the field, growers may want to consider incorporating several cultural practices to manage SCN in their fields.

Cultural practices

The impact of SCN infection is exacerbated on stressed plants. Providing optimal crop growth conditions by paying careful attention to soil fertility and weed management reduces the yield loss due to SCN infection. Soybean cyst nematode is an obligate parasite that, once hatched, requires the presence of susceptible hosts to mature and multiply. Thus, incorporation of non-host crops, such as corn, wheat, grain sorghum and other crops (Table 57.1) in a rotational scheme will reduce SCN populations. Short-term use of a non-host crop will not eliminate the SCN population from an infested field since the nematode eggs may survive for years in the absence of host crops.

In a controlled storage environment, Inagaki and Tsutsumi (1971) showed that eggs within SCN cysts could remain viable for as many as 11 years. The amount of SCN population reduction due to non-host crop rotation varies with geographic location. In the northern plains, a rotation scheme that includes two or more years of a non-host crop before planting soybean is recommended. Unfortunately, the economic values of the
alternative non-host crop are, at times, limited. In this case, a rotation scheme should incorporate resistant and tolerant soybean varieties. Care should be taken to use SCN-resistant soybean varieties with different sources of resistance in a rotation to avoid the buildup of SCN populations that can become virulent on a source of resistance.

Avoiding such a buildup of SCN populations can also be achieved by planting tolerant/susceptible varieties as a part of the rotation scheme. Even though tolerant varieties do not limit the growth of SCN population feeding on their roots, SCN infection on tolerant soybean varieties causes lower yield loss than infection on non-tolerant varieties.

Because SCN is moved with soil, sanitation practices that limit movement of soil from one field to another should be practiced. Such practices include cleaning tillage and harvest equipment between fields.

**Host plant resistance**

Soybean varieties with resistance to SCN are widely available. Even though SCN can still survive and multiply on resistant soybean varieties, its population growth is more limited and the population of the pest is often suppressed. Consequently, soybean varieties with SCN resistance typically produce higher grain yield than susceptible varieties when planted in SCN-infested fields. There are a number of sources of SCN resistance used in public and private breeding programs. The soybean accession PI 88788 is a very common source of resistance. Other sources of SCN resistance include PI 90763, PI 209332, PI 437654, Peking, and Hartwig. As noted in the cultural practices section above, it is advisable to use soybean varieties from different sources of resistance in a rotation.

**Chemical control**

A number of seed treatment products are currently marketed to protect soybeans from SCN, including ones with abamectin or a biological agent, *Bacillus firmus*, as the active ingredient. Trial of various seed treatments conducted in 2011 and 2012 at Hurley and Beresford (South Dakota) showed inconsistent results in terms of SCN population control. While numerical difference can be detected between the average yield of treated and untreated seeds, no statistical difference was detected between treatments.

**References and additional information**


Plant Management Network website has a series of timely webinar on soybean management. Some of the topics in this series are highly pertinent to soybean cyst nematode management. Available at [http://www.plantmanagementnetwork.org/infocenter/topic/FocusOnSoybean/](http://www.plantmanagementnetwork.org/infocenter/topic/FocusOnSoybean/)

Soybean cyst nematode management guide. Currently in its 5th edition, the guide sponsored by North Central Soybean Research Program is a regularly updated management guide based on field research contributed by multiple states. South Dakota State University faculty regularly contribute to the research informing this guide. Available at [http://www.planthealth.info/pdf_docs/SCNGuide_5thEd.pdf](http://www.planthealth.info/pdf_docs/SCNGuide_5thEd.pdf)

**Acknowledgements**

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Bacterial Diseases of Soybeans in South Dakota

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Marie. A.C. Langham (Marie.Langham@sdstate.edu)

The two main bacterial diseases found in South Dakota soybeans are bacterial blight and bacterial pustule. These diseases are often spread from plant to plant by wind and rain and through natural openings or wounds caused by high winds, hail, insects, and other causes. Symptoms associated with bacterial diseases include leaf spots, water-soaked lesions, blights, and wilting. Keys for better understanding bacterial problems are provided in Table 58.1. The purpose of this chapter is to discuss the biology and management options associated with bacterial blight and bacterial pustule.

Table 58.1. Keys for an improved understanding of bacterial blight and bacterial pustule.

1. Foliar fungicides do not offer protection against bacterial diseases, because bacterial diseases are caused by a bacterial pathogen, not a fungal pathogen.
2. Plant disease-tolerant cultivars and varieties, use pathogen-free seed, and use appropriate rotations.
3. Bacterial blight is generally found early in the growing season.
   - *Pseudomonas savastanoi pv. glycinea* is splashed onto healthy plant tissues by wind and rainfall.
4. Bacterial pustule is commonly confused with Asian soybean rust.
   - *Xanthomonas axonopodis pv. glycines* overwinters on crop residues and is spread by wind-blown rain, rain splashing up from the soil, and often during cultivation when the foliage is wet. Bacteria gain entrance to the plant through natural openings and wounds. Bacterial pustules develop in warm (85-90°F), moist conditions.
5. Copper fungicides can be used for bacterial blight and pustule management early in the disease cycle. However, copper fungicides are not as effective on bacterial infection as on fungal problems.
Bacterial Blight

In South Dakota, soybean bacterial blight infection is a wide-spread occurrence that is often found early in the growing season. Dry hot summer weather provides a natural check (stop) to continued disease development.

Symptoms

Small, angular, translucent, water-soaked, yellow to light brown lesions (spots) are often found on soybean leaves, but may also be found on soybean stems, petioles, and pods. As these lesions begin to age they turn color; starting with yellow, turning to reddish-brown, and then to black, leaving a yellowish-green halo (border) around the edge of the water-soaked tissue (Fig. 58.1). As time continues the centers of the lesions will drop out or tear away and leave a rugged, torn appearance especially after a rain storm event (Fig. 58.2).

![Figure 58.1. Bacterial blight on soybean. Yellow-green halo is observed surrounding the brown lesions. (Photo courtesy of Clemson University – USDA Cooperative Extension Slide Series)](image1)

![Figure 58.2. Aged lesions eventually fall out of the leaf giving the foliage a torn and ragged appearance. (Photo courtesy of Howard F. Schwartz, Colorado State University)](image2)

Bacterial blight biology and life cycle

Bacterial blight on soybean is caused by the bacterium *Pseudomonas savastanoi* pv. *glycinea*. This bacteria over-winters in crop residues in the field. Cool, wet weather (70-80°F) favors infection throughout the growing period. Inoculum in crop debris is splashed onto healthy plant tissues by wind and rainfall. Infection typically occurs early in the season as disease development is reduced in hot, dry conditions. Bacterial blight may also be transmitted through infected seeds.

Management

1. Plant disease-tolerant cultivars and varieties. Make sure to use pathogen-free seed.
2. Crop Rotation. Rotate soybeans with a non-legume.
4. Copper fungicides can be used, but must be applied early in the disease cycle to be an effective control measure. Just a word of caution when using copper fungicides to treat a bacterial infection: they are not as effective when used as a bactericide as they are as a fungicide for disease control. They are not considered a simple curative measure for control of a bacterial infection.
Bacterial Pustule

Bacterial pustule has been found in South Dakota. Due to the pustule formation this disease is commonly confused with Asian soybean rust (which has not been found in South Dakota). Unlike bacterial blight, it is important to note that bacterial pustule is not checked by warm temperatures and will continue to spread infection.

Symptoms

Early symptoms include small, light green spots with raised centers (Fig. 58.3) which are found on either side of the leaf but are often observed on the lower leaf surface (Fig. 58.4). As disease progression continues, light-colored pustules often develop in the center of the lesion. As lesions grow together, they form large, irregular areas (patches) of dead tissue (Fig. 58.5). Leaves often have a ragged appearance when the dead tissue has been removed from the leaves due to wind or rain.

Bacterial pustule biology and life cycle

Bacterial pustule on soybean is caused by Xanthomonas axonopodis pv. glycines. This bacteria overwinters on crop residues and is spread by wind-blown rain, rain splashing up from the soil, and often during cultivation when the foliage is wet. Bacteria gain entrance to the plant through natural openings and wounds. Bacterial pustule develops in warm (85-90°F), moist conditions.

Management

1. Plant disease-tolerant cultivars and varieties. Make sure to use pathogen-free seed.
2. Crop Rotation. Rotate soybeans with a non-host crop such as corn.
4. Copper fungicides can be used, but must be applied early in the disease cycle to be an effective control measure. Just a word of caution when using copper fungicides to treat a bacterial infection: they are not as effective when used as a bactericide as they are as a fungicide for disease control. They are not considered a simple curative measure for control of a bacterial infection.

(Left) Figure 58.3. Early symptoms of bacterial pustule infection include small, light green spots with raised centers. (Photo courtesy of Daren Mueller, Iowa State University)
(Right) Figure 58.4. Bacterial pustule on underside of soybean leaf. Pustules often have a raised center. (Photo courtesy of Martin Draper, USDA-NIFA)
Figure 58.5. Bacterial pustule shown on surface of soybean leaf. Lesions grow together and form large, irregular patches of dead tissue. (Photo courtesy of Adam Sisson, Iowa State University)

References and additional information

Acknowledgements
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Fungal and Fungal-like Diseases in Soybeans

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Marie A.C. Langham (Marie.Langham@sdstate.edu)

A number of foliar, stem, or root fungal diseases are found in South Dakota soybean fields. Under certain conditions fungal and fungal-like diseases can produce substantial losses. The purpose of this chapter is to discuss soybean fungal disease characteristics, life cycles, and management. Fungal diseases discussed in this chapter include Phytophthora root and stem rot, white mold, stem canker, brown spot, charcoal rot, frogeye, leaf blight and purple seed stain, downy mildew, powdery mildew, brown stem rot, sudden death syndrome, anthracnose, soybean rust, and Cercospora blight. A management timeline which provides details on disease scouting is provided in Chapter 28, seed treatment information is provided in Chapter 8, and information on specific fungicide treatments and rates are available at http://igrow.org/up/resources/03-3005-2012.pdf.

