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iGrow Corn: Best Management Practices

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Clues on how to maximize corn yields can be gleaned from corn contest winners. Most winning corn growers agree that achieving higher yields requires: 1) paying attention to management details, 2) building soil organic matter, 3) using innovative technologies combined with appropriate variety selection that can minimize pest stress, 4) timely planting, fertilizing, and scouting for pests, and 5) conducting on-farm testing. This chapter provides an eight-step plan to optimize corn yield (Table 1.1).

### Table 1.1 An eight-step plan to optimize corn yield and profit for South Dakota producers includes:

1. Be a lifelong learner and conduct your own on-farm product testing.
2. Identify site-specific yield limiting factors (Chapters 16, 17, 19, and 21).
3. Use archived field records to: a) identify successful, as well as unsuccessful management strategies, b) design crop rotations that build soil health, and c) select hybrids and plant populations (Chapters 13 and 24).
4. Actively manage crop residues (Chapter 13).
5. Proactively manage field water. This may involve installing tile drainage in poorly drained soils. However, prior to installing tile drainage, check the soils for suitability with NRCS personnel to determine legal requirements (Chapters 30, 31, and 32).
6. Improve the soil nutrient program.
   a. Conduct N and P assessments (Chapter 29).
   b. Optimize fertilizer rates, timing, and sources (Chapters 25, 26, 27, and 29).
7. Proactively manage weeds, insects, and diseases (Chapters 39 through 52).
   a. Select hybrids that optimize yield and minimize pest stress (Chapter 10).
   b. Monitor weather conditions, scout fields regularly, track and map pest infestations.
   c. Use pre-emergence and post-emergence herbicides, apply insecticides and fungicides when needed, and rotate pesticide chemistries to avoid pest resistance.
8. Prepare and calibrate field equipment.
   a. Calibrate and prepare your planter for seeding.
   b. Clean, repair, and calibrate fertilizer and pesticide applicators (Chapter 41).
   c. Prepare the combine for harvest (Chapters 37 and 47).

### 1. Be a Lifelong Learner

Over the past 160 years, researchers and growers have learned that corn responds to multiple stresses simultaneously (Bloom et al., 1985; Rubio et al., 2003; Kim et al., 2008; Kharel et al., 2011), and for this reason, the strategy to increase corn yields involves examining many factors simultaneously. Companies are constantly introducing new products, all touted to help relieve plant stress, and enhance yield. However, not all products can be tested through unbiased research. Growers need to take responsibility...
to gain information about the appropriate use of these technologies. On-farm research will help provide information for deciding whether a product or technology is a good fit for your operation. Some of the products that are tested may fail, but this information is also valuable, and in the long run, will help in deciding what, if any, changes should be made.

2. Identify Site-specific Yield-limiting Factors
Most land parcels are not uniform, exhibiting variability in soil types and topography. This variability often means that cropping problems are not uniform and that a one-size-fits-all solution may not work. Therefore, fields should be scouted to determine WHAT and WHERE the problems are occurring.

Scouting can be a complex process, but the ultimate goal is to identify yield-limiting factors by area and rectify the problem(s) in a timely manner. Scouting intensity should be increased during high-risk periods (e.g., when climatic conditions are optimal for disease outbreak, or weed emergence). However, scouting is labor intensive and its efficiency may be improved through the use of a drone, aerial, or satellite imagery (Fig. 1.1), if combined with ground-truth information.

It is important to understand that solutions to problems may require multiple years of intervention. A specific example, crop lodging, is outlined below. Following scouting, the local agronomists determined that 40% of the field's higher elevation areas was lodged. Solving this problem will take multiple years. At harvest, the farmer should consider harvesting the field against the direction of lodging. In following years, lodged areas should be scouted to determine the amount of volunteer corn. These volunteer plants may harbor diseases and insects or be a highly competitive weed for the planted crop. To solve the problem, the core problem must be identified. Lodging can result from many causes, including extremes in soil moisture, poor root development, high-wind events, poor plant nutrition (K deficiency), excessive population, disease incidence (such as stalk rot), and/or insect damage (corn rootworm and/or corn borer), alone or in combination. Possible solutions may include:
1. Decreasing the corn seeding rate.
2. Seeding corn hybrids with quick dry-down time, shorter maturity rating, and improved stalk rot and insects resistance.
3. Increasing the amount of K added to the field. K deficiency symptoms often include yellowing and necrosis of lower leaves and can contribute to weak stalks and increased incidence of stalk rot. The deficiency may be exacerbated by crop residue harvesting, adverse climatic conditions, and organic or sandy soils (Sawyer, 2004).

3. Use Archived Field Records
Archived field records can be used to assess the effectiveness of the soil fertility program and pest strategies. For example, if the soil test P values have increased from 20 to 30 ppm over the past 10 years, consider reducing the P application rate. Archived field records will also provide critical information needed to select an appropriate hybrid and plant population and areas where specific pests have, in the past, been problematic.

Selecting a Corn Hybrid
Selecting the most appropriate hybrid is complicated by the release of new products with different traits or trait combinations. This means that varieties seeded last year may not be available or the best choice...
for next year. Corn hybrids are often classified as “racehorses,” “workhorses,” and “defensive.” Racehorse hybrids produce relatively high yields under good and excellent conditions but low yields under poor conditions. Workhorse hybrids produce good yields under high- and low-yielding conditions. However, the maximum yield for these hybrids in the best conditions is often below the yield potential of the racehorse hybrid. Defensive hybrids produce relatively high yields under poor conditions but lower yields than racehorse or workhorse hybrids under good conditions. Variable-hybrid seeders provide the opportunity to replace workhorse hybrids that are typically uniformly sown across a field with defensive hybrids sown into low-yielding areas and racehorse hybrids sown into high-yielding areas (Chapter 10).

Determining the Plant Population Rate
Corn grows taller and produces a larger ear and thicker stalk when grown at low populations and has the opposite response at high population. This observation suggests that lodging can be partially solved by decreasing the seed rate. However, the population must be matched with water availability because if water is limiting, especially during the early reproductive stages, portions of the ear or whole ears may be barren. Too high of a population can result in poor root development that will increase the chance of lodging. Examples for calculating site-specific corn seeding rates are provided in Chapter 8.

Corn’s growth in high populations also provides an opportunity to increase yields by reducing 30-inch row spacing to narrower rows, such as 20-inch spacing. The 30-inch row spacing was developed to: 1) allow for traffic of field equipment during in-season management of nutrients and pests, 2) reduce disease problems, and 3) match rows to harvest equipment. The advantages of narrow row systems include rapid closure of the canopy, reduced weed pressure, improved light interception, reduced evaporation, and less in-row crowding. The primary disadvantages of narrow rows are increased risk of compaction, reduced opportunity for field cultivation, and difficulty in making in-crop applications of fertilizers and pesticides.

4. Manage Plant Residues
Managing residue is critical for optimizing seed germination. Over the past 30 years, residue-management problems have increased because corn yield, and consequently, corn residue have doubled. When returned to the soil, corn residue has helped South Dakota farmers increase soil organic matter (Soil OM) content of most fields. Soil OM in cornfields of eastern South Dakota increased an average of 24% from 1985 to 2010 (Clay et al., 2012). However, the higher amounts of crop residues have complicated seedbed preparation, slowed soil warming, and contributed to a corn “yield drag” (i.e., lower corn yields than expected) (Gentry et al., 2013). Techniques to reduce residue problems include:

1. Chopping the corn residue with a stalk chopper or chopping combine header. Combine corn headers often are integrated with stalk choppers that have enhanced capacity to chop residue. Chopping residue helps improve stand uniformity and yields (Gentry, 2013).

2. Adopting tillage techniques that minimize contact between the seed and the surface residue, (for example strip-tillage in the planting zone).

3. Harvesting and baling residue after grain harvest. This technique has been widely adopted in the recent past. However, problems with soil erosion, soil organic matter reduction, and nutrient deficiencies should be considered when deciding whether to harvest residue or how much to harvest. Baling residue may also have the benefit of helping the soil warm up.

5. Proactively Manage Water
Over the past 40 years, corn yield increases in eastern South Dakota have been linked to improvements in water-use efficiency (WUE). For example, corn WUE was 6 bushels per acre-inch of rain in the 1950s, whereas in 2012 the water-use efficiency was over 9 bushels of grain per acre-inch of water. New hybrids are being developed that are expected to further improve WUE (Chang et al., 2014).

The location and magnitude of water problems are predictable in each field. Upper landscape positions (summit and shoulder areas) are often limited by too little water, whereas lower landscape positions (foot and toe slopes) are frequently limited by too much water. In addition, rainfall generally decreases from the east to west in South Dakota. If yields are limited by too little water, reducing the tillage intensity, installing
irrigation, and/or planting drought-tolerant hybrids may increase yields (Chang et al., 2014). Irrigation is costly and in many areas high-quality water suitable for irrigation is not available. Additional information on irrigation is available in Chapter 33. If water is available, proper permits from the South Dakota Department of Water and Natural Resources must be obtained. In addition, an economic assessment should be conducted prior to installing a system. A general rule of thumb is that to pay for the irrigation costs, the irrigation water must produce a 50 to 70 bu/acre annual increase in corn grain yield.

Glaciation on the eastern side of the state has produced rolling topographies, and many fields contain troughs between the hill slopes. Drainage and grass waterways have been used to reduce ponding and erosion in these areas. Additional information on drainage is available in Chapter 30. In areas where too much water limits crop growth (a high water table), the installation of drain tile can increase yields from near zero to match a field’s highest yielding areas. Fundamental differences between drainage in South Dakota and surrounding states include:

1. Most South Dakota fields do not have a designated drainage ditch, therefore discharging drainage water can be legally challenging.
2. South Dakota has many sodium-affected soils where tile drainage can contribute to the conversion of productive soil to nonproductive soil.

Historically, tillage was conducted to prepare a seedbed and help manage excess water. Tillage reduces plant available water 2 to 3 inches annually. To save water, tillage should be minimized and the amount of crop residue on the soil surface increased.

6. Improve the Soil Nutrient Program

Each nutrient has unique chemical reactions that impact its availability. Some negatively charged nutrients (NO$_3^-$ and SO$_4^{2-}$) can be rapidly lost with deep percolating water, whereas positively charged nutrients are retained near the surface (Table 1.2).

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Dominant species in soil</th>
<th>Leaching potential</th>
<th>Loss with erosion</th>
<th>Gaseous losses</th>
<th>Transport to root</th>
<th>Reactions within plant</th>
<th>Deficiency symptom</th>
<th>Consider as capital expense</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>NO$_3^-$</td>
<td>high</td>
<td>low</td>
<td>mass flow</td>
<td>mobile</td>
<td>yellowing</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>NH$_4^+$</td>
<td>low</td>
<td>high</td>
<td>high</td>
<td>diffusion</td>
<td>mobile</td>
<td>yellowing</td>
<td>no</td>
</tr>
<tr>
<td>P</td>
<td>H$_3$PO$_4^-$</td>
<td>low</td>
<td>high</td>
<td>none</td>
<td>diffusion</td>
<td>mobile</td>
<td>dark green/purple</td>
<td>yes</td>
</tr>
<tr>
<td>K</td>
<td>K$^+$</td>
<td>low</td>
<td>high</td>
<td>none</td>
<td>diffusion</td>
<td>mobile</td>
<td>dark green with necrosis of leaf margins</td>
<td>yes</td>
</tr>
<tr>
<td>Mg</td>
<td>Mg$^{2+}$</td>
<td>low</td>
<td>high</td>
<td>none</td>
<td>diffusion</td>
<td>mobile</td>
<td>green-yellow with dark yellow interveinal chlorosis</td>
<td>yes</td>
</tr>
<tr>
<td>S</td>
<td>SO$_4^{2-}$</td>
<td>moderate</td>
<td>low</td>
<td>low</td>
<td>mass flow</td>
<td>moderate</td>
<td>uniform pale yellow</td>
<td>no</td>
</tr>
</tbody>
</table>
use precision grid sampling to help define this variability and areas where nutrient application would or would not be profitable. Scouting, tissue sampling with laboratory analysis, or remote sensing, through aerial, satellite or drone technologies, may be used to better assess the effectiveness of the nutrient program (Chapter 22).

The effectiveness of the transport process is dependent on the mobility of the nutrient. For mobile nutrients, deficiency symptoms are first observed in older vegetation, whereas for immobile nutrients, the deficiency symptoms are first observed in younger vegetation. The mobile nutrients are N, P, K+, and Mg, whereas B and Ca are considered immobile. Nutrients that are moderate mobility include Cu, Fe, Mn, Mo, S, and Zn. During a plant's reproductive growth stages, the nutrients contained in the grain increase from zero at tasseling to accounting for over 50% of the N and P contained in the plant at black layer (physiological maturity) (Chapter 5; Benter et al., 2013).

Theoretically, long-term nutrient sustainability requires that nutrient removal be balanced with nutrient supply or resupply (Table 1.2). A 300 bu/acre corn crop contains approximately 404 lbs N (corn 0.9 ×300 + 8.4 ton stover ×16 = 404), which is supplied by the soil and supplemental fertilizer applications. When nitrogen fertilizer is applied, there is a potential that a portion can be lost through volatilization or leaching. Using products that slow urea hydrolysis or nitrification can reduce N losses under some conditions.

To grow 300 bu/acre corn, most agronomists believe that soil phosphorous and potassium levels should be in the very high soil test category. In South Dakota, very high soil test levels of P and K are > 16 ppm and > 161 ppm, respectively. Sampling date and soil drying can impact soil test P and K values based

Table 1.3 Nutrients removed in corn, soybeans, and wheat. (Modified from Clay et al., 2011)

<table>
<thead>
<tr>
<th>Crop</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 grain</td>
<td>bu</td>
<td>0.90</td>
<td>0.38</td>
<td>0.27</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Corn stover</td>
<td>ton</td>
<td>16</td>
<td>5.8</td>
<td>40</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Corn silage</td>
<td>ton</td>
<td>9.7</td>
<td>3.1</td>
<td>7.3</td>
<td>2</td>
<td>1.1</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>Soybean stover</td>
<td>ton</td>
<td>40</td>
<td>8.8</td>
<td>37</td>
<td>8.1</td>
<td>6.2</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>
<tr>
<td>Wheat straw</td>
<td>ton</td>
<td>14</td>
<td>3.3</td>
<td>24</td>
<td>2</td>
<td>2.8</td>
</tr>
</tbody>
</table>
on laboratory analysis. Generally, nutrient concentrations are lower in the fall following harvest than in the spring following a period of recharge. In addition, drying and grinding a soil sample can increase the amount of extractable K. When considering raising the soil test results, on average (varies with soil) approximately, 20 lbs of $P_2O_5$/acre are needed to increase the soil test P value by 1 ppm, whereas 12 lbs of $K_2O$/acre are needed to increase the soil test K value by 1 ppm.

In most fields, P leaching through the soil to groundwater is not a problem. However, if the soil P levels are extremely high or the soil has a sandy texture, leaching can occur. Environmental impacts can generally be eliminated by band injecting the P fertilizer into the soil or incorporating surface applied P into the soil. However, in South Dakota, it is not recommended to apply P, either as fertilizer or manure, if the Olsen soil test value is > 100 ppm.

During grain harvest (and if stover is removed), secondary (Mg, Ca, and S) and micronutrients (B, Zn, Mn, Fe, Cu, Mo, and Cl) are also removed from the field. Mass balance dictates that for long-term sustainability, these nutrients must be returned. Even though South Dakota research has not consistently documented the need for these nutrients, many farmers routinely supply micronutrients. Recent research suggests that drought stress can result in the down expression of many genes associated with nutrient uptake (Hansen et al., 2013). These findings suggest that if nutrient levels are low, plants may respond to micronutrient fertilizers in water-stressed areas (summit and shoulder areas) due to greater availability. Summit/shoulder areas also may have experienced high soil erosion rates, which would reduce the topsoil depth, water-holding capacity, and nutrient-supplying ability of the soil. The plant population and nutrient applications need to be well-managed to optimize yield.

7. Use Proactive Management for Weeds, Insects, and Diseases
Scouting and mapping pest infestations provides valuable information for improved management. Preventative measures, such as cleaning equipment, should not be skipped in the interest of time as new infestations often can be traced to poor sanitation. To prevent the development of pests that are resistant to chemical control mechanisms, rotate the control approaches (Chapter 43).

Weeds present during the critical weed-free period of corn growth (V1 to V6 or longer depending on weather conditions) can irreversibly reduce corn yields. These yield reductions are not necessarily caused by plant competition for water, nutrients, and light but rather by a reduction in the plant's photosynthetic capacity (Moriles et al., 2012). To minimize these losses, pre-emergence compounds should be applied to minimize early weed development and supplemental post-emergence herbicides should be applied if further control is needed. Since early planting is often recommended to maximize yield, fungicide and insecticide seed treatments are also recommended. Combining appropriate genomic traits and good agronomic practices with pesticide solutions for weeds, insects, and disease control is also encouraged.

8. Prepare and Calibrate Field Equipment
Many agronomists believe that the most important machine on the farm is the planter and that it must be in perfect condition to obtain top yields. Assessing seed population and spacing between adjacent seeds within a row can help determine planter efficiency. The desired and measured population should be similar, and in a general sense, decreasing seed spacing variability improves yield. Over the past several years, planter improvements in seed singulation, seed delivery, depth of placement, and opener technology have improved planter efficiency. It is recommended that planters be tested and calibrated annually by a knowledgeable planter mechanic.

Fertilizer and pesticide applicators also need to be calibrated. Maladjusted sprayers can apply either too little or too much in different portions of the field. If the rates are too low, the chemical treatment may not work, whereas if the rates are too high, yields may be reduced. Combines that are not properly adjusted can result in grain that is left on the field. A rule of thumb is that 2 kernels of corn/ft$^2$ or 5 soybean seeds/ft$^2$ on the ground behind a combine amounts to a 1 bu/acre harvest loss. Techniques to minimize grain losses include: 1) driving at an appropriate speed, 2) measuring yield losses and making appropriate adjustments,
3) using a reel speed (soybeans) that is 10% to 25% faster than the combine speed, and 4) harvesting the crop at an appropriate moisture content (Chapters 36 and 37).

References and Additional Information


Acknowledgements

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Even though modern equipment generally operates trouble free, problems still occur (Fig. 2.1). In some situations, attempting to fix the equipment can void warranties. The following chapter provides basic troubleshooting guides for precision agricultural equipment, and it does not provide techniques to overcome proprietary defenses.

**General GPS Guidance Systems**

A majority of precision agriculture equipment relies on the Differential Global Positioning System (DGPS) to provide accurate locations during planting, harvesting, and applying precision treatments. DGPS, which is often referred to as GPS, can provide sub-inch accuracy. Unfortunately, when the GPS fails, your farming operation may be at a standstill until repaired. Troubleshooting GPS guidance systems may require contacting the manufacturer’s technical support. However, there are some simple steps that you can follow before calling a technician.

**Problem:** Not receiving a GPS signal.

1. Check for software or firmware updates that may be required by the system. Not having the current software updates can lead to communication issues between implements and control modules, causing the equipment to malfunction.

2. Make sure the GPS receiver is not adjacent to buildings, tree lines, or vehicles and that it has a clear view of the sky. Attempt to install and test the guidance system before the equipment is needed. In most situations, guidance systems cannot be tested in the shop because GPS signals are transmitted over relatively weak signals and small obstructions can interfere with the signal.

**Problem:** The vehicle has a clear view of the sky but still does not have a GPS signal.

1. Check for tight and secure connections, starting at the globe on the roof, to the receiver, to the display cable. Check all connectors to make sure that the pins have not been pushed sideways. Loose connections can cause a loss of or a sporadic signal.
2. Check the indicator lights on the receiver (if equipped). If the cab roof receiver’s green light is on, the receiver is receiving a GPS signal. If the receiver has a signal, but the display indicates no connection, there is a problem between the receiver and the display.

3. Check if the correct differential correction is selected. For example, the display may be set to utilize WAAS for differential correction when it needs to be set to OmniSTAR or StarFire.

4. If the GPS light is yellow or blinking (depending on manufacturer), there is an interference with the signal. Trees or buildings that are blocking the signal between the satellite and the receiver can cause interference.

5. A red light or amber blinking light on your GPS indicates no communication between satellites and your receiver as you attempt to restart the system. If the problem persists, contact your local dealer.

6. Check the baud rate, which is the speed at which the system communicates with satellites. Baud rate is the rate at which information is transferred from the receiver to the computer, and if it is not set to the correct setting, the GPS system will not work. Recently purchased systems have baud rates that often are 19,200 or 38,400. Older systems may have baud rates of 4,800 or 9,600. Check your manual for correct baud rate settings.

7. Check the Controller Area Network (CAN) bus systems to make sure that the appropriate baud rates for the receiver, wheel-angle sensors, and steering valve are appropriate (Bartak, 2014).

**Problem:** The location is not correct.

1. This is a common problem when the GPS system has been off for an extended period of time. When the system is turned on, the software uses old information to calculate its location. As the almanac (which is a list of all the satellites and their location in orbit) is obtained, the locations will become more accurate. Wait until convergence is down to 2”-5” if using a satellite-based correction system (Breuer, 2014).

2. Poor location accuracy can be caused by the satellite arrangement in the sky. The satellites may not be evenly distributed in the sky, or close to the horizon rather than overhead. This can lead to poor Dilution of Precision (DOP) values, which can be found in the display. Typical numbers desired for DOP are: 0-3 good, 3-5 acceptable, and above 5 unusable (Breuer, 2014).

3. Make sure that the receiver is at the highest point on the vehicle. For example, if you added extensions to the combine’s grain tank and the receiver is on top of the cab, the extensions may protrude above the receiver, reducing the number of viewed satellites. It also could cause a multipath error. Multipath error occurs when the GPS signal bounces off of an object (in this case the extension) and then is picked up by the receiver (Fig. 2.2). This causes the receiver to receive multiple signals, one directly from the satellite, and one from the signal bouncing off of the bin extension.

4. It is possible that the receiver is communicating with the GPS satellites, but not receiving a correction signal from a WAAS / OmniSTAR / StarFire satellite. When this happens, the GPS correction will not be accurate enough for most purposes. All displays have a screen that indicates the type of GPS correction. It is important that you are receiving Differential GPS (DGPS).

5. An additional frequent problem is the vehicle wandering off course. Two-way radios and citizens band (CB) radios can interfere with GPS signals, causing loss of satellites. If the vehicle is wandering off course, change the frequency of the radios and CBs. Electrical noise from a bad alternator can also cause degradation or loss of GPS signal quality.
Planting and Application Issues

Problem: The planter shutoffs/startups are producing gaps in the field (Fig. 2.3)

1. This can be an issue if the offsets are not correctly entered into the display. The machine needs to know where everything is in respect to the GPS receiver. Many companies offer default settings that auto-populate based on the vehicle model and implement model numbers. These values must be checked.
2. Check whether the tire size has been changed, the GPS receiver has been moved, or the hitch type has been changed.
3. Most systems also have a lead-in or turn-on/turn-off time that can be adjusted. If the product application starts too soon, decrease the turn-on time. If application starts too late, increase turn-on time. If product application stops too soon, decrease turn-off time, and if product application stops too late, increase turn-off time (Popkens, 2014).

Problem: Row does not shut off when entering a headland.

1. 1) The headland or turnrow is the end of each planted field. These areas are subject to greater compaction than the rest of the field. To avoid double planting, double fertilizing, and double spraying, farmers often turn off the equipment when entering these areas. If the wire controlling the row clutch is broken, the planter will default to plant mode. Check the wiring coming from the individual row clutch and replace if broken.
2. 2) With planters and other application equipment, it is not uncommon to tie one brand of implement to another type of tractor. This can lead to having multiple displays in the tractor cab, utilizing one for guidance lines and the other to run the planter or application equipment.
   a. Feed GPS from the tractor monitor into the planter monitor for row shutoffs, and variable-rate planting.
   b. Make sure the proper NMEA sentences are being sent to the planter monitor from the tractor display.
      i. Typical message strings are the GGA, VTG and ZDA message strings, depending on the piece of equipment.
      ii. Check with the manufacturer or owner’s manual to confirm which NMEA 0183 message strings will be needed for input to the implement prior to planting season.
      iii. If the message strings are correct, set the communication rate in Hertz. Hertz is the number of times per second the sentence is communicated.
      iv. A typical setting when communicating with application equipment is 5 Hz – 10 Hz. This means the sentences are sent to the implement 5 times per second (5 Hz), meaning the implement is receiving its location information 5 times per second.
      v. A setting of 1 Hz would cause a slower reaction time of the planter. As an example, if you are planting at 5 mph, you travel at a rate of 7.33’ or 88” per second. The planter would travel 7.33’ between rate adjustments (Weaver, 2014).

Harvest Issues

Problem: The yield map does not make sense.
Yield maps are a powerful resource and contain a vast amount of information when made correctly. However, if the yield-monitoring system is not calibrated and set up correctly, the data has little value. To minimize errors, calibrate the system using the prescribed protocols. Grain yield can be calibrated by measuring combine grain harvested compared with a local elevator’s estimates.

Problem: Combine is counting bushels but not showing yield.
Every combine with a yield-monitoring system has a header height sensor that tells the system if the
header is down (combine should be recording yield) or up (combine should not be recording yield). If you are harvesting and the monitor is counting the bushels but not showing a yield, the problem might be improper header-height calibration. Check your owner’s manual for the correct calibration methods. This is a common problem when switching from soybeans to corn. With soybeans, the head rides on the ground, and when switched to corn, the yield-monitoring system may think the header is up.

**Problem:** The yield displayed is not correct.

Check each of the sensors used to determine yield. The combine calculates yield using the header width, the combine speed, and measured grain flow. Make sure speed sensors are communicating properly and that the header width is entered correctly. Common problems are that the header width is not correct and the vibration calibration was not conducted. To conduct the vibration calibration, follow the manufacturer’s protocols. Additional suggestions are:

1. With an impact sensor yield-monitoring system, harvested grain is deflected by a plate at the top of the clean grain elevator. As the plate flexes, a voltage signal is produced. Vibration makes these estimates unreliable.
2. If the impact plate is dirty or worn, the accuracy of the reported values decreases. Inspect and clean these plates.
3. With an optical yield-monitoring system, check the eyes for dirt/dust debris. Next, check the clearance between the sensor plate and the paddles of the clean grain elevator. In most systems, this should be approximately one-half inch.
4. Clean the clean grain elevator speed sensor. This sensor is used to indicate to the display the speed of the clean grain elevator, which is used to determine the amount of time each paddle is allowed to fill. Typically, this has a minimum and a maximum speed range, commonly 250 – 600 (Bartak, 2014).

**Mapping**

**Problem:** Which map is correct?

This problem can be avoided by identifying the fields correctly when harvesting. To minimize errors, identify field names during the winter months and then place a list in each vehicle/machine.

**Troubleshooting Electrical Problems**

**Problem:** You have an electrical problem somewhere in the system.

Based on the electrical schematic (back of operator’s manual or from the manufacturer), a voltmeter can be used to check voltages at specific pins and continuity of wires. A series of steps are outlined below:

1. For all electrical problems, start the diagnosis by checking all fuses. Check the fuse by touching each end of the leg of the fuse with a lead from the digital multimeter (DMM) while set on the continuity setting. If the DMM beeps, the fuse is good; if the DMM does not react, the fuse is bad. A blown fuse is an indicator that there is short circuit in the electrical system.
2. Check the voltage of the system. Voltage is simply the electrical potential, or electrical pressure. Think of the voltage as being the equivalent of fluid pressure in a hydraulic system. A DMM measures the “pressure” and has nearly infinite resistance, like a hose with such a small diameter, no fluid would be allowed to flow. Volts are comparable to psi, the higher the psi, the more “push” a fluid has. It is the same for volts, higher volts means more “push.”
3. Check the battery by setting the DMM to voltage DC in the range that corresponds with the likely voltage of the battery. For a 12-volt battery, set the range to 20 DCV. Put the voltmeter probes on the battery terminals. If the probes are backward, the only consequence is a negative reading.
4. To measure a voltage drop across a piece of the circuit such as a light bulb, connect the digital multimeter in parallel with the light bulb (Fig. 2.4). This analysis is useful because it provides information if the circuit is operating correctly. All sensors typically output a voltage that corresponds to a specific speed, position, and temperature. For example, if your auto-steer system is not steering correctly, you may want to check the wheel-angle sensor to ensure it is functioning properly. To do this, connect one probe to the input wire and the other to the ground wire of the sensor. As you turn the wheels from left to right, you should see the voltage change accordingly (hypothetically -2.5 – +2.5
If the DMM does not return a smooth voltage signal as the wheel is turned, this could indicate a bad wheel-angle sensor. If you can’t get to a bare wire with your DMM lead, one trick is to poke a hole through the insulation with a thin sharp needle. When you have completed the assessment, use waterproof silicone to fill the hole.

5. Current is the electrical flow through a circuit and is usually measured in amps or milliamps. To measure the current running through a circuit, break the circuit and reconnect the circuit using the probes. Again, if you hook the probes up backward, you will merely get a negative reading. The DMM acts as though it has no resistance in this setup, so it does not change the circuit but it will measure the electrical flow. Make sure to have the probes plugged into the right ports for current measurement and have the settings at the correct range (Fig. 2.5).

6. The resistance (measured in ohms) is the measurement of resistance to electrical flow. The resistance of a resistor, section of wire, a switch, or anything can be measured. A variable resistor, or potentiometer, is usually a dial or slider that changes resistance as it is adjusted to create larger or smaller voltage drop. Variable resistors are used to set the resistance accordingly. Unlike measuring current and voltage, a circuit must be disconnected from power when measuring resistance. To measure resistance, place a probe on each side of the piece you are trying to measure.

7. Continuity is a test that detects electrical flow through the system. The DMM will signal a 1 and beep when electricity is flowing. This is very useful when checking wires, fuses, connections, and switches. It is also useful in a bundle of wires to match the inputs with the outputs. Short circuits are identified by testing for continuity between components that should not be connected.