Table 59.1. Key factors to control fungal problems.

1. Correct disease identification is a must in order to develop effective control strategies.
   a. Different problems require different treatments. (Table 59.2)
   b. Seed or foliar application fungicides can be used and fungicides are most effective when applied at an appropriate time. The selection of seed or foliar application should depend on the best option to control the targeted pathogen.

2. The risk of developing fungicide resistant pathogens can be reduced by:
   a. applying fungicides at recommended rates,
   b. applying appropriate fungicides only when the diseases are present, and
   c. by rotating pesticide chemistries.

Table 59.2. Foliar diseases and possible management approaches.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Rotations</th>
<th>Tillage</th>
<th>Variety Selection</th>
<th>Fungicide</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phytophthora</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>Can destroy entire fields.</td>
</tr>
<tr>
<td>White mold</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Can reduce yields 4bu/a for each 10% increase in incidence.</td>
</tr>
<tr>
<td>Stem canker</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>Northern stem canker can reduce soybean yields 50 to 80%.</td>
</tr>
<tr>
<td>Brown spot</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>Overwinters on infected leaf and stem debris.</td>
</tr>
<tr>
<td>Charcoal rot</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>Drought may increase.</td>
</tr>
<tr>
<td>Frogeye</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Use clean seed.</td>
</tr>
<tr>
<td>Downy mildew</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>Use clean seed.</td>
</tr>
<tr>
<td>Powdery mildew</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>Temps above 86°F halt disease.</td>
</tr>
<tr>
<td>Brown stem rot</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>Use shorter maturities.</td>
</tr>
<tr>
<td>Sudden death syndrome</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>Install drainage and delay planting.</td>
</tr>
<tr>
<td>Anthracnose</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>Use seed treatment (Chapter 8).</td>
</tr>
<tr>
<td>Soybean rust</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>Not typically found in South Dakota.</td>
</tr>
<tr>
<td>Cercospora blight</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>Favored by high temperatures and can reduce soybean quality due to purple staining of the seed.</td>
</tr>
<tr>
<td>Growth Stages</td>
<td>April 30</td>
<td>May 7</td>
<td>May 14</td>
<td>May 21</td>
<td>May 28</td>
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<tr>
<td>Scout Phytophthora Root/Stem Rot</td>
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<tr>
<td>Scout Damping off/Pythium Seed Rot</td>
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<tr>
<td>Watch for root rots and Rhizoctonia</td>
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<td></td>
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<tr>
<td>Scout Soybean Mosaic Virus</td>
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<tr>
<td>Scout Bean Pod Mottle Virus</td>
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<tr>
<td>Scout Brown Spot</td>
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<tr>
<td>Scout Downy Mildew</td>
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<td></td>
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<tr>
<td>Scout Cercospora Leaf Spot</td>
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<tr>
<td>Scout Soybean Aphids</td>
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<tr>
<td>Check roots for cysts</td>
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<tr>
<td>Scout for Bacterial Leaf Blight</td>
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<tr>
<td>Scout Phytophthora Root/Stem Rot (2nd event)</td>
<td></td>
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<tr>
<td>Scout for Soybean Cyst Nematodes</td>
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<tr>
<td>Scout Anthracnose</td>
<td></td>
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<tr>
<td>Scout Frogeye Leaf spot</td>
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<td></td>
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<tr>
<td>Scout Brown Stem Rot</td>
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<tr>
<td>Scout Sudden death Syndrome</td>
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<tr>
<td>Scout Sclerotinia Stem Rot (white mold)</td>
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<tr>
<td>Scout Pod and Stem Blight</td>
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<tr>
<td>Scout Northern Stem Canker</td>
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<tr>
<td>Scout Charcoal Rot</td>
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</table>
Phytophthora Root and Stem Rot

Extent of the problem

Phytophthora root and stem rot (PRR) in soybeans is one of the most destructive soybean diseases in South Dakota and the North Central region of the U.S. State wide, annual losses range from 4% to 6%. PRR has also been reported from Argentina, Australia, Brazil, Canada, the People's Republic of China, Hungary, Italy, Japan, and the countries composing the former Soviet Union.

Damage from PRR is directly related to annual weather patterns, especially by rainfall amounts and cycles. Fields or sites within fields that receive heavy rainfall or irrigation are susceptible to plant mortality from PRR with 100% yield loss in heavily affected field areas. PRR can destroy entire fields when the conditions are favorable (Draper and Chase, 2001; Dorrance et al., 2012; Schmitthenner, 2000).

Symptoms

PRR can appear in any stage of soybean development. Fields that should routinely be scouted include those that: 1) contain wet spots; 2) are poorly drained; 3) contain high clay contents; 4) have been in continuous no-till or soybean; 5) have a history of PRR; and 6) large weedy areas due to poor stand development. PRR symptoms change as the plant matures (Dorrance et al., 2012; Schmitthenner, 2000).

Early-season Phytophthora root and stem rot symptom may be found in areas with poor seed germination. Seed rot and decay can occur if infection occurs between seed swell and germination. Affected seeds may be very soft and brown, and often individual seeds completely disintegrate. In severe cases, replanting may be necessary. Optimum temperatures for disease development range from 77°F to 86°F (25°C to 30°C) (Draper and Chase, 2001; Dorrance et al., 2007; Schmitthenner, 2000).

This disease also causes damping-off which is most likely to occur several days prior to or after seedling emergence. Damping-off is marked by wilting and death of pre-emergent or emerging soybean seedlings. Affected areas of the stem may look water-soaked or bruised and often disintegrate. Symptoms include yellowing, wilting, and light brown-soft necrosis (decay and rot) of the stem. Affected stem areas may have a dark discoloring, and colonized seedlings may die. Plants typically are easily pulled from the ground due to root damage. The severity of damping-off may be variable depending on the amount of PRR resistance in the variety. Early-season PRR is promoted when flooding occurs within the first week following planting. Damping-off symptoms can develop 5-14 days after the soil has been saturated with water (Draper and Chase, 2001; Dorrance et al., 2007, 2012; Iowa State University Extension, 2010).

Stem and root rot midseason PRR symptoms can be observed around the first of July (Figs. 59.1 and 59.2). At this stage, PRR infection begins in the root system and progresses into the lower stem. Symptoms include dark-brown discoloration on the lower stem that advances from below soil level to several nodes on the stem. In severely affected plants, stem girdling, destruction of the lateral roots, and rot of the taproot can be lethal to severely affected plants. Leaf wilting followed by drooping of the petioles follows, and this wilting advances upward from the bottom of the plant. Leaves may develop a grayish cast and yellow spots prior to permanent wilting. Symptoms on older soybean plants are related to the susceptibility of the soybean cultivar. Cultivars with low tolerance may continue to die throughout the season; although, they were infected during early growth stages; (Draper and Chase, 2001; Dorrance et al., 2007; Iowa State University Extension, 2010; Schmitthenner, 2000).

Late in the growing season areas within a row where plants have been killed by PRR may be hidden by healthy plants that have grown tall enough to disguise this problem (Fig. 59.3). Large areas in poorly drained fields where plants have died due to PRR may be covered by colonizing weeds. Thus, late-season PRR is often underestimated due to being concealed within the canopy or by weed growth (Draper and Chase, 2001).
**Causal pathogen and life cycle**

Phytophthora root and stem rot (PRR) is caused by Phytophthora sojae. Phytophthora is a member of the Kingdom: Stramenopila and the Phylum Oomycota. These organisms were traditionally classified as fungi, but recently, basic differences in their composition and genome have caused these organisms to be reclassified. They are now called fungal-like organisms. *P. sojae* has a large amount of genetic variability that forms a number of races (also called pathotypes). These races are identified by the combination of virulence and avirulence genes. Races 1, 3, 4, and 25 are the most common races in South Dakota (Draper and Chase, 2001; Iowa State University Extension, 2010).

*P. sojae* produces oospores (Fig. 59.4) and zoospores. Oospores are thick-walled spores that are produced through sexual reproduction. They can remain dormant in soybean residue or soil without a host for many years. The infection cycle begins when oospores germinate to form sporangia (the structure where zoospores are produced). Temperature is one of the principal triggers for this germination (Draper and Chase, 2001; Schmitthenner, 2000).
Zoospores are rapidly produced through asexual reproduction. *P. sojae*-infected soybean tissue produces sporangia and zoospores as long as moisture and temperatures remain favorable. Zoospores are unique in that they have flagella which allow them to discover new sites to infect by swimming from one site to the next (Draper and Chase, 2001).

A video of the zoospores swimming, produced by Dr. Thomas Chase, is available at http://www.youtube.com/watch?v=gDT5Pg3_nsM%20%20. In the soil, zoospores find soybean roots by following gradients of root exudates (daedzein, genistein, and other isoflavonoids) to the plant roots. Soil temperatures above 60°F promote germination and infection of *P. sojae*. Although capable of initial plant infection through the leaves, *P. sojae* seldom infects leaves because this mechanism requires that soil be splashed onto leaves (Draper and Chase, 2001; Dorrance et al., 2007; Schmitthenner, 2000).

![Figure 59.4. Oospores are the sexual spores formed by *Phytophthora sojae* and other related fungi. Their sturdy thickened cell wall structure helps these spores to survive adverse conditions in the soil in order to overwinter. (Photo courtesy of Martin Draper, USDA-NIFA)](image-url)

**Management**

PRR requires a combination of crop management and disease monitoring to manage, particularly in low-lying fields or fields with compacted soils. In order to minimize PRR, a combination of management approaches is needed. (Draper and Chase, 2001).