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Acknowledgements
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Integrated pest management (IPM) is not new but has gained interest as growers attempt to reduce production costs while simultaneously reducing the risk of pest resistance to chemical and biological agents. IPM activities may include using crop rotation, early harvesting, rotating pest control mechanisms, adjusting planting dates and populations, conducting mechanical cultivation, applying appropriate fertilizers, using crop varieties with disease or insect resistance, minimizing planter and chemical application skips, and using biological control agents. All IPM tactics require using the labeled rate. The adoption of IPM is important because: 1) pests are becoming resistant to chemical control agents, 2) most of the new chemical control agents are reformulations of old chemistries, and 3) chemical and biological control mechanisms also kill beneficial organisms. This chapter discusses the role of IPM and how adopting IPM practices can improve long-term sustainability.

What is IPM?
Integrated pest management (IPM) is a sustainable decision-making process that requires continued assessment of the crop situation and knowledge of the pest being controlled. A critical component of IPM is the use of a record-keeping system. A good field record system includes information such as field location, rotation, scouting date, genetics used in the field, fertilizers applied, soil test numbers, current field conditions, previous pest infestations, and previous pesticides applied. Mapping of the present pest locations in the field makes future management decisions easier (Chapter 4).

Enough information should be collected when scouting to make an accurate recommendation. Scouting should note the plant growth stage, pest growth stage, size of the infestation, type and density of the infestation relative to the economic threshold, health of the pest, and whether the pest population is increasing or decreasing. In addition, an image of the pest should be collected and placed in the scouting book. In general, the ability to respond effectively to a pest increases with scouting frequency. However, the scouting intensity should be balanced against costs. Scouting information is needed to determine the appropriate control measures. When the pest population approaches economically damaging levels, the producer will need to monitor more frequently and be prepared to make a decision.

Before applying a pest treatment, the agronomist should ask: is treatment necessary? The presence of a pest may fall below the economic threshold value. Most plants have internal mechanisms to control pests. For example, plants may grow faster in response to shading, whereas other plants may release chemicals that
attract beneficial insects. Most plants can tolerate at least some pest damage before economic yield loss occurs. The point where the control costs are equal to the yield loss is the economic threshold.

If treatment is necessary, does the entire field or just part of the field need to be treated? Depending on the pest and crop involved, a border treatment may reduce costs while preventing further damage. And finally, when should an action be taken? Timing is very important because the damage is different for different growth stages.

**IPM is based on Prevention, Suppression, and Eradication**

**Prevention:** The first line of defense.

In prevention, a treatment is implemented in response to known problem. Preventative approaches include hybrid selection, rotations, modifying row spacing, adjusting plant populations, using cover crops, using pest-free seed, preventing weeds from reproducing, using insect trap crops, and using maturity dates that avoid pest problems. Other possible cultural tactics include elimination of alternate hosts or sites for insect pests and disease organisms, such as clearing field borders or waterways, and practicing good sanitation measures, such as cleaning tillage and harvesting equipment when moving from field to field.

**Suppression:** The second line of defense.

1. 1) In suppression, corrective solutions are used after a problem has been detected. The goal of suppression is to reduce the economic impact of the problem. Common examples include cultivation, mowing, flaming, flooding, and plastic mulches. Keeping a weed from going to seed by mowing, clipping, or plowing the infested area is an example of physical control. The biological controls work best where the long-term impacts are the primary objective.

2. 2) Chemical control techniques are widely used to reduce pests. When using chemical control, consider the economic threshold, do not use partial rates, and make sure the applicators are calibrated. Faulty or worn-out equipment should be replaced. When applying chemicals it is important to rotate the chemistries if possible. Pests are resilient, and in many situations, the routine use of any given control mechanism can result in the development of resistant populations. Precision technology provides the opportunity to reduce this risk by actually applying pesticides to areas of the field where the pest populations usually exist. Safety of the pesticide being used should always be a concern.

**Eradication:** The third line of defense.

Eradication is the complete elimination of the pest and generally it is used for exotic pests that produce dire consequences. Draining a lake to control an invasive plant or fish would be considered eradication. In most agricultural activities, eradication has produced short-term successes. An example is Plum Pox virus eradication in plums in Pennsylvania and New York.

**Pest Monitoring**

The pest monitoring process is referred to as field scouting, and specific scouting methods have been developed for different pests and crops (Chapters 5 and 45). Scouting tools include sweep nets, sticky traps, aerial images, and pheromone traps. The plant growth stage (Chapter 5) is a common technique used to assess plant development. Proper identification of the pest, plant growth stage, soil conditions, and climatic conditions is extremely important in the monitoring process.

Scouting frequency varies with temperature, crop growth, developmental stage, and pest population potentials. If a pest population is approaching economically damaging levels, the field may require more intense scouting. Cost of scouting may impact scouting intensity and frequency. A general guideline is to scout each field at least weekly during the growing season.

A good field-scouting program should provide the following information about the field:

1. What pests are present and level of infestation.
2. Stage of growth of each pest and the crop.
3. If the pests are parasitized or diseased.
4. If aphids look mummified.
5. If pest infestation level is increasing or decreasing.
6. General physical field conditions.

Checklist for scouting:
2. Sweep net.
5. Pocketknife/scissors.
8. Recent pest alert report.
10. Notebook and pen/pencil or iPad.

In summary, IPM is not a single product that can be purchased, like a drum of pesticide, and it does not rely on one “silver bullet” method to solve all problems. Successful IPM programs require planning and knowledge of the crop pests.

References and Additional Information


Acknowledgements
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Field records provide information needed to avoid future problems. Field records are created by combining your field-specific information into a single document. This chapter discusses what should be included in your field records and how to integrate this information into the decision process.

**Importance and Federal Regulations**

The time spent maintaining careful records can help to improve profits and overall efficiency of your enterprise. Records provide information needed to identify successes and failures, and they should be as detailed and complete as possible. Field record information may include field location, crop type, hybrid number, genetic enhancements, soil type(s), previous crops and yields, tillage, planting information, maps showing problem areas, soil test results, and any fertilizer/manure applications or pesticide applications. Scouting maps and the results of soil and manure tests should be attached or included in the records. If available, daily or monthly weather records should be attached to the yearly record.

Federal law requires that all private applicators keep records of applications of all restricted-use pesticides (RUP). These records must be kept for a minimum of 2 years. Restricted-use pesticides will be clearly labeled for “restricted use,” and they can be purchased or applied only by a certified applicator. Additional

![Field records of current and prior pest populations can be used to assess current and future risks. This image shows a cornfield with very few pests.](image-url)
information on pesticide and general field record keeping is available from the South Dakota Department of Agriculture, http://sdda.sd.gov or from local Extension educators.

**Field Records**
Corn production costs can exceed $500/acre or $80,000 for a quarter section. To ensure that these resources are well-invested, fields are routinely scouted to identify problems (Fig. 4.2). This information is compiled can be used as a benchmark for identifying successes and failures. Although rarely discussed in achieving high yields, we believe that maintaining accurate records is a critical step in optimizing yields. Field records should include information about field productivity, previous soil test information and fertilizers applied, historical information, and insect and weed pest management history.

**Field Productivity**
Many decisions come down to the expected cost and return from each investment. An economic analysis can be based on a single or multiple years. A critical component when conducting an economic analysis is knowing your input costs and expected returns. Examples of these costs are available in Chapter 54. Input production costs are associated with the cost of the seed, fertilizer, herbicide, or insecticide, whereas the financial return is the expected yield times the selling price. Expected yields can be estimated from long-term field records. If long-term productivity information is not available, it may be possible to assess yield improvements using archived Landsat images or soil survey information. If the data suggests that yields have not increased, then the land may not have been managed properly. Yield data is a valuable tool for evaluating management strategies. Difference between the observed and expected yields can be used to identify problem areas.

**Soil Fertilizers and Test Results**
A periodic assessment of your corn soil fertility program will help determine whether you are applying the right fertilizer, at the right rate, at the right time, and at the right location. This assessment would reveal if changes in the soil nutrient levels had occurred. This assessment requires that historical soil test results and yields be available. Details on conducting this assessment are available in Chapter 29.

**Historical Information**
Historical information is a valuable source of information. When South Dakota was homesteaded, most quarter sections had a farmstead where livestock were maintained. Even though many of these homesteads were removed over 50 years ago, their location can still be located in soil nutrient maps (Fig. 4.3). Depending on prior management, the size of area with high nutrient concentration can be small or large. These areas should be sampled separately from the rest of the field. Old aerial photographs may be available in the local USDA-NRCS office.
**Pest Management History**
Field records and record keeping are critical components of an integrated pest management program (IPM). Field pressure from weeds, plant diseases, nematodes, and insects is affected by tillage and crop management practices. Historically, tillage was used to bury the surface residues, which reduced disease pressures. Each of these pests is discussed throughout the manual.

**Weeds**
The weed-control management history provides a picture of previous and potential problems (Fig. 4.4). Past records of weeds and their associated control reveal information about what worked and what did not work. Weed records can also be used to identify herbicide resistance. Increasingly, chemical companies are reformulating old chemistry into “new” products. Therefore, record the trade name as well as the common name of the active ingredients and mode of action. To reduce the risk of developing pest resistance, avoid using compounds with similar modes of action.

![Figure 4.4 Cornfield with high weed pressure.](image)

**Insects and Diseases**
A complete history of each field should include any insect and disease infestations, and the effectiveness of the different control practices. Records of the crop rotation, tillage, planting dates, insect identification, insect scouting reports, and economic losses can be used to predict future risks. When assessing insects, scout the borders of your field. Many insects overwinter in plants found outside of the field boundaries. Keep records of insecticides used, including genetically modified organism (GMO) traits, for insect control. Refuge areas should be maintained or refuge-in-a-bag planted to reduce resistant insect populations. Volunteer corn in soybeans can increase corn rootworm problems in the following corn crop.

**Conclusion**
Detailed field records can provide a wide variety of valuable information. The use of yield monitors provides an opportunity 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. Accurate, concise field records and data provide information to creatively minimize risks and maximize profits.

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As the corn plant develops, it undergoes physical and biochemical changes, which impact its response to different management decisions. By understanding these changes, management inputs can be made more efficient. The purpose of this chapter is to highlight corn growth stages.

**Introduction**

The rate that corn grows and develops changes during the season. Young corn plants increase in weight slowly, but as more and more leaves are produced, the rate of dry-matter accumulation increases (Fig. 5.1). Under normal growing conditions, the rate of plant development is largely dependent on temperature. Environmental factors, such as water and nutrient deficiencies, can alter the relationship between plant growth and temperature. In South Dakota, water and nitrogen (N) are important resources that limit corn growth and development, and ultimately influence yield. If water, nitrogen, or other resources become limiting, especially when the plant is rapidly growing, yield is often reduced. Other factors can also stress corn plants, thereby limiting growth and reducing yield. Disease and insect infestations can interfere with water and nutrient uptake or severely damage the plant to the point of yield loss. Weeds have many effects on corn growth, including causing the down regulation (nonexpression) of many genes during the weed-free period and creating direct competition for water, nutrients, and light (Moriles et al., 2012). Stress from temperature and water impacts nutrient availability and susceptibility to pests.

Many management decisions consider the stage of growth and development of the crop. For example, some pesticide products are labeled for use only at...
certain stages because of potential for crop damage or other undesirable effects. Fertilizer applied at the right time can provide a greater crop response; however, if fertilizer is applied at the wrong growth stage, benefits can be reduced or negative responses can occur. Water stress at certain stages is more critical than at other stages. Management efficiency can be improved by matching the crop's need to the treatment. Understanding how a corn plant grows and develops is important for maximizing efficiency.

**Corn Growth Stages**

A number of classification approaches can be used to identify a corn plant's growth stage. However, in South Dakota the most widely used system is the Iowa State classification approach (Ritchie et al., 1993). This system divides corn growth and development into vegetative (V) and reproductive (R) stages (Table 5.1). The VE (emergence) occurs when the coleoptile pushes through the soil surface. After emergence, the vegetative stages are designated numerical subdivisions as V1, V2, V3; through Vn where n is the number of leaves with collar visible until the tassel emerges (VT). The collar is where the leaf blade visually breaks away from the sheath and the stalk of the corn plant (Fig. 5.2), and vegetative growth stages are based upon the number of visible leaf collars. Leaves within the whorl, not

![Figure 5.2 Corn 1st, 2nd, and 3rd leaf collars. (Courtesy: Iowa State)](image)

![Figure 5.3 Corn growth stages typically observed in South Dakota.](image)
fully expanded and with no visible leaf collar are not included. For example, a plant with 3 collars would be called a V3 plant, although more than 3 leaves may be showing on a plant (Fig. 5.3). It is important to note that the number of leaves vary depending on the corn hybrid and environmental conditions. In South Dakota, early season (maturity rating < 95 d) can begin reproductive development after the V12 stage. It is not uncommon for late maturing hybrids (RM > 100 d) to develop more leaves after the V12 growth stage. At about V6 stage, the small lower leaves are torn from the plant due to increasing stalk and nodal root growth. This loss of lower leaves needs to be taken into consideration when determining the vegetative stage. Reproductive stages begin at silking (R1) and end at maturity or “black layer” (R6).

Under warm, moist conditions, corn will germinate and emerge 4 to 6 days after planting. Optimal temperature and soil water are critical at this time. Germination and emergence are delayed when soil water is limiting because the seed needs to imbibe water to germinate. Alternatively, too much water also delays emergence and root development. In residue-covered soils or if spring air temperatures are low, germination may be slow due to cool soil temperature. Temperatures below 50°F may delay seed germination. Ideally, corn should be planted at a depth of 1.5 to 2.0 inches. Shallow planting (< 1.5 inches) into warmer soil can accelerate emergence but may result in poor root development. Planting deeper than 2 inches may result in first leaves emerging below the soil surface.

The first leafy structure that appears aboveground is the coleoptile ("spike"), followed by true leaves (Fig. 5.4). Warm, moist, and well-aerated soil conditions promote vigorous growth and development. New leaves are produced at a single “growing point” near the tip of the stem. The “growing point” is below the soil surface for up to 4 weeks after planting. When the growing point is below the soil surface, the crop usually survives light frost or minor hail. However, corn plants are most susceptible to flood damage during this stage and flooding can results in severe yield losses.

Corn roots do not explore a significant volume of soil during early growth stages but develop rapidly as the plant develops. Corn has seminal and nodal roots. Seminal roots emerge immediately after germination, cease growth at V3, but continue to function throughout the life of the plant. Nodal roots are initiated at formation of the first node (V1) and continue to develop until kernel blister. By the V6 growth stage, nodal roots become the major supplier of water and nutrients.

Nutrient deficiencies, especially phosphorus (P), are common early in the growing season if soil is cool and wet. The application of starter fertilizer will usually prevent this problem. If fertility levels are sufficient, early season nutrient deficiencies often disappear and usually do not reduce yield. Scouting fields for weeds are crucial during early growth.

**Table 5.1 Growth and development stages in corn. (Adapted from Ritchie et al., 1993)**

<table>
<thead>
<tr>
<th>Vegetative Stages</th>
<th>Reproductive Stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>VE</td>
<td>Emergence</td>
</tr>
<tr>
<td>V1</td>
<td>First leaf collar</td>
</tr>
<tr>
<td>V2</td>
<td>Second leaf collar</td>
</tr>
<tr>
<td>V3</td>
<td>Third leaf collar</td>
</tr>
<tr>
<td>V(n)</td>
<td>nth leaf collars visible</td>
</tr>
<tr>
<td>VT</td>
<td>Tasseling - last branch of tassel is completely visible</td>
</tr>
</tbody>
</table>

**Figure 5.4 Corn seedling showing seminal and nodal roots. (Modified from Ritchie et al., 1993, courtesy Iowa State)**
Six-Leaf (V6) to Seven-Leaf (V7) Stage
In South Dakota, corn is usually at V6 in early to mid-June. At the V6 stage, rapid stem elongation begins and ear shoots begin to develop. A new leaf emerges about every three days, while lower leaves begin to degenerate. The growing point is above the soil surface and frost or hail can cause significant damage. The root system is well-developed and distributed in the soil, and the plant has an improved capacity to absorb nutrients. Scouting to determine whether additional fertilizer is needed is critical at the V6 growth stage. Sidedressing nitrogen (N) is most effective when applied between V6 and V8. In addition, scouting for corn rootworm and other root-pruning insects is also critical. Because control options for these insects are limited, the best option is to plant resistant or genetically modified hybrids.

Eight-Leaf (V8) to Eleven-Leaf (V11) Stage
At this stage many ear shoots, which are potential ears, are present. Eventually, only one or two upper shoots form harvestable ears. The number of ears formed depends on the corn hybrid, with prolific hybrids forming more than one ear when planted at low plant populations. At this stage, deficiencies in macronutrients and micronutrients can start to show. If not corrected, nutrient deficiencies can seriously restrict leaf growth. By V10, the plant is growing rapidly, with new leaves appearing every 2 to 3 days. The plant requires substantial amounts of water and nutrients to maintain this growth rate. Stress from pests, heat, lack of nutrients, and/or water can slow development.

Twelve-Leaf (V12) to more leaves
The number of leaves on a plant is dependent on the plant’s maturity rating and the type of corn. For example, silage corn may have more leaves than corn designed to produce grain. The higher the maturity rating, the higher the number of leaves. The potential number of kernels per ear and ear size are determined at the V12 growth stage. The rate of corn plant development at the V12 stage is influenced by hybrid maturity. Earlier-maturing hybrids progress through these stages in a shorter time, resulting in smaller ears compared to later-maturing hybrids. If water and nutrient availability can support a higher population, yield differences between early and late hybrids can be equalized by increasing plant density or population. Stress at the V12 stage can reduce kernel numbers and ear size. The plant has a peak water demand during this growth stage and it can use one-quarter of an inch per day. The corn plant also needs and utilizes large amounts of nitrogen, phosphorus, and potassium at this stage. Severe hailstorms that strip leaves and break tassels can result in complete crop loss.

Tasseling (VT)
The tasseling stage occurs 2 to 3 days before silking (Fig. 5.5). At this stage, the plant has reached full height and the last branch of the tassel is fully visible, but silks have not yet emerged from the ear shoot. The length of time between VT and R1 (silk stage) varies depending on the corn hybrid and environmental conditions. Pollen shed usually takes place from late morning to early evening. At this stage, the impact of a hailstorm can be very severe compared to any other corn growth stage, since all leaves have emerged. Any damage to or complete loss of the tassel may result in very poor to no grain formation.

Silk (R1) Stage
The emergence of silk (R1) marks the first stage of the reproductive period (Fig. 5.6). Every potential kernel (ovule) on the ear grows its own silk. Silks begin to elongate soon after the V12 stage. At the R1 stage, the silks emerge and capture pollen shed from the tassel. Pollen captured by the silks fertilizes ovules on the cob within 24 hours, which then develop into kernels. Pollen shed typically occurs during early or mid-morning, when moisture and temperature conditions are favorable. This stage is one of the most crucial reproductive stages and unfavorable environmental conditions can severely reduce yield. Dry (low humidity) and hot (> 95°F) conditions result in reduced fertilization because of the drying of the exposed
Silks and killed pollen. With no fertilization, ears are barren. Silks grow at a rate of approximately 1.5 inches a day. The silks continue to grow until pollen is captured and germinate or until they degrade as they mature. Environmental conditions such as drought stress can result in delayed silk elongation and emergence. Generally, silks remain receptive to pollen for up to 10 days after silk emergence, though they start to deteriorate only five days after emergence. Under favorable environmental conditions, there is synchrony between pollen-shed and silk emergence making silk receptivity of little concern. Insect pests, such as corn rootworm destroy silks through feeding and can produce reduced yields. To minimize losses, fields should be scouted for corn rootworm beetles at silking (R1) and controlled if populations exceed the economic threshold.

Potassium (K) uptake is complete at silking, but nitrogen (N) and phosphorus (P) uptake continues. If N and P are limiting, the plant will attempt to compensate by moving these nutrients from older leaves into upper leaves or the developing grain. At this stage, N- and P-deficiency symptoms can be observed in lower leaves. Unfortunately, nutrient application either at this time or later in development will not make up for these deficiencies.

**Kernel Blister Stage (R2)**

After pollination, kernel formation begins. The kernels at the R2 stage are whitish and shaped like blisters. They appear approximately 10 to 14 days after silking. At this stage, silks turn brown and dry rapidly. Starch begins to accumulate in the kernel as the plant initiates a period of kernel fill. At the R2 growth stage, the radicle, coleoptile, and the first embryonic leaf have formed in the embryo. The kernel moisture content at the R2 stage is about 85%. Any severe stress at pre-blister and blister stage can result in aborted kernels and reduce the number of kernels on the cob. At this stage, the plant will need 960 growing-degree days (GDD), also called growing-degree units, to reach physiological maturity. Additional water at or after R2 does not enhance yield, slows dry-down, and may encourage stalk and grain diseases.

**Kernel Milk Stage (R3)**

The kernel milk stage occurs approximately 22 days after silking (Figure 5.7). At this stage, kernels are mostly yellow on the outside, starch accumulation occurs rapidly, kernels contain a milky white fluid, and cell division in the endosperm is complete. Observable kernel growth is mainly due to cell expansion and starch accumulation, severe stress can cause kernel abortion. The kernel moisture content is about 80%, and approximately 880 GDD are required to reach physiological maturity. Although not as critical as the R1 growth stage, stress at this time can reduce kernel size and weight.

**Kernel Dough Stage (R4)**

As the kernels mature to the dough (R4) stage, they change from a milky consistency to soft and sticky. At R4, the kernels have accumulated nearly half of their mature weight and the cob has a color ranging from light red to pink. At this stage, four embryonic leaves are formed and the kernel moisture content is approximately 70%. Unfavorable environmental conditions or nutrient deficiencies can reduce kernel weight.

**Kernel Dent Stage (R5)**

At the R5 growth stage, nearly all of the kernel crowns are denting, the moisture content is approximately 55% (Fig. 5.8), and a distinct horizontal line called the milky line can be seen between the yellow (starchy-
solid) and white (milky-liquid) areas on the kernel. As the kernel matures and starch hardens, this line slowly progresses to the tip end of the kernel. A hard frost at R5 can kill the plant, thus reducing yield and kernel development. Corn plants killed at this stage generally have low test weight and a slower dry-down rate. Selecting a hybrid that matures 2 to 3 weeks before fall frost reduces these risks. If early frost kills the plant, the crop can be harvested and ensiled as high-moisture grain for animal feed.

**Physiological Maturity (R6)**
The corn plant is at physiological maturity (R6) about 55 to 65 days after silking. At this stage, kernel dry-weight has reached its maximum, the kernels are physiologically mature and safe from frost damage, the moisture content ranges from 30% to 35%, the starch line has advanced to the kernel tip, and a black layer has formed at the base of the mature kernels. The black layer forms from the tip of the kernels to the basal kernels. Severe stress after this stage has little effect on grain yield, unless the integrity of the stalk or ear is compromised by disease such as stalk rots or insect feeding. At this time, allowing the crop to dry in the field reduces drying costs if the crop is to be harvested for grain. Moisture content of 15% allows corn to be stored safely for less than six months. For long-term storage, corn should be dried to 12% moisture to avoid spoilage. Hybrids have subtle differences in growth and development (with respect to number of leaves, ears, maturity, dry-down, and other traits). Early harvest is rarely profitable because of drying costs or dockage. Corn can be left in the field if stalks maintain strength, ear drop is not a problem, and there is limited risk of ear and kernel rots — especially under hot, dry conditions. Harvest loss from lodging and ear drop can be significant in fields damaged by European corn borer or Western bean cutworm. In these situations, early harvesting to reduce harvest losses should be weighed against drying costs. Scouting to assess stalk condition, ear retention, ear rots, and grain moisture is recommended.

**Growing-degree Days: Rating Corn Hybrids**
Regional differences in the corn growing season have resulted in multiple methods to match hybrid characteristics to environmental conditions. Corn growth rate is controlled primarily by temperature, and this is often characterized by a calculation called growing-degree days (GDD). Most seed corn companies rate hybrid maturity based on GDD or heat units (HU).

The GDD accumulation for a single day is the average of the low and high temperature, minus 50°F. The calculation subtracts 50°F because corn plants have limited growth below 50°F. If the low temperature for any given day is < 50°F, the low temperature is defined as 50°F, and if the temperature is > 86°F, the high temperature is defined as 86°F. This method of calculating GDD is often referred to as the (86,50) system. Different pests or crops have different critical values. Example calculations are provided in Chapter 10.

GDD are calculated for each day beginning with the day after planting. The GDD accumulation for the growing season varies depending on the location and year. The number of GDD required for the corn plants to reach a particular stage of development is fairly consistent. Tables 5.2 and 5.3 show the GDD needed for a plant to reach a certain vegetative or reproductive stage. The duration of the growing season for corn hybrids is directly related to their GDD requirements, with late-maturing hybrids or long-season hybrids requiring more GDD than shorter-season hybrids. The U2U (Usable to Useful) Project website can be used to calculate the date of different growth stages based on the hybrid and planting date.
Table 5.2 Comparison between leaf collar and FCIC¹ corn growth staging systems for a 120-day (RM²) hybrid

<table>
<thead>
<tr>
<th>FCIC</th>
<th>Leaf Collar</th>
<th>Description</th>
<th>Days/Stage</th>
<th>GDUs/Stage</th>
<th>Days after Seeding</th>
<th>GDUs after Seeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>V0</td>
<td>Seeding to Germination</td>
<td>5 – 10</td>
<td>100 – 150</td>
<td>5 – 10</td>
<td>100 – 150</td>
</tr>
<tr>
<td>-</td>
<td>VE</td>
<td>Coleoptile Opens</td>
<td>2 – 4</td>
<td>66</td>
<td>7 – 14</td>
<td>166 – 216</td>
</tr>
<tr>
<td>V2</td>
<td>V1</td>
<td>1st Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>13 – 20</td>
<td>298 – 348</td>
</tr>
<tr>
<td>V3</td>
<td>V2</td>
<td>2nd Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>19 – 26</td>
<td>430 – 480</td>
</tr>
<tr>
<td>V4</td>
<td>V3</td>
<td>3rd Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>22 – 29</td>
<td>496 – 546</td>
</tr>
<tr>
<td>V5</td>
<td>V4</td>
<td>4th Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>25 – 32</td>
<td>562 – 612</td>
</tr>
<tr>
<td>V6</td>
<td>V5</td>
<td>5th Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>28 – 35</td>
<td>628 – 678</td>
</tr>
<tr>
<td>V8</td>
<td>V6</td>
<td>6th Leaf Collar</td>
<td>-</td>
<td>-</td>
<td>31 – 38</td>
<td>694 – 744</td>
</tr>
<tr>
<td>V9</td>
<td>V7</td>
<td>7th Leaf Collar</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>V10</td>
<td>V7</td>
<td>8th Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>34 – 41</td>
<td>760 – 810</td>
</tr>
<tr>
<td>V11</td>
<td>V8</td>
<td>9th Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>37 – 44</td>
<td>826 – 876</td>
</tr>
<tr>
<td>V12</td>
<td>V9</td>
<td>10th Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>40 – 47</td>
<td>892 – 942</td>
</tr>
<tr>
<td>V13</td>
<td>V10</td>
<td>11th Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>43 – 50</td>
<td>958 – 1,008</td>
</tr>
<tr>
<td>V14</td>
<td>V11</td>
<td>12th Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>46 – 53</td>
<td>1,024 – 1,074</td>
</tr>
<tr>
<td>V15</td>
<td>V12</td>
<td>13th Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>49 – 56</td>
<td>1,090 – 1,140</td>
</tr>
<tr>
<td>V16</td>
<td>V13</td>
<td>14th Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>51 – 58</td>
<td>1,138 – 1,188</td>
</tr>
<tr>
<td>V17</td>
<td>V14</td>
<td>15th Leaf Collar</td>
<td>3</td>
<td>66</td>
<td>55 – 62</td>
<td>1,234 – 1,284</td>
</tr>
<tr>
<td>V18</td>
<td>V15</td>
<td>16th Leaf Collar</td>
<td>2</td>
<td>48</td>
<td>57 – 64</td>
<td>1,282 – 1,332</td>
</tr>
<tr>
<td>V19</td>
<td>V16</td>
<td>17th Leaf Collar</td>
<td>2</td>
<td>48</td>
<td>59 – 66</td>
<td>1,330 – 1,380</td>
</tr>
<tr>
<td>V20</td>
<td>V17</td>
<td>18th Leaf Collar</td>
<td>2</td>
<td>48</td>
<td>61 – 68</td>
<td>1,378 – 1,428</td>
</tr>
<tr>
<td>V(n)</td>
<td>V18</td>
<td>19th Leaf Collar</td>
<td>2</td>
<td>48</td>
<td>65 – 72</td>
<td>1,478 – 1,528</td>
</tr>
<tr>
<td>VT</td>
<td>V19</td>
<td>Tassel Extended – No Silks</td>
<td>4</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All values are approximations, as the values may vary over years, production environments, and locations. (Adapted from USDA-FCIC, Corn Loss Adjustment Standard Handbook, 2007)

¹ Federal Crop Insurance Corporation (FCIC), operated by the United States Department of Agriculture, Risk Management Agency

² Relative maturity (RM)
Table 5.3 Comparison between leaf collar and FCIC1 corn growth staging systems for a 120-day (RM2) hybrid

<table>
<thead>
<tr>
<th>Stages</th>
<th>Leaf Collar</th>
<th>FCIC1</th>
<th>Start of Silking</th>
<th>End of Silking</th>
<th>Start of Blister</th>
<th>End of Blister</th>
<th>Start of Milk</th>
<th>End of Milk</th>
<th>Start of Late Milk</th>
<th>End of Late Milk</th>
<th>Start of Dent</th>
<th>End of Dent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silked</td>
<td>R1</td>
<td>Silked – Pollen Shed</td>
<td>4</td>
<td>100</td>
<td>69 – 76</td>
<td>1,578 – 1,628</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silks Brown</td>
<td>R1</td>
<td>Silks 75% Brown</td>
<td>5</td>
<td>125</td>
<td>74 – 79</td>
<td>1,703 – 1,753</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-Blister</td>
<td>R1</td>
<td>No Fluid in Kernels</td>
<td>4</td>
<td>100</td>
<td>78 – 85</td>
<td>1,803 – 1,853</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blister</td>
<td>R2</td>
<td>Kernels are watery</td>
<td>4</td>
<td>100</td>
<td>82 – 89</td>
<td>1,903 – 1,953</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Milk</td>
<td>R2</td>
<td>Kernels Begin to Yellow</td>
<td>4</td>
<td>100</td>
<td>86 – 93</td>
<td>2,003 – 2,053</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>R3</td>
<td>Kernels Yellow, No Solids</td>
<td>5</td>
<td>100</td>
<td>91 – 98</td>
<td>2,103 – 2,153</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Milk</td>
<td>R3</td>
<td>Kernels Contain Semi-Solids</td>
<td>4</td>
<td>100</td>
<td>95 – 102</td>
<td>2,203 – 2,253</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Soft Dough</td>
<td>R4</td>
<td>Kernels Pasty</td>
<td>5</td>
<td>100</td>
<td>100 – 107</td>
<td>2,303 – 2,353</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Dent</td>
<td>R4</td>
<td>Kernels Begin to Dent</td>
<td>5</td>
<td>100</td>
<td>108 – 115</td>
<td>2,403 – 2,453</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dent</td>
<td>R5</td>
<td>Kernels Soft but Dented</td>
<td>5</td>
<td>125</td>
<td>113 – 120</td>
<td>2,528 – 2,578</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Dent</td>
<td>R5</td>
<td>Kernels Dented but Drying</td>
<td>5</td>
<td>125</td>
<td>118 – 125</td>
<td>2,653 – 2,703</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nearly Mature</td>
<td>R5</td>
<td>Kernel Embryo not Hard</td>
<td>5</td>
<td>125</td>
<td>123 – 130</td>
<td>2,778 – 2,828</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mature</td>
<td>R6</td>
<td>Black Layer</td>
<td>5</td>
<td>125</td>
<td>128 – 135</td>
<td>2,903 – 2,953</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All values are approximations, as the values may vary over years, production environments, and locations. (Adapted from USDA-FCIC, Corn Loss Adjustment Standard Handbook, 2007)

1 Federal Crop Insurance Corporation (FCIC), operated by the United States Department of Agriculture, Risk Management Agency

2 Relative maturity (RM)
References and Additional Information


Nielsen, R. L. 2013. Grain fill stages in corn. Corn News Network, Agronomy Department, Purdue University. West Lafayette, IN.