1. **Selecting tolerant or resistant varieties** is the first practice to utilize in PRR management. Tolerance and race-specific resistance options are available. **Tolerance** is a partial solution and does not eliminate the risk of PRR. Tolerance delays disease onset, severity, and losses. This approach is typically effective across many races, and it generally more effective at late rather than early growth stages. **Race-specific resistance** targets a specific *P. sojae* race. Two mechanisms of race-specific resistance exist (incompatible interaction and root resistance). When incorporated into a soybean cultivar, this resistance provides complete resistance against a specific *P. sojae* race. However, prior to deploying race-specific resistance, the *P. sojae* race in a producer’s field should be identified. Additionally, fields may have multiple *P. sojae* races present. Producers should also be alert for signs of PRR in a resistant variety that has previously performed well. This could signal the development of a *P. sojae* race adapted to the resistance gene used in that variety (Draper and Chase, 2001; Dorrance et al., 2012; Iowa State University Extension, 2010; Schmitthenner, 2000). Consult SDSU Extension for available information of the current status of race-specific resistance.

2. **Fungicide seed treatments** can reduce PRR. Details on fungicide seed treatments are available in Chapter 8. Generally: 1) metalaxyl and related fungicides, such as mefamoxam, are effective against *Phytophthora*; 2) seed treatments are more effective at lower rates and more cost effective than band applications over the row; and 3) band applications of metalaxyl have been highly effective when soybeans are planted in wide rows on compacted soil (Draper and Chase, 2001). Fungicide recommendations can be obtained at http://igrow.org/up/resources/03-3005-2012.pdf or by checking with SDSU extension personnel.
3. **Use crop rotation.** Crop rotation can assist in PRR management. Continuous soybeans increase Phytophthora inoculum in the soil and promote the development of new races. Extended rotations into corn, small grains or other non-host crops may reduce PRR levels in severely affected soybean fields (Draper and Chase, 2001; Dorrance et al., 2012; Iowa State University Extension, 2010).

4. **Improve soil drainage, aeration, and structure.** Water is a vital part of the Phytophthora's life cycle. Thus, decreasing the amount of standing water in fields with a history of PRR is an important part of control. Additionally, *P. sojae* infection is often higher in compacted, fine-textured, and poorly drained soils (Draper and Chase, 2001).

5. **Manage tillage practices.** Reduced tillage practices including no-till can maintain high concentrations of oospores in the soil zone where the new soybean plants are establishing roots. Additionally, no-till soils retain moisture and dry out more slowly, and moisture promotes the disease risk. However, deep tillage with heavy equipment or working water-logged soils can increase compaction and water retention. Ridge tillage and other similar tillage practices are preferred for drying wet soils (Draper and Chase, 2001; Iowa State University Extension, 2010).

6. **Manage residual nitrogen.** High residual nitrogen level, particularly where swine manure has been injected into fields (especially in the spring), may increase the severity of PRR when soil moisture is adequate for infection (Draper and Chase, 2001).

**White Mold (Sclerotinia Stem Rot)**

White mold, caused by *Sclerotinia sclerotiorum*, is a chronic problem disease that can severely damage soybeans, sunflowers, dry beans and other legumes, and many other dicotyledonous crops. In soybeans, white mold has been estimated to cause a 4 bu/ha yield reduction for every 10% increase in disease incidence. White mold damage may be moderate when disease incidence is less than 20%. Moderate damage is attributed to the soybean plants’ ability to compensate for the damaged plants. In South Dakota, soybean grown in the eastern region are more at risk that soybean grown in western regions (NCSRP, 2012).

**Symptoms**

*S. sclerotiorum* may first be identified when apothecia have formed (Fig. 59.5). Apothecia are vase or cuplike structures that emerge from the overwintered sclerotia (Figs. 59.5 and 59.6). Since these structures are formed from fungal tissues, they are referred to as signs rather than symptoms. If a field is being scouted for the apothecial stage of white mold, this should be timed to coincide with canopy closure and it should target poorly drained areas with high relatively humidity (NCSRP, 2012).

Infected plants may appear wilted during the reproductive growth stages. *S. sclerotiorum* progresses from the young pods to the nodes and to the stem. It may girdle the stem which disrupts the transport of water and nutrients to the leaves. As the fungus invades the stem, plant tissues die (necrosis) and the necrosis progresses upward from the point of infection. Inspection of the lower stem may reveal a bleached area starting from a leaf axil and extending in each direction. Leaves and stems of plants affected by white mold may turn brown.

In fields with thick canopy growth, infected plants may be hidden, and the necrotic leaves and stems may only be found when the thick canopy is pushed open. When necrotic plants are closely examined, lesions and thick mats of white fungal mycelium may be found (Fig. 59.7). As the infection progresses (Fig. 59.8), dark pellet-like structures (sclerotia) will be formed on the mats. Sclerotia are important for overwintering, and they can remain viable in the soil or debris for many years. Sclerotia may also form in the pith of infected soybean stems and may be found only when they are split open (Fig. 59.9) (Iowa State University Extension, 2010; NCSRP, 2012; Westphal et al., 2006).
Figure 59.5. Apothecia are forming in a petri dish from a sclerotium produced by S. sclerotiorum to demonstrate how the apothecia is produced from the sclerotia and the number of apothecia than can be produced by one sclerotium. (Photo courtesy of Martin Draper, USDA-NIFA)

Figure 59.6. Apothecia are forming at the soil surface in the center of this photograph. These apothecia will produce thousands of ascospores to start the infection cycle in the spring. (Photo courtesy of H.F. Schwartz, Colorado State University, Bugwood.org)

Figure 59.7. Abundant white mycelial growth is a distinctive characteristic of white mold. (Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)

Figure 59.8. Sclerotia are the hard dark structures forming on the infected plant stem. (Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)

Figure 59.9. Sclerotia can be seen forming in the pith of infected soybean stems. (Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)
**Causal pathogen and life cycle**

*Sclerotinia sclerotiorum* is the fungus that causes white mold. *S. sclerotiorum* belongs to the Kingdom Fungi and the Phylum Ascomycota. *S. sclerotiorum* overwinters in the soil by producing hardened, dark, pellet-like structures called sclerotia. These structures are composed of tightly compacted fungal mycelium covered with a dark black covering (rind). Sclerotia can be found in crop debris or can fall to the soil during harvesting. Sclerotia can survive in the soil for many years (NCSRP, 2012).

In the spring, *S. sclerotiorum* produces sexual spores by forming an abundance of ascospores in vase or cup-like structures called apothecia (Figs. 59.25 and 59.26). This plays an important role in white mold as the apothecia provide ascospores for the primary inoculum to restart each year’s disease cycle. The ejection of these ascospores, which adhere to the dying flower petals attached to young pods, begins the infection phase of white mold. Ascospores may also infect nearby plants or be wind-blown to nearby fields. Apothecia develop when the soil has been continuously moist for 10-14 days. Dense canopies, high moisture levels, and irrigation before flowering favor apothecia development (NCSRP, 2012; Staton, 2012; Westphal et al., 2006).

**Management**

Soybean white mold incidence is favored by dense soybean canopies, rain events during flowering, high humidity and fogs, and extended dew periods. Other risk factors that should be considered are a history of white mold in the field, rotation history, pockets of poor drainage, air movement barriers, early canopy closure, narrow rows, excessive plant nutrition, and weed management. Managing white mold combines variety selection with minimizing the impact of high moisture levels and heavy rainfall in the soybean canopy and reducing the sclerotia number and spread (NCSRP, 2012).

1. **Select a tolerant soybean variety is a good first step.** No soybean varieties, with complete resistance to white mold, are available, but tolerant varieties are often effective in managing white mold and increasing yields. Additionally, selecting soybean varieties that are short and do not lodge easily will also improve white mold management. Susceptible varieties should be avoided in poorly drained fields with a white mold history (NCSRP, 2012).

2. **Manage the canopy coverage and row spacing.** Tight canopy coverage in soybeans slows down moisture evaporation, drying of wet soils, and increases the relative humidity within the canopy. Thus, production practices that allow more air movement through the canopy reduce the potential for white mold development. Wider row spacing is a very effective method for opening the canopy to air movement and decreasing white mold risk (NCSRP, 2012; Westphal et al., 2006).

3. **Use an effective crop rotation.** Continuous soybean production systems increase the potential for white mold. Rotation with crops that are not susceptible to white mold (such as corn, wheat, or other cereals) is needed to decrease the white mold potential. Typically, 2-3 years of rotation is recommended before returning to soybeans, particularly in severely infected fields. Additionally, weed control of dicotoloydenous plants (such as lambs-quarters and pigweed) that are alternate hosts for *S. sclerotiorum* is critical during nonsoybean years (Iowa State University Extension, 2010; NCSRP, 2012; Westphal et al., 2006).

4. **Avoid excessive moisture.** Moisture promotes white mold infection. Thus, excessive irrigation should be avoided until after flowering (the prime infection period) (NCSRP, 2012).

5. **Consider tillage.** When buried deep in the soil, sclerotia can survive up to seven years. However, only sclerotia that are buried within two inches of the soil surface can germinate and produce ascospores. Thus, burying the sclerotia by tillage can be effective. Subsequent tillage, however, can bring buried sclerotia to the surface. In no-till situations, the sclerotia tend to remain close to the surface, but following soybeans in rotation with a non-host crop allows a large number to germinate during the non-host years (NCSRP, 2012; Westphal et al., 2006).
6. **Minimize the spread of disease by field equipment and seed.** White mold can be spread between fields by seed (Figs. 59.10 and 59.11), equipment, manure, and soil movement. Sclerotia present in soybean stems, debris, or seed can be trapped on harvest combines and other equipment. Because combines can move sclerotia from infected to non-infected fields it is recommended to harvest infected fields after non-infected fields. After harvesting infected areas, it is recommended to clean the combine, other equipment used in the field during harvest, and any seed from that field. Seed cleaning is critical because sclerotia and soybean seeds have similar size and shape, and sclerotia mixed in with soybean seeds can initiate infections in new fields (NCSRP, 2012; Westphal et al., 2006).