THE U2U PROJECT: Useful to usable (U2U): Transforming climate variability and change information for cereal crop producer.
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Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov;

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Optimizing corn profitability starts with purchasing high-quality hybrid seed. Seed-testing information is critical in making this decision. This chapter discusses the standard tests that are required on seed offered for sale, and the additional tests that might provide insights into the seed quality. Key components are provided in Table 6.1 and an image of germinated seeds are in figure 6.1.

Table 6.1 Key components in producing and testing seed quality:
1. Inspect the label to make sure it meets your goals.
2. Adjust the seeding rate based on information contained in the label.
3. Different tests provide different information about your seed.
4. Carryover seed not planted last year most likely will have lower seed quality than new seeds.

Corn Seed Testing

Seed-Testing Laboratories
Seed tests can be conducted at the SDSU Seed Testing Lab. Seed sample envelopes may be obtained from Extension Service offices or by contacting the SDSU Seed Testing Lab. Samples being submitted to SDSU should be sent to:

SDSU Seed Testing Lab
Box 2207-A
Brookings, SD 57007 (U.S. Postal Service)

Figure 6.1 Corn seedlings evaluated after 7 days in a germination test. The two on the left are considered “normal seedlings,” capable of producing a productive plant in the field, whereas the three on the right are “abnormal seedlings” and are not capable of producing a productive plant.
Samples can also be submitted to other laboratories. Information about these laboratories is available at the Association of Official Seed Analysts or the Society of Commercial Seed Technologists.

**Required Standard Tests**

In South Dakota, it is required that all purchased seed must be tested for purity, noxious weeds seeds, and seed germination. The Association of Official Seed Analysts Rules for Testing Seeds (AOSA Rules) defines the protocols for these tests. Seed tests provide information needed to determine seeding rates. For example, a seed lot with 80% labeled germination rate requires more seed per acre than a seed lot with a 90% germination rate.

Not having a current seed label or seed-testing information puts producers and their investment at risk. Germination rates are valid in South Dakota only for 9 months from the time of testing, and company carryover seed requires a new germination test. Selected tests, purposes, analysis times, and advantages/disadvantages are provided in Table 6.2.

**Additional Seed Tests that Provide Useful Information**

**Herbicide/insect Tolerance/resistance Trait Test**

Most commercial corn varieties on the market today are tolerant to at least one of the commonly used herbicides (Roundup*, Clearfield*, and Liberty*, with others on the way) and have at least one form of BT (Bacillus thuringiensis) insect resistance. Seed bioassay, lateral flow strips, enzyme-linked immunosorbent assay (ELISA) tests, and polymerase chain reaction (PCR) tests can assess herbicide/insect trait resistance.

**Fast Green Test**

This test exposes corn seed to a green chemical stain that is subsequently rinsed off. Damage to the pericarp is readily apparent as any cracks or breaks will stain green. Damage will be classified as light, medium, and severe. The test is very useful in seed-conditioning facilities to maximize output while minimizing damage to the seed from machinery.

**Genetic Purity Tests**

Hybrid corn seed is always tested after production to check the hybridity, self’s, and outcross levels. Each company has developed a quality specification for acceptable levels of hybridity that must be achieved to market the seed. These quality specifications must meet or exceed the minimum requirements of the Federal Seed Act. Electrophoresis or PCR testing methods are commonly used for evaluating hybridity level.

**Producing High-Quality Seed**

Corn seed is produced (often with contract growers) and conditioned primarily by seed companies with the proper seed handling and cleaning equipment. Farmer producers who produce, dry, and process their own corn seed are extremely rare.

**Fertility and Moisture Content**

High quality corn seed production begins in the field. Soil fertility plays a crucial role in ensuring the proper nutrients are present for quality seed/grain production. Nutrient deficiencies can result in small seeds with low emergence rates. The seed moisture content at harvest may influence seed quality. Corn seed will be harvested anywhere from 25% to almost 40% moisture content and carefully dried down to 12-13% moisture to minimize seed deterioration. Seed vigor and viability can be decreased by mechanical damage during the harvest and post-harvest seed-handling processes.
Purchasing Corn Seed

There are many companies that produce and sell corn hybrids. There is also a growing market for non-GMO corn and/or organic corn seed, and a small market for open-pollinated corn. Check with your local agronomist for a variety with the appropriate maturity and traits for your region.

Almost all the corn seed sold is protected under the Plant Variety Protection Act (PVP-94) and/or has a utility/plant patent (Roundup Ready trait, BT, etc.), which means that seed cannot be saved after harvest for replanting or sold by the farmer except as grain. These protections virtually eliminate the legal ability of farmers to plant seeds harvested on their farm. Conventional open-pollinated varieties are one exception that can be saved and replanted. However, over 90% of the seed currently sold and planted in South Dakota is GMO seed with some herbicide/insect resistant trait. Seed quality is crucial and it is recommended that you purchase seed from reputable dealers.

<table>
<thead>
<tr>
<th>Test</th>
<th>Purpose of the test</th>
<th>Laboratory time to complete analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed counts</td>
<td>This is not a required test but is crucial in determining seeding rates. Seed counts in corn will vary by genetics and kernel size (flats, rounds, or a mixture of flats/rounds). Corn seed when sold in “bushel” bags is sold in units of 80,000 seeds.</td>
<td></td>
</tr>
<tr>
<td>Corn germination test</td>
<td>The percentage of seeds that can be expected to grow and produce plants. Laboratory germination tests are conducted under favorable conditions, which do not always occur in the field.</td>
<td>6-7 days</td>
</tr>
<tr>
<td>Purity analysis</td>
<td>This test provides information about the physical makeup of the seed lot.</td>
<td>1-3 days</td>
</tr>
<tr>
<td>Noxious weed exams</td>
<td>It is prohibited to sell corn if the seed lot contains prohibited noxious weed seeds.</td>
<td>1-3 days</td>
</tr>
<tr>
<td>Tetrazolium (TZ) test</td>
<td>This is a rapid (24-48 hour) chemical viability test that can be used to estimate germination. It can also be used to assess vigor and mechanical damage.</td>
<td>1-2 days</td>
</tr>
<tr>
<td>Vigor test(s)</td>
<td>Not all viable seeds are capable of completing their life cycle, and a vigor test provides information on this issue. Although not required by law, this test provides important information for seed-corn marketing decisions. A vigor test is recommended for carryover seed. Not all vigor tests are equivalent. When selecting a test to use, consult with your seed adviser, agronomist or the seed lab staff on what works best for your needs.</td>
<td></td>
</tr>
<tr>
<td>Accelerated aging test (AA)</td>
<td>This test is conducted under high humidity and temperature, and it provides an excellent indicator of corn seed vigor. This test simulates less than optimum field conditions and it should be conducted in conjunction with a standard germination test. The AA test results should be within 15% of the germination test results. For example, if your germination is 90%, the acceptable AA would be &gt; 75%.</td>
<td>10 days</td>
</tr>
<tr>
<td>Corn cold test</td>
<td>This rapid test is conducted using cold temperatures. Even though the cold test is not as consistent and reliable as the accelerated aging (AA) test, it is more useful than the AA test. The cold test is considered a direct vigor test and results are correlated to field emergence under less than optimal conditions. For acceptable quality, the cold test results should be &gt; 80%.</td>
<td>12-14 days</td>
</tr>
<tr>
<td>Saturated cold test</td>
<td>This test is conducted using saturated conditions and cold temperatures. The test is used to assess how well the seed will do under constant saturated soil conditions.</td>
<td>10-15 days</td>
</tr>
</tbody>
</table>
**Leftover Unplanted Seed**

Often a producer purchases more seed than he/she plants, or the weather causes a change in planting plans that results in some unplanted seed (carryover seed). Most corn seed sold has been treated with a fungicide/insecticide and, therefore, cannot be sold as grain. Due to the lifespan of corn, any unused seed should be kept in a cool, dry environment, if not returned to the source of purchase. One to three months prior to planting, a vigor test, at minimum, should be conducted. If the vigor has dropped, the seeding rate should be increased. If the seed vigor is too low, the seed must be disposed of using appropriate disposal methods. Substandard seed may be donated or planted to food plots for wildlife.

Planting low-quality seed can result in stand failures, while overplanting or underplanting rates can also cause lower yields. In addition, low-quality seed deteriorates rapidly and may produce poor stands. Corn seed has a longer lifespan (1-4 years) than soybeans (1-2 years) and can usually be carried over for a year without a significant loss of germination or vigor if stored in a dry, cool location.

**References and Additional Information**

Association of Official Seed Analysts (AOSA).

Iowa State University Seed Testing Lab.

Society of Commercial Seed Technologists (SCST).

SDSU Seed Testing Lab. South Dakota Crop Improvement Association. South Dakota Department of Agriculture.
Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, South Dakota Seed Testing Lab, and the South Dakota Corn Utilization Council. Chapter reviewed by Nick Schiltz, Mike Stahr, and Brent Reschly.


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Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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Crop insurance is an important component for managing production and economic risks. Crop insurance refers to the U.S. Department of Agriculture’s Risk Management Agency (RMA) programs that cover yield or revenue loss from multiple perils. The coverage is sold to growers and landowners by private crop insurance companies and agents, although the policies are regulated and premium rates are established by the RMA.

The purpose of this chapter is to provide an overview of the common types and levels of crop insurance used in South Dakota corn production. The cost of crop insurance can vary with changes in yield history, changes in price levels in the current year, and changes in the volatility for revenue products. An understanding of the coverage types available is important because the premium cost varies with insurance type and because the insurance coverage should be matched to commodity marketing practices. Knowledge of the coverage level is important because it may need to be adjusted to remain cost effective.

Insurance coverage for corn production was provided to 5.2 million South Dakota acres in 2015. The statewide level of liability coverage for corn production was $2.2 billion, averaging $426 per insured acre in protection. The liability was less than the expected value of the crop, reflecting the deductible. The total premium averaged $73 per acre, but after subsidies the producer premium averaged $21 per acre. The subsidy has led to a high adoption of insurance and coverage at higher levels than would otherwise be observed (O’Donoghue, 2014). The adoption of coverage in South Dakota mirrors that in the Midwest, and a majority of corn acres have been insured in South Dakota since the late 1990s.

Available Coverage
Information about crop insurance is commonly obtained from a crop insurance agent or the RMA website. Corn coverage details are outlined in the “Common Crop Insurance Policy,” the “Coarse Grains Crop Provisions,” and the “Commodity Exchange Price Provisions,” or CEPP. Yellow corn grown for grain on nonirrigated or dryland acres and using conventional production practices is the most common parameter used in South Dakota. The RMA also has a fact sheet on corn for South Dakota (Billings Regional Office, 2015).

1 The RMA website is www.rma.usda.gov.
2 Other parameters are available. Corn can be insured specifically as silage. Example nontypical types include high amylase and blue corn. Irrigated acres can be specifically insured. Organic production is an insurable practice. There are also specific counties with coverage for popcorn and hybrid corn seed.
Like for other crops, growers wanting farm-level coverage have to establish a production history. Edwards (2014) provides an overview of building a yield history and choosing among units when buying coverage. Growers can use yield adjustments, where low yields for a unit can be replaced with 60% of the county transitional yield. Units can be basic, optional, enterprise or whole-farm, and the premium subsidy is tied to the unit choice and coverage level. In discussions with growers and agents, there has been a shift toward using enterprise units on corn. This observation is consistent with the average observed premium subsidy that falls between that of basic/optional units and that of enterprise units. Since 2012, many counties in South Dakota have had positive trend-adjustment factors for corn. The factor is more heavily weighted for earlier years in a grower’s production history, resulting in a higher approved yield. The RMA reported that since 2012 there has been strong adoption of trend-adjusted yields in South Dakota.

The Agricultural Act of 2014 introduced other coverage options. With the yield exclusion option, a yield year may be excluded from a grower’s yield history if the county yield was sufficiently low. For example, low yields (or exclusion eligible yields) were common for corn in many central, south-central and southeast South Dakota counties in 2012 given the drought conditions that year. The Supplemental Coverage Option (SCO) provides shallow-loss coverage, spanning the space between the farm-level election level of a policy and 86% of the county yield level or revenue level. However, to be eligible for the SCO, a producer’s base acres for the crop also need to be enrolled in Price Loss Coverage (PLC). Based on data from the Farm Service Agency, less than 2% of the corn acres in South Dakota were enrolled in PLC. Thus, adoption of SCO has been minimal.

Several dates are critical to assure the proper coverage is selected and in effect when needed. For corn, the insurance must be purchased or changed by March 15 and the earliest planting date is April 10. The final planting dates for full coverage vary slightly. Corn for grain has a final planting date on irrigated and nonirrigated fields of May 25, except for counties in the southeast where the deadline is May 31 (Fig. 7.1). For silage corn, the final planting date is May 31 regardless of the county or irrigation practice. Silage has a price or value set by the RMA prior to the coverage deadline. After the final planting date, there is a 25-day late-planting period that provides reduced coverage. The coverage is in effect until December 10.

Policy dates are aligned with the marketing patterns that are reported by the National Agricultural Statistics Service (NASS). South Dakota corn planting dates generally range from April 30 through June 20, and the range of harvest dates is from September 30 through November 20. Historically, corn has been marketed in October and November following harvest.

Claims can begin after the earliest planting date. In the event of a loss, producers typically have 72 hours to notify their insurance agent of a potential claim. After the final planting date, the most commonly used policies have prevented planting provisions, covering some of the expense of not growing the insured crop. A grower may try to plant the insured crop in the late period or switch to a different crop. Growers are responsible for using good farming practices, as defined in their policy, even after a partial loss, meaning they have to continue to take care of the crop. Common reasons for insurance claims include: 1) drought, 2) natural causes (e.g., hail and wind), and 3) reduced corn quality.

**Policy Types and Coverage Levels**

For corn production, the main policy types include: 1) Revenue Protection (RP), 2) Yield Protection (YP), 3) Revenue Protection with the Harvest Price Exclusion (RP-HPE) and 4) Catastrophic Risk Protection (CAT). These policy types are based on farm level yields. Area Risk Protection Insurance (ARPI) is also
available in some counties to cover county-level yield or revenue loss, but it is seldom used (Fig. 7.2). Statewide in 2015, 97% of the insured corn acres were covered by RP. The remaining acres were covered by YP, CAT, RP-HPE and ARPI.

**Revenue Protection (RP)**
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 use forward price contracts or hedge using futures contracts. Note that there is a 200% limit on price changes by harvest, which is a feature specific to RP. This caps the indemnity payment and could be managed by covering sales with call options.

**Yield Protection (YP)**
With YP, a producer receives an indemnity payment at the fixed price per bushel if the resulting yield falls below the yield coverage level.

**Harvest Price Exclusion (RP-HPE)**
RP-HPE is limited to downside revenue protection at a slightly higher cost than YP. A price decline could trigger an indemnity payment with RP-HPE when YP would not have one. RP-HPE costs less than RP and may be preferred if little forward pricing is expected.

Several counties in western South Dakota do not have grain coverage for nonirrigated acres: Butte, Custer, Fall River, Harding, Jackson, Lawrence, Meade and Pennington (Fig. 7.2). The Noninsured Crop Disaster Assistance Program (NAP) has been available in these counties with coverage for dryland grain. In the Agricultural Act of 2014 the coverage for NAP was authorized to be available with buy-up to higher yield elections and with up to 100% of the price election level (formerly capped at 55%). The cost is set at 5.25% of the liability.

**Selecting Price Elections and Coverage Levels**
Once a policy type has been selected, a coverage level needs to be selected. With RP and RP-HPE there is no price election option; one must use 100% of the projected price. For YP, a producer can select less than 100% of the projected price. To minimize the insurance premium, a producer could use a price election that closely aligns the insured price with the expected cash price. For example, if the expected cash price is below the RMA’s projected price, a price election of less than 100% may be appropriate.

Coverage level often refers to the yield coverage level or percent of the producer’s production history. Across policy types, the yield coverage level must be selected and can range from 50% to 85% coverage. Between 2011 and 2015, most South Dakota corn producers selected 75% yield coverage. However, the optimal level depends on a producer’s willingness to be self-insured.

There is substantial variability in how much coverage is available across counties. Specific to nonirrigated corn, the highest transition or “T” yield in 2015 was in Moody County at 156 bushels per acre and the lowest was in Todd County at 35 bushels per acre. Producers may elect yield adjustments, yield exclusions, and trend-adjusted yields. As a result, the approved yield can be much higher than T-yields. Approved yields can be backed out of county data that includes irrigated and nonirrigated acres across policy types. For example, the average approved yield in 2015 in Moody County was 178 bushels per acre for growers using RP with 75% coverage. Observed average approved yields at the county level have been 10-40% higher than T-yields in recent years.
Marketing Considerations
The RMA price discovery periods use the CBOT (Chicago Board of Trade) December corn futures contract. The projected price discovery period is from February 1 to February 28. During this period, the average of the closing December corn futures contract prices is used to determine the Projected Price. 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 from October 1 to October 31. During this period, the average of the closing December corn futures contract prices is used to calculate the Harvest Price. 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 14 years (Table 7.1). The average change has been -$0.15 per bushel, which is not statistically different from zero. Extreme moves are also evident as the price increased $1.82 per bushel in 2012 and decreased $1.27 per bushel in 2008.

The RP and RP-HPE insurance premiums are functions of the corn price volatility. The volatility factor, as defined and measured by the RMA in late February for corn, has changed substantially through time and has ranged from 0.18 to 0.37 (Table 7.1). Growers often respond to premium changes by adjusting yield coverage levels. For planning purposes, knowing the volatility factor is useful to project premium costs. Prior to the purchase deadline, the volatility factor can be estimated by finding the implied volatility (usually quoted as an annual percentage) of the December futures price and adjusting it by 0.8 to adjust for the insurance period. Implied volatility can be backed out of option prices or obtained from a market information provider.

Basis is the difference between the cash and future prices. 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. For reference, the statewide price received by farmers (from NASS) is shown for October along with the basis relative to the Harvest Price (Table 7.1). Basis variability is evident, ranging from -$0.13 per bushel in 2004 to -$1.44 per bushel in 2010, and this basis risk is not insurable. Growers should be mindful that spot price changes may not correspond with indemnity payments.

The insurance settles during a fixed or static month (October), and therefore may not always line up with

<table>
<thead>
<tr>
<th>Year</th>
<th>Projected Price ($/bushel)</th>
<th>Harvest Price ($/bushel)</th>
<th>Change ($/bushel)</th>
<th>Volatility Factor</th>
<th>October Cash Price ($/bushel)</th>
<th>Basis ($/bushel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>2.32</td>
<td>2.52</td>
<td>0.20</td>
<td>0.18</td>
<td>2.21</td>
<td>-0.31</td>
</tr>
<tr>
<td>2003</td>
<td>2.42</td>
<td>2.26</td>
<td>-0.16</td>
<td>0.20</td>
<td>1.95</td>
<td>-0.31</td>
</tr>
<tr>
<td>2004</td>
<td>2.83</td>
<td>2.05</td>
<td>-0.78</td>
<td>0.21</td>
<td>1.92</td>
<td>-0.13</td>
</tr>
<tr>
<td>2005</td>
<td>2.32</td>
<td>2.02</td>
<td>-0.30</td>
<td>0.21</td>
<td>1.60</td>
<td>-0.42</td>
</tr>
<tr>
<td>2006</td>
<td>2.59</td>
<td>3.03</td>
<td>0.44</td>
<td>0.23</td>
<td>2.37</td>
<td>-0.66</td>
</tr>
<tr>
<td>2007</td>
<td>4.06</td>
<td>3.58</td>
<td>-0.48</td>
<td>0.26</td>
<td>3.09</td>
<td>-0.49</td>
</tr>
<tr>
<td>2008</td>
<td>5.40</td>
<td>4.13</td>
<td>-1.27</td>
<td>0.30</td>
<td>3.99</td>
<td>-0.14</td>
</tr>
<tr>
<td>2009</td>
<td>4.04</td>
<td>3.72</td>
<td>-0.32</td>
<td>0.37</td>
<td>3.31</td>
<td>-0.41</td>
</tr>
<tr>
<td>2010</td>
<td>3.99</td>
<td>5.46</td>
<td>1.47</td>
<td>0.28</td>
<td>4.02</td>
<td>-1.44</td>
</tr>
<tr>
<td>2011</td>
<td>6.01</td>
<td>6.32</td>
<td>0.31</td>
<td>0.29</td>
<td>5.67</td>
<td>-0.65</td>
</tr>
<tr>
<td>2012</td>
<td>5.68</td>
<td>7.50</td>
<td>1.82</td>
<td>0.22</td>
<td>6.61</td>
<td>-0.89</td>
</tr>
<tr>
<td>2013</td>
<td>5.65</td>
<td>4.39</td>
<td>-1.26</td>
<td>0.20</td>
<td>4.22</td>
<td>-0.17</td>
</tr>
<tr>
<td>2014</td>
<td>4.62</td>
<td>3.49</td>
<td>-1.13</td>
<td>0.19</td>
<td>3.09</td>
<td>-0.40</td>
</tr>
<tr>
<td>2015</td>
<td>4.15</td>
<td>3.83</td>
<td>-0.32</td>
<td>0.21</td>
<td>3.37</td>
<td>-0.46</td>
</tr>
</tbody>
</table>

(Sources: USDA-RMA and USDA-NASS)
crop sales. Thus, for growers hedging with futures or options, it may reduce the basis risk to use December contracts and lift or roll hedges in October. For planning purposes, a five-year moving average of historical basis is reasonable. The basis during October has averaged -$0.51 per bushel from 2010 to 2015.

**Example with Basis**

There are subtle differences across product types with implications for effectiveness in managing different risks. Here is an example of the mechanics of how crop insurance works when considering basis (Table 7.2).

<table>
<thead>
<tr>
<th>Indemnity Returns</th>
<th>A: $Y_H = 140; P_H = $5.50; C_H = $4.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>YP</td>
<td>$0</td>
</tr>
<tr>
<td>RP</td>
<td>$665.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indemnity Returns</th>
<th>B: $Y_H = 90; P_H = $4.00; C_H = $3.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>YP</td>
<td>$67.50</td>
</tr>
<tr>
<td>RP</td>
<td>$360.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indemnity Returns</th>
<th>C: $Y_H = 105; P_H = $4.00; C_H = $3.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>YP</td>
<td>$0</td>
</tr>
<tr>
<td>RP</td>
<td>$341.25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indemnity Returns</th>
<th>D: $Y_H = 90; P_H = $5.50; C_H = $4.74</th>
</tr>
</thead>
<tbody>
<tr>
<td>YP</td>
<td>$67.50</td>
</tr>
<tr>
<td>RP</td>
<td>$495.00</td>
</tr>
</tbody>
</table>

Assume a producer has an approved yield of 140 bushels per acre. The selected yield coverage level is 75%, implying that a yield below 105 bushels (140 bushels times 0.75) would trigger an indemnity (depending on the coverage type). The Projected Price is assumed to be $4.50 per bushel. The base guarantee is thus $472.50 per acre (105 bushels times $4.50 per bushel). With a conservative harvest basis estimate of -$0.75 per bushel, the expected cash price at harvest, is $3.75 per bushel. The cash price at harvest, C_H, may reflect a basis change. If the actual yield at harvest, $Y_H$, equals the approved yield, there would be no indemnity payment and the expected return is $525.00 per acre (140 bushels times $3.75 per bushel). In general, Returns = (C_H times $Y_H) plus Indemnity, which are before production and insurance costs.

When yield and/or price are low, the Projected Price and the Harvest Price ($P_H$) are needed to calculate indemnity payments. Following the method in Woodard et al. (2010) for insurance products available before the common policy, the respective indemnity calculations are as follows:

\[
\text{IndemnityYP} = \text{max}[0, \text{Projected Price} \times (\text{Trigger yield} - \text{Actual yield})]
\]

\[
\text{IndemnityRP} = \text{max}[0, \text{Trigger yield} \times \text{max}(\text{Projected Price}, \text{Harvest Price})] - (\text{Harvest price} \times \text{Actual yield})
\]

\[
\text{IndemnityRP-HPE} = \text{max}[0, (\text{Projected Price} \times \text{Trigger yield})] - (\text{Harvest Price} \times \text{Actual yield})
\]

Indemnity payments and returns under these coverage options are shown in Table 7.2.

In scenario A, the Harvest Price is greater than the Projected Price and the yield is high enough that no indemnity payments are made. The returns are fully realized from market sales.
In scenario B, the actual yield is lower than the trigger yield (of 105 bushels per acre) and indemnity payments would occur across all insurance types.

In scenario C, the harvest price is low enough to trigger indemnity payments for the revenue protection types of insurance, but the actual yield is not sufficiently low to trigger indemnity payments for yield insurance.

In scenario D, the disparity across insurance types is evident. The actual yield is low enough to trigger an indemnity from the yield insurance. When coupled with the higher harvest price, the higher guarantee level means a larger indemnity with RP coverage. Because the projected revenue was exceeded (the higher harvest price offset the lower actual yield), there is no indemnity payment with RP-HPE.

**Conclusions**

The Revenue Protection plan is the most frequently chosen insurance type by South Dakota corn producers. However, when selecting among Revenue Protection or other common insurance types (Yield Protection and Revenue Protection with the Harvest Price Exclusion), it is necessary to consider local details that can impact the decision of the optimal insurance product.

**References and Additional Information**


Edwards, W. Proven Yields and Insurance Units for Crop Insurance, FM-1860, Iowa State University, Revised September 2014.


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.


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(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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Optimum seeding rate depends upon the variety, the yield potential, the grain selling price, and seed cost. Generally, seeding rates increase with rainfall and yield expectations. Optimal corn target populations in South Dakota vary from ~ 15,000 to 36,000 plants per acre. Highly productive soils with sufficient drainage and available water can support higher populations. New corn planters provide the option to vary the seeding rate across the field. This chapter provides directions for calculating a seeding rate and guidelines for optimizing seeding rates are provided in Table 8.1.

### Introduction

The optimal seeding rate for corn grain production is ultimately determined by the interplay of nutrient and water availability and competition between the developing plants. The relationship between corn yield and plant population follows a nonlinear response and generally yield increases with population until it levels off (plateau). At this point, additional increases in population can reduce yields (Tokatlidis and Koutroubas, 2004; Boomsma et al., 2009). The economic optimum rate is the point where seed inputs equal the economic increase in yield. Yield decreases at very high population levels may result from increased lodging or increased yield reductions resulting from increased abiotic (water and light) and biotic (insects, weeds, and diseases) stressors (Clay et al., 2009; Ciampitti and Vyn, 2011).

### Determining the Corn Seeding Rate

**Determining the Ratio Between the Seed Cost and Commodity Price**

Determining the seeding rate is a three-step process. First the ratio between the seed cost and expected selling price must be determined (Table 8.2). The data in Table 8.2 provides calculated values for the ratio between the investment (costs) and returns (prices). For example, if the cost of a bag of seed is $300 or $3.75/1000 kernels and the expected selling price is $4/bu then the ratio between the purchasing price for...
1000 kernels and the selling price per bushel is 0.94. This value when combined with the yield response function and expected yield is then used to calculate the seeding rate.

<table>
<thead>
<tr>
<th>Seed Cost ($/80,000 kernel bag)</th>
<th>200.00</th>
<th>250.00</th>
<th>300.00</th>
<th>350.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed Cost ($/1000 kernels)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.50</td>
<td>3.13</td>
<td>3.75</td>
<td>4.38</td>
<td></td>
</tr>
<tr>
<td>Corn Commodity Price ($/bu)</td>
<td>3.00</td>
<td>4.00</td>
<td>5.00</td>
<td>6.00</td>
</tr>
<tr>
<td>Ratio of Seed Cost to Commodity Value ($/1000 kernels:$/bu)</td>
<td>0.83</td>
<td>0.63</td>
<td>0.50</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>1.04</td>
<td>0.78</td>
<td>0.63</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>1.25</td>
<td>0.94</td>
<td>0.75</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>1.46</td>
<td>1.10</td>
<td>0.88</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Estimating the Yield Potential

Corn yields are a function of many factors, including the location in a field and where the farm is located in the state. In many fields, yields routinely vary across the field (Fig. 8.1). Topography has a large effect on yield in a relatively short distance. To account for this variability, seeding rates can be selected for the whole field or portions of the field. When selecting a single rate, planting a high population in the lowest-yielding areas can reduce the yields, and planting a low population in the highest-yielding areas can result in lower yields. The analysis of yield monitor data can provide information needed to account for this variability (Butzen et al., 2014).