7. **Fungicide can be used to help control the disease.** In cases of severe white mold incidence or fields with a history of white mold, fungicide usage may be desired. Complete control of white mold is not possible, but fungicides may reduce the white mold incidence. A challenge with effective control is getting the fungicide to penetrate into the dense soybean canopy. Penetration can be improved by increasing the spray volume, reducing the groundspeed, and using 40 PSI nozzle pressure and a flat fan nozzle that produces fine to medium drops (Staton, 2012). Contact SDSU Extension plant pathologist and pathology field specialists for currently labeled fungicide recommendations, spraying hints, and fungicide rates.

8. **Biocontrol may be an option.** Some antagonistic fungi are available that may colonize and reduce sclerotal number in soil (Iowa State University Extension, 2010; Westphal et al., 2006).

![Figure 59.10. Sclerotia forming in the seed pod can lead to the sclerotia being included in harvested seed or caught in farm machinery. (Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)](image)

![Figure 59.11. Sclerotia mixed in with harvested seed can be a source of inoculum for white mold if these seed are used for planting. (Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)](image)

**Stem Canker**

Northern stem canker was a major disease in the Midwest through the 1950s and 1960s, but the use of less susceptible cultivars has curbed this disease. However, since 2000, a resurgence of this disease has been found in South Dakota, Wisconsin, Minnesota, and Iowa. Northern stem canker can reduce soybean yields 50% to 80% (Chase, 2012; Hadi, 2012).

**Symptoms**

Early-season symptoms occur only rarely and are typically small reddish lesions on cotyledons. This early infection may spread into the stem and cause seedlings to die. Seed germination rate can be reduced and seedling decay and death can occur if infected seeds are planted.
In most cases stem canker symptoms can be observed in the mid to late August. The most prominent symptoms are reddish-brown lesions on one side of a leaf petiole branch base or stem nodes. As the disease develops, the lesion becomes sunken, elongates, and turns dark gray-brown (sometimes with reddish margins) (Fig. 59.12). A distinctive characteristic of the lesions is the presence of green stem tissue above and below the canker. Brown discolorations, which can be seen when the stem is split, can develop inside the stem (Chase, 2012; Hadi, 2012; Iowa State University Extension, 2010).

Toxins produced by the pathogen are translocated to the leaves where it causes an interveinal yellowing that progresses to death of the leaves. Leaves remain attached to the plant after death. As the lesion progresses, the stem can be girdled which cuts off water transport to the leaves. This in turn causes the soybean plants to wilt. Stem girdling has a large impact on yield because it affects pod fill and yield. Early occurrence of stem girdling reduces yield, and late occurrence reduces seed size and weight. Close examination of the lesion may reveal tiny dark black dots that are spore-producing structures (perithecia) for the pathogen (Fig. 59.13). Plants that are dead or have the upper portion killed become visible after the R3 stage. These distinctive plants with their attached blackened leaves can be identified when scouting (Chase, 2012; Hadi, 2012).

**Figure 59.12.** Stem canker presents as an elongated lesion with a gray-brown center and a reddish-brown edge. (Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)

**Figure 59.13.** Stem canker lesions form dark black perithecial clusters that look like dots in the lesion in order to produce ascospores. (Photo courtesy of Martin Draper, NIFA)

**Causal pathogen and life cycle**

Stem canker belongs to a complex of diseases referred to as the *Diaporthe/Phomopsis* complex. This *Diaporthe* (sexual stage) / *Phomopsis* (asexual stage) complex of pathogens contains *Diaporthe phaseolorum* var. *caulivora* (causal agent of Northern stem canker); *Diaporthe phaseolorum* var. *meridionalis* (causal agent of Southern stem canker); *Diaporthe phaseolorum* var. *sojae* (*Phomopsis sojae*, causal agent of soybean pod and stem blight); and *Phomopsis longicolla* (causal agent for Phomopsis seed decay of soybean) (Chase, 2012).

*Diaporthe* belongs to the kingdom Fungi and the Phylum Ascomycota in the Class Pyrenomycetes. *Diaporthe* produces clusters of long-necked, black fruiting bodies called perithecia (Fig. 59.13). Inside the perithecia, sac-like structures called asci produce ascospores. Unlike the apothecia produced by *S. sclerotiorum*, these ascospores are not open to the air and are exuded from the long neck of the perithecia.
Diaporthe also produces areas of mycelium called stroma. Both the perithecia and stroma are able to survive for long periods in the soil. D. phaseolorum overwinters typically in infested plant debris and seed. Seed infection rate is estimated to be 10-20%. Infected seed can cause reduced germination, seedling decay, and seedling mortality (Chase, 2012; Hadi, 2012).

In the spring, the pathogen on last season’s residue produces spores that are carried by wind or rain to the plant surface. Infection occurs during the soybean vegetative stages, although, symptoms do not occur until reproductive stages. Infection of soybean at the V3 growth stage correlates with the highest disease severity. High rainfall and temperatures during the vegetative growth stages favors stem canker infection. Once infected, the damage can be increased by dry weather during the reproductive stages (Chase, 2012; Hadi, 2012).

**Management**

Due to D. phaseolorum’s ability to survive for extended periods of time in the soil, fields with a history of stem canker are at high risk for future outbreaks. Stem canker can be managed through accurate diagnosis and a combination of control measures (Chase, 2012).

1. **Use resistant or tolerant soybean varieties.** Soybean varieties with resistance or tolerance to stem canker are available and should be selected particularly in fields with a history of stem canker problems (Chase, 2012; Hadi, 2012).

2. **Crop rotation.** Avoid planting soybeans in fields with a history of high stem canker incidence. The risk of this disease is increased by a continuous soybeans rotation or planting alternative hosts (such as alfalfa and other weeds). Thus, weed control should be maintained during the soybean-free rotation periods (Chase, 2012; Grau, 2006).

3. **Tillage and cultural practices.** Infected soybean residue can allow D. phaseolorum to survive in no-till or conservation tillage fields. Although not appropriate in all production systems, deep plowing after harvest can help manage stem canker by burying soybean residue contaminated with stem canker. Seed should be planted into a warm, fertile, well-prepared seedbed to establish seedlings with vigorous growth. Increased infection has been associated with low fertility (particularly K). Thus, maintaining good soil fertility is a cultural practice that can decrease stem canker incidence (Chase, 2012; Grau, 2006; Hadi, 2012).

4. **Clean seed should be planted.** As D. phaseolorum is a seed-borne pathogen, clean high-quality seed should be used when possible. Seed should be well cleaned to eliminate infected pieces of debris and certified to have a high germination rate. Seed treatment with fungicide will reduce stem canker, but it will not completely eliminate it (Chase, 2012; Grau, 2006; Hadi, 2012).

5. **Consider applying foliar fungicides during the vegetative stages.** However, this may not always be economically beneficial (Hadi, 2012).

6. **Obtain an accurate diagnosis.** Stem canker may be confused with white mold, PRR, or other late-season diseases. Thus, accurate diagnosis can promote accurate management (Chase, 2012).

7. **Avoid delayed harvest.** Soybeans in infected fields should be harvested as soon as mature. Rain-delayed harvests often allow infection to spread into seeds throughout the plant (Chase, 2012).

**Brown Spot (Septoria Leaf Spot)**

Brown spot is found in almost every South Dakota soybean field. Typically it is found on older leaves in the lower canopy. This disease may move up throughout the plant if the weather is warm and moisture is available. As the season progresses, infected leaves may turn rusty brown or yellow and fall off prematurely (Fig. 59.14). Brown spot is often found on the same plants as bacterial blight and is commonly misidentified as bacterial blight or soybean rust.
**Symptoms**

Irregular, dark brown lesions (spots) (Fig. 59.14) that vary in size are often observed on both the upper and lower leaf surfaces but are often observed first in the lower canopy (Fig. 59.15). Lesions merge together to form irregularly-shaped blotches (Fig. 59.16). Browning may occur along leaf vein or leaf edges and infected leaves can turn rusty brown or yellow and fall off the plant prematurely.

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**Causal pathogen and life cycle**

Brown spot is caused by the fungus *Septoria glycines* and may be called Septoria leaf spot. *Septoria glycines* overwinters on infected leaf and stem debris from the previous soybean crop. Splashing rain and wind carry the spores or conidia from the soil surface to the soybean plant. Fruiting bodies develop in lesions on infected cotyledons and unifoliate leaves. Spores are developed and provide inoculum for later infections. Warm (60°F to 85°F), moist weather is optimal and favors the spread of infection and disease development. A leaf wetness period of six or more hours is required for infection. Hot, dry weather typically halts the spread of this disease.
Management

1. **Utilize crop rotation.** This allows time for soybean debris to be broken down and fruiting bodies to degrade.

2. **Employ tillage practices.** Bury residue for faster debris decay.

3. **Use fungicides.** Fungicides applied to South Dakota soybeans between bloom and pod fill can reduce disease severity and may increase yields if brown spot has been a problem. *The R3 (pod set) growth stage is recommended for fungicide application.* Brown spot has been shown to reduce yield by two to four bushels. It is a coin flip on whether it is deemed economically feasible to manage this disease.

Charcoal Rot

**Symptoms**

Charcoal rot can develop in South Dakota when the weather has been hot and dry. The most evident symptom of charcoal rot is a gray speckling within the lower stem (Fig. 59.17). This gray speckling is microsclerotia which are very small black structures. Early in the season symptoms may be difficult to distinguish. A reddish streak may be observed along the hypocotyl. This disease may also kill the growing point at the tip of the stem resulting in "twin stems" (two stems instead of one). Later in the season, infected plants will lose vigor and may die prematurely. Leaflets often turn yellow, then die and shrivel but often remained attached to the plant. Seedlings can become infected early, but the fungus grows slowly until the weather becomes hot and dry after flowering occurs.

![Figure 59.17. Charcoal rot infection on soybeans. Note the gray discoloration observed on the root tissues.](Photo courtesy of Martin Draper, USDA-NIFA, Bugwood.org)

**Causal pathogen and life cycle**

Charcoal rot is caused by *Macrophomina phaseolina*. This fungus can survive in dry soil as microsclerotia for two years or longer, but is short-lived (7-8 weeks) in wet soil. The fungus can sustain itself in the soil by growing on available nutrients and plant debris. Soil populations build quickly when soybeans are grown continuously.

Management

1. **Utilize crop rotation.** This helps prevent the build-up of microsclerotia in the soil.

2. **Follow recommended plant populations.** Densely planted soybeans will compete for moisture under drought conditions which favor disease development.

3. **Select resistant varieties.** Plant varieties that are not highly susceptible to charcoal rot. Some resistance sources have been identified.
Frogeye Leaf Spot

**Symptoms**

Lesions (spots) are small, gray spots with reddish-brown to purple borders (Fig. 59.18). Smaller lesions may grow together to form larger, irregular spots on the leaves (Fig. 59.19). In severe cases, premature leaf drop may occur. Lesions may also occur on the pods. Lesions on pods are reddish-brown and may appear shrunken and are often circular to elongate in shape.

![Figure 59.18. Frogeye leaf spot lesions showing reddish-brown to purple borders.](Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)

![Figure 59.19. Small lesions growing together to form larger, irregular lesions.](Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)

**Causal pathogen and lifecycle**

Frogeye leaf spot is caused by *Cercospora sojina*, and is a close relative of the fungus that causes Cercospora leaf spot and purple seed stain. *Cercospora sojina* survives on crop residue left on the soil surface. Rain splashing will carry spores from plant residues to young soybean leaves. Symptom development will occur in 7 to 12 days after inoculation. Conidia will develop from these lesions and easily spread to other areas on the plant, or also spread to surrounding plants and fields. This disease is considered a polycyclic disease which means the number of lesions will continue to increase as long as conditions are favorable for disease development. Warm, humid, wet weather favors this disease's development.

**Management**

1. **Plant resistant varieties.** Single gene resistance has been effective in managing Frogeye leaf spot.
2. **Plant clean, pathogen-free seed.** Infected seed may contain higher levels of inoculum.
3. **Practice crop rotation.** Rotating away from soybeans helps to reduce the inoculum level in the field.
4. **Consider residue management.** Burying residues will help reduce the amount of inoculum in the field.
5. **Utilize fungicide applications.** Fungicide timing is most effective at the R3 stage of growth.

Cercospora Leaf Blight and Purple Seed Stain

Cercospora Leaf Blight is becoming more common in the North Central region. Yields may be reduced, while the fungus, which causes Cercospora blight, can also affect the value of the crop as it is often downgraded due to the seed quality from the color variation (purple seed stain).
**Symptoms**

The leaf blight may start at the beginning of seed set. A dark, reddish-purple bronzing may be observed on infected leaves (Fig. 59.20). Lesions vary in size and may be on both the leaf surface or leaf underside. Red-brown spots may develop on leaves, stems, pods, and may merge together to form large lesions.

Infected soybean seed may appear healthy or have pink to purple spots that range in size from small specks to large blotches that cover the entire seed surface (Fig. 59.21). Discoloration often extends from the hilum. Soybean yield is typically not affected by the seed stain phase of this disease, but the value of the crop is typically downgraded due to the seed quality and color variation. Infected seeds typically have higher protein content and lower oil content compared to healthy seed. Germination and seedling emergence is also reduced when compared to healthy seed. Infected cotyledons often shrivel, turn purple, and drop.

![Figure 59.20. Dark reddish purple bronzing observed on soybean leaves infected with Cercospora leaf blight. (Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)](image)

![Figure 59.21. Infected soybeans displaying the purple seed stain. (Photo courtesy of Adam Sisson, Iowa State University, Bugwood.org)](image)

**Causal pathogen and life cycle**

Cercospora leaf blight of soybean is caused by the fungus *Cercospora kikuchii*, a close relative of the frogeye leaf spot pathogen, *Cercospora sojina*. *Cercospora kikuchii* overwinters in infected seeds and plant residue. Spores are formed on the surface of the residue during periods of warm (75°F to 80°F), humid weather. Wind and rain move the spores to new soybean tissue where infection occurs. Seeds become infected when the fungus invades the pod and grows through the upper vein. The hilum and eventually the seed coat become infected.

**Management**

1. **Plant clean, pathogen-free seed.** Infected seed may contain higher levels of inoculum.
2. **Plant resistant varieties.** Use varieties with some resistance to this disease if they are available.
3. **Practice crop rotation.** Rotating away from soybeans helps to reduce the inoculum level in the field.
4. **Consider residue management.** Burying residues will help reduce the amount of inoculum in the field.
5. **Utilize a chemical/biological control.** Use a seed treatment fungicide. Foliar fungicides may be applied during early pod stages R3-R5 to help prevent blight and pod infections.
**Downy Mildew**

**Symptoms**

Early infection on the upper surface of the leaves appear as pale green to light yellow spots which enlarge into bright yellow spots (Fig. 59.22). The underside of the leaf will appear gray and fuzzy (Fig. 59.23). The centers of the spots turn brown and are bordered by yellow margins. Infected seeds have a dull white appearance and are partially or completely covered in a coating of fungal spores.

**Figure 59.22.** Early infection of downy mildew. Note pale green lesions on upper surface of soybean leaf. (Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)

**Figure 59.23.** Underside of soybean leaf showing downy mildew infection. Note the gray and fuzzy appearance. (Photo courtesy of Virginia Tech Plant Pathology Archive, Virginia Polytechnic Institute and State University, Bugwood.org)

**Causal pathogen and life cycle**

Downy mildew is caused by the fungus, *Peronospora manshurica*. There are 33 reported races of this fungus, and this number is projected to increase as more research is done. *P. manshurica* overwinters in crop residues and on the surface of seed. Wind and rain move the spores on the plants causing infection which can spread quickly throughout the field during periods of cool, wet, or humid weather.

**Management**

1. **Plant resistant varieties.** Use varieties with some resistance to this disease.
2. **Plant clean, pathogen-free seed.** Infected seed may contain higher levels of inoculum.
3. **Practice crop rotation.** Rotating away from soybeans helps to reduce the inoculum level in the field.
4. **Consider residue management.** Burying residues will help reduce the amount of inoculum in the field.

**Powdery Mildew**

**Symptoms**

White, powder-like patches form on all plant parts (Fig. 59.24). Patches continue to enlarge and merge until plant parts are covered. Different cultivars may develop different symptoms such as chlorosis or yellowing, leaf scorching, rusty colored patches, and premature leaf drop. Damage is caused by the fungal utilization of nutrients produced by the plant and by thick mats of fungal mycelium blocking the sunlight reaching the leaf and reducing photosynthesis.
Causal pathogen and life cycle

Powdery mildew is caused by the fungus, *Microsphaera diffusa*. Infection occurs when conidia (asexual spores) land, germinate, and penetrate the epidermal cells. The conidia form germ tubes and attach to the cells via an anchorage structure. An infection peg forms under the anchorage structure and penetrates the epidermis. This allows the first feeding structure (haustoria) to form. The rest of the fungus body (mycelium) grows over the epidermal cells. Chains of conidia soon develop and become wind-borne, start new infections, and repeat the disease cycle until soybean plants mature. Cool weather (65°F to 76°F) favors disease development while temperatures above 86°F halt the growth and reproduction of the fungus. Black sexual fruiting bodies are sometimes produced in mildew colonies late in the fall. It is believed that the sexual spores are released in the spring and serve as a means of primary infection.

Management

1. **Plant resistant varieties.** Use varieties with some resistance to this disease if they are available
2. **Utilize fungicide applications.** Foliar fungicides may be used to control powdery mildew, but they have not been very economical.

Brown Stem Rot

Brown stem rot is often confused and misdiagnosed with another soybean disease called Sudden Death Syndrome. A great diagnostic check for brown stem rot of soybean involves splitting the lower stem of affected plants and checking for brown discoloration. Healthy plants will have white pith.

Symptoms

The most common symptom of brown stem rot is the brown to reddish-brown discoloration of the stem pith (Fig. 59.25). In severe infections, the outside base of the stem can have a greasy appearance. When present, foliar symptoms consist of wilting, chlorosis, and tissue browning between veins. Brown interveinal tissue surrounded by yellow to green tissue along the veins represents typical foliar symptomatology.
**Causal pathogen and life cycle**

Brown stem rot is caused by *Phialophora gregata*. *Phialophora gregata* survives in crop residues left on the soil surface. The brown stem rot fungus produces spores that germinate, invade soybean roots, and progresses into the vascular systems of soybean seedlings. Cool weather (60°F to 80°F) is needed during pod development for disease infection. After pod formation, symptoms of brown stem rot can be found in affected plants.

**Management**

1. **Practice crop rotation.** Rotating away from soybeans helps to avoid build-up of brown stem rot fungus levels in the field.
2. **Plant resistant varieties.** Use varieties with some resistance to this disease if they are available.
3. **Select the best cultivars.** Plant cultivars with shorter relative maturity.
4. **Consider residue management.** Deep burying of residue reduces the survival of the fungus but this practice should also be used with long crop rotation sequences.
5. **Manage soil fertility.** Maintain optimum soil fertility and pH for soybean production.