When selecting a yield, it is important to consider regional variability. Yield generally decreases from east to west across South Dakota (Table 8.3). This variability is predictable. For example, in the east-central region, the average yield was 162 bu/acre in 2014, whereas in the west-central region of South Dakota the yield was 81 bu/acre.

<table>
<thead>
<tr>
<th>East</th>
<th>Central</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE</td>
<td>EC</td>
<td>NE</td>
</tr>
<tr>
<td>SC</td>
<td>C</td>
<td>NC</td>
</tr>
<tr>
<td>SW</td>
<td>WC</td>
<td>NW</td>
</tr>
<tr>
<td>bu/acre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>165</td>
<td>162</td>
<td>156</td>
</tr>
<tr>
<td>102</td>
<td>132</td>
<td>145</td>
</tr>
<tr>
<td>99</td>
<td>81</td>
<td>91</td>
</tr>
</tbody>
</table>

### Determining the Seeding Rate

Once the cost-to-return ratios and yield potentials are calculated, the optimum plant population can be determined based on data provided in Table 8.4. The seeding rate is then determined by accounting for germination. For example, if the optimum seeding rate is 29,000 plants per acre, then the seeding rate should be 32,000 plants per acre (29,000/0.9) if the germination rate is 90%.
Defining Seeding Rates Based on Soil Characteristics
Seeding rates can also be defined using soil characteristics (Table 8.5). Generally, highly productive soils with adequate drainage and available water can support higher populations. In the drier, western portion of the state, hybrids with a longer maturity rating (> 100 days) are a risky choice. A rule of thumb is that 1 inch of rain is needed for a four-day increase in hybrid maturity (Klein and Lyon, 2011). For example, a hybrid with a relative maturity of 100 days would require 3 additional inches of water than an 88-day hybrid. In South Dakota, 8-11 inches of water is the minimum requirement to produce a corn crop (Klein and Lyon, 2011).

Table 8.4 The optimum plant population based on ratio between seed cost and selling price of corn and the yield estimate. The cost of seed/seed cost per bushel is provided in Table 8.2. These seeding rates need to be adjusted for the germination rate (Chapter 34). The seeding rates were based on coefficients developed using the equation: seeding rate = \[1000 \times \text{yield} \times A \times (e^{n \times \text{yield}})\]. The coefficients for this equation are provided. The values of n and A are defined below.

<table>
<thead>
<tr>
<th>Equations coefficient</th>
<th>$0.5$</th>
<th>$0.75$</th>
<th>$1.0$</th>
<th>$1.5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n)</td>
<td>$-0.00383$</td>
<td>$-0.00357$</td>
<td>$-0.00329$</td>
<td>$-0.00261$</td>
</tr>
<tr>
<td>(A)</td>
<td>$0.377919$</td>
<td>$0.346804$</td>
<td>$0.316176$</td>
<td>$0.256593$</td>
</tr>
</tbody>
</table>

Yield estimates bu/acre
Optimum planting rate (*1000)/acre

<table>
<thead>
<tr>
<th>Yield estimates bu/acre</th>
<th>Optimum planting rate (*1000)/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>15.6</td>
</tr>
<tr>
<td>100</td>
<td>14.5</td>
</tr>
<tr>
<td>150</td>
<td>31.9</td>
</tr>
<tr>
<td>200</td>
<td>35.1</td>
</tr>
<tr>
<td>250</td>
<td>36.2</td>
</tr>
</tbody>
</table>

Table 8.5 Relationship between the yield potential and soil characteristics on the target population in no-tilled and tilled systems. Influence of soil type and yield potential on target population and seeding rate. These calculations were based on corn seed selling for $240/bag and corn grain selling for $6/bu.

<table>
<thead>
<tr>
<th>Yield potential by soil type</th>
<th>Target population (1,000 plants/acre)</th>
<th>Planting rate(^1) (1,000 seeds/acre)</th>
<th>No-till</th>
<th>Tilled</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Yield Potential (200 bu/acre)</td>
<td>33-35</td>
<td>35 – 37</td>
<td>34-36</td>
<td></td>
</tr>
<tr>
<td>• deep loams</td>
<td>33-35</td>
<td>35 – 37</td>
<td>34-36</td>
<td></td>
</tr>
<tr>
<td>• well-drained</td>
<td>33-35</td>
<td>35 – 37</td>
<td>34-36</td>
<td></td>
</tr>
<tr>
<td>Moderate Yield Potential (150 bu/acre)</td>
<td>27-29</td>
<td>30 – 32</td>
<td>28 – 30</td>
<td></td>
</tr>
<tr>
<td>• clays – sandy loams</td>
<td>27-29</td>
<td>30 – 32</td>
<td>28 – 30</td>
<td></td>
</tr>
<tr>
<td>• well-drained to moderately well-drained</td>
<td>27-29</td>
<td>30 – 32</td>
<td>28 – 30</td>
<td></td>
</tr>
<tr>
<td>Low Yield Potential (120 bu/acre)</td>
<td>19-22</td>
<td>21-24</td>
<td>20-23</td>
<td></td>
</tr>
<tr>
<td>• droughty soils</td>
<td>19-22</td>
<td>21-24</td>
<td>20-23</td>
<td></td>
</tr>
<tr>
<td>• somewhat poorly drained to poorly drained</td>
<td>19-22</td>
<td>21-24</td>
<td>20-23</td>
<td></td>
</tr>
<tr>
<td>• excessively drained</td>
<td>19-22</td>
<td>21-24</td>
<td>20-23</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Increase population by 10% for silage corn.

Corn Hybrid Specific Responses
Different corn hybrids have different yield vs. plant population responses. When possible, use hybrid-specific information. Over the past 50 years, genetic changes have produced plants that have the capacity to increase yields in response to intense crowding (Boomsma et al., 2009). However, in response to increasing populations, per plant yields are lower (Clay et al., 2009). Lower per plant yields with increasing
population are the result of the down expression of many critical genes. A plant’s ability to respond to increasing crowding generally decreases as the plant matures, which in turn accounts for corn’s weed-free period (V2-V6). Hybrids are being developed with improved water-use efficiency (Chang et al., 2014). Many of these hybrids increase yields only under water-stressed conditions. These hybrids have been developed using traditional and transgenic techniques. The impact of improved water-use efficient hybrids on South Dakota seeding rates has yet to be determined.

Example 8.1 Use the data in Tables 8.2 and 8.4 to calculate the economically optimum seeding rate if corn is selling for $5/bu, the desired yield is 200 bu/acre and a bag of seed costs $300.

Answer

From Table 8.2 the seed cost is $3.75/1000 seeds (=300/80), and the ratio between the seed cost and corn value is 0.75

From Table 8.4 the optimum plant population is 33,900 plants/acre.

If the germination rate is 95%, then the germination-adjusted seeding rate should be 35,700 seeds/acre (=33,900/0.95).

Corn Seeding Rate for Silage

Generally, corn-seeding rates are 10% higher for silage than grain seeding rates. It may be possible to increase silage yields further by planting narrow rows. See Chapter 18 for more information.

References and Additional Information


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.


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Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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This chapter provides a brief overview on how rotations can increase long-term sustainability and resilience against climate variability for South Dakota producers. Crop rotation is a complex subject where biological factors, farm management resources, and market forces all interact to influence rotation effectiveness.

**Introduction**

Crop rotations are long-term plans that improve sustainability and profitability. A producer considering crop rotation should examine:

- Profitability, equipment, and labor availability.
- Climate and market variability.
- Soil health.
- Short-term gains vs. long-term sustainability.
- The impact on weed, insect, and disease problems.
- Pest resistance to various control mechanisms.
- Matching crop production requirements with available resources.

Crop rotations are a foundational element of sustainability and long-term profitability. 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 technology improvement provided food and the labor required for England’s Industrial Revolution. Opposite results can occur if the production systems adopt extractive rather than sustainable techniques. For example, it is thought that the ancient inhabitants of Easter Island deforested their island leading to soil erosion, a loss of productivity, and societal collapse. Although in a different environment, similar loss of soil resources occurred in the Mediterranean 1500 years ago (Thirgood, 1981).

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. Natural systems keep the soil covered and protect the soil from erosion. 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. 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 benefit of the next crop.
Designing a Rotation
Rotations should be adaptable to local conditions and challenges. There are many factors that must be considered when designing a rotation. Producers need to look at rotations as one tool for optimizing long-term profitability and reducing risk. Achieving these goals is complicated, as one management practice may have negative implications on other practices. For example, reducing tillage intensity without use of a sustainable rotation can increase the risk of plant diseases (Table 9.1).

Table 9.1 Some corn diseases that can be influenced by rotations.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen and Environment</th>
<th>Inoculum source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goss’s wilt</td>
<td><em>Clavibacter michiganensis</em> (bacteria); associated with injury from violent weather (e.g., wind and hail); favored by moderate temperatures, and can overwinter on some weeds.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overwinters on residue; also some grassy weeds act as alternate hosts; moves with rain.</td>
<td></td>
</tr>
<tr>
<td>Gray Leaf Spot</td>
<td><em>Cercospora zeae-maydis</em> (fungi); favored by moderate to warm temperatures and high humidity.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overwinters on residue; moves with wind and rain.</td>
<td></td>
</tr>
<tr>
<td>Anthracnose leaf blight</td>
<td><em>Colletotrichum graminicola</em> (fungi); favored by warm temperatures and long periods of cloudy, humid weather.</td>
<td></td>
</tr>
<tr>
<td>and stalk rot</td>
<td>Overwinters on residue; moves with wind and rain.</td>
<td></td>
</tr>
<tr>
<td>Eyespot</td>
<td><em>Kabatiella zeae</em> (fungi); favored by cool, wet weather.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overwinters on residue; moves with wind and rain.</td>
<td></td>
</tr>
<tr>
<td>Northern Corn Leaf Blight</td>
<td><em>Exserohilum turcicum</em> (fungi); favored by moderate temperatures and humid weather.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overwinters on residue; moves with wind.</td>
<td></td>
</tr>
</tbody>
</table>

Rotations and Plant Diseases
Rotation is a very valuable tool for breaking disease cycles, particularly in no-till and conservation tillage systems. Crop residue acts as an inoculum source for many important diseases in corn (Table 9.1). Hence, rotations that use nonhost crops or resistant hybrids/varieties provide an opportunity for the residues to decompose, which should decrease pest risks.

Because certain pests persist in the soil, there are some diseases, such as seedling damping off (*Pythium* spp) and root rots (*Rhizoctonia solani* and *Fusarium* spp), that can be managed only by combining the rotation with other techniques. Additional methods might include using appropriate seed treatments, delaying seeding, and installing tile drainage.

Rotations and Weed Management
Rotation can have large impacts on weed pressure. Rotations provide the opportunity to rotate the herbicide mode of action, which should reduce the risk of creating herbicide-resistant weeds. A “stacked” rotation can be effective in reducing this risk. In a stacked rotation, 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). Alfalfa can also be used for this purpose.

Similarly, an advantage can be gained by a 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 life cycles such that the weed seeds have to survive for three years.
before they get the opportunity to grow and multiply (Fig. 9.1).

**Rotation, Residue, and Nutrient Availability**

Corn produces more residue than either soybeans or small grains. For example, a 150 bu/acre corn crop will produce about 8400 lbs residue/acre, whereas a 45 bu/acre soybean crop generates about 2500 lbs residue/acre, much of this being leaves which quickly decompose. A 60 bu/acre wheat crop will produce about 3600 lbs residue/acre. The large amount of residue from corn is an asset in building soil organic matter and protecting the soil from erosion. If current climate projections, i.e., more intense storms, hold true (Seeley, 2012), then the value of the residue becomes increasingly important. However, large amounts of residue can also pose challenges in creating a ‘good’ seedbed, controlling pests, and recycling nutrients. The high level of corn residue is a concern for wheat because it acts as a host for the fungi Fusarium graminearum, which causes wheat head scab. For this reason, it is not a good idea to follow a corn crop with a wheat crop.

Soybeans tend to tolerate high-residue situations better than many other crops. The persistence of corn residue may slow nutrient recycling and the release of N from decaying stover. Following corn with a legume crop such as soybeans can be used to overcome this problem.

The use of cover crops before and following corn is a topic that needs additional investigation. Research at the SDSU Southeast Research Farm suggests that corn yields are higher following fall-planted, cool-season broadleaves (brassicas and legumes such as radish and peas) than grass-dominated cover crops (Sexton et al., 2012, 2014). Benefits of cover crops on corn yields is attributed to improved nutrient recycling and increased plant diversity (Sexton et al., 2009).

**Impacts on Yield in a Corn-Soybean System**

Studies in South Dakota, Minnesota, Wisconsin, and Nebraska have reported a 10% to 22% yield benefit for corn grown in rotation with soybeans versus a continuous corn cropping pattern (Porter et al., 1997; Reidell et al., 2009; Stanger and Lauer, 2008; Wilhelm and Wortmann, 2004) (Fig. 9.2). Similar results were observed for soybeans where there was an 8% to 10% yield advantage when grown in rotation with corn rather than a continuous soybean rotation (Porter et al., 1997; Pederson and Lauer, 2004; Wilhelm and Wortmann, 2004). The rotational effect is attributed to many factors including enhanced root growth (Nickel et al., 1995).

Crop rotations can impact profitability. A 15-year Wisconsin study compared the corn-soybean rotation with continuous corn and rotations that contained oats and alfalfa (Stanger et al., 2008). This study reported that the corn-soybean rotation was more profitable than continuous corn and rotations that include oats and alfalfa.

While a corn-soybean rotation has been shown to be superior to continuous corn, it is still not a very diverse system. In many fields, there is a corn yield decrease of about 5% to 15% for second-year corn relative to first-year corn. The greatest yield reductions are typically measured between first- and second-year corn but can also be high when weather is unfavorable. Yield reductions generally stabilize after the third-year corn. Soybeans have similar responses and generally yield 5% to 8% more when following two or more years of corn. Crookston et al. (1991) conducted a 9-year study looking at corn and soybean yields in
southwestern Minnesota. They concluded that “a superior cropping sequence … would include at least three crops and possibly more.” Additional benefits from diverse rotations include reduced development of pest resistance, improved ability to manage variable weather conditions, and increased economic diversification.

Rotations and Water Use
Rotations can be used to improve water management. For example, rotations provide protection from summer droughts by distributing the critical water-use periods across the growing season. Research conducted by the author shows that corn, wheat, and soybeans have different critical periods for water stress. Wheat partially avoids drought-stress by flowering and completing its lifecycle earlier in the growing season than either corn or soybeans (Fig. 9.3). Soybean flowering is spread over several weeks so that it can better avoid the effects of drought. The corn crop, on the other hand, flowers and sets seed at one point in time and does this during the warmest part of the year, when evaporative demand (water use) is at its peak. High temperatures and drought stress can reduce corn kernel set by decreasing pollen viability and delaying silking. By seeding hybrids of different maturities, the length of the pollination period for the farm can be expanded.

A worksheet for calculating agricultural intensity for different rotations is available at the South Dakota Lakes website. This calculator can be used to determine water harvesting from the different crops in a rotation. Along with water-use timing, crop rooting depth should be considered. Crops with deep extensive root systems that grow late into the season (e.g., sunflower and alfalfa) are likely to leave less reserve moisture than shallower-rooted, earlier maturing crops (e.g., peas, flax, and lentils). Cropping more frequently with high water-use crops increases the cropping system intensity. Barley, winter wheat, field peas, and canola are low water-use crops, whereas corn, soybean, and alfalfa are high water-use crops.

Crop Diversity
When considering diversity, crop rotations can increase diversity and reduce problems with labor, equipment, disease, weeds, and insects. Diversity assessments should consider the type of plant. In South Dakota, commonly grown crops can be classified as:

1. Cool-season grass: spring wheat, winter wheat, barley, durum wheat, oat, and winter rye.
2. Warm-season grass: corn, sorghum, sudangrass, and millet.
3. Warm- and cool-season broadleaf plants such as field pea, lentil, canola, mustard, crambe, flax, safflower, chickpea, sugar beet, sunflower, dry edible bean, soybean, and alfalfa.

When selecting a crop rotation it is important to avoid potential conflicts between the seeding and harvest times of different crops (i.e., trying to seed one crop when harvesting another, or harvesting more than one crop at a time).

Rules of Thumb for Increasing Diversity in Semi-arid Regions
1. Use soil survey information to evaluate soil water storage. Determine the appropriate cropping intensity based on this information.
2. Manage crop residues to facilitate soil water storage.
3. Manage crop nutrients to optimize yields while minimizing competition with weeds.
4. Utilize legume crops and animal manure to increase energy efficiency and improve soil quality.

Figure 9.3 Estimated crop water used by spring wheat, corn, and soybeans grown over a season at Huron, S.D. Based on data from the University of Minnesota Extension, www.extension.umn.edu, and South Dakota climate archives, www.climate.sdstate.edu. Note: Drought stress is reduced by shifting wheat water use earlier in the season.
5. Adopt techniques that minimize wind and water erosion.
6. Anticipate equipment and/or labor requirements for growing new crops.
7. Use cover crops to increase crop rotation intensity and diversity.
8. Consider a perennial crop, such as grass or alfalfa. They provide excellent weed suppression in a rotation, particularly if the crop following perennial plant is planted with minimal soil disturbance.
9. Consider the marketability of the commodity prior to planting a crop.
10. Avoid using crops with the same pests after each other. For example, soybeans should not follow field peas.

**Importance of Linking Tillage and Crop Rotations**
Crop rotation and tillage should be considered simultaneously. Designing appropriate crop rotations is a mix of art and science. For any given situation, there will be a range of rotations that are appropriate. Within this range, there are rotations and tillage practices that reduce or increase risks. Additional information on tillage systems is available in Chapter 11.

**References and Additional Information**


Acknowledgements
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Hybrid selection is one of the most important management decisions made by a corn producer because the genetic yield potential of different corn hybrids varies greatly and directly impacts yield and input costs. There are many factors to consider when selecting hybrids including: yield potential, maturity rating, drought resistance, nutrient efficiency, and pest resistance. Useful information about specific hybrids can be obtained from many sources including state and regional testing programs, on-farm strip trial testing, independent and company agronomists, seed company catalogs, and company demonstration trials (Fig. 10.1).

**Yield Potential**

If a businessman were choosing a location to begin a new retail store, a real-estate agent would tell him that the three most important factors for choosing a successful site are “location, location, and location.” In the same manner, a corn grower planning for next season should recognize that the three most important characteristics for selecting hybrids are “yield, yield, and yield.” A hybrid with poor yield potential cannot be made into a “good” hybrid with better management. Examination of the 2013 corn hybrid trial results (100 days relative maturity rating or less) showed that at the SDSU Volga Research Farm, there was a 35-bushel per acre yield difference between the highest- and lowest-yielding hybrid. Assuming a long-term average corn price of $4/bu, this equates to an increase in gross income of $80 and $140 per acre, respectively.

**Table 10.1 Tips for selecting corn hybrids (starting points):**

1. Obtain reliable information on hybrid performance.
2. Identify the field problems. For example:
   a. Does it have a history of Goss’s wilt.
   b. Is lodging a problem.
3. Identify a realistic yield goal and select appropriate hybrids. To achieve this goal select racehorse or defensive hybrids. Racehorse hybrids are designed to maximize yields under optimum conditions, whereas defensive varieties are designed to produce a “good” yield under less than optimum conditions.
4. Select a hybrid with an appropriate maturity rating.
There are many resources available for producers to evaluate hybrid performance. Information is available from the SDSU Extension Crop Performance Testing program (CPT) or F.I.R.S.T. trials. Additional information can be obtained by conducting side-by-side yield tests on your own farm or searching seed dealership or local agronomy company websites. Keep in mind that most side-by-side tests are one replication and therefore results may not be as reliable as a multiple replication test. When studying yield trial results, it is best to focus on hybrids that perform well over multiple locations and years. Consistent performance over multiple locations with different soil and weather conditions is important because of the variability in growing conditions between seasons.

When examining yield results, it is important to note not only the yield performance of a hybrid but also the LSD (Least Significant Difference) of the hybrid yield averages (Table 10.2). The LSD value is used to determine which hybrids are statistically different from one another. In Table 10.2 it is the last row in the table. Examination of Table 10.2 shows an LSD\textsubscript{0.05} value of 19.1 bu/acre. This value means all hybrids exhibiting yields within 19.1 bu/acre from one another are considered to be similar with 95% confidence. For example, a yield of 248 bu/acre is not significantly different from any hybrids with yields > 228.9 bu/acre.

Another important statistic is the coefficient of variation (CV). This statistic is 100 times the standard deviation divided by the mean value for the trait of interest (e.g. yield, test weight, etc.). The CV is an indicator of the repeatability and reliability of the measurements. The lower the CV the better. The CV value of 6% in Table 10.2 is considered excellent.

<table>
<thead>
<tr>
<th>Brand</th>
<th>Hybrid</th>
<th>Relative maturity</th>
<th>Yield</th>
<th>Grain moisture</th>
<th>Test weight</th>
<th>Lodging</th>
<th>Final stand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>bu/acre</td>
<td>%</td>
<td>lbs/bu</td>
<td>%</td>
<td>*1000</td>
</tr>
<tr>
<td>Channel</td>
<td>197-68STX</td>
<td>97</td>
<td>248</td>
<td>21.0</td>
<td>55.9</td>
<td>0.8</td>
<td>27.9</td>
</tr>
<tr>
<td>Wensman</td>
<td>W80978VT3PRO</td>
<td>97</td>
<td>246</td>
<td>19.5</td>
<td>55.2</td>
<td>0</td>
<td>28.5</td>
</tr>
<tr>
<td>Renk</td>
<td>RK96SSTK</td>
<td>98</td>
<td>244</td>
<td>20.3</td>
<td>57.5</td>
<td>0</td>
<td>27.4</td>
</tr>
<tr>
<td>Channel</td>
<td>197-33STX</td>
<td>97</td>
<td>241</td>
<td>19.8</td>
<td>57.1</td>
<td>0</td>
<td>28</td>
</tr>
<tr>
<td>Hoegemeyer</td>
<td>HPT 7042 AMX-R</td>
<td>100</td>
<td>241</td>
<td>21.0</td>
<td>57</td>
<td>0</td>
<td>28.2</td>
</tr>
</tbody>
</table>

| Trial average | 227 | 19.1 | 56.7 | 0.08 | 27.4 |
| LSD (0.05)    | 19.1 | 1.5 | 1.1 | 2.2 | 0.9 |
| CV            | 6   | 5.6 | 1.4 | 2.4 |

**Geographic Suitability and Stability**

It is important to examine yield data from studies with climatic conditions similar to those observed on your farm. In drier areas, where yield potential may be < 100 bu/acre, producers may want to select defensive hybrids, whereas in areas with a high yield potential, (>200 bu/acre), racehorse hybrids might be the best choice. The average precipitation and growing degree map shown in Figures 10.2 and 10.3 describes regional variability. Care must be used in applying these maps because average conditions rarely occur. Standard deviation of the precipitation averages can be used to assess the expected variability. For example if the standard deviation is 5 inches and the average rainfall is 20 inches, then 68% of the time the area will receive between 15 and 25 inches of rainfall. This variability means that on average, the value of the testing site decreases with increasing distance from your farm.
Maturity

Hybrids are rated based on their relative maturity (RM). Selecting an appropriate maturity rating is important because if the hybrid does not reach physiological maturity (black layer) before the first killing frost, yield and test weight may suffer. Black layer occurs when there is a layer of dark cells near the kernel tip. Images showing black layer are available in Chapter 5.

Hybrid maturity may have a significant impact on final grain yield, moisture content, and test weight. Drying grain costs money and reduces profits. Chapter 53 provides information on corn storage and drying. A rule of thumb is that 2 bushels of corn are needed to dry corn 1%.

Different classification systems can be used to characterize corn maturity ratings. A comparison between several systems is available in Chapter 5. One of the most widely used approaches is the number of growing-degree days (GDD) to reach maturity. GDD can also be reported as growing-degree units (GDU). An example of growing-degree day calculations are provided in Example 10.1. See Chapter 5 for additional information.

Example 10.1 Estimating corn growing-degree days (GDD) over a three-day period. In this calculation, the corn GDD base is 50°F and the GDD max is 86°F. These values mean that if the temperature is less than 50°F use 50°F (see day 1) or if the temperature is >86°F use 86°F (see day 3). The general equation is, 
\[
GDU = \frac{(\text{max temperature} + \text{minimum temperature}) - \text{lower base temperature}}{2}
\]

Additional discussion is in Chapter 5.

<table>
<thead>
<tr>
<th>Day</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
<td>72</td>
</tr>
<tr>
<td>2</td>
<td>52</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>62</td>
<td>88</td>
</tr>
<tr>
<td>GDU\text{day }1</td>
<td>(50+72)/2 - 50 = 11</td>
<td></td>
</tr>
<tr>
<td>GDU\text{day }2</td>
<td>(52+80)/2 - 50 = 16</td>
<td></td>
</tr>
<tr>
<td>GDU\text{day }3</td>
<td>(62+86)/2 - 50 = 24</td>
<td></td>
</tr>
<tr>
<td>GDU\text{accumulated}</td>
<td>11+16+24 = 51</td>
<td></td>
</tr>
</tbody>
</table>

Table 10.3 Growing-degree days over a 3-day period.
The second approach for ranking corn maturity is the Comparative Relative Maturity (CRM). CRM assigns ranks to hybrids according to “days” of maturity. These ranks are related to the accumulated GDDs. When considering CRM it is important to consider that selecting a 90-day corn does not mean it will mature in 90 days. Two hybrids may reach physiological maturity at the same time but dry down at different rates, thus having identical GDD hybrid ratings but different CRM ratings. The two systems are related, and generally:

1. An 85-90 day hybrid requires 2000-2100 GDD.
2. A 90-95 day hybrid requires 2100-2250 GDD.
3. A 95-100 day hybrid requires 2250-2350 GDD.
4. A 100-105 day hybrids require 2350-2500 GDD.
5. A 105-110 day hybrids require 2500-2650 GDD.

It is important to choose hybrids suited to the environment where they will be grown. Most seed companies publish detailed information about corn hybrids, including the specific number of growing-degree days required to reach physiological maturity. As a rule of thumb, selected hybrids should reach maturity (black layer) at least 10 days before the first average killing frost (32°F). Keep in mind that production systems may affect maturity selection. For example, in cooler spring soil temperatures, no-till systems with heavy residue may slow plant maturity.

Some growers will also look closely at the silk CRM (GDUs to silking) of individual hybrids. Earlier-silking hybrids have been known to work well in droughty and hot environments because they may enter the reproductive growth stages prior to severe drought and heat stress.

**Pest Resistance**

In recent years, genetically modified (GM) traits in corn hybrids have been used to minimize the damage from pests. These GM corn hybrids provide increased crop resistance to insects and diseases, improved drought tolerance, and tolerance to broad-spectrum herbicides. Consideration of technology costs, the marketability of the crop, and the risk of developing weed or insect pest resistance should be considered when planting a GM crop. The starting point to obtain information about GM seed corn traits is from seed suppliers.

Transgenics are a type of genetic modification where genes (such insect resistance) are transferred from nonplant sources into plants. In corn, for example, the Bt (*Bacillus thuringiensis*) genes were obtained from soil bacteria *Bacillus thuringiensis* and inserted in the corn plant to combat insect pests. One type of Bt gene provides resistance to corn rootworm while other Bt genes provide resistance to European corn borer, Southwestern corn borer, western bean cutworm, fall armyworm, corn earworm, and black cutworm.

Transgenic modifications have also provided crop tolerance to herbicides such as Roundup® and Liberty®. Stacked hybrids contain two or more genetic traits. For example, Monsanto’s Genuity® VT Triple Pro® RIB Complete® contains two separate genes for protection from aboveground insects such as corn borer and earworm, and a single gene for protection from belowground insects such as rootworm in addition to providing a 10% refuge (to combat insect resistance). Many hybrids have an integrated refuge in the bag (RIB) whereas others may require a separate corn borer and/or corn rootworm refuge for insect resistance management.

Insect and weed pests are becoming increasingly more resistant to chemical and genetic solutions. To slow the development of pest resistance the control strategies should be rotated. Tips to avoid problems include:

1. Know the terminology. For example: GT (Glyphosate Tolerant), LL (LibertyLink®), RR2 (Roundup Ready 2 Yield®).
2. Understand the trait biology.
3. Check seed bag tags to make sure what was ordered was delivered.
4. Check herbicide traits multiple times prior to herbicide application.
5. Save seed bag labels for your field records.
Other Agronomic Characteristics
Corn hybrids have a wide variety of agronomic characteristics relating to plant structure and health. Seed companies generally provide trait ratings for seedling vigor, stalk strength, and ear retention. Seedling vigor refers to the ability of a corn plant to cope with stress early in the growing season. Hybrids with good seedling vigor may perform better in cool, moist conditions. This may be important in no-till and high-residue production systems.

Good stalk strength can decrease lodging but there are no guarantees. All hybrids can lodge or break off if undesirable weather events or insect/disease infestations occur during periods of rapid stalk growth. Poor stalk strength can reduce yields by increasing harvest losses. If lodging and/or ear drop is an issue, select hybrids that provide protection against shank-boring insects, drought tolerance during pollination, and good ear retention. Harvest problems associated with lodging may be alleviated somewhat by adjusting the combine accordingly. Information on measuring and adjusting combines to reduce losses is available in Chapter 37.

Seed Corn Production
Corn hybrids are produced by crossing inbred lines that are developed over several seasons. Plant scientists select for specific traits by inbreeding (self-pollinating) corn plants and then discarding progeny that has undesirable characteristics. Plant vigor is often lost during the inbreeding process but it can be recovered by crossing with other inbred lines. Hybrids can be produced by crossing two (single-cross), three (three-way-cross), and four inbred lines (double-cross). If a single cross is used, then all plants within a field will have near uniform characteristics, whereas hybrids produced using double-crosses will have the most variability. Generally, single-cross hybrids have the highest hybrid vigor.

Use On-farm Testing to Verify the Best Hybrids
Different hybrids have characteristics that make them better-suited for one environment over another. An approach that can be used to examine hybrid performance is on-farm strip-trial testing. On-farm testing can be used to match hybrids to your conditions. Be sure to use a well-calibrated yield monitor and/or compare weights from strips using scales on grain carts for accurate harvest data when conducting on-farm strip trial testing. Understand that replication in strip trials is very important for determining which hybrids are actually better performers. Replicated, split-planter testing can help overcome many of the inherent variables that occur in agronomic testing.

Consider field-by-field hybrid placement to maximize yield of each hybrid. Many seed and data-mining companies are putting a lot of effort into analyzing large amounts of yield data to determine which hybrids perform better on individual soil types. This type of technology is still in the early stages but “prescription” hybrid selection based on soil type may become commonplace in the future. Consult with your local seed experts to match hybrids to your soil and environmental conditions.

Seed Quality
It is possible to purchase hybrids with specific seed-quality characteristics. For example, high-lysine, high-amylpectin (waxy corn), or white corn hybrids are available. High-lysine corn hybrids were created for feed for nonruminant animals, such as hogs, whereas waxy corn hybrids were created to increase milk production efficiency. White corn was created specifically for the food market (tortillas). Specialty corn hybrids may have specific management requirements that should be followed. Additional information on specialty corn hybrids are available in Dickerson (2003).

Summary
Selecting a genetically diverse lineup of locally adapted hybrids that vary in maturity and agronomic strengths can help growers lower their risk of crop loss. Spreading out maturities helps manage weather-related risk as well as spreading out the harvest interval so the crop is not all too dry or too wet at harvest. Hybrids should be considered/selected for the following key traits: yield, maturity, drought tolerance, standability, pest resistance, dry-down time, grain quality, and harvestability. Consulting with seed experts
in your area to understand the agronomic characteristics of locally adapted hybrids is a good starting point.

References and Additional Information


Thomison, P. Specialty corns: Waxy, high amylose, high oil, high lysine corn. AGF-112-91, Ohio State University Extension,
Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council. Special thanks to Curt Hoffbeck and Keith Alverson for their helpful insights.


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1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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Historically, tillage was used to manage residues, diseases, insects, weeds, excess water, and soil compaction with little consideration given to its impact on soil health, water quality, and erosion. The extreme drought during the 1930s helped change this perception. Tillage was and is still used to prepare a seedbed. Today, innovations in production tools (e.g., planters, herbicides, and genetically modified crops) provide an opportunity to replace moldboard plows (Fig. 11.1) with conservation-tillage systems. Alternate tillage systems are listed in Table 11.1.

Different Tillage Systems
When considering tillage systems, it is important to consider that compaction can be caused by all systems as well as by grain wagons, combines, and trucks driving across the field. Field traffic should be minimized to minimize compaction. Excessive tillage can increase soil crusting and compaction. Moldboard plowing or excessive tillage is not considered a Best Management Practice (BMP) for South Dakota production systems because of erosion and compaction risks. Additional information on compaction is provided in Chapter 14.

Clean-till
Clean-tillage involves inverting the soil so that most of the residue is buried. Moldboard plowing followed by preplant disking is a common clean-till procedure. Because crop residue is mostly buried, the soil surface is exposed to wind and rain, increasing the potential for erosion and a loss of soil moisture. Of the tillage systems discussed, clean-tillage carries the greatest wind and water erosion risks. Clean-tillage

Table 11.1 Tillage systems for corn production:

1. Clean-till, <30% residue cover
   - Moldboard plow.
   - Chisel/disk.
   - Not considered a Best Management Practice (BMP).
2. Conservation-till, >30% residue
   - Chisel plow followed by a disk.
3. Ridge-till, >30% residue cover
   - Requires special equipment for ridge-building.
4. No-till or strip-till, >30% residue
   - Requires special equipment and a residue-management plan.
is not considered a conservation tillage system. The advantages and disadvantages of clean-till systems are shown in Table 11.2. Clean-tillage may be best-suited for bottomland or poorly drained soils because it speeds soil heating and reduces soil water content, and water erosion risks are low. However, moldboard plowing can result in a plow pan that can restrict plant root growth. The use of deep rippers to overcome a plow-pan problem will provide only temporary relief.

**Conservation-till**
Conservation-tillage systems leave at least 30% or more crop residue on the soil surface following planting. Directions for calculating residue were prepared by McCarthy et al. (1993). There are a number of implements that can be used in conservation-till. The most common conservation tillage-systems are spring disking and chisel plowing (Fig. 11.2). Different systems provide different amounts of surface residue. Advantages and disadvantages are provided in Table 11.3.

Increasing the residue on the soil surface decreases the potential for erosion and soil water loss. Crop residues create a barrier between the soil, water, and wind that reduces erosion. The amount of residue left on the soil surface is directly related to available water, and the length of time needed for the soil to warm. The amount of residue remaining on the soil surface can be increased by:
1. Including a high-residue-producing crop in the rotation.
2. Conducting tillage operations in the spring.
3. Reducing the number of tillage passes.
4. Using cover crops.
5. Driving slower during tillage.
6. Setting chisels and disks to a shallower soil depth.
7. Using straight shanks and sweeps rather than curved implements.

**Ridge-tillage**
Ridge-tillage is a conservation-tillage system where crops are grown on permanent beds (or “ridges”). With ridge-tillage, the planter must be able to cut residue, penetrate the soil to the desired depth, and in many situations, clear the ridge of the previous years’ crop residues (e.g., stalks and rootballs). Following planting, cultivators are used to control weeds, and rebuild and shape the ridges. Ridge-tillage is well-suited to relatively flat landscapes and is often furrow irrigated in arid climates. Advantages and disadvantages are provided in Table 11.4.

In ridge-tillage, crop residue and organic matter tend to accumulate between the ridges. If mechanical cultivation and ridge-building take place during the growing season, these materials are generally mixed...
into the upper portion of the soil profile. Relative to conventional-tillage, ridge-tillage generally increases water infiltration and reduces surface runoff. Banding the fertilizer into the ridge can reduce nitrogen leaching. Herbicides may be applied to the ridge, with cultivation used between the rows for 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. For sandy soils, the amount of N plus K\(_2\)O applied with the seed should not exceed 5 lbs/acre. This limit increases to 10 lbs/acre for fine-textured (clay) soils. The effectiveness of P and K applications is often improved by banding.

**Strip-tillage**

Strip-tillage is a conservation-tillage system where the seedbed (8- to 10-inches wide) is tilled and cleared of residue and the rest of the area is not disturbed (Fig. 11.4). Strip-till systems prepare a seedbed that is relatively free of residue, even in a corn-following-corn rotation. The spreading of residue at harvest can reduce residue interference at planting. Strip-tillage may be conducted in the fall or spring. Spring strip-till uses a tillage tool that tills strips ahead of the seed openers on the planter. If strips are prepared in a separate operation: 1) it can be challenging to consistently follow the strip with the planter, and 2) it is recommended to follow the same direction with the planter. Failing to follow the strips with the planter can affect fertilizer placement with respect to the seed.

If P or K fertilizers are needed, they can be fall banded into the strips. As with any tillage system, N fertilizer should not be fall-applied until soil temperatures are below 50°F. Starter fertilizer can be used; however, the total amount of N + K\(_2\)O applied in contact with the seed should not exceed 5 pounds in a sandy soil and 10 pounds in fine-textured soils. Many producers have problems when attempting to plant into fall-created strips in rolling terrain. Plant growth can be compromised if the seed rows are too close or too far away from the fertilizer band.

Soil in the strip-tilled systems tends to warm faster than areas where residue is present. 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 in a band.

**No-tillage**

Properly managed no-till systems leave the most residue on the soil surface (Fig. 11.5). This residue conserves soil water and can increase yields and profitability. Compared with other systems, no-tillage has higher water infiltration rates and less potential for erosion. Lower erosion losses are attributed to increased water infiltration and reduced runoff, resulting from the development of macropores (old root and earthworm channels). Considering the potential conservation and production benefits, no-tillage should be strongly considered by South Dakota producers. Advantages and disadvantages are provided in...
Table 11.5.  

No-tillage requires the optimization of planting and residue-management systems (Fig. 11.6). A common misconception is that residue managers can compensate for nonuniform residue distribution. Residue management begins at harvest. Using stripper headers for harvesting wheat and other crops allows straw to remain upright and attached, and prevents residue from being moved by wind or water. In corn, this is accomplished by adjusting the combine to keep the stalk intact and upright. Uniformly spreading chaff 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.

Residue managers work best in situations where residue is uniform. However, in situations when residue is not uniform, it is almost impossible to properly adjust residue managers. Single-disc fertilizer openers placed at the same depth and 2 to 3 inches to the side of the seed-opener path can serve a dual purpose, cutting residue and placing the sideband fertilizer. When compared with conservation tillage, no-till soils generally remain cooler in the spring. Cooler soil temperatures can slow nitrogen (N) and sulfur (S) mineralization. Placing nutrients such as N and S as a sideband improves early season plant vigor.

The planter is the most important implement in a no-till system. Germination can be improved when seeds are covered with loose material and firmly planted at the right depth in warm, moist soil. The basic corn planter was designed for use in well-tilled seedbeds. Consequently, modifications are needed to assure optimal seed placement. 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 uneven germination and growth. Hair-pinning is worse when residue is cut into short lengths and soil structure is poor. Continuous long-term no-till systems have less of a problem with this issue.

Once the seed is placed in the trench, it needs to be pressed into the soil and covered. In no-tillage systems, the best method is to separate the firming (seed pressing) and covering operations. Several companies make 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 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 the type that uses 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 no-till systems because they have difficulty 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 (e.g., 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 the seed is planted into loose soil created by the strip-tillage operation, which allows for optimal operation of standard closing wheels.

Other attachments needed for conversion of a standard planter to a no-till planter are fertilizer openers and residue managers. 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 2 to 3 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 the amount of N applied to one-third to one-half of the seasonal N requirement.

The likelihood of planter plugging in heavy residue can be reduced by using residue managers that cut residue before it is moved and by replacing wide-depth wheels with narrow-depth wheels. 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, 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 no-till seeding equipment is that while it does not have to be complex, it needs to work effectively. No-till systems are becoming increasingly popular. Additional information is available at www.sdnotill.com and at www.dakotalakes.com.

References and Additional Information


Acknowledgements
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(3) email: program.intake@usda.gov;

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Historically, land rolling was used to improve germination in alfalfa and grass-seed production systems. Recently, land rolling has been expanded to row-crop production systems. Land rollers are used to push rocks into the soil, thereby reducing the risk of harvest losses and combine breakdowns. Benefits from land rolling include reduced equipment breakdowns, reduced harvest losses, reduced operator fatigue, ability to place the combine head closer to the soil surface, and improved emergence. Lowering the combine head can reduce soybean losses because the pods can be very close to the soil surface. However, in corn production lowering the combine head to near the soil surface will produce a minimal impact on harvest efficiency. Primary disadvantages are increased compaction and erosion. We suggest that land rolling should be considered only in fields containing a large number of rocks. This chapter investigates the impact of land rolling on corn production.

**Land Rolling Introduction**

Land rolling is simply pulling a large cylindrical roller over the field to smooth and push small rocks into the soil. Land rollers range in price and can cost up to $50,000. Custom land-rolling rates in Iowa average $6.55/acre (Wolkowski, 2011). There are many types of land rollers and they range in size from 20 to 85 feet wide. Land rollers can have smooth, notched, and coil drums. The coil and notched systems leave the soil rougher than the smooth-drum system. Coil drums help break up rootballs, whereas notched system breaks up rootballs and push rocks into the soil (DeJong-Hughes et al., 2012). Drums have a packing force similar to the closing wheels on a planter.

**Benefits of Land Rolling**

1. Ability to operate sprayers and combines at faster speeds.
2. Reduced equipment breakdown during critical periods.
3. Reduced harvest losses.
4. Reduced operator fatigue.
5. Improved seed germination.
6. Accelerated microbial decomposition as a result of pushing crop residues into the soil.
7. Reduced stand variability.

Rollers effectively push rocks down into the soil, and in a no-tillage system, a land roller will lower mounds left by burrowing rodents and dramatically reduce the risk of equipment damage. A fist-sized or
larger rock can cause significant damage to a corn combine, especially cylinders and/or concaves. Repair costs resulting from rock damage can potentially cost tens of thousands of dollars to a $300,000 combine. Mounds left by burrowing animals, such as pocket gophers, can be equally problematic. Land rolling may also help speed surface residue mineralization by breaking apart corn rootballs, and reducing the risk of flat tires.

Animal mounds can bounce and jar spraying and harvest equipment, leading to structural or mechanical damage and malfunction. Land rolling can partially smooth these areas and minimize undue stress on equipment. Combining at high speeds in fields with animal mounds can increase the chance of ears bouncing out of the header. Adjusting the combine header to avoid rocks, reduces the risk of combine damage and repair costs, but can leave low-hanging ears in the field. Land rolling conducted after planting can reduce this risk as well as improve contact between the corn seed and the soil.

Disadvantages of Land Rolling
1. Crushes soil aggregates and destroys the surface roughness that protects the soil from wind and water erosion. This can result in soil sealing and reduced seedling emergence.
2. Increases weed seed germination by improving soil to weed seed contact (Lessen, 2009).
3. Leads to seedling damage if rolling is conducted after emergence.
4. Reduces water infiltration and increases erosion rates (Al-Kaise et al., 2011).
5. Increases soil compaction.
6. Includes difficult-to-document economic benefits (DeJong-Hughes et al., 2012).

Mitigating the Disadvantages of Land Rolling
1. Return the crop residue and maximize residue cover after planting.
2. Roll only areas containing rocks.
3. Avoid land rolling after plant emergence.
4. Do not roll wet fields.
5. Do not roll fields to level tire ruts.
6. Configure tractor and roller tire size and spacing to your row spacing.

References and Additional Information


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.


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Crop residues that are not uniformly distributed can cause uneven soil temperatures and soil moisture levels that impact seed germination and stand variability. A goal in residue management and seedbed preparation is to minimize this variability. The purpose of this chapter is to provide a checklist of residue-management options (Table 13.1).

### Residue Removal and Crop Yields

In a continuous corn rotation, harvesting corn residues can produce a short-term yield increase in the following corn crop that often diminishes with time (Chapter 24). This increase is attributed to many factors including warmer soils, improved germination, and reduced variability of the distance between adjacent plants. However, the practice may also produce a long-term yield decrease that is attributed to a gradual decline in soil health and organic C. The organic C is important because it builds soil resilience and provides important nutrients to the plant (Clay et al., 2012). Clay et al. (2014) reported that 22%, 63%, and 36% of the increases in corn, soybean, and wheat yields, respectively, from 1974 to 2012, could be linked to soil health improvements. They also reported that improved soil health had a $1.1 billion impact on the South Dakota economy in 2012. Removing the surface residue can place these gains in jeopardy.

### Residue Management and Seedbed Preparation

Since 1970, the corn harvest index \[\text{harvest index} = \frac{\text{lbs of grain}}{\text{lbs of stover} + \text{lbs of grain}}\] has remained stable at about 0.5, while statewide corn yields have been increasing at a rate of 2.9 bu/acre. This means that as yield increased from 75 to 150 bu/acre, the amount of surface residue increased from 3550 pounds of biomass/acre to 7400 pounds of biomass/acre. This residue contains nutrients required by the plant and helped South Dakota farmers increase their soil organic matter content 24% over the past 25 years.

<table>
<thead>
<tr>
<th>Table 13.1 Checklist for preparing for seeding:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Seedbed preparation starts by evenly distributing crop residues during harvest.</td>
</tr>
<tr>
<td>2. A good residue-management plan can reduce pest problems. However, it does not replace the importance of using an appropriate seed treatment or using pre- and post-plant herbicide treatments.</td>
</tr>
<tr>
<td>3. Removing corn residue is not generally recommended in South Dakota for disease management. Options for improved disease management are tillage, use of residue manager, rotations, seed treatments, and foliar fungicide applications, if warranted.</td>
</tr>
<tr>
<td>4. Review the seeder owner’s manual.</td>
</tr>
<tr>
<td>5. On the planter, replace worn parts, calibrate seed meters, calibrate planter fertilizer and pesticide applicators, check down-pressure springs, maintain even and recommended tire pressure, and lubricate bearings and other moving parts.</td>
</tr>
<tr>
<td>6. Do not plant if soil is too wet.</td>
</tr>
</tbody>
</table>
years (Clay et al., 2012). However, the increased crop residue has complicated preparing a “good” seedbed and slowed soil warming in the spring (Gentry et al., 2013).

Good residue management starts in the fall during harvest and continues through planting. The residue-management plan should consider both the chaff and straw. Chaff is discharged from the cleaning unit, whereas straw consists of corncobs, husks, and cornstalks. A chaff spreader uses spinning discs to distribute the fine materials, whereas a straw chopper uses knives to break or cut residue prior to distribution. Additional information for individual combines is available in Butzen et al. (2015).

A corn combine that chops the stalks can be used to evenly spread the residue on the soil surface. If the combine does not have the equipment to uniformly distribute residue, an aftermarket purchase may be needed. Recommendations for improving residue distributions include:
1. Visit with your dealer and refer to the owner’s manual.
2. Check the distribution pattern and add residue-spreading attachments if needed.
3. Check residue distribution pattern periodically during harvest.
4. Do not overcorrect for windrowing problems.
5. Adjust the speed of the straw spreaders by changing the pulleys.
6. Inspect, sharpen, and replace chopper blades when needed.

A good residue-management plan can also reduce disease and insect problems, while improving stand uniformity and yields (Gentry et al., 2013). A poor residue-management plan can:
1. Push residue into the seed furrow.
2. Slow soil warming.
3. Cause toxic impact on the germinating seed.
4. Delay emergence.
5. Increase overwintering of insects and diseases.

**Plant at Appropriate Soil Moisture Content**
Planting a field when it is too wet can cause emergence and compaction problems. When planting, the top 4 inches of soil should be dry enough that it crumbles easily and does not form a ribbon when compressed in your hand. The soil moisture content should be below field capacity to avoid sidewall compaction, which can lead to a shallow root system. Field capacity is the amount of water remaining in the soil after gravity has removed the gravitational water. Most soils approach field capacity 2 or 3 days after a rainfall. If the soil is too wet, the disc openers can cause sidewall compaction, which produces variable emergence. Compaction can also be reduced by lowering the tire pressure to the minimal allowable pressure, using flotation tires, and installing larger diameter tires.

**Preseason Pest Management**
High residue can shelter germinating pests from chemical pesticides. In high-residue systems, consider using a variety of control strategies. Since early planting is recommended, a fungicide and insect seed treatment is also suggested. Producers are encouraged to combine practices such as including residue cleaners on planters, using strip-tillage to devoid the planting zone of residue, or incorporating genomic and cultural options with chemical solutions for weed, insect, and disease control.

**Planter Maintenance and Preparation**
A corn planter is a piece of precision equipment that requires all of the components to be adjusted correctly. Research suggests that the uniform spacing of seed can increase yields up to 20 bu/acre (Doerge and Hall, 2000). Although plant spacing and density are conducted too late to correct an in-season problem, stand counts and planter variability information is useful in assessing whether a new planter or refurbishing is needed. Examples for determining emergence rates are available in Chapter 34.

Growing conditions should also be evaluated to assess whether soil crusting, compaction, temperature, or moisture could be responsible for nonuniform stands. Information for assessing compaction is available
Potential yield losses due to uneven stands can be estimated (Carlson et al., 2000; Chapter 34). If planter calibration is necessary, always follow the manufacturer's instructions for calibrating seed-metering equipment. Assistance is available from local Extension educators, crop consultants, seed dealers, and the equipment manufacturer. Different adjustments may be required for different tillage systems. For example, the downward pressure of the planter should be higher for no-tillage vs. a tilled seedbed.

During planting, it is important to place seed at the proper depth and ensure that the opener does not smear the walls of the furrow. Down-pressure tension should be adjusted if the seed is not placed at the desired depth (1½ to 2 inches). Closers or packing wheels should apply enough pressure for “good” seed-to-soil contact; too much pressure will compact the seedbed, whereas too little will provide poor soil-to-seed contact. Adjust down-pressure tension in consideration of soil moisture and residue conditions.

As no-till and reduced-till systems become increasingly popular, the planter takes on the added responsibility of assisting in residue management. Hence, there are more parts to wear out and maintain. Residue managers can help cut residue and clear a path for the planting unit. If residue is not managed appropriately, it can interfere with seed placement, delay germination, produce a physical barrier to the emerging seedling, slow plant growth, increase pest problems, and reduce nutrient efficiency.

**Planting Dates**

The spring planting window generally ranges from late April to mid-June. Historically, 90% of the corn acres in South Dakota are seeded by mid-May and completed by mid-June. Seed germination depends on soil moisture and temperature. Care should be taken to avoid tillage and planting operations when the soil is wet.

As a general rule, corn should not be planted until the soil temperature (measured at 2” between 7 and 8 a.m.) approaches 50°F. In cold soil conditions (below 50°F), seeds will readily absorb water but will not initiate root or shoot growth. This can lead to seed rots and poor emergence. If circumstances force planting before soil temperatures reach 50°F, it is recommended to use a seed treatment and consult with a reputable seed dealer or agronomist to select an appropriate hybrid. Delaying seeding can reduce corn grain yields (Table 13.2).

**Use of a Packer Wheel**

High germination rates require good soil-to-seed contact. Packer wheels can improve soil-to-seed contact, nutrient uptake, and stand uniformity in dry soil, whereas in wet soil, packer wheels can increase soil compaction and crusting. The use of packer wheels should be based on the soil conditions at the site when planting.

**Delayed Planting and Replanting Considerations**

Delayed planting reduces the number of growing-degree units (GDU) accumulated during the season, hindering the crop from maturing before the first fall killing frost. Corn killed by frost before maturity will have lower yields and higher drying costs. If planting is delayed, late-maturing hybrids can lose up to 1.1 bu/acre per day compared with earlier-maturing hybrids. Often, the trade-off is that earlier hybrids have a lower yield potential.

The number of GDUs that a hybrid needs to reach physiological maturity is related to maturity ratings. Hybrids with an 80-day maturity rating often require 1900 growing-degree days (GDD), whereas a 95-day hybrid requires approximately 2200 GDD. Additional information is available in Chapter 10. A rule of thumb is to plant 20% of your acres with a full-season hybrid, 60% with a mid-season hybrid, and the remaining 20% with a short-season hybrid (i.e., the “20-60-20 rule”). When you are developing a seeding strategy, you should also develop a harvest strategy. If planting is delayed, growers are urged to consult their seed dealer to determine whether an earlier-maturing hybrid is warranted or available.

**Depth and Planting Operations**

Under optimal conditions (warm, moist soil), seed placement is 1½ to 2 inches below the soil surface.
However, in dry soil it may be advantageous to plant deeper (2 to 3 inches). Planting deeper than 3 inches is not recommended because seed emergence is very low. Although soil conditions may be dry, consider the probability of rain in the near future. Rain can seal the soil surface, resulting in soil crusting and reduced emergence rates. Seeds should be placed at shallower depths (< 2 inches) if rain is likely.

When planting into areas with heavy residue, seed depth should be at least 1.25 inches but not deeper than 1½ inches if soil moisture conditions are favorable. High residue can result in seeds being left on the surface and variable soil temperature and emergence. Seed left on the soil surface or in the residue layer will not properly develop. To ensure that seeds are placed at the proper depth, check seed depth in high-residue situations. These measurements should not include any surface residue. If residue is problematic, consider residue management planter attachments (residue cleaners).

References and Additional Information


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.


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Soil compaction reduces soil drainage, aeration, yields, root growth, and the ability of plants to recover from disturbance, while simultaneously increasing surface runoff and soil erosion. Compaction can be severe in wet, clay soil and it is increased by the use of heavy machinery during planting and harvesting, especially in wet soil conditions. Generally, conventional-tillage (e.g., moldboard plowing, chisel-plow, etc.) leads to the development of a plow layer or pan near the interface of soil and the bottom of the tillage implement (Fig. 14.1). This chapter discusses soil compaction and possible remediation strategies to reduce these risks.

Locating Compacted Zones
Compaction is caused by a downward pressure that squeezes the soil and increases the soil bulk density (Wolkowski and Lowery, 2008). Compacted zones can be located by scouting the field for reduced crop growth. Compacted areas are typically associated with areas where tillage was conducted on wet soil and areas with extensive traffic. Compaction problems can be diagnosed by:
1. Driving a metal stake into noncompacted and suspected compacted zones.
2. Digging a trench across two corn rows in a suspected area or pushing a long screwdriver into soil in the suspected compacted area.
3. Inspecting root growth (Fig. 14.2) or assessing soil hardness by crushing soil aggregate.
4. Determining the soil bulk density or penetrometer resistance (Duiker, 2002; USDA-NRCS, 2014).

Bulk Density
Bulk density of soil is the dry weight of soil in a given volume of soil. It is measured by using core method, and calculated by the weight of soil mass divided by the volume of the soil core. Most rocks have a bulk density of > 2.65 g/cm³, whereas productive soils have bulk densities between 1.2 and 1.3 g/cm³. Sandy soils have higher bulk densities than silt loam soils. Bulk densities can be used to identify problem areas where root growth is restricted (Table 14.1).
Tools needed to measure bulk density include a steel ring of known dimensions, a shovel, plastic bag, balance, microwave, and a knife. The steps are:
1. Push the ring into the soil (Fig. 14.2).
2. Use the shovel to recover the ring.
3. Cut the soil, outside of the ring, from the top and bottom.
4. Place soil into a plastic bag.
5. Dry using a microwave.
6. Determine the volume of the ring, \( \text{vol} = \pi r^2 h \).
7. Calculate the density, dry weight/volume of ring.

Additional details for determining the bulk density are available in Arshal et al. (1996).

**Soil Resistance**

Soil penetration resistance is the resistance that a root experiences as it tries to expand into a new soil zone. Penetration resistance is measured with a penetrometer that is pushed into the soil (Duiker, 2002; Fig. 14.3). Details for this method are provided by Duiker (2002). Root growth critical resistance values are dependent on plant species. Duiker (2002) suggested a compaction assessment can be determined by measuring resistance at a number of points across a field. Duiker reports that if the resistance exceeds 300 PSI, root growth is severely slowed. The results of these measurements are then compiled and interpreted (Table 14.2).

### Reducing Soil Compaction

**Check Soil Moisture Prior to Field Operations**

Wet soils are more prone to compaction than dry soils. To minimize compaction, it is recommended that the soil moisture content can be checked prior to field operations. For medium-textured soils such as silt loams and silty, clay loams, soil from the top 6 inches should be placed between the forefinger and the thumb and squeezed. If the ribbon breaks within several inches, the soil is most likely appropriate for additional work. If the soil stretches out for 4 to 5 inches, it is most likely too wet.

**Reduce Tillage**

Only conduct tillage that is absolutely necessary. Primary and secondary tillage (disking in particular) and cultivation break soil aggregates and speeds up the mineralization of soil organic matter. Tillage problems can be minimized by:
1. Carefully balancing the need for timely planting and field operations.
2. Using equipment that has an appropriate size and weight.
3. Varying the tillage depth from year to year.
4. Using tillage equipment that is well-maintained with sharp, soil-engaging leading edges.
5. Delaying tillage until the soil has an appropriate moisture content. Strip-tillage, no-tillage, and ridge-tillage systems are techniques that can be used to reduce tillage and thus compaction.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Root growth restricted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy</td>
<td>&gt; 1.8</td>
</tr>
<tr>
<td>Silty</td>
<td>&gt; 1.65</td>
</tr>
<tr>
<td>Clayey</td>
<td>&gt; 1.47</td>
</tr>
</tbody>
</table>

Table 14.1 Bulk densities where root growth is restricted in sandy, silty, and clayey soils.

<table>
<thead>
<tr>
<th>% points with values &gt; 300 PSI</th>
<th>Compaction rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 30</td>
<td>little to none</td>
</tr>
<tr>
<td>30-50</td>
<td>slight</td>
</tr>
<tr>
<td>50-75</td>
<td>moderate</td>
</tr>
<tr>
<td>&gt; 75</td>
<td>severe</td>
</tr>
</tbody>
</table>

Table 14.2 Interpretation of penetrometer results. This analysis is based on root growth being restricted with PSI values > 300. (Modified from Duiker, 2002)

Figure 14.2 Measuring the bulk density (top images) and soil resistance (bottom images) in a field. (Courtesy of the authors)
**Improve Soil Organic Matter**

Adding organic matter increases surface-soil friability, water infiltration, soil structure, and water-holding capacity, and reduces soil erosion. Generally, tillage breaks the soil clods, which, in turn, accelerates soil organic matter oxidation. Organic matter can be increased by adding manure, growing perennial crops, planting cover crops, reducing tillage, and not removing crop residues. The impact of adding organic matter on compaction generally decreases with increasing depth. Information on rotations and cover crops are available in Chapters 9 and 15.

**Control Wheel Traffic**

Grain carts can increase soil compaction and reduce yields (Table 14.3). Grain carts can have axle loads that often exceed the axle load of a combine, large manure tank, or tractor. To minimize the compaction risk from grain carts, load them in the road or headlands and don’t drive across the field to catch the combine.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Ton/axle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combine with 250 bu grain</td>
<td>18</td>
</tr>
<tr>
<td>Grain cart with 875 bu grain</td>
<td>23</td>
</tr>
<tr>
<td>Large manure applicator</td>
<td>17</td>
</tr>
<tr>
<td>175 hp 2-wheel-drive tractor</td>
<td>8</td>
</tr>
</tbody>
</table>

**Use of Deep Tillage**

If compaction is between 10 to 20 inches deep in the soil, consider subsoiling. Subsoiling is a temporary solution and it should be combined with other techniques to minimize deep compaction. Subsoilers can have: 1) parabolic shanks with or without wings, or 2) straight shanks with or without a coulter. Subsoilers work by shattering the soil and they can leave the soil very rough. Secondary tillage is often needed to prepare a seedbed. Additional information on deep tillage is available in Thomason et al. (2009).

**Check Air Pressure in Field Equipment**

Field equipment often has tire pressures that are higher than recommended. Using the lowest recommended tire pressure widens the tire footprint and reduces the down pressure. Tandem axles will have less surface compaction than single-axle equipment. Staton (2013) recommended:

1. Tires should be inflated to the lowest manufacturer-recommended tire pressure.
2. Instructions from the manufacturer for your configuration (single, duel, or triple axle) should be followed.
3. Correctly ballasting the tractor and determining weight carried per tire.
4. Tire pressure should be checked frequently with a high-quality gauge.
5. All tires on the same axle should be set to the same pressure.
6. That if the tires contain fluid ballast the pressure should be checked with the stems in the same location.

**References and Additional Information**


**Acknowledgements**

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Cover crops are noncash crops grown with or after a cash crop. Benefits from cover crops may include: 1) reduced wind and water erosion, 2) reduced nitrate leaching, 3) increased soil organic matter and water infiltration, 4) improved nutrient recycling, 5) improved water quality, 6) improved soil health, 7) enhanced weed suppression, 8) remediation of saline and sodic soil problems, and 9) increased forage for livestock and wildlife. Establishing cover crops in the region's semi-arid, frigid soils can be challenging. Viable options for planting cover crop seed include: planting after wheat harvest, planting in-season after the critical weed-free period (see Chapter 44), and in the fall, following corn harvest. When deciding to plant cover crops, caution must be used to ensure that cover crops do not void your crop insurance and that your weed-control and cover-crop objectives are aligned.

The purpose of this chapter is to discuss the strengths and weaknesses of including cover crops in South Dakota cropping systems.

Table 15.1 Steps for integrating cover crops into your rotation:
1. Identify specific objectives and agronomic requirements the desired cover crop.
   a. Determine the season(s) when cover crops are desired and fit the rotation.
   b. Determine if the cover crop will exacerbate pest problems.
   c. Determine if herbicides used during the cropping season allow establishment and growth of the chosen cover crops.
2. Select a cover-crop mixture (cocktail) and seeding rates, planting date, and seeding method that are compatible with the applied herbicides and landscape position to obtain the greatest benefits with no loss to the cash crop.
3. Determine costs (e.g., seed, planting, future control, if needed) and expected returns.

If carefully chosen, cover crops will not overwinter and cause problems in the following spring. Herbicides, application timing, and labor costs must be considered if the cover crop does overwinter or produces viable seed.
**Identify Cover-crop Goals**
Successful cover crops require planning and a clear identification of goals (MCCC, 2012; Table 15.2). For example, if the purpose is to utilize excess nutrients, then a cover crop should be established after the cash crop has met most of its nutrient needs. However, if the purpose is to provide cattle forage or increase water filtration, then the cover crop should be seeded as early as possible in the season to maximize fall growth.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Cover-crop species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grazing</td>
<td>turnips, lentils, canola, radish, rye, oat</td>
</tr>
<tr>
<td>Reducing compaction</td>
<td>radish, canola, sugar beets, sunflower, turnip</td>
</tr>
<tr>
<td>Soil moisture management</td>
<td>canola, clover, winter wheat, rye</td>
</tr>
<tr>
<td>N fixation</td>
<td>clovers, vetches, lentils, cowpeas, chickling vetch</td>
</tr>
<tr>
<td>Residue cycling</td>
<td>brassicas (canola, radish, turnips, mustards)</td>
</tr>
<tr>
<td>Nutrient cycling</td>
<td>sunflower, sugar beets, brassicas, small grains</td>
</tr>
<tr>
<td>Salinity remediation</td>
<td>sugar beets, barley, winter or spring canola</td>
</tr>
</tbody>
</table>

**Cover Crops and Compaction**
Cover-crop cocktails that include brassicas (grazing radish) can be used to reduce soil compaction. These plants produce a taproot that can penetrate soils down to 2 feet or more. The plant roots can rapidly decompose leaving large pores in the soil. These old root channels aid in water infiltration and soil aeration, and provide root pathways for following crops.

**Cover Crops and Soil Health**
Cover-crop mixtures can help provide food for beneficial soil organisms such as earthworms, bind the soil together, and speed up the mineralization of crop residues (Fig. 15.2, Ketterings et al., 1997). Crop residues with high C to N ratios such as wheat straw or corn stover generally mineralize slowly, whereas those with low C to N ratios, such as brassicas (e.g. turnips and radishes), peas or soybeans, generally mineralize rapidly. The mineralization rate influences how much of the nitrogen contained in residue will be available to the following crop.

**Soil Residue Cover, Trapping Nutrients and Managing Salts**
When determining a cover-crop blend to plant, 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 low C:N ratios should be seeded. The decomposition rate of surface residues will increase if brassicas are used in the cover-crop mixture.

Cover crops can be useful in salt management by increasing water loss through transpiration instead of evaporation, and reducing capillary movement of water and salts into surface soil. In South Dakota, barley, sugar beets, rape, rye, canola, and western wheatgrass can be seeded into salty soil zones.

**Cover Crops and Rotational Sequences**
Selecting the appropriate cover-crop species and seeding rates is critical for achieving your goals. Mixing multiple species allows for several goals to be addressed by a single planting, and often enhances the opportunity for successful establishment. Care must be taken not to plant at too high a rate, as cover crops can use water needed for the following crop and act as a weed that limits cash-crop yield. If many species are planted together, the rate of each must be evaluated because competition among these plants can impact survival.

In South Dakota, considerable success has been achieved by seeding a cover crop after winter or spring
wheat harvest (typically early to mid-August) that allows for fall growth. In this system, the cover crop is planted after the short-season crop and before next season's corn planting. Care in selecting the cover crop should be taken. Crops such as winter rye or hairy vetch are often suggested, as these plants usually overwinter. However, roller crimping or herbicide application may be required to kill them before corn planting. Another risk is that seed shattering from cover crops that matured in the fall or spring may behave as weeds in the next crop.

Other opportunities for seeding cover crops include following a failed crop (e.g., late spring frost, early fall frost, or hail damage) or after corn’s weed-free period (V6). Our research at SDSU indicates that if cover crops are planted at or just before corn planting, the cover crop can be an ideal weed (Vos, 1999). In this example, even though the cover crop was a legume (annual medic), this species at this planting time outcompeted corn for N, resulting in N-deficiency and a corn-yield loss at the end of the season. However, if a cover crop was planted during the middle or near the end of corn’s critical weed-free period (V6 or later), the cover crop did not reduce the corn yield (Figs. 15.4 and 15.5; Bich et al., 2014).

**Planting Cover Crops**

In SDSU research, drilled and broadcast planting techniques were compared. Drilling the cover crop into the interrow of corn had superior stand establishment and growth compared with any type of broadcast seeding (Figs. 15.3, 15.4, 15.5). Even if rains followed the broadcast application of seed, the seed remained on the soil surface, sprouted, and most died before establishment. Drilled seeds, on the other hand, became well-established and provided green forage in the fall, even though planted in July. In addition, if drilled between rows, the distance from the corn can be maximized to lessen the cover crop’s impact as a weed, whereas broadcast applications are imprecise and may negatively influence corn growth and development.

**Cover-crop Composition: Warm- vs. Cool-Season Plants**

The ideal cover-crop mixture is dependent on the cover-crop goals, weed-control program, planting time, and soil characteristics (Tables 15.4 to 15.8). Cover-crop mixtures need to be developed for each unique situation. For example, cool-season grazing blends often consist of turnips, radishes, and grasses, whereas cowpeas, millet, and sudangrass can be used for warm-season grazing.

Selecting an appropriate seeding mixture is critical. Cover-crop cocktail 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 when temperatures are warm (>80°F). Cool-season broadleaves can be divided into (1) brassicas, and (2) legumes. Cool-season grasses include barley, oats, winter wheat, and rye. In a South Dakota fall, a cool-season cover-crop mixture is often blended with broadleaf and grass species.

Warm-season plants grow best in warm temperatures (soil temperatures > 50°F). 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 bluestem, corn, and sorghum. Warm-season species typically do not tolerate frost and will die quickly as fall temperatures decrease.

**Match Herbicides and Cover Crops**

The use of pre-emergence herbicides with residual activity reduces the germination and growth of cover-crop seeds and seedlings (Table 15.3). For example, if grass herbicide was broadcast-applied in May, it may be difficult to establish hearty stands of rye in August. The solution is planning. Many herbicides have activity for a relative long period of time (Table 15.3). For example, Roundup® (glyphosate) has no residual soil activity and no restrictions to planting any crop after application. In comparison, Maverick (sulfsulfuron) has a long residual activity (22 months), and planting to anything except small-grain crops is not recommended. Matching the herbicide rotation to the desired cover crop is critical for cover-crop success.

<table>
<thead>
<tr>
<th>Herbicide active ingredient</th>
<th>Trade name or premix name</th>
<th>Examples of rotational crop restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrazine</td>
<td>Aatrex</td>
<td>Second cropping season after application alfalfa, canola, beans, wheat, flax, lupines, oat, peas, rye, sugar beet</td>
</tr>
<tr>
<td></td>
<td>Premix products with similar restrictions as atrazine: Buctril + atrazine; Bullet; Degree Extra; Expert; Field Master; Fultime; Guardsman; Harness Xtra; Keystone Premix types; Lumax; Marksmans; Shotgun</td>
<td></td>
</tr>
<tr>
<td>Clopyralid; flumetsulam; nicosulfuron; rimfulsuron</td>
<td>Accent Gold</td>
<td>26 months – canola, lupines, flax, sugar beet 18 months – sunflower 10 months – alfalfa, bean, pea 8 months – barley, spring wheat, oat, rye 4 months – winter wheat</td>
</tr>
<tr>
<td>Rimfulsuron; nicosulfuron</td>
<td>Basis</td>
<td>18 months – alfalfa, canola, flax, pea, sugar beet 10 months – bean, sunflower 9 months – barley, spring wheat, oat 4 months – rye, winter wheat</td>
</tr>
<tr>
<td>Rimfulsuron; nicosulfuron; atrazine</td>
<td>Basis Gold</td>
<td>18 months – alfalfa, barley, canola, bean, wheat, flax, lupines, oat, pea, rye, sugar beet</td>
</tr>
<tr>
<td>Atrazine; s-metolachlor</td>
<td>Bicep Lite II Magnum</td>
<td>Second cropping season – alfalfa, barley, bean, lupines, oat, pea, rye, spring wheat, sugar beet 15 months – canola, flax, winter wheat</td>
</tr>
<tr>
<td>s-metolachlor; mesotrione</td>
<td>Camix</td>
<td>Next cropping season – barley, oat, rye 18 months – alfalfa, canola, bean, flax, lupine, pea, sugar beet 4.5 months – winter and spring wheat</td>
</tr>
</tbody>
</table>
### Table 15.3 Examples of rotational crop restrictions; see individual product label for full details. Trade names are provided for the reader’s convenience; products with other trade names may contain the same or similar active ingredients. Always read and follow label directions. (Adapted from University of Minnesota Applied Weed Science Research, www.appliedweeds.cfans.umn.edu., accessed 12/14)

<table>
<thead>
<tr>
<th>Herbicide Combination</th>
<th>Trade Name</th>
<th>Rotational Crop Restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diflufenopyr; dicamba; nicosulfuron</td>
<td>Celebrity Plus</td>
<td>Dependent on soil pH and rainfall; generally 10 to 18 months for crops</td>
</tr>
<tr>
<td>Diflufenopyr; dicamba</td>
<td>Distinct</td>
<td>One month – alfalfa, barley, canola, bean, flax, lupine, oat, pea, rye, sugar beet</td>
</tr>
<tr>
<td>Foramsulfuron; iodosulfuron</td>
<td>Equip</td>
<td>18 months – alfalfa, canola, bean, flax, lupine, pea, rye 8 or 9 months – barley, wheat, oat, spring wheat, sugar beet 2 months – winter wheat</td>
</tr>
<tr>
<td>acetochlor</td>
<td>Harness</td>
<td>(see atrazine restrictions)</td>
</tr>
<tr>
<td>Clopyralid; flumetsulam</td>
<td>Hornet</td>
<td>(see Accent Gold above)</td>
</tr>
<tr>
<td>Acetochlor; atrazine</td>
<td>Keystone premixes</td>
<td>(see atrazine restrictions)</td>
</tr>
<tr>
<td>Bentazon; atrazine</td>
<td>Laddok</td>
<td>(see atrazine restrictions)</td>
</tr>
<tr>
<td>Imaclathapyr; imazapyr</td>
<td>Lightening</td>
<td>40 months – canola, sugar beet 18 months – oat 9.5 months – alfalfa, barley, bean, lupine, pea 4 months – rye, wheat ‘other restrictions apply, see label for details</td>
</tr>
<tr>
<td>s-metolachlor; mesotrione; atrazine</td>
<td>Lumax</td>
<td>(see atrazine restrictions)</td>
</tr>
<tr>
<td>Dicamba; atrazine</td>
<td>Marksman</td>
<td>(see atrazine restrictions)</td>
</tr>
<tr>
<td>Primisulfuron; dicamba</td>
<td>Northstar</td>
<td>18 months – canola, flax, lupine, sugar beet 8 months- alfalfa, barley, oat, pea, spring wheat 3 months – rye, winter wheat</td>
</tr>
<tr>
<td>Atrazine; 2,4-D</td>
<td>Shotgun</td>
<td>(see atrazine restrictions)</td>
</tr>
<tr>
<td>Nicosulfuron; rimsulfuron</td>
<td>Steadfast</td>
<td>10 months – alfalfa, canola, bean, lupine, pea 8 months – barley, spring wheat, oat, rye 4 months – winter wheat</td>
</tr>
<tr>
<td>Nicosulfuron; rimsulfuron; atrazine</td>
<td>Steadfast ATZ</td>
<td>18 months – barley, canola, bean, flax, lupine, oat, pea, rye, spring wheat, sugar beet 10 months – alfalfa, winter wheat</td>
</tr>
<tr>
<td>Halosulfuron; dicamba</td>
<td>Yukon</td>
<td>36 months – sugar beet 15 months – canola 9 months – alfalfa, lupine, pea 2 months – barley, bean, oat, spring wheat, winter wheat</td>
</tr>
</tbody>
</table>

### Table 15.4. Cover-crop blends for grazing. (Revised from Jason Miller, NRCS, Pierre, SD)

<table>
<thead>
<tr>
<th>Grazing blend</th>
<th>Type</th>
<th>Full rate</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Grazing warm</th>
<th>Season</th>
<th>Grazing compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lentils</td>
<td>Cool/broad</td>
<td>30</td>
<td>30</td>
<td>9</td>
<td>40</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Turnip</td>
<td>Cool/broad</td>
<td>4</td>
<td>30</td>
<td>1.2</td>
<td>30</td>
<td>1.2</td>
<td>20</td>
</tr>
<tr>
<td>Radish</td>
<td>Cool/broad</td>
<td>8</td>
<td>10</td>
<td>0.8</td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>Cool/broad</td>
<td>5</td>
<td></td>
<td>30</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oat</td>
<td>Cool/broad</td>
<td>70</td>
<td>30</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copea</td>
<td>Warm/broad</td>
<td>30</td>
<td></td>
<td>40</td>
<td>12</td>
<td>30</td>
<td>9</td>
</tr>
<tr>
<td>Millet</td>
<td>Warm/broad</td>
<td>25</td>
<td></td>
<td>60</td>
<td>15</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Sudangrass</td>
<td>Warm/broad</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>5</td>
</tr>
</tbody>
</table>
Table 15.5 Cover crops that may aid in reducing compaction. (Revised from Jason Miller, NRCS, Pierre, SD)

<table>
<thead>
<tr>
<th>Grazing blend</th>
<th>Type</th>
<th>Full rate</th>
<th>Compaction</th>
<th>Grazing/comp.</th>
<th>Residue/comp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td></td>
<td>lbs/a</td>
<td>lbs/a</td>
<td>lbs/a</td>
<td>lbs/a</td>
</tr>
<tr>
<td>Lentils</td>
<td>Cool/broad</td>
<td>30</td>
<td>9</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Radish</td>
<td>Cool/broad</td>
<td>8</td>
<td>4.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canola</td>
<td>Cool/broad</td>
<td>5</td>
<td>0.5</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>Cowpea</td>
<td>Warm/broad</td>
<td>30</td>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Millet</td>
<td>Warm/broad</td>
<td>25</td>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Sudangrass</td>
<td>Warm/broad</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turnip</td>
<td>Cool/broad</td>
<td>4</td>
<td>1.2</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

Table 15.6 Cover crops that may enhance residue-cycling compaction. (Revised from Jason Miller, NRCS, Pierre, SD)

<table>
<thead>
<tr>
<th>Grazing blend</th>
<th>Type</th>
<th>Full rate</th>
<th>Residue cycling</th>
<th>Compaction present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td></td>
<td>lbs/a</td>
<td>lbs/a</td>
<td>lbs/a</td>
</tr>
<tr>
<td>Lentils</td>
<td>Cool/broad</td>
<td>30</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Canola</td>
<td>Cool/broad</td>
<td>5</td>
<td>2.5</td>
<td>2</td>
</tr>
<tr>
<td>Radish</td>
<td>Cool/broad</td>
<td>8</td>
<td></td>
<td>2.4</td>
</tr>
</tbody>
</table>

Table 15.7 Cover crops that may potentially germinate under saline conditions. (Revised from Jason Miller, NRCS, Pierre, SD)

<table>
<thead>
<tr>
<th>Grazing blend</th>
<th>Type</th>
<th>Full rate</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td></td>
<td>lbs/a</td>
<td>lbs/a</td>
<td>lbs/a</td>
<td>lbs/a</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>Cool/broad</td>
<td>4</td>
<td>2</td>
<td>2.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Barley</td>
<td>Cool/broad</td>
<td>50</td>
<td>25</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Canola</td>
<td>Cool/broad</td>
<td>5</td>
<td></td>
<td>2</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 15.8 Cover crops that may reduce soil moisture and enhance nitrogen cycling. (Revised from Jason Miller, NRCS, Pierre, SD)

<table>
<thead>
<tr>
<th>Grazing blend</th>
<th>Type</th>
<th>Full rate</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td></td>
<td>lbs/a</td>
<td>lbs/a</td>
<td>lbs/a</td>
<td>lbs/a</td>
</tr>
<tr>
<td>Hairy vetch</td>
<td>Cool Broad</td>
<td>15</td>
<td>7.5</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>Canola</td>
<td>Cool Broad</td>
<td>5</td>
<td></td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>Rye</td>
<td>Cool grass</td>
<td>100</td>
<td>50</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Triticale</td>
<td>Cool grass</td>
<td>60</td>
<td></td>
<td></td>
<td>30</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 that grows under wet soil conditions and tends to grow better in heavy clay soils than cereal rye, whereas cereal rye grows better in well- to moderately well-drained sites.

Cereal and annual rye overwinter like winter wheat. The major problems with cereal rye are that if excessive spring growth is not controlled: 1) soil moisture can be depleted, and 2) it can produce stands up to 6 feet tall, which may be too much biomass for no-till planting. Typically, herbicide is used in spring to burn down annual rye when its growth is 8 to 16 inches tall. However, during cool spring weather, glyphosate may have limited effectiveness against annual rye. Under these conditions, annual rye seeds can become a future weed problem.

Cover crops may reduce available moisture for the cash crop, but they also increase water infiltration and snow catch. Depending on the situation, our research suggests that they can reduce or increase available moisture for the row crop. Cover crops increase plant diversity, which can in turn increase soil biological diversity. Depending on which species is seeded, cover crops may increase or decrease mycorrhizae (Fig. 15.6).

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.

References and Additional Information


Acknowledgements
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Washington, D.C. 20250-9410;

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Soil information is used for a multitude of decisions including determining fertilizer rates, identifying soil characteristics linked to specific pest problems, identifying areas prone to moisture stress, and identifying areas with poor drainage. The purpose of this chapter is to provide a hands-on example on how to integrate Web Soil Survey (WSS) information into the decision process.

Introduction

In this rapidly changing world, technological advances (e.g., precision farming methods, smartphones, tablets, iPads, apps of various kinds, and Internet sources) allow resource managers to rapidly inventory the soil resource using the USDA-NRCS Web Soil Survey. Web Soil Survey (WSS) is a powerful, user-friendly search engine for obtaining modern, detailed soil survey information. The most recent WSS version 3.1 was released in December 2013. An online tutorial and written directions are available (Malo, 2008; 2012; 2013). Visual and tabular information can be obtained from WSS. The basic steps in using WSS include defining your area of interest, creating a soil map for the area of interest, exploring soil suitabilities, and developing a customized map.

Step 1 – Define Area of Interest (AOI)

The AOI is used by WSS to generate tabular and visual data for use in later steps. First, identify and define the AOI where information about a field, farm, or parcel of land is needed. The AOI can be located using the various Quick Navigation options or the Interactive Map option (Fig. 16.2) in the WSS navigation window or imported from a previous session. When using the Quick Navigation option, you can locate your AOI by entering any one of the following:

1. Local street address.
2. State and county identification.
3. Soil survey area.
4. Longitude and latitude.
5. Legal land description (PLSS – section, town, and range. Remember to select the proper Principal Meridian (PM), if needed, for your AOI. Use the drop-down menus in the program to assist you in picking the proper PM [Fig. 16.3]).
6. Other data sources such as the Bureau of Land Management Field Office (BLM), Defense Department Installation (DOD), US Forest Service (USFS), National Park Service (NPS), or Hydrologic Unit (HU) Code (8-digit code).

If you cannot use the Quick Navigation options, items 1-6 above, then use the Interactive Map on the home page (Fig. 16.2) to find your AOI.

Once the AOI has been located, the boundaries of the AOI need to be entered into the WSS application. Select one of the two boundary buttons. The left button allows you to identify the AOI boundaries using a rectangular box, while the right button allows you to use polygons (Fig. 16.3). Once the AOI has been outlined, double-click to electronically define and enter the AOI into WSS. After the AOI is defined and accepted, the area (in acres), availability of soil data/maps, and an aerial photo of the AOI are provided (Fig. 16.4).

Step 2 – Create Soil Map for AOI
WSS allows users to view and print the soil map of the AOI selected. Answers to selected questions regarding the interactive map functions are available by going to websoilsurvey.sc.egov.usda.gov and clicking on Frequently Asked Questions (see Interactive Map section). Click on the Soil Map tab at the top of the WSS webpage to create a modern, detailed soil survey map (Fig. 16.5). The information available includes: 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. 16.6) includes:
1. MU setting – elevation, annual precipitation, average annual temperature, frost-free period (days), and farmland classification (e.g., prime or unique).
2. MU composition – lists all the major and minor soil units with their composition percentage.
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. Typical profile horizon names, thicknesses, depths, and textures.
   c. Selected soil properties and qualities – percent slope, restrictive layers, drainage class, permeability, depth to water table, flooding and ponding frequency, lime (calcium carbonate) content, salinity (electrical conductivity [EC]), sodium adsorption ratio (SAR), and profile plant available water holding capacity.
   d. Interpretive groups – Land Capability Classification, Hydrologic Soil Group, Ecological Site (formerly Range Site), and Other Vegetative Groups (e.g., Forage Suitability Groups).
4. A brief description of each minor MU component – explains how the minor soil differs from the named major MU component(s).

If you would like to copy 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. 16.7). There are two options, Printable Version or Add to Shopping Cart. The Printable Version allows you to download a PDF of the soil map and associated documentation. The Add to Shopping Cart adds the soil map to a file and saves the file until you are done with your WSS session. The customized AOI web-based soil survey report, including the soil map with other maps and tables, can be printed. Note that when either the Printable Version or the Add to Shopping Cart button is selected, it will fade.

Step 3 – Explore Soil Suitabilities/Limitations/Properties and Characteristics for AOI
Once the AOI is identified, the soil map is prepared and you can explore and assess the suitability and
Figure 16.2 Web Soil Survey's AOI selection window, showing Quick Navigation and Interactive Map options.

Figure 16.3 Using the WSS legal land description section in the Quick Navigation tool for locating AOI. The 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.

Figure 16.4 Web Soil Survey's AOI selection window with the AOI defined as the cross-hatched area.

Figure 16.5 Web Soil Survey's Soil Map for the AOI information.

Figure 16.6 Sample WSS Map Unit Description, obtained by clicking on the Map Unit Name, e.g., Z157A, Fairdale loam.

Figure 16.7 Location of Printable Version tab and Add to Shopping Cart tab in upper right-hand corner of WSS window. The 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.
limitations of soils for selected uses. Maps and tables of selected soil physical/chemical properties and characteristics, as well as land productivity information, are available. Answers to selected questions on the Soil Data Explorer are available by going to websoilsurvey.sc.egov.usda.gov and clicking on Frequently Asked Questions (see the Soil Data Explorer section). To look at various soil properties, qualities, and uses (Suitabilities and Limitations), select the Soil Data Explorer tab at the top of the webpage (Fig. 16.8). A new window appears giving you the following options:

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

Select the Suitabilities and Limitations for Use tab and a drop-down list appears on the left side of the webpage window (Fig. 16.8). If you click the Open All button, all the options for each category (e.g., Land Classifications, Sanitary Facilities, Vegetative Productivity, etc.) will be displayed. The categories of Land Classification, Land Management, Vegetative Productivity, Waste Management, and Water Management are most commonly used for agricultural production and management decisions. Crop-yield estimates can be obtained by using the actual crop-yield data for those states having actual crop-yield data or by using the Crop Productivity Index (CPI) data. In this paper, we will use the CPI data. The CPI values are assigned relative soil potential rankings (0-100) for intensive crop production. The CPI ratings are based on the following assumptions:

1. Adequate management.
2. Natural weather conditions (no irrigation).
3. Drainage installed where needed.
4. No frequent flooding in low-lying areas.
5. No leveling or terracing employed.
6. CPI values will remain constant with time.

The CPI rating map and tabular data are shown, respectively, in Figures 16.9 and 16.10. The potential corn yield can be estimated by multiplying soil-specific digital CPI by a specific crop high yield.

Example: Soil is Z181A – Brandt silty clay loam with CPI of 85.
Brookings County, SD high corn yield estimate = 200 bu/a
Estimated corn yield for Brandt soil = 200 bu/a x (85/100) = 170 bu/a

For each soil suitability or limitation listed, the dominant condition within the soil mapping unit (MU), the dominant soil within a MU, all components of a MU, and weighted average of all components within a MU are available.

In addition to soil suitabilities and limitations for land use, there is a tab for Soil Properties and Qualities at the top of the webpage (Fig. 16.11). If the Soil Properties and Qualities tab is selected, a drop-down list with various categories (e.g., 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 soil mapping unit (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 also can select the soil-depth range, e.g., surface, part of a profile, or all of a profile (Advanced Options, Fig. 16.12). Many different options are available for viewing soil property maps (Fig. 16.13) and tables (Fig. 16.14). The single-purpose maps, associated legends, description information, and other related materials can be printed by using the Printable Version tab or Add to Shopping Cart tab in the upper right-hand corner of the webpage window. Note that the tabs in the Add to Shopping Cart area fade when selected. When the report becomes large (> 8 MB), the NRCS will send you the report by email as a PDF file after it is created.
Figure 16.8 The WSS Suitabilities and Limitations for Use window with drop-down list on the left. If you want all options to be visible in the drop-down area, click the Open All button.

Figure 16.9 Sample WSS Soil Data Explorer window for the Suitabilities and Limitations for Use tab (Crop Productivity Index, CPI) for the AOI, right, and legend, left. Note: click the Legend tab to cause the suitability Map Legend to appear. To estimate a crop yield (e.g., corn) for each soil MU, multiply the top yield in the county by the CPI value.

Figure 16.10 Sample WSS Soil Data Explorer yield table and descriptive information for Crop Productivity Index (CPI) map created in Figure 16.9. This information is located below (scroll down) the CPI map.

Figure 16.11 The WSS Soil Properties and Qualities window with drop-down list on the left. If you want all options to be visible in the drop-down area, click the Open All button.

Figure 16.12 WSS View Options and Advanced Options in the drop-down list of the Soil Properties and Qualities window.

Figure 16.13 Sample WSS Soil Data Explorer window, showing the Soil Properties and Qualities tab and Surface Soil pH for the AOI, right, and Map Legend, left. Note: click the Legend tab to cause the Soil Property Map Legend to appear.
The fourth tab in the Soil Data Explorer window, Ecological Site Assessment, provides ecological site information (Fig. 16.15). This information includes an ecological site assessment map and associated tabular data for the AOI including MU name, MU components (percentage of MU), ecological site ID for each component, and detailed information about each ecological site.

The ecological site information for rangeland is available. For selected counties, ecological sites for pasture groups are also provided. The information given for a rangeland ecological site includes: a photo of the plant communities, a brief ecological site description and impacts of management on species (composition and abundance), and a transition diagram illustrating the impact of management on the plant communities in the ecological site (Fig. 16.16). Within each ecological site various plant communities are further explained (e.g., community description, management impacts, production total, species identification, species productivity, and plant growth curves) relative to the impact of management on plant communities in this ecological site.

In addition to the interpretive maps, tabular data for the AOI can be downloaded (Fig. 16.17). Tabular data is available when you use the Soil Reports tab in the Soil Data Explorer window. 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. An explanation as to what is contained in each table can be viewed using the View Description tab or View Soil Report tab on the left side of the window. This information can be printed or saved 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 webpage window.

**Step 4 – Create Custom Soil Survey Report for Area of Interest (AOI)**

Electronically store and/or print the available data generated by the WSS session using the Shopping Cart and Checkout Option tabs. Answers to selected questions concerning data downloads and printable reports are available by going to websoilsurvey.sc.egov.usda.gov and clicking on Frequently Asked Questions (see the Data Downloads and Printable Maps and Reports sections).

After creating all the maps and tables needed and saving them to the Add to Shopping Cart tab, you need to click on the Shopping Cart tab at the top center of the webpage (Fig. 16.18). This option allows you to create your own 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 Table of Contents, select the Checkout Options tab (upper right-hand corner of window).

For small reports (< 8 MB), a Checkout 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.