**Sudden Death Syndrome (SDS)**

Sudden death syndrome (SDS) is often confused with brown stem rot as foliar symptoms often resemble one another. When diagnosing Sudden Death infection, be sure and look at the pith color. SDS-infected soybeans will have a white or slightly cream pith color while brown stem rot infected soybeans will have a brown pith color. Disease development is favored by cool, wet soils. There is discussion that fields infected with soybean cyst nematode should be scouted for sudden death syndrome. To date, SDS has not been officially identified in South Dakota.

**Symptoms**

Symptoms first appear as small chlorotic spots on soybean leaves. Spots coalesce (come together) until the entire leaf is chlorotic. Chlorosis of the leaves continues until necrosis occurs which gives the leaves a fired look (a very bold and striking difference in color) (Fig. 59.26). Leaves appear tattered as the necrotic tissue gives way (falls off) from the leaf. Leaf veins typically remain green, and the leaves often drop off the plant leaving the petioles still attached to the stem. The foliar symptoms develop very rapidly. Roots are often rotted and may have a blue-colored fungus (Fig. 59.27) on them. When roots are split, the pith remains white to a slightly creamy white color.

![Figure 59.26. Chlorosis and necrosis displaying the fired look (very bold and striking color) associated with sudden death syndrome in soybeans.](Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)
Causal pathogen and life cycle

Sudden death syndrome is caused by the soilborne fungus *Fusarium solani* f. sp. *glycines*. The fungus overwinters as chlamydospores in crop residues or in the soil. If soybean cyst nematodes are found, the field should also be checked for SDS. The fungus can also be found in soybean cyst nematode cysts. SDS fungus is found in the soil and can be also found in soybean cyst nematode cysts but does not mean the disease (SDS) will develop. When the soil is wet, the fungus produces a toxin which invades the roots of the plant. These toxins are then translocated to the leaves.

Management

1. **Delay planting date.** Cool, wet soils make young soybean plants vulnerable to sudden death syndrome infection.
2. **Utilize tillage practices.** Compacted soils which retain water and restrict root growth of plants promotes SDS development. Correcting soil drainage and compaction with the use of tillage helps reduce the risk of SDS.
3. **Plant resistant varieties.** Some of the SDS-resistant varieties also have resistance to soybean cyst nematode (SCN).

**Anthracnose**

**Symptoms**

Warm, moist weather conditions favor the development of anthracnose. Symptoms of anthracnose include reddish veins, rolled leaves (Fig. 59.29), dark blotches on stems (Fig. 59.30), pods (Fig. 59.31), and leaf petioles. Sunken, dark brown lesions may appear on the cotyledons of soybean seedlings. Later in the season, a hand lens may be used to observe black spines on the infected areas. Premature defoliation may also occur. Infected seed may have no symptoms while others may develop brown or gray areas with black specks.
Causal pathogen and life cycle

The primary pathogen that causes anthracnose in the Midwest is the fungus Colletotrichum dematium var. truncatum. It overwinters in crop residues and infected seeds. This disease overwinters in infested crop debris and is spread by conidia (spores). It has also shown to be seedborne.

Management

1. Practice crop rotation. Rotating away from soybeans helps to reduce the inoculum level in the field.
2. Consider residue management. Burying residues will help reduce the amount of inoculum in the field.
3. Plant clean, pathogen-free seed. Infected seed may contain higher levels of inoculum.
4. Utilize fungicide seed treatments. Use of a fungicide seed treatment may be beneficial for reducing disease infection.

Soybean Rust

Soybean rust has not been found in South Dakota. This disease dies back every year to the freeze line in the United States (U.S.) and causes significant yield loss in unmanaged soybean fields in the southern U.S. Foliar fungicides are labeled for disease control here in South Dakota for if and when we get this disease.

Figure 59.30. Dark blotches displayed on soybean stems infected with anthracnose. (Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)

Figure 59.31. Anthracnose infection on soybean pod. (Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)
**Symptoms**

Lesions first appear as small, chlorotic, irregularly-shaped spots which turn to tan or brown or reddish in color as the disease progresses (Fig. 59.32). Lesions are usually confined to veins or close to the veins. Soybean rust pustules are typically observed on the underside of the leaf (Fig. 59.33) but may also occur on stem, pods, and petioles. The fungus produces spores in cone-shaped pustules (Fig. 59.34). Soybean rust causes premature defoliation and yield loss.

![Soybean rust observed on soybean leaves.](Photo courtesy of Florida Division of Plant Industry Archive, Florida Department of Agriculture and Consumer Sciences, Bugwood.org)

![Soybean rust pustules shown under magnification.](Photo courtesy of Reid Frederick, USDA Agricultural Research Service, Bugwood.org)

![Cone-shaped rust pustules.](Photo courtesy of Daren Mueller, Iowa State University, Bugwood.org)
Causal pathogen and life cycle

Soybean rust is caused by the fungus *Phakopsora pachyrhizi* and *Phakopsora meibomiate*. Development of soybean rust is favored by prolonged periods of leaf wetness with temperatures between 46°F to 82°F. Rust pustules appear on the leaf surface 9 to 10 days after infection. Spores are easily spread by the wind and splashing rain. Rust pathogens are considered obligate pathogens because they survive on living plant material. Soybean rust is not able to overwinter in the Midwest. The disease dies back to the freeze line in the southern United States. It overwinters on kudzu that is not killed back by freezing, and it can produce spores for the primary inoculum that infects southern soybeans. This pathogen travels by wind currents and has to be reintroduced each year to the Midwest.

Management

1. **Use foliar fungicides.** The first fungicide application should be made before rust appears or shortly after onset of the disease. Scouting and application is beneficial through the R1-R5 soybean growth stages.
2. **Plant resistant varieties.** Use varieties with some resistance to this disease if they are available.

Fungicide Treatments

Information on the effectiveness of different products on foliar diseases is available in Ruden (2012) [http://igrow.org/up/resources/03-3005-2012.pdf](http://igrow.org/up/resources/03-3005-2012.pdf) and Giesler and Gustafson (2008) ([http://ianrpubs.unl.edu(epublic/live/g1862/build/g1862.pdf](http://ianrpubs.unl.edu/epublic/live/g1862/build/g1862.pdf)). Always read and follow label directions for approved uses of these products, and check with the South Dakota Department of Agriculture for up-to-date state product registration information.

To reduce the risk of resistance development, fungicides with different modes of action should be used. The following fungicide information has been modified from Larry Osborne at [http://www.sdaba.org/agronomyconference/pdfs/FungicidesOsborne.pdf](http://www.sdaba.org/agronomyconference/pdfs/FungicidesOsborne.pdf).

Strobilurin fungicides

- High risk for fungicide resistance.
- Products include: Aproach™ (picoxystrobin); Evito® (fluoxastrobin); Headline® (pyraclostrobin);
- Quadris®(azoxystrobin); Vertisan™ (penthiopyrad).

Triazole fungicides

- Broad spectrum and may be effective against rusts.
- High risk of resistance.
- Products include Alto® (cyproconazole); Domark® (tetraconazole); Folicur® & other generics (tebuconazole); Laredo® (myclobutanil), and Tilt® (propiconazole).

Strobilurin + Triazole premixes

- Evito T® (fluoxastrobin + tebuconazole); Stratego® (propiconazole, trifloxystrobin); Stratego YLD® (prothioconazole, trifloxystrobin); Quilt® (azoxystrobin, propiconazole); Quilt Xcel® (azoxystrobin(2x), propiconaxole), Priaxor® (pyraclostrobin, fluxapyroxad).
References and additional information


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Viral Diseases of Soybeans

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Four soybean viruses infect South Dakota soybeans. Bean Pod Mottle Virus (BPMV) is the most prominent and causes significant yield losses. Soybean Mosaic Virus (SMV) is the second most commonly identified soybean virus in South Dakota. It causes significant losses either in single infection or in dual infection with BPMV. Tobacco Ringspot Virus (TRSV) and Alfalfa Mosaic Virus (AMV) are found less commonly than BPMV or SMV.

Managing soybean viruses requires that the living bridge of hosts be broken. Key components for managing viral diseases are provided in Table 60.1. The purpose of this chapter is to discuss the symptoms, vectors, and management of BPMV, SMV, TRSV, and AMV.

Table 60.1. Key components to consider in viral management.
1. Viruses are obligate pathogens that cannot be grown in artificial culture and must always pass from living host to living host in what is referred to as a “living or green” bridge.
2. Breaking this “living bridge” is key in soybean virus management.
   a. Use planting dates to avoid peak populations of insect vectors (bean leaf beetle for BPMV and aphids for SMV).
   b. Use appropriate rotations.
3. Use disease-free seed, and select tolerant varieties when available.
4. Accurate diagnosis is critical. Contact Connie L. Strunk for information. (605-782-3290 or connie.strunk@sdstate.edu)
5. Fungicides and bactericides cannot be used to manage viral problems.
What are viruses?

Viruses that infect soybeans present unique challenges to soybean producers, crop consultants, breeders, and other professionals. Plant viruses are submicroscopic pathogens composed of single or multiple RNA or DNA strands surrounded by a protective protein layer or coat. Their unique size and composition challenge soybean producers and professionals because unlike fungal pathogens, they cannot be seen with the naked eye, magnifying lens, or light microscope. Additionally, they are obligate pathogens that cannot be grown in artificial culture and must always pass from living host to living host in what is referred to as a “living or green” bridge. Breaking this “living bridge” is key to management of soybean viruses.