**Use and Limitation of Web Soil Survey (WSS) Information**

Web Soil Survey (WSS) information is useful in understanding how soils differ and will perform under various land-management systems. Examination of key soil-property and quality-attribute information can aid you in making management decisions.

You can manage soil resources more economically and with increased environmental sustainability using detailed WSS soil-survey data along with yield-monitor maps. Producers can integrate WSS data with yield-monitor and other collected on-site data (Reitsma and Malo, 2011). One key point to remember is that many soil maps in WSS were originally prepared at a scale of 1:20,000 and 1:24,000. As a result, the soil interpretations included inside a soil mapping-unit (MU) boundary have limitations.

The smallest delineation that can be shown on modern soil-survey maps in South Dakota, for example, is about 2 acres. Areas smaller than 2 acres are not shown on the map. Most soil MU descriptions include descriptions of these inclusions to let the user know that these other soils exist in the soil MU.
Figure 16.14 Sample WSS Soil Data Explorer tab, showing soil properties and qualities ratings and descriptive information for surface pH for map created in Figure 16.13. This information is located below (scroll down) the pH map.

Figure 16.15 Sample WSS Soil Data Explorer window, showing Ecological Site Assessment tab (Dominant Ecological Site-Rangeland) for AOI, right, and Map Legend, left. Note: click the Legend tab to cause the Ecological Site - Rangeland Map Legend to appear.

Figure 16.16 Sample WSS Soil Data Explorer Ecological Site Assessment information (Plant Community Transition Diagram) for selected ecological site (e.g., Linear Meadow) for AOI created in Figure 16.15. This information appears when each ecological site is selected in the left-hand set of drop-down boxes. The diagram on the left shows management impacts on native plant communities.

Figure 16.17 Sample WSS Soil Data Explorer window, showing 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 button. Example: drop-down box for Non-irrigated Yields by Map Unit is shown. Selected crops for table creation are checked.

Figure 16.18 Sample WSS Soil Shopping Cart window with the Checkout Options tab selected (upper right-hand corner).
For intensive management of areas smaller than 2 acres, a more detailed soil map is needed. The soil MUs in WSS allow the user to develop field zones where sound management decisions can be made. With modern GPS, soil-survey data, yield-monitoring data, and scouting reports, it may be possible to increase profitability and reduce the impact of agriculture on the environment.

**Conclusions**

This chapter outlines how to use Web Soil Survey (WSS) to obtain soil and land-attribute information. Samples of output and WSS 3.1 and a listing of other websites with valuable soil and natural resource information are provided (Table 16.1).

<table>
<thead>
<tr>
<th>Name</th>
<th>Information available</th>
<th>Web address (verified 25 June 2015)</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Fact Finder (US Census Bureau)</td>
<td>Source of population, housing, economic, and geographic data by state, town, county, or zip code area</td>
<td><a href="http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml">http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml</a></td>
</tr>
<tr>
<td>California Soil Resource Lab</td>
<td>Soil survey data, soil web apps</td>
<td><a href="http://casoilresource.lawr.ucdavis.edu">http://casoilresource.lawr.ucdavis.edu</a></td>
</tr>
<tr>
<td>Canada Centre for Mapping and Earth Observation</td>
<td>General remote sensing information and educational materials</td>
<td><a href="http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/9271">http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/9271</a></td>
</tr>
<tr>
<td>Current Research Information System (CRIS)</td>
<td>Current agricultural research results and publications</td>
<td><a href="http://cris.nifa.usda.gov/">http://cris.nifa.usda.gov/</a></td>
</tr>
<tr>
<td>EROS Data Center (USGS)</td>
<td>Home page, satellite and aerial images, research projects and programs</td>
<td><a href="http://eros.usgs.gov/">http://eros.usgs.gov/</a></td>
</tr>
<tr>
<td>Google Maps/Google Earth</td>
<td>Various maps of US in 2 and 3 dimensions</td>
<td><a href="http://maps.google.com/">http://maps.google.com/</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="https://www.google.com/earth/">https://www.google.com/earth/</a></td>
</tr>
<tr>
<td>iGrow (SDSU Extension Service and ABS College)</td>
<td>Production and management information</td>
<td><a href="http://igrow.org/">http://igrow.org/</a></td>
</tr>
<tr>
<td>National Agricultural Statistics Service</td>
<td>Agricultural statistics for state and county</td>
<td><a href="http://www.nass.usda.gov/">http://www.nass.usda.gov/</a></td>
</tr>
<tr>
<td>National Institute of Food and Agriculture (NIFA)</td>
<td>USDA NIFA Home page and agricultural research information</td>
<td><a href="http://nifa.usda.gov/">http://nifa.usda.gov/</a></td>
</tr>
<tr>
<td>NRCS – Major Land Resource Areas (MLRAs)</td>
<td>Physiography, geology, climate, water resources, soils, biological resources, and kinds of land use</td>
<td><a href="http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref?cid=nrcs142p2_053624#handbook">http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref?cid=nrcs142p2_053624#handbook</a></td>
</tr>
</tbody>
</table>

Table 16.1 Online sources of soil and natural resources information. These locations are provided for the convenience of the reader, however, locations frequently change.
Table 16.1 Online sources of soil and natural resources information. These locations are provided for the convenience of the reader, however, locations frequently change.

<table>
<thead>
<tr>
<th>Name</th>
<th>Information available</th>
<th>Web address (verified 25 June 2015)</th>
</tr>
</thead>
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<tr>
<td>NRCS – National Centers</td>
<td>National NRCS Centers (e.g., Water + Climate, Soil Survey, Agroforestry, and others)</td>
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</tr>
<tr>
<td>NRCS – National Water and Climate Center</td>
<td>Climate and water conservation planning information</td>
<td><a href="http://www.wcc.nrcs.usda.gov/">http://www.wcc.nrcs.usda.gov/</a></td>
</tr>
<tr>
<td>NRCS – Offices/Centers</td>
<td>State and county office location and address information</td>
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</tr>
<tr>
<td>NRCS – Soil Data Mart</td>
<td>Soil physical, chemical, and characterization data</td>
<td><a href="http://ncsslabdatamart.sc.egov.usda.gov/">http://ncsslabdatamart.sc.egov.usda.gov/</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="http://sdmdataaccess.nrcs.usda.gov/">http://sdmdataaccess.nrcs.usda.gov/</a></td>
</tr>
<tr>
<td>NRCS - Soils</td>
<td>Home page, soil classification, lab data</td>
<td><a href="http://www.nrcs.usda.gov/wps/portal/nrcs/site/soils/home/">http://www.nrcs.usda.gov/wps/portal/nrcs/site/soils/home/</a></td>
</tr>
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<td>NOAA</td>
<td>Weather data, drought monitoring, current conditions</td>
<td><a href="http://www.weather.gov/">http://www.weather.gov/</a></td>
</tr>
<tr>
<td>Service Center Locator (USDA)</td>
<td>Service Center locator and contact information</td>
<td><a href="http://offices.sc.egov.usda.gov/locator/app">http://offices.sc.egov.usda.gov/locator/app</a></td>
</tr>
<tr>
<td>Site Specific Management Guide</td>
<td>Site specific management for agriculture</td>
<td><a href="http://www.ipni.net/ssmg">http://www.ipni.net/ssmg</a></td>
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<td>Soil Orders</td>
<td>Images of 12 soil orders</td>
<td><a href="http://soils.cals.uidaho.edu/soilorders/">http://soils.cals.uidaho.edu/soilorders/</a></td>
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<tr>
<td>US Forest Service</td>
<td>Home page</td>
<td><a href="http://www.fs.fed.us/">http://www.fs.fed.us/</a></td>
</tr>
<tr>
<td>Abbreviations</td>
<td>Description</td>
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<tr>
<td>-------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>1:1 – one part soil to 1 part water</td>
<td>MU – soil mapping unit</td>
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<tr>
<td>AOI – area of interest</td>
<td>NCCPI – National Commodity Crop Productivity Index</td>
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<tr>
<td>BLM – Bureau of Land Management</td>
<td>NIFA – National Institute of Food and Agriculture</td>
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<tr>
<td>CaCO₃ – calcium carbonate (lime)</td>
<td>NIMSS – National Information Management and Support System</td>
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<tr>
<td>CEC – cation exchange capacity</td>
<td>NOAA – National Oceanic and Atmospheric Administration</td>
<td></td>
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<tr>
<td>cm – centimeter</td>
<td>NPS – National Park Service</td>
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<tr>
<td>CRIS – Current Research Information System</td>
<td>NRCS – Natural Resources Conservation Service (formerly the SCS)</td>
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<tr>
<td>CPI – Crop Productivity Index</td>
<td>PAW – plant available water holding capacity</td>
<td></td>
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<tr>
<td>dS/m – deciSiemen per meter (measure of electrical conductivity)</td>
<td>Pct, pct – percent</td>
<td></td>
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<tr>
<td>EC – electrical conductivity (soil salinity measurement)</td>
<td>PDF – portable document format</td>
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<tr>
<td>EROS – Earth Resources Observation Satellite</td>
<td>pH – soil reaction</td>
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<tr>
<td>GIS – geographic information systems</td>
<td>PM – principal meridian</td>
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<tr>
<td>GPS – global positioning system</td>
<td>RUSLE2 – Revised Universal Soil Loss Equation</td>
<td></td>
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<tr>
<td>HU – hydrologic unit</td>
<td>SAR – sodium adsorption ratio</td>
<td></td>
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<tr>
<td>K factor – soil erodibility (soils inherent susceptibility to water erosion)</td>
<td>SCS – Soil Conservation Service (now the NRCS)</td>
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<tr>
<td>kml – keyhole markup language</td>
<td>T value – tolerable soil loss (maximum amount of soil loss by wind and water and not decrease long-term productivity</td>
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</tr>
<tr>
<td>Ksat – saturated soil hydraulic conductivity</td>
<td>USDA – United States Department of Agriculture</td>
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<tr>
<td>MLRA – Major Land Resource Area</td>
<td>USDOI – United States Department of Interior</td>
<td></td>
</tr>
<tr>
<td>MB – megabyte</td>
<td>USFS – United States Forest Service</td>
<td></td>
</tr>
<tr>
<td>meq/100g – milliequivalents per 100g (measure of cation exchange capacity), 1 meq/100g = 1 cmolc /kg</td>
<td>USGS – United States Geological Survey</td>
<td></td>
</tr>
<tr>
<td>mmhos/cm – millimhos per centimeter (measure of electrical conductivity), 1 mmhos/cm = 1 dS/m</td>
<td>WSS – Web Soil Survey</td>
<td></td>
</tr>
<tr>
<td>mm – millimeter</td>
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References and Additional Information


Acknowledgements

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(1) mail: U.S. Department of Agriculture
Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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The SoilWeb app is a new approach for obtaining digital soils information. This program can be accessed online at casoilresource.lawr.ucdavis.edu (click on SoilWeb Apps). The purpose of this chapter is to provide a hands-on example on how to access SoilWeb (SWA) information (Fig. 17.1).

Introduction
Digital soils information can be obtained from the USDA-NRCS Web Soil Survey (WSS) website (websoilsurvey.sc.egov.usda.gov) and the University of California Davis, California Soil Resource Lab (casoilresource.lawr.ucdavis.edu/soilweb-apps/). The SoilWeb app (SWA) works on desktop computers, tablets, iPads, or smartphones. Other apps that are available at this website include: 1) SoilWeb Earth, 2) SEE: Soil Series Extent Explorer, and 3) Soil Properties. These websites are regularly updated with new options, features, and data.

SoilWeb Application (SWA)
SoilWeb (SWA) provides detailed information about the soil map units and their components (casoilresource.lawr.ucdavis.edu/gmap/). Figure 17.2 shows the startup window for SWA. To select an area to study, use the drop-down menu found in the upper left-hand corner of the page (Fig. 17.3). Select Zoom to Location and another drop-down box appears. You can select either your present location or enter a location using: 1) complete address, 2) city and state, 3) zip code, 4) landmark, or 5) latitude and longitude. Once the map appears, it can be

Figure 17.1 SoilWeb Apps home page (casoilresource.lawr.ucdavis.edu/soilweb-apps/).

Figure 17.2 Opening page of SoilWeb application. Note the drop-down options in the upper left-hand corner of the page when the Menu button is clicked.
moved (left, right, up, down, or diagonally) by holding down the left button on your mouse and moving the cursor to the location of your study site.

The map background can be changed by selecting Map Settings from the Menu. Another drop-down list appears, offering the following map types: 1) satellite image, 2) a highway-only image, 3) a hybrid (satellite and highway) view, or 4) a terrain image (Fig. 17.4). Selections can be saved for the next session (Fig. 17.4). The Menu’s Help tab provides a list of soil survey terms employed in the website and their definitions (Fig. 17.5).

Once the image background and location is determined, the latitude and longitude values of specific points are determined by moving the mouse cursor (+) to the desired location. You can zoom in or out by using the features (e.g., rotary wheel or other) of your mouse. At the bottom right-hand corner of the image the latitude and longitude information for the + is provided (Fig. 17.6).

To obtain soils information for a specific study area, double-click the cursor and a red circle with a white x will appear, and the soil mapping unit (MU) information at that specific location is displayed on the left side of the image (Fig. 17.7). The soil (MU) information available includes: MU name; MU symbol and surface texture; MU composition (what soils are present); MU slope and flooding or ponding; and MU data (type, farmland classification, plant available water holding capacity for 0 to 100 cm depth, flooding frequency, drainage class [dominant condition, wettest component], % hydric soils, water table depth [maximum and minimum], minimum bedrock depth, and source of the soils data). Additional information on a soil term or property can be obtained by clicking on a blue button containing a question mark (Fig. 17.7).

Click on a soil name under the Map Unit Composition tab to obtain specific information about a map unit component. A drop-down list appears with additional information about each soil (Fig. 17.8). The soils information available under the soil series selected (Brandt series) tab includes:

1. Soil Data Explorer – this link provides soil series information for the selected soil (Fig. 17.9). The information available includes: official series description, available lab data {e.g., % sand, % silt, % clay, bulk density, % total carbon, % organic carbon, % organic matter, pH, base saturation, CEC [cation exchange capacity], % gypsum, % CaCO$_3$ [lime], SAR [sodium adsorption ratio], and others} (Fig. 17.10), component and series associations (Fig. 17.11), block diagrams of typical landscapes (Fig. 17.12), a listing of the soil mapping units where the selected soil is dominant (Fig. 17.13), and a visual map of where the selected soil is found in the US (Fig. 17.14).

2. Soil profiles
   a) Profile sketch – visual image of the typical profile including horizons and depths.
   b) Selected soil property values are graphically shown by soil depth: % organic matter (Figs. 17.15 and 17.16 [shows help information]), % clay, % sand (Fig. 17.17), Ksat (saturated hydraulic conductivity or permeability), K factor (soil erodibility), pH by water, EC (electrical conductivity, salinity), SAR (sodium adsorption ratio), % CaCO$_3$ (lime content), % gypsum, CEC (cation exchange capacity at pH 7.0), linear extensibility % (shrink-swell potential), and data source.

Additional information about the selected soil can be found in the Soil Taxonomy, Land Classification, Hydraulic and Erosion Ratings, and Soil Suitability Ratings sections in the drop-down list (Fig. 17.18). The information available under the Soil Taxonomy tab includes: order, suborder, great group, subgroup, family, series, and source of the data. The information available in the Land Classification tab includes: Land Capability Class (irrigated and nonirrigated), Ecological Site Description (Fig. 17.19), and Forage Suitability Group. In the Soil Suitability Ratings tab (Fig. 17.18) information can be obtained about Waste Related (manure, food-processing waste, and wastewater), Engineering (e.g., construction materials, septic-tank filter fields, roads and excavations, shallow excavations, dwellings, commercial buildings, lawns, landscaping, landfills), Irrigation (ponds, dikes, irrigation methods, water management, and pond reservoirs [Fig. 17.20]), Urban Recreational (camps, picnic areas, paths/trails, playgrounds, and off-road motorcycle trails), Wildlife, and Runoff. NOTE – Not all states, counties, or areas will have data for all options within a category.
Figure 17.3 Zoom To Location options available from the Menu in SWA.

Figure 17.4 Map Settings options accessed via the SoilWeb Menu.

Figure 17.5 Soil Survey Definitions accessed via the Help tab in the SoilWeb Menu.

Figure 17.6 SoilWeb application image for Section 24, T110N, R50W, Brookings County, SD. The cross (+) location (latitude and longitude) is shown in lower right-hand corner.

Figure 17.7 Soil Mapping Unit drop-down list for site located (red spot with a white x) in SoilWeb application.

Figure 17.8 Soil profile sketch in the drop-down list for Brandt soil in map unit Z181A in SoilWeb application.
Figure 17.9 Soil Data Explorer page for Brandt soil in map unit Z181A in SoilWeb application. The page opens with the Official Series Description.

Figure 17.10 Lab data available for Brandt soil in map unit Z181A in SoilWeb application. There are three pedons of data available.

Figure 17.11 Soil Series Association profile sketches for the Brandt series in map unit Z181A in SoilWeb application.

Figure 17.12 Sample block diagram available from SoilWeb, Soil Data Explorer option.

Figure 17.13 List of soil map units in the United States where Brandt soil series is dominant using the SoilWeb application.

Figure 17.14 Series extent map in the United States for the Brandt soil in map unit Z181A using the SoilWeb application.
Figure 17.15 Soil organic matter levels data for the Brandt soil in map unit Z181A using the SoilWeb application.

Figure 17.16 Example of help information for Brandt soil organic matter data in map unit Z181A using the SoilWeb application.

Figure 17.17 Percent sand data for the Brandt soil in map unit Z181A using the SoilWeb application.

Figure 17.18 Additional soil information available in the drop-down sections for the Brandt soil in map unit Z181A using the SoilWeb application.

Figure 17.19 Example of the Ecological Site opening page for the Brandt soil in map unit Z181A using the SoilWeb application.

Figure 17.20 Irrigation Ratings for the Brandt soil in map unit Z181A using the SoilWeb application.
Other SoilWeb Apps

SoilWeb Earth Application
The SoilWeb Earth application delivers soil survey data in Keyhole Markup Language (kml) files allowing you to observe mapped areas in 3-D using Google Earth™ or some other means to view the kml files (casoilresource.lawr.ucdavis.edu/soilweb-apps/).

SEE: Soil Series Extent Explorer Application
The SEE: Soil Series Extent Explorer application allows you to visually observe the geographic distribution of named soil series. The app allows up to three series to be observed at one time. (casoilresource.lawr.ucdavis.edu/see/).

Soil Properties Application
The Soil Properties application is an interactive map that allows you to visually explore soil properties aggregated on a regional and statewide basis. This app is currently available only for California.

Use and Limitation of SoilWeb Application (SWA) Information
SoilWeb application (SWA) information is useful in understanding how soils differ and will perform under various land-management systems. Producers can integrate SWA data with yield-monitor information and other data to improve seeding, fertility, pest management, water/erosion conservation, tillage, and other crop-related management decisions (Reitsma and Malo, 2011).

It is important to point out that the SWA maps are based on NRCS soil maps, which were originally prepared in South Dakota at scale of 1:20,000 or 1:24,000. As a result, the smallest delineation that can be shown on a South Dakota soil survey maps is about 2 acres. Soils located in areas less than 2 acres are generally noted in the unit descriptions as inclusions. If higher resolution is needed, a more detailed soil map is required.

Conclusions
This chapter outlines how to use SWA to obtain soil and land attributes for making land-use and management decisions. Samples of output and the SWA website use are presented to demonstrate the potential and capabilities of SWA. There are numerous useful, credible, and user-friendly websites providing soil and natural resource information. Explore the sites and see the incredible wealth of information available to you online.

Abbreviations are provided in Chapter 16.
References and Additional Information


Acknowledgements
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Silage is a high moisture fermented fodder used as a feed for livestock. It is produced by allowing chopped green vegetation to ferment under air-tight conditions. During the ensiling process water-soluble carbohydrates are converted to acids, which lowers the pH and protects the silage from further deterioration. To optimize silage production, management practices specifically designed for this purpose should be followed. This chapter focuses on the production of the corn crop used to produce silage and provides examples on how to assess its quality. When growing corn for silage, it is important to consider animal performance in addition to yield.

Selecting a Corn Hybrid
Selecting the same corn hybrids and management practices to produce silage and grain may reduce silage feed quality. Good corn silage hybrids have high yields, high energy, high digestibility, and good animal performance.

Critical to maximize silage yields is the selection of the right variety. With lower corn silage yields, there is a greater need for livestock supplementation, which increases feed costs. However, because grain provides needed starch, it is unlikely that corn grain will be completely removed from the ration. Since starch is deposited in the kernels, the amount of grain in the ration is associated with the energy content of the silage. In the past, the rule of thumb for the corn silage grain-to-forage ratio was 50:50. The improved grain yield per unit area of modern corn hybrids is because of the increased optimum plant population rather than the improved grain yield per plant.

For example, hybrid 1 produces 150 bu/acre or 20 tons/acre of corn silage at 65% moisture. This hybrid has a grain equivalent per ton of corn silage of 7.5 bushels, and the proportion of grain per ton of dry silage as percent of the whole plant is 420 lbs (7.5×56) divided by 700 (350×2) or 60% grain per ton of dry matter.

Hybrid 2, produces 200 bu/acre or 29 tons per acre at 65% moisture. This corn hybrid has a grain equivalent per ton of corn silage of 6.8 bushels, and the proportion of grain per ton of dry silage as percent of the whole plant is 380 lbs (6.8×56) divided again by 700 (350×2) or 54% grain per ton of dry matter.

By difference, one can infer that the forage fraction of 150-bushel corn yielding 20 tons of silage per acre is 40% (100-60), whereas the forage fraction of the 200-bushel corn is 46% (100-54). If we estimate, 0.7 megacalories (MCal) of net energy for gain (NEg) per pound of corn grain the 150-bushel produces:
Desirable hybrid characteristics for grain production, such as hard and fast-drying kernels, are exactly the opposite of what are needed in corn silage. Corn hybrids for silage need to have both high yields and increased starch and fiber (NDF) digestibility.

Corn Silage Planting Date, Population, Fertilizer, and Insect Control
Where possible, select corn silage hybrids that have a slightly higher maturity rating than grain hybrids, and cultivate early at rates 2,000 to 3,000 plants/acre higher than for grain production. Row spacing should be appropriate for the agricultural system, and harvesting corn for silage removes more N, P, and K than harvesting corn for grain (Chapter 24). If the field is routinely harvested for silage, consider increasing the amount of fertilizer or manure applied to the field.

Climatic conditions can impact silage quality. Dry conditions during stalk development generally increase digestibility, but drought conditions can result in silage with very high nitrate concentrations. However, because much of the nitrate is contained in the lower portions of the stalk, high nitrate concentrations can be minimized by raising the chopper cutter blade. The concentration of nitrate that causes toxicity in ruminants depends on total intake (diet + water), the acclimation of the animal to the nitrate, and its overall nutritional and health status. As a rule of thumb, forage with less than 5,000 ppm nitrate (mg NO₃/kg dry silage) or 1130 ppm NO₃-N is considered safe. Forage containing 5,000 to 10,000 ppm NO₃ (1130 to 2260 mg NO₃-N/kg dry silage) is considered potentially toxic when it is the only source in the diet (Whittier, 2014). If the forage has more than 10,000 ppm NO₃ (2260 mg NO₃-N/kg dry silage) it can be fed to nonpregnant, healthy ruminants provided it’s diluted with other safe, nitrate-free forages. Generally, pest control practices are similar in corn grown for silage and grain. However, if pesticides are applied to the field, it is important to follow labeled rates for silage.

Improving the Nutritive Value

Starch Digestibility
The energy value of corn silage is highly dependent on the content and digestibility of starch and fiber components. The digestibility of both fractions in ruminants differs. Fiber is mostly fermented in the reticulo-rumen and the products of this fermentation are utilized by rumen microorganisms. There are corn silage varieties that have higher starch digestibility. In general, corn silage hybrids with softer and slower drying kernels, preserve better in the silo and have higher total starch digestibility. Starch is mostly fermented in the rumen. However, some may escape and potentially be digested and its end products absorbed in the lower digestive tract. Its high water-resistance allows some starch to escape rumen fermentation before bacteria can degrade it. This “protection” from degradability can also reduce accessibility to starch-degrading enzymes in the small intestine. With corn silage starch of lower digestibility (i.e. flinty), a portion can end up in the manure, particularly with higher rates of passage typical of animals with high feed intakes. Thus, it is important to understand the constitutitional factors influencing grain digestion.

In a University of Wisconsin study, Hoffman and Shaver (2014) showed that starch digestibility decreased 0.86 percentage units per percentage unit increase in prolamin content when expressed as percent of the starch. This negative relationship was attributed to the prolams interfering with starch digestion. Corn hybrids with a more diffuse protein matrix allow for greater water penetration and improved starch accessibility (Hoffman and Shaver, 2014). During the fermentation process, prolamin protection of starch is reduced.

<table>
<thead>
<tr>
<th>Prolamin percent of starch classification</th>
<th>NDF classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Very high</td>
</tr>
<tr>
<td>9</td>
<td>High</td>
</tr>
<tr>
<td>8</td>
<td>Moderate</td>
</tr>
<tr>
<td>7</td>
<td>Low</td>
</tr>
<tr>
<td>6</td>
<td>Very low</td>
</tr>
</tbody>
</table>

Source: AgriAnalysis Inc. 2010
Fiber Digestibility

Corn silage nutritive value is affected by its content of grain, stalks, cobs, leaves, and ash (natural minerals from the plant and/or soil contaminant). Relative proportions of these plant components in corn silage will determine the amount of fiber (neutral detergent fiber; NDF), starch, and protein content. Corn silage is low in protein and provides fermentable starch, energy, and relative amounts of effective fiber (depending on its particle size). Fiber has a greater negative impact on nutritive value because of its lower digestibility compared with starch.

When confronted with high corn prices, livestock producers need to decide whether the corn should be harvested for silage or sold as a cash crop. To address this question one important consideration is forage digestibility. More tonnage means more grain but also more plants and, consequently more fiber-rich stems that dilute energy concentration. To make the most out of corn silage, it is very important to select varieties not only with more grain, but also with increased fiber digestibility (NDF). This is particularly important in diets for milking cows where forage fiber represents the largest nutrient fraction.

In ruminant diets, the fiber fraction is reported as neutral detergent fiber (NDF) and acid detergent fiber (ADF). The residue in the NDF is negatively correlated with feed intake and thus with energy uptake. Analyzing samples for NDF digestibility (NDFD) provides an estimation of the amount of energy the ruminant is able to obtain from that forage (see “Assessing Quality” below). For example, an increase of 1 percentage unit in NDFD can result in 0.37 lb increase in forage dry matter (DM) intake per day (Oba and Allen, 1999a; 1999b). Jung et al. (2004) reported that dairy cows ate 0.26 lb/day more feed DM when in vitro NDFD of corn silage increased by one unit. Cows fed corn silage with greater NDFD are able to eat more and obtain more total energy. This is the result of a faster emptying of the rumen, which reduces distension and allows for additional feed to be consumed. As a result, energy requirements can be fulfilled with less grain.

Brown midrib (BMR) is a natural mutation that occurs in corn and other crops. Brown midrib varieties have lower lignin concentrations and greater NDFD. Research has shown that NDFD of BMR corn silage varieties ranges from 64.4% to 72.8%, whereas NDFD in normal corn silages ranges from 44% to 63.8% (Hoffman and Combs, 2004). One other concern of BMR varieties is that they can have approximately 10% to 20% lower DM yields than normal varieties. Recent results (Darby et al., 2014) reported by the University of Vermont showed that 22 tons of corn silage at 35% DM per acre (44.8 fresh) were achieved with one BMR corn silage variety.

Research has shown that although BMR varieties have slightly less starch than forage-quality hybrid counterparts, they can be up to 30% more digestible. This is the reason, livestock producers should evaluate corn silage hybrids not only by tonnage and yield, but more importantly by animal performance. In dairy cows, a milk-per-acre index can aid in this evaluation. The University of Wisconsin has the milk-per-acre selection index that combines yield and quality into a single term allowing an easier ranking of forages and hybrid selection. Using this information, the milk-per-ton of corn silage is estimated, and then multiplied by the silage yield to calculate the amount of milk produced per acre of corn silage. Research conducted by Penn State University together with the W.H. Miner Agricultural Research Institute (Roth et al., 2001) suggest that improved plant digestibility can compensate for reductions in DM yields of BMR varieties. Researchers from the latter institution reported that NDF ratio is lower in the BMR hybrid, whereas starch content is higher. These findings suggest that the quality of the BMR hybrid is better than that of the conventional corn hybrid. This is true, however, only when cows respond with production. Several studies have shown that milk production can be increased by BMR corn (Oba and Allen, 1999a, 1999b; Nennich et al., 2000; Stone et al., 2012; Ballard et al., 2001).

Based on forage quality, BMR corn should be targeted to fresh and peak lactation cow groups to maintain intake and reduce rumen fill, leading to greater production and feed efficiency. This underscores the economic importance of assigning the right forage to the right animal group regardless of corn silage hybrid.
Kernel Processing
Harvesting corn silage at the black layer stage maximizes starch content in the kernels. Research has shown that digestibility decreases with increasing maturity. Bal et al. (1997) reported that corn silage moisture content decreased from 69.9% to 58% and NDF of the silages decreased from 52% to 41.3% as corn matured from early dent to black layer. Milk production was maximized at the 2/3 milk line stage, when the silage was 64.9% moisture. A second trial by the same research group evaluated silages at early dent (71% moisture), half milk line (64% moisture), and black layer (48% moisture). In this trial, milk production was highest at the early dent stage. The researchers found that starch and fiber digestibility decreased at the black layer stage. Based on these results, there is limited benefit in harvesting after the half milk line stage. The authors concluded that a target of 65% moisture seemed best, but that producers should begin harvesting at 70% moisture to avoid silage drying down excessively. Roth (2015) reported that corn silage moisture contents have increased from 58% to 63% from 2000 to 2010.