Insect or other vectors (organisms that transmit the virus) allow soybean viruses to pass from plant to plant along this “living bridge” by overcoming the plant’s protective barriers and depositing virus in living cells. Thus, vectors are responsible for introducing the initial viral infection into a field and for disseminating (spreading) virus throughout the field. Vectors have such an important role in the transmission of viruses that they can be considered an additional component to the typical disease pyramid representing the factors necessary for viral disease development (Fig. 60.1).

![Diagram](Diagram courtesy of M.A.C. Langham, SDSU)

Viral soybean diseases are a serious economic threat to soybean production impacting growth and yields without being widely recognized. Yield losses caused by soybean viruses can exceed 50% depending on the plant variety, infecting virus, and the growth stage of soybean when infected. However, the variety of symptoms produced by viral diseases, symptom suppression during certain soybean growth stages, and limited familiarity with viral disease symptoms contribute to difficulties in diagnosis.

Additionally, soybean viral diseases are one component in the complex of viral diseases infecting all legumes (Fig. 60.2). Legume viruses can be roughly categorized into clusters as those that infect soybeans; those that infect dry beans, pulses, peas, and cowpeas; and those that infect alfalfa and other forages. However, there are some viruses that can pass between two of these clusters, and more rarely, a few viruses can pass between all three clusters. Viral vectors may also move between these three legume clusters. Therefore, this interaction between viral diseases, vectors, and legume type plays an important part in the epidemiology of soybean viral diseases and needs to be considered when developing soybean virus management strategies.
Bean Pod Mottle

Bean pod mottle virus (BPMV) was first described in 1948 (Zaumeyer and Thomas, 1948). BPMV was limited in United States soybean production to Southern soybean-producing states until late 1998 and 1999 when BPMV incidence in the Northern Plains states increased dramatically (Giesler et al., 2002). It was first identified from South Dakota in 1998 and has been present as an economic threat ever since (Langham et al., 1999). BPMV has been found in the majority of southeastern South Dakota (Fig. 60.3), and it extends into northern counties. Extremely high incidence levels have been detected in individual fields and counties. Due to high incidence levels and yield losses, BPMV has a significant economic impact on South Dakota soybean production.

Symptoms

BPMV-infected plants are distinguished by leaves with light green or yellow in a mosaic or mottle pattern with a darker green (Figs. 60.4 and 60.5) (Brunt et al., 1996; Semanick, 1972). Mosaic or mottle patterns are typically prominent in the vegetative or early reproductive stages, but tend to fade (symptom suppression) as the plants mature and summer temperatures increase (Gergerich, 1999). A second prominent symptom is distortion of the leaf lamina as seen in Figures 60.4 and 60.5 (Gergerich, 1999). Leaf distortion is only partially suppressed by maturity or temperature and tends to remain present at this decreased level throughout the season. BPMV-infected plants can be severely stunted (Fig. 60.6), but maturity delays in infected soybeans can allow these plants to continue growing after other plants have reached maturity. Thus, infected plants may appear to “catch up” to non-infected plants late in the season.

Maturity delays are also responsible for BPMV-infected soybeans remaining green after other soybeans in the field have matured and abscised (shed) their leaves. Fields with BPMV-infected soybeans may not close the canopy in row spacing as quickly or thoroughly as healthy soybeans due to delays in maturity and reduction in branching (Fig. 60.7). Some soybean cultivars produce seed mottling when infected by BPMV due to color bleeding from the hilum in seeds from infected plants (Fig. 60.8). Seed mottling is typically a quality issue as the virus found in the seed is generally confined to the testa (seed coat).

Yield reduction caused by BPMV in soybean is dependent on cultivar and soybean growth stage when infected (Fig. 60.9) (Langham et al., 2005). Nationally, yield reductions due to BPMV have been reported to vary from 3% to 52%. In South Dakota cultivar evaluations, yield reductions ranging from 1% to 56% have been observed with an average reduction of one pod per node and 0.7 seeds per pod (Fig. 60.7) (Strunk, 2005). Changes in oil and protein percentages of the seed have also been observed in BPMV-infected soybeans.
Figure 60.3. South Dakota Counties with confirmed incidences of BPMV during surveys are shaded green. Leaf samples from fifty random plants were tested by ELISA from five

Figure 60.4. Soybean leaves infected with BPMV display mosaic and distortion on the leaves of the infected soybeans. (Photo courtesy of M.A.C. Langham, SDSU Plant Virology Project)

Figure 60.5. A comparison of BPMV infected soybean (A) and the same soybean line which is not infected (B) demonstrates the differences in mottling and distortion seen in infected soybean at midseason. (Photo courtesy of M.A.C. Langham, SDSU Plant Virology Project)
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Figure 60.6. Stunting is seen when comparing BPMV inoculated soybeans (I) with a row of the same soybean line (SD99-026R) that was not infected (C). Yellow arrow helps to demonstrate the height differences. (Photo courtesy of C.L. Strunk, SDSU)

Figure 60.7. BPMV infected soybeans (I) have reduced branching and reduced pod set as compared to non-infected soybeans (C) when mature. (Photo courtesy of C.L. Strunk, SDSU)

Figure 60.8. Seed mottling in seeds from BPMV infected soybeans (B) can be compared with seeds from soybean plants that were not infected (A). Seed mottling can result in significant grade reductions. (Photo courtesy of SDSU Plant Virology Project)
**Causal agent**

BPMV (Genus *Comovirus*; Family *Secoviridae*) is a 30 nm icosahedral virus particle (Fig. 60.10). The virus has two single strands of genomic RNA which are each packaged in different particles. Thus, both types of particles must be transmitted into the same cell to cause infection (Semancik, 1972).

**Vector**

BPMV is vectored by leaf-feeding beetles. Transmission by beetles is unique among virus and vector associations because its specificity is not solely dependent on the association of virus and vector, but it is also controlled by the ability of the virus to move rapidly away from the beetle feeding site and to establish primary infection sites in unwounded cells.

The bean leaf beetle, *Cerotoma trifurcata* (Forster), is the principal vector for BPMV and is responsible for the majority of transmission in soybean (Fig. 60.11). It is also important in BPMV epidemiology as overwintering adult beetles transmit the primary inoculum into the fields in the spring as well as transmitting the virus within fields during the season.

Other beetles that have been associated with transmission of BPMV are grape colaspis (*Colaspis brunnea* (F), *C. flavida*, *C. lata*), banded cucumber beetle (*Diabrotica balteata* Le-Conte), spotted cucumber beetle (*Diabrotica undecimpunctata howardi* Barber), striped blister beetle (*Epicauta vittata* (F)), Mexican bean beetle (*Epilachna varivestis* Mulsant), soybean leaf miner (*Odontota horni*), and Japanese beetle (*Popillia japonica*) (Gergerich, 1999; Hadi et al., 2012; Werner et al., 2003; Wickizer and Gergerich, 2007).
**BPMV management**

Management of BPMV focuses on breaking the “living bridge” and reducing the opportunity of BPMV to infect the soybean plant. Key components are provided below.

1. Select a soybean planting date that avoids the peak bean leaf beetle populations (Fig. 60.11). Typically, this has been attempted by delayed planting. Predictive models to use for beetle emergence are developing and can be used to assist in avoiding peak beetle emergence.

2. Use of insecticidal seed treatment or foliar insecticide sprays between soybean emergence and the first trifoliate emergence. This is can be useful in fields where BPMV has been a problem in previous years, but consider the cautions discussed below as mixed results have been reported.

3. Select tolerant soybean cultivars for planting.

4. Utilize disease-free seed.

5. Accurate diagnosis of suspected viral diseases is highly recommended, because different viruses and their differing vectors require unique approaches to management.

6. **Cautions to consider**—Primary BPMV management principles strive to avoid exposure of newly emerging soybeans to overwintered bean leaf beetles vectoring BPMV until the soybeans are mature enough for BPMV effects to be less damaging. Thus, delayed planting dates, insecticide treatment, or foliar insecticide applications after soybean emergence and before emergence of the first trifoliate are often recommended. However, these methods have had mixed results in studies. Their effectiveness depends heavily on whether they are in place prior to beetle emergence and that they limit even small amounts of beetle feeding since primary BPMV infection in a field can be established by even single sites of viruliferous beetle feeding.

Additional information on BPMV management is available at Hadi et al., 2012 and NCSRP, 2012.

**Soybean Mosaic**

Soybean mosaic virus (SMV) is an economic threat across U.S. soybean production. In South Dakota, it has been identified in at least 15 eastern South Dakota counties (Fig. 60.12). Soybean mosaic is reported to produce yield losses of 8-35% in susceptible cultivars (Hill et. al., 1999). However, SMV can form a synergistic relationship when it occurs in co-infection with BPMV. Yield losses up to 75-94% have been reported from the double infection (Giesler, 2009, Hill et. al., 1999). With both viruses occurring in South Dakota, this synergistic reaction presents a true concern for South Dakota soybean production.
Figure 60.12. South Dakota counties (green) with confirmed incidences of SMV during surveys are shaded green. Leaf samples from fifty random plants were tested by ELISA from five producer fields in each county. (Photo courtesy of M.A.C. Langham, personal research data)

Figure 60.13. SMV infecting soybean causes mosaic and distortion of the leaf lamina seen in part A. The distinctive downward curling of the leaves is featured in part B. (Photographs courtesy of S. Tolin, Virginia Polytechnic Institute & State University)
**Symptoms**

SMV-infected soybeans have mosaic color patterning on the leaves (Fig. 60.13). In some cultivars, this mosaic is more subtle than those found with many other soybean viruses. An additional color patterning that can be present in SMV-infected plants is a narrow, darker green band along the veins with lighter green in the lamina between veins. This vein banding does not occur in all soybean cultivars, but can be distinctive in some cultivars. Distortion of the leaf lamina or deformation of leaf shape is also prominent, particularly downward curling of leaves. Stunting also occurs in infected plants. SMV also causes prominent seed mottling in soybean seed from infected plants (Fig. 60.14). Color bleeding from the seed hilum such as that seen with BPMV is also present, but it is often darker than that caused by BPMV.