To harvest corn silage at higher maturities and maintain animal performance, the protein matrix that encapsulates the starch needs to be disrupted. This has sparked the interest in feeding processed (rolled) corn silage. Processing is a harvesting method where corn silage harvesters are equipped with post-cutting processing rolls. These rolls consist of two opposing, groove-ridged cylinders that roll to crush and physically damage grain and forage outer layers, which improves digestibility. For the system to work properly, the separation between roll surfaces is critical. It needs to be close enough to allow for proper “damage” of the plant material, yet not so close as to create excessive friction that wears the rolls. Self-propelled forage choppers are now available in the market.

In an early trial, Bal et al. (1997) compared corn silage harvested at half milk line, 67% moisture, and chopped at 3/8” theoretical length of cut (TLC) using a pull-type chopper and no rollers with other silages that were rolled. The other corn silages were harvested at 3/8”, 9/16”, and ¾” TLC and were rolled using the same pull-type chopper but fitted with a crop processor (1 millimeter roll spacing). On the unrolled silages, whole and half cobs were retained in the upper sieve of the Penn State particle separator, which could result in feed sorting in the feedbunk. Cows fed the rolled silages ate 1.5 lbs more dry matter per day compared with those fed unrolled silage. Cows fed the rolled silage also produced 2.5 lbs more milk and 3.5 more fat-corrected milk (FCM) daily. Milk fat was also 0.10% units higher on these cows, which could possibly be explained because of less sorting of the cobs in the bunk. The authors recommended a ¾” TLC with 1-mm roller clearance, except on wetter silages where the clearance could be expanded to 2 to 3 mm. Longer chop lengths are not recommended because of the potential for equipment wear and less packing in the silo. On a posterior trial, the same authors found that processing corn silage harvested later (at black layer) did not improve the digestibility of the fiber in the corn silage, which was reduced. From these results it does not appear that harvesting should be delayed.

New silage processors handle grain better than previous ones, allow for greater flexibility at harvest, and reduce feed sorting by the cows. In 2010 a new method of harvesting corn silage was developed in South Dakota. The system, named “Shredlage®” (Scherer Corrugating & Machine, Inc. Shredlage® LLC, Tea, SD) consists of cross-grooved crop-processing rolls mounted on a conventional corn silage harvester. According to the developer, Shredlage® silage has a number of benefits compared with traditional kernel processing silage as follows:

1. Longer chopped particles (26 to 30 mm vs. the traditional 19 mm), which reduce other forage fiber sources in the total mixed ration (TMR).
2. Longer plant stems, which increase the disrupted surface area. This enhances rumen microbial accessibility to cell contents, improves total tract digestion, and results in an overall enhanced rumen fermentation.
3. Stalks ripped lengthwise into planks and strings allowing for better packing.
4. Prolonged window for silage harvesting since it allows processing at greater maturities without losing too much digestibility.
In general, Shredlage® manufacturer guidelines show (Table 18.2) the higher the forage moisture, the longer the cut and wider the roll gap, whereas at lower moistures, the cut will be shorter and the roll gap narrower. Brown midrib (BMR) corn silage has spongier stalks and as a result may require a narrower roll setting than the current recommendations for conventional corn.

The use of Shredlage® as part of the total mixed ration for dairy cows was tested recently (Ferrareto and Shaver, 2012; Fig. 18.1). In one trial, Shredlage® and conventionally processed corn silage were harvested using self-propelled forage harvesters. The Shredlage® processing rolls were set for a 30-mm length of cut (LOC) (half of the knives removed). The processor gap spacing was set at 2.5 mm, whereas the conventional silage was set for a 19-mm LOC, with conventional processing rolls with 3-mm separation. The percentage starch passing through a 4.75-mm screen was greater for Shredlage® than conventional (75.0% vs. 60.3%) silage. The proportion of coarse particles retained on the Penn State top sieve was greater for the shredded silage (31.5% vs. 5.6%). Packing density in the silo bags was similar and averaged 272 kg of DM/m3 (17 lbs /ft3). Feed sorting was minimal and not different between silage processing methods. Cows fed TMR with Shredlage® tended to consume more feed but there was no difference in average milk yield (95 lbs/day). Milk component concentrations and yields were not affected by the type of silage. Cows fed Shredlage®, however, tended to have greater yields of 3.5% fat- and energy-corrected milk (2.2 and 2 lbs/day, respectively). Starch digestibility in the rumen was greater in cows fed Shredlage®.

Ferrareto and Shaver (2012) suggested that feeding Shredlage® may be a potential tool for dairy producers and their nutritionists desiring to feed higher corn silage diets without compromising kernel breakage for corn silage chopped at a greater LOC. The research also suggests that shredded silage maintained an adequate packing density of 17.5 lbs of DM per cubic feet compared with 17.2 of the conventional kernel-processed corn silage. The proportion of coarse particles retained on the 19-mm screen of the Penn State Particle Separator at feed-out was 31.5% vs. 5.6% for the Shredlage® and kernel processed corn silage, respectively. Once the shredded and kernel-processed corn silages were fed, milk yield tended to be greater (100.1 lbs/day) in cows fed shredded vs. those fed kernel processed corn silage (97.8 lbs/day). The key to successful application of this technology would be to determine whether feeding shredded corn silage results in less risk of acidosis in high-producing cows. In addition, it will be necessary to ensure that Shredlage® allows for adequate processing of the corn kernel to ensure maximum starch utilization by the cow. Being able to maximize the inclusion of corn silage in the diets of high-producing dairy cows will allow for the reduction of highly priced corn grain.

**Preservation and Utilization**

There are some critical aspects to the production and utilization of corn silage as a livestock feed. In very broad terms, they can be classified as plant, procedure, and feeding.

<table>
<thead>
<tr>
<th>Forage Moisture (%)</th>
<th>Length of Cut (mm)</th>
<th>Roller gap (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>26-30</td>
<td>2.25</td>
</tr>
<tr>
<td>69</td>
<td>26-30</td>
<td>2.25</td>
</tr>
<tr>
<td>68</td>
<td>26-60</td>
<td>2.25</td>
</tr>
<tr>
<td>67</td>
<td>26-30</td>
<td>2.25</td>
</tr>
<tr>
<td>66</td>
<td>26-30</td>
<td>2.25</td>
</tr>
<tr>
<td>65</td>
<td>26-30</td>
<td>1.75</td>
</tr>
<tr>
<td>64</td>
<td>23</td>
<td>1.75</td>
</tr>
<tr>
<td>63</td>
<td>23</td>
<td>1.75</td>
</tr>
<tr>
<td>62</td>
<td>21</td>
<td>1.5</td>
</tr>
<tr>
<td>61</td>
<td>21</td>
<td>1.5</td>
</tr>
<tr>
<td>60</td>
<td>21</td>
<td>1.5</td>
</tr>
</tbody>
</table>

(Source: Shredlage.com)
**Plant**
Adapting animal and plant genetics to the environment (soil or climate) makes more sense environmentally and economically than attempting to modify the environment to fit the genetics. Harvesting the hybrid at the optimum time is determined by a compromise between yield and livestock performance. It makes little economical sense to sacrifice silage yield and maximize quality, if the livestock producer will have to add wheat straw to the TMR to increase effective fiber and make it a safer diet.

**Procedure**
Corn silage is chopped to improve silo preservation and enhance animal performance. From this perspective a one-size-fits-all chopping strategy is not available. More mature, drier corn silages (i.e., those harvested at black layer) may have more starch stored in their kernels, however this starch is not as accessible as in those harvested earlier. If too dry it will not pack and ferment well, and thus heating and molding are possible. Drier, mature silages may benefit from post-chopping kernel processors or Shredlage®, described previously.

On the other hand, corn silage with moisture levels higher than 70 percent, may lead to butyric acid fermentation. If the odor of the silage changes because of butyric fermentation, it may result in reduced palatability and total feed intake, as well as feed sorting at the feed bunk. This may result not only in reduced milk production or weight gains, but also in increased incidence of other disorders, such as acidosis and displaced abomasum as a result of feed sorting. Extremely wet silages also have more seepage with high nutrient loss, and they make it more difficult to remove silage for feeding during the cold winter months because of freezing. In addition seepage from fermented silage has a very high biochemical oxygen demand (BOD). The BOD is the oxygen required for bacteria to convert biologically available nutrients into energy and new cells. To avoid problems from too wet or too dry corn, it should be periodically tested for moisture content. If it is too wet, chopping should be delayed several days.

**Feeding**
The low protein concentration in corn grain and corn silage could be considered a disadvantage from a nutritional standpoint. However, this feature turns out to work in favor of the nutritionist. One of the constraints with feeding corn and its associated feedstuffs is that its protein is deficient in the amino acid lysine. As a result, there is oftentimes a need for higher-quality forages (e.g., alfalfa) and other feedstuffs that will supply additional lysine in the diet. This is particularly true when feeding high-performance animals such as the dairy cow in early lactation. If low-protein corn grain and silage did not dilute the protein supplied by alfalfa and other high-protein feeds, the protein requirements of the ruminant would be exceeded and the excess nitrogen excreted in the urine and feces. Corn and corn silage can thus be considered “ideal” feedstuffs particularly in the Midwest.

When corn prices increase sharply, livestock producers consider replacing corn grain in livestock diets with other forages. In this scenario, corn silage may become the primary forage in the ration. Corn silages with greater percentage of leaves usually have greater digestibility as the higher lignified stalks represent a smaller portion of the total silage mass. This is the reason that leafy corn hybrids are more digestible. Researchers conducted two trials evaluating hybrid differences (Roth, 2015). In the first trial they compared a conventional hybrid with a leafy hybrid. Hybrids were evaluated at two plant populations—24,000 plants per acre or 32,000 plants per acre. These were chopped at ¾” TLC without a processor and fed in a ration that consisted of 2/3 of the forage from corn silage and 1/3 from alfalfa. They observed lower ADF digestibility and higher starch digestibility with the leafy hybrid. The higher starch digestibility was presumably due to the softer kernel texture of the leafy hybrid. They found no milk production difference among hybrids or population treatments. Silages varied in these trials by 2 units in NDF and 2.8 units in digestibility, yet no milk response was noted. These results are similar to another trial recently conducted by the University of Minnesota (Roth, 2015). Based on these results, the authors suggested that hybrid selection for leafy and normal hybrids could be based on yield per acre and agronomic performance.
Digestibility of corn silage can be increased by adjusting corn silage height to prioritize ears and leaves over stems. Cutting corn plants at 8 inches (normal cut) compared with 24 inches (high cut) and chopped at 0.4 inches reduced total silage dry-matter yield by 8.3%, increased grain content by 11.6% and decreased stalks by 38.5% (Dominguez-Diaz and Satter, 2004). With the high-cut silage, the concentration of dry matter, protein and starch increased 9.1%, 4.8% and 22.3%, respectively, while the fiber fractions and lignin were reduced. Feed intake was similar between the normal and high-cut corn-silage diets (53.7 and 54.1 lbs/day). However, the high-cut silage diet increased production and 3.5% fat-corrected milk (88.9 vs. 86.5 and 91.5 vs. 89.8 lbs/day, respectively). Feed efficiency (pounds of feed intake per pound of milk produced) increased with the high-cut treatment (1.66 vs. 1.62). Cutting corn silage higher, although reducing total forage yield by 8%, resulted in increased total milk and fat-corrected milk production, and improved efficiency of feed utilization. Leaving 16 additional inches of cornstalks in the field can also be an advantage when high nitrate concentrations might pose a problem.

**Frost-damaged or Immature Corn Silage**

Harvesting frost-damaged and (or) immature corn as silage is similar to producing silage from more mature corn. However, it is difficult to estimate the moisture content of damaged corn because it appears drier than it actually is. Leaves that have been damaged by frost will brown and dry rapidly; however, the stalk, ears, and undamaged leaves are still wet. Milk line alone should not be used as an indicator of moisture content in frost-damaged, immature corn. When determining the appropriate time to harvest silage, it is important to ponder the moisture content of the whole plant against the potential reduction in dry matter because of leaf loss (Seglar, 2012). If extensive leaf loss has already occurred, the nutritive value and amount of dry matter remaining should be carefully evaluated to determine whether it is economically feasible to harvest the crop as silage.

The nutritive value of corn silage from immature plants depends on plant growth stage. Drought-stressed corn or corn that has not been pollinated will produce little or no grain crop for the crop farmer to sell, but producers can use the nonpollinated corn for silage. On a dry-matter basis, the drought-stressed corn may be nearly equal in feeding value to normal corn silage. The best way to determine the feeding value of drought-stressed silage is to test the forage. Forage analysis is useful for buying, selling, or using the silage for ration balancing. Buyers of drought-stressed silage high in crude protein and slightly lower total digestible nutrients values may be willing to pay a price similar to that of well-eared silage of equal dry matter content.

Silage from corn that has had some ear and kernel development can have similar energy content as that produced under normal conditions. According to the University of Minnesota, corn in the blister stage can be as high as 80% moisture. To ensure proper fermentation in a horizontal silo, the moisture content should be between 63% and 68%. For upright silos, moisture should be between 60% and 65%. Silage that is too wet, may have excessive seepage and off odor. The effluent (fluid that seeps out of the silo) contains high nutrient concentration, which reduces the nutritive value of the forage and could potentially contaminate the environment. In terms of N, P and K, the nutrient concentration of silage effluent is similar to typical liquid dairy manure. The effluent has an approximate pH of 4.0, as it contains organic acids that are necessary for proper ensiling and preservation. This acidity is another potential pollution issue that can be observed as characteristic burnt/dead plants surrounding ensiled material. Silage effluent ranks among the highest sources from a contamination standpoint because of its high biological oxygen demand. The oxygen demand of silage seepage is approximately 50,000 mg of oxygen per L of effluent, 100 times more than raw domestic sewage. From a biological impact standpoint, a gallon of silage effluent can deplete the amount of oxygen needed for fish to survive in 10,000 gallons of freshwater.

Finally, the fermentation that occurs at higher moisture concentrations can result in the production of butyric acid, which gives silage a sour smell that can reduce palatability and potential feed intake. In contrast to immature corn, mature corn will dry very rapidly after a killing frost. It is suggested to consider cutting the silage as soon as possible after the frost, setting the equipment to chop the silage as
fine as possible. Harvesting silage that is too dry can create packing problems that can lead to heating and mold development. Silos that contain silage of questionable moisture content should be monitored closely and care should be taken when opening the silo for feeding. Both pH and dry-matter content are used as criteria for measuring silage quality. In silages with more than 35% dry matter, low pH becomes less critical from the point of view of preservation, as limited availability of water will inhibit proliferation of undesirable bacteria. Silages that undergo limited fermentation, as measured by pH and acid content, tend to show heat damage more frequently. This is also true for high dry-matter silages, which tend to be higher in pH and “brown” more frequently. As dry-matter loss increases, there is an increase in the pH as a result of losses of sugars that are not available for lactic acid production. It has been demonstrated that low pH by itself is not enough to prevent aerobic deterioration, as there are yeasts that can grow under acid conditions. Silage that has undergone heating can be a safety concern. When opening a heated silo, there is potential for spontaneous combustion that could result in personal injury or property damage.

**Assessing Silage Quality**

Corn silage test results are of little value unless they are understood and used appropriately. Results can be used to balance rations and to improve future crop management. Results of analysis are expressed on an “as received” and on a “100% dry matter (DM)” basis. As-received is sometimes referred to “as-fed” or “fresh.” The as-received basis includes the water or moisture contained in the feed. Nutrients expressed on this basis represent the nutrient content of the feed when it was received at the lab. Dry matter basis means all moisture has been removed. The nutrient concentration is that which is contained in the dry-matter portion of the feed. Values reported on a dry-matter basis are always larger than the as-received values. To convert from an as received to a dry-matter basis, use the following formula:

\[
\text{Nutrient (as received basis)} \times 100 = \text{Nutrient (DM basis)} \div \text{DM}
\]

For example, if a sample of corn silage (30% DM) contains 2.7% crude protein (CP) on an as-received basis, it contains 9.0% (CP) on a dry-matter basis: 2.7% CP \times 100 = 9% CP 30% DM

**Moisture/Dry Matter (DM)**

Moisture content is the amount of water in the feed. Percent moisture = 100 - % DM. Dry matter is the percentage of feed that is not water. Percent DM = 100 - % moisture. A sample of corn silage with 30% dry matter contains 70% water. Knowing moisture content of corn silage is critical to balancing rations properly. Lower moisture contents are usually associated with more mature plants, which can alter its digestibility and energy content. Adequate fermentation is also highly dependent on adequate moisture content, which for corn silage should be between 60% and 70%. If ensiled in an upright silo, 60-65% moisture is desirable to minimize seepage. Knowing the moisture content of forages is essential for making and preserving high-quality hay and silage.

Using a microwave oven can be a fast and reliable method to determining moisture content. Changing weather conditions can oftentimes make adequate predictions of moisture in corn plants to be ensiled difficult. Testing the plants for the right moisture content is critical to determine the ideal conditions for an adequate fermentation. Oetzel et al. (1993) evaluated on-farm methods to determine the dry-matter content of ensiled feeds. In this study, the authors looked at ease of use, time required to conduct the determination, repeatability, and accuracy relative to a standard drying method (drying oven). The methods evaluated were: sequential drying in a microwave oven, Koster tester method, and the electronic moisture tester method. All methods produced repeatable results. Although the microwave-oven method was more accurate than the standard method, it also required the most time. The Koster tester tended to leave some moisture on the feeds and was not as repeatable as the microwave. The procedure for measuring crop moisture content using a microwave oven was described by Tidwell et al. (2002). Regardless of the method used, it is critical to obtain a representative sample of the silage. About 2 gallons of silage should be collected from random locations of the exposed surface, avoiding areas close to the top, bottom, and sidewalls. The measuring procedure requires a paper plate, a glass of water, a small scale, and a microwave oven. Follow these simple directions:
1. Dry the paper plate on high power for 1 1/2 to 2 minutes and weigh it.
2. Weigh (precisely) about 100 grams (3 ounces) of forage sample and spread it evenly on the plate.
3. Place a glass of water in the back corner of the microwave oven to protect the oven magnetron when sample moisture is low (if not, the sample and the oven may catch fire!).
4. For corn silage or chopped corn plant samples, dry for 5 minutes at 50 percent power.
5. Repeat this step as needed, shortening the drying period to 2 minutes once the sample dries substantially.
6. Continue until weight change between dryings is less than 2 grams.
7. If the sample is charred, discard and repeat the test.
8. Calculate % moisture content with the equation.

\[
\text{\% moist} = 100 \times \frac{(\text{wet sample weight} + \text{dry paper weight}) - (\text{dry sample weight} + \text{dry paper plate})}{(\text{dry sample weight} + \text{dry paper plate}) - \text{weight of dry paper plate}}
\]

The rest of the nutrient fractions analysis should be performed in a reputable forage testing laboratory. These laboratories can use wet chemistry or near infrared reflectance spectroscopy (NIRS) to determine quality. In wet chemistry, a feed sample is chemically analyzed to determine the nutrient fractions. In the NIRS analysis, a dried ground feed sample is subjected to infrared light and the divergence of this light is measured and used to calculate the feed composition. The chemical analysis is more time-consuming and expensive than the NIRS analysis.

**Crude Protein (CP)**
Crude protein is an estimation of total protein based on nitrogen in the feed (nitrogen x 6.25 = crude protein). Crude protein includes true protein and nonprotein nitrogen (NPN) such as urea nitrogen and ammonia nitrogen. The crude protein value provides no information about amino acid composition, intestinal digestibility of that protein, or the rumen degradability of that protein.

**Acid Detergent Fiber (ADF)**
ADF consists primarily of cellulose, lignin, and acid detergent fiber crude protein. It is closely related to indigestibility of forages and is the major factor in calculating energy content of feeds. The greater the ADF, the less digestible the feed and the less energy it will contain.

**Neutral Detergent Fiber (NDF)**
The total fiber content of a forage is contained in the NDF or cell walls. This fraction contains cellulose, hemicellulose, and lignin. NDF gives the best estimate of the total fiber content of a feed and is closely related to feed intake. As NDF values increase, total feed intake will decrease. Grasses will contain more NDF than legumes at a comparable stage of maturity.

**Digestible NDF 48 (dNDF 48)**
The importance of measuring dNDF 48 has been recently recognized. Fiber digestibility differs between legumes and grasses harvested at a similar stage of maturity, and even for the same species when grown under different weather conditions. By digesting NDF more rapidly, ruminants can move feed through their rumen faster, thus allowing for enhanced animal performance. Decreases in dNDF 48 are usually a reflection of higher lignin content in the NDF fraction. DNDF 48 is measured from an in vitro NDF digestion for 48 hours.

**Lignin**
Lignin is a polymer component of the plant cell walls that provides rigidity and structural support to plants. It cannot be digested by animal enzymes. It increases as plants mature and is higher for a same plant species grown under warm weather conditions. The higher the lignin content of a forage, the lower the dNDF.

**Crude Fat**
Also known as ether extract (EE). This term comprises all substances that are soluble in ether (thus the
term ether extract). Although it will mainly contain lipids, it will also include other fat-soluble substances such as chlorophyll and fat-soluble vitamins, and it is high in energy when the fraction represents primarily lipids.

**Neutral Detergent Fiber Digestibility (NDFD)**
NDFD is dNDF expressed as a percent of NDF. Therefore, NDFD = dNDF/NDF × 100.

**Ash (ASH)**
Ash is the remaining residue after all organic matter present in a sample is completely incinerated, thus 100 – ASH = organic matter. It comprises all inorganic matter (or mineral matter) in the feed, as well as inorganic contaminants, such as soil or sand.

**Minerals**
Calcium (Ca), phosphorus (P), magnesium (Mg), and potassium (K) values are expressed as a percentage of each in the feed.

**Total Digestible Nutrients (TDN)**
TDN represents the sum of digestible crude protein, digestible carbohydrates, and digestible fat (fat is multiplied by 2.25 to compensate for its higher energy content). Since feeds are utilized differently by different species, percent TDN in a feed is different for each species, and it is highly correlated with the energy content in feeds. TDN is estimated in many different ways. TDN in SDSU lab reports is estimated from the NEL value, which in turn is calculated from the ADF content of the silage. The equation for calculating TDN is: TDN = 31.4 + (53.1 × NEl)

**Net Energy for Lactation (NEI)**
Net energy for lactation is the term used by the NRC (National Research Council) for assessing the energy requirements and feed values for lactating cows. It is expressed as megacalories per pound (Mcal/lb) or megacalories per kilogram (Mcal/kg). Corn silage NEI is calculated from ADF with the following equation: NEI = 1.044 - (0.0124 × ADF)

**Net Energy for Maintenance (NEm) and Net Energy for Gain (NEg)**
The net energy system used by NRC for beef cattle assigns both energy values to each feedstuff and similarly subdivides animal requirements for energy. Feed energy is used less efficiently for depositing new body tissue than for maintaining existing body tissue. NEm is the net energy value of feeds for maintenance. NEg is the net energy value of feeds for the deposition of body tissue, growth, or gain. Both NEm and NEg are needed to express the total energy needs of growing cattle. They are usually expressed as megacalories per pound (Mcal/lb) on SDSU lab reports and can also be expressed as megacalories per kilogram (Mcal/kg).

\[
\begin{align*}
NEm &= -0.508 + (1.37 × ME) - (0.3042 × ME^2) + (0.051 × ME^3) \\
NEg &= -0.7484 + (1.42 × ME) - (0.3836 × ME^2) + (0.0593 × ME^3)
\end{align*}
\]

Where ME (metabolizable energy) = 0.01642 × TDN.

**References and Additional Information**
Agri-Analisis Inc. Testing Cereal Grains for Prolamin - Agri Analysis Inc.


Acknowledgements

Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.


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Precision farming is the site-specific implementation of management practices that will economically optimize yields while maintaining the soil, water, atmospheric, plant, and animal natural resources. Precision farming can involve the use of integrated pest management (IPM), precision conservation, site-specific nutrient management, site-specific pest management, global positioning systems (GPS), geographic information systems (GIS), remote sensing, and detailed landscape analysis. In the past, the adoption of precision systems was limited by barriers related to complexity, economic returns, equipment breakdowns, incompatible software and hardware products, and time demands during critical periods. Today, many of these barriers have been resolved and adoption is mainly limited by the difficulty of converting locally collected information into practical solutions. The goal of this chapter is to provide an introduction to precision farming.

**Precision Farming Basics**

In precision farming, a wide variety of location-based information layers are used to develop better decisions. These layers include yield, remote sensing, scouting, soil nutrients, elevations, weeds, insects, and disease population information (Figs. 19.1, 19.2, 19.3). Precision farming may or may not lead to variable-rate treatments. Over the past several years there have been many technological advances that simplify precision farming. Some of these include:

1. Equipment improvements that simplify precision farming.

### Table 19.1 General guidelines for precision farming:

1. Precision farming is the site-specific implementation of management practices that will economically optimize yields while maintaining the soil, water, atmospheric, plant, and animal natural resources.
2. Many tools are available to implement precision farming.
3. Precision farming includes identifying the goal, assessing the potential economic impact, and field testing the technique using on-farm research.
2. Electronics improvements that improve communication.
3. The development of Unmanned Aerial Vehicles/Systems (UAV/S) that collect high-resolution images.
4. The wide-scale availability of digital databases, making highly accurate elevation information publicly accessible.
5. Training is available that reduces adoption barriers.

Spatial Data
Spatial information contains longitude (X), latitude (Y), elevation, and one or more measured values. The longitude and latitude values can be identified with a differentially corrected global positioning system (DGPS). When using GPS it is important to remember that complex mathematics is used to solve very difficult problems. The complexity of the mathematics has resulted in slightly different techniques that are based on a projection and datum, to convert a curved surface to a flat map. Two commonly used projections are UTM and Geographic, and two common datum are NAD-83 and WGS-84. The latitude and longitude values can be different for different projections. When using geographic information system (GIS)

<table>
<thead>
<tr>
<th>Types</th>
<th>Vector</th>
<th>Raster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>Point</td>
<td>Line</td>
</tr>
<tr>
<td>Formats</td>
<td>Text (txt, csv), Shape</td>
<td>Shape</td>
</tr>
<tr>
<td>Data sets</td>
<td>Yield monitor data, Soil test data, Veris Cart EC data</td>
<td>Soil survey data</td>
</tr>
</tbody>
</table>

Table 19.2 The types and formats of spatial data that are used for precision agriculture.
软件，投影和数据对每个空间数据集的需要必须被指定。地理空间信息也可以存储在一系列的格式中（表19.2），这些格式通常用于每个收集系统或数据类型（表19.2）。

收集空间信息

产量监测器、海拔、土壤养分和害虫地图、遥感、土壤电导率和土壤地图是可用于生产有用的地点特定实施地图的信息层。然而，每个数据层可能具有独特的特征，影响其有用性。

产量监测数据

配备有产量监测器的联合可以用于收集产量数据。每个收集系统具有独特的特征。例如，Ag Leader的PF3000 / PF Advantage / YM2000模型有*.yld格式，而INTEGRA / VERSA / COMPASS有*.agdata格式。John Deere的Greenstar 2或3有*.ver格式，而Greenstar GSY或GSD有*.gsy或*.gsd格式。为了确保数据的准确性，必须对监测器进行校准。产量监测数据可用于识别产量目标管理区、养分去除地图和可变播种地图（第8章和29章）。

高程数据

高程信息可以从不同来源获得，包括联合GPS数据收集时的收获田地，你已经进行的地形图测量，或者可以公开获取的数字高程模型（DEM）。最近，高程地图正在从LiDAR数据中创建。LiDAR技术使用脉冲激光来测量传感器与目标表面之间的距离。基于这种信息，可以创建精确的三维地图和图像。其他信息层，如产量、遥感和电导率地图可以叠加到LiDAR高程地图上。LiDAR具有垂直误差小于1英尺。

空间土壤养分和害虫信息

在过去，空间土壤养分和害虫信息的获取非常昂贵。在田间，土壤养分地图是通过从网格点、管理区或矩阵细胞收集土壤样本创建的。这些样本然后分析出感兴趣的养分（图19.2）。空间害虫地图是通过在田间行走并计数一定数量的害虫在一定数量的采样点获得的（图19.3）。

遥感

在未来，可能将通过卫星、飞机或UAV对田间进行的害虫监测增加。卫星和航空数据的缺点包括成本、分辨率、及时性和可用性（图19.4）。它们也依赖于从阳光的照射，这就引入了从一个卫星通道到下一个通道的变异性。在过去，许多农学家使用Landsat图像，这些图像具有30 m（98 ft）的多光谱图像分辨率（图19.4）。图像每16天捕获一次，来自不同波长（带）的信息可以结合（图19.5）计算归一化差植被指数（NDVI）和绿色归一化差植被指数（GNDVI）值。这些指数已被用于识别作物的压力。这些指数与植物压力有关，值的计算公式为：

\[
\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}
\]

\[
\text{GNDVI} = \frac{(\text{NIR} - \text{Green})}{(\text{NIR} + \text{Green})}
\]

图19.4 不同传感器可以收集的分辨率。 （Dalsted et al., 2003）
The recent availability of UAVs has the potential to increase the use of remote sensing for management decisions (Fig. 19.1). UAVs have the potential to collect high-resolution information quickly when you need it. Some UAV systems collect geometrically corrected data.

**Soil Electrical Conductivity (EC)**

High salt areas can be identified by conducting a visual survey or an apparent electrical conductivity survey, using a Geonics EM38 (Mississauga, Ontario, Canada) or the Veris Soil EC Mapping System manufactured by Veris Technologies (Salina, Kansas). Maps produced by these systems are quick to collect and provide information that can be used to identify management zones (Fig. 19.6). The electrical conductivity is the ability of a material to transmit (conduct) an electrical current and high values are often correlated with poor drainage.

**Soil Survey Information**

STATSGO2 (State Soil Geographic) has a scale of 1:250,000 and is designed for broad-based planning and management at the regional, state, and multi-state areas. The database is maintained and distributed as spatial and tabular data sets by the USDA-NRCS. The original STATSGO data for South Dakota was published in 1995. SSURGO (Soil Survey Geographic database) is mapped and described at a smaller scale than STATSGO2. The intended use of SSURGO is for natural resource planning and management by landowners, townships, and counties. Details for accessing this data layer are available in Chapters 16 and 17.
Like STATSGO2, SSURGO consists