**Causal agent**

SMV (Genus: *Potyvirus*; Family: *Potyviridae*) is a long, flexuous rod virus approximately 15 nm by 750 nm (Fig. 60.15) (Bos, 1972). This virus has a single-stranded RNA genome that is coiled inside the particle and performs a vital role in holding the particle together. Thus, these particles do not form unless the RNA is present whereas some icosahedral viruses, such as BPMV, can form the protein coat into a particle before RNA is added.

**Vectors**

SMV is vectored by more than 16 species of aphids with the soybean aphid (*Aphis glycines*) being the primary vector (Bos, 1972) (Fig. 60.16). Emergence of the soybean aphid has provided SMV with a prolific vector for transmission. SMV is transmitted by aphids in a nonpersistent manner. This means that the aphids can acquire or transmit the virus in only a few seconds. Thus, the aphid can transmit SMV almost as rapidly as it can land on the soybean plant.

**Seed transmission**

SMV is transmitted by true seed transmission with the soybean embryos being infected during seed formation. True seed transmission is extremely important in SMV epidemiology, because it provides a site for the virus to overwinter as well as introducing the primary inoculum into the soybean field. Viruses with efficient aphid vectors can rapidly spread to high incidence levels when introduced even by very low levels of seed transmission. SMV seed transmission rate ranges from 5-75% with many current varieties having transmission rates at the lower end of this range (Bos, 1972; Hadi, 2012b). However, this is a trait that must continue to be evaluated as new soybean cultivars are developed to maintain these low SMV transmission levels.

**Management**

(Hadi, 2012b; NCSRP-PHI, 2012b)

1. Use SMV-free seeds in planting. Infected seed provide a primary source of initial inoculum that can quickly be spread within the field by its aphid vectors.
2. Infection in early growth stages causes the greatest damage. Managing planting dates to avoid peak aphid populations can limit the spread within the fields.
3. Use resistant or tolerant soybean varieties when available for your growth area. The number of resistant cultivars is currently limited, but more promising varieties are in development and will be available in the future.
4. Foliar applications of insecticides have not been effective in limiting the transmission of SMV. The presence of migratory aphids entering the field may be responsible for this, but insecticides have also been shown to be ineffective in limiting the spread of nonpersistently transmitted viruses in other crops due to the rapidity of transmission and the sampling feeding behavior with which SMV transmission is associated.
Tobacco Ringspot

Tobacco ringspot virus (TRSV) is the third viral disease affecting soybeans in South Dakota. TRSV is not as widely recognized as some of the other soybean viruses. However, it can have significant impacts on soybean with yield losses reported to range from 25-100% (Malvick, 1992). Additionally, TRSV is unique among the soybean viruses in South Dakota because it has a wide host range that includes many hosts that are not legumes where many other soybean viruses are limited to legume hosts.

**Symptoms**

TRSV causes mosaic, necrotic spots, chlorotic ringspots and veinbanding in infected soybean plants. However, these symptoms typically disappear soon after infection (Brunt et al., 1996; Stace-Smith 1985). TRSV is more often recognized for the bud necrosis that it causes. When plants are infected at an early stage,
bud blight causes necrosis and death of the terminal bud, resulting in a crook shape as it bends down. Other buds may also become brittle and shatter. TRSV-infected plants have maturity delays, and they often remain green long after other plants have matured (Fig. 60.17). These plants may have pods that are flattened and contain only one seed (Fig. 60.18). TRSV may also reduce root growth and nodulation (Malvick 1992).

**Causal agent**

TRSV (Genus: *Nepovirus*; Family: *Secoviridae*) has 25-28 nm icosahedral virus particles that closely resemble the ones found in BPMV. It also has two single-stranded RNA genome pieces that are packaged in separate particles (Brunt et al., 1996; ITCVdB, 2006).

**Vector**

_Nematode and Insect Vectors_—The most well established vector for TRSV is the dagger nematode (*Xiphinema americanum*). Abundant evidence has been established for its specific relationship with TRSV. However, TRSV’s ability to spread rapidly in some soybean fields has led to a search for insect or mite vectors that could also be transmitting TRSV. Two aphids (*Myzus persicae* and *Aphis gossypii*), grasshoppers, the tobacco flea beetle, and thrips have been tested and may have a nonspecific relationship with TRSV, but these relationships are neither strong nor capable of explaining the rapid transmission that has been documented in some soybean fields. Thus, the search for a more efficient TRSV vector continues (Brunt et al., 1996; ITCVdB, 2006; NCRSP, 2012c).

_Seed and Pollen Transmission_—TRSV can be transmitted by seed and by pollen. Anthers in TRSV-infected plants produce less pollen, and the pollen that they produce germinates more poorly than the pollen from healthy plants (Yang and Hamilton, 1974). Plants that are infected early and have severe bud necrosis...
produce few seeds, but these seeds have a high risk of seed transmission (90%). Soybeans that are infected later and have less severe symptomatology have a low risk of seed transmission (Brunt et al., 1996; ITCVdB, 2006; NCRSP, 2012c).

**Management**
(Malvick, 1992; NCRSP, 2012d)

Management practices for TRSV are not as well established as for BPMV and SMV. However, there are some practices that can improve TRSV management. These key factors are provided below.

1. Accurate diagnosis will allow you to determine that TRSV rather than other legume viruses is your problem.
2. Plant clean seed. Although many seeds from TRSV-infected plants are small and are lost during harvest and processing, insuring that you have clean seed will prevent TRSV introduction into your field.
3. If your field has a TRSV history, control of dicotyledonous (plants with two seed leaves) weeds that may act as secondary hosts for TRSV can help limit transmission from these hosts.

**Alfalfa Mosaic**

*Alfalfa mosaic virus* (AMV) is a fourth virus that is found in South Dakota soybeans. It is unique in that it is one of the viruses that infect hosts from all three clusters of legumes. Of the four viruses identified in South Dakota soybeans, AMV is the one that is the least commonly identified, but it has a large potential for expansion due to the number of alternate legume hosts in South Dakota.

**Symptoms**

AMV is known for the bright mosaic that it produces in soybean. This mosaic tends to have bright yellow areas or patches (Fig. 60.19) (Brunt et al., 1996; Jaspers and Bos, 1980). It is often referred to as a calico or flashy mosaic. Calico mosaic refers to leaves having a primarily yellow background with small areas of green and is thought to resemble a calico print. Flashy mosaic refers to the fact that many AMV cases are spotted in the field when a leaf with this bright mosaic moves in the wind and a flash of bright color is spotted. AMV also produces a bright vein banding. Stunted plants and distorted leaves are also found in AMV-infected soybean.

**Causal agent**

AMV (Genus: *Alfamovirus*; Family: *Bromoviridae*) has four bacilliform particles (elongated with rounded ends). The particles are 18 nm wide and are 30, 35, 43, and 56 nm in length. With three strands of genomic single-stranded RNA and a requirement for coat protein in order to replicate, AMV is the most complex of the soybean viruses found in South Dakota (Brunt et al., 1996).

**Vector**

AMV is transmitted in a nonpersistent manner by at least 15 aphid species including the soybean aphid (Brunt et al. 1996; Grau ----). It can also be transmitted by five species of the parasitic seed plant, dodder (*Cuscuta* spp.). However, the role of dodder as a vector in soybean is limited to fields with prominent dodder infestation (Jaspars and Bos, 1980). AMV is seed-transmitted in soybean; although, the level of seed transmission is dependent on the AMV strain infecting the soybean (C. Grau, personal communication).
**Management**

1. AMV management is dependent on avoiding aphid transmission at early stages of development similar to SMV.
2. Accurate diagnosis insures that you are dealing with AMV and not other soybean viruses or a combination.
3. Use clean seed.
4. In severe cases, nearby forage legume fields should be checked to see if they are serving as an alternate AMV source.
5. AMV-resistant soybeans are not widely available. As they are developed, AMV-resistant varieties should be added to management practices.

**Summary**

Four soybean viruses infect South Dakota soybeans. BPMV is the most prominent and causes significant disease losses. SMV is the second most commonly identified soybean virus in South Dakota. It causes significant losses either in single infection or in dual infection with BPMV. TRSV and AMV are found less commonly than BPMV or SMV. However, they can cause significant damage where they are found. All four of these viruses can occur in mixed infection, but the effects of these combinations are less well known than the effects of BPMV and SMV co-infections. These four viruses are only a portion of the viruses that infect soybean.

Watchfulness should be maintained to detect movement of additional soybean viruses found in neighboring states, such as *tobacco streak virus* and *soybean vein necrosis virus*, into South Dakota. Vigilance and accurate detection are the best long-term management practices that can be applied in South Dakota soybean production.

**References and additional information**


Grau, C. (Date not available). Epidemiology and control of the major soybean viruses in Wisconsin. University of Wisconsin-Madison, Departments of Agronomy, Entomology, and Plant Pathology. Available at www.plantpath.wisc.edu/soyhealth


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Today’s global challenges and opportunities place great demand on modern agriculture to address worldwide food security, while at the same time advancing U.S. interests in renewable energy, food safety, human health, natural resource sustainability, and global economic competitiveness.

Agricultural research and SDSU Extension programs have responded to the emerging opportunities with new technologies to increase crop yields, reduce input costs, and protect crops against pests and diseases. We are reaching new boundaries of knowledge that ultimately will make American agriculture more profitable and productive.

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Soybeans are an important crop in South Dakota. This book, iGrow Soybeans: Best Management Practices for Soybean Production, contains the principles that growers need to increase profitability and production. The partnership of farmers, scientists, SDSU Extension specialists make it possible for America to feed the world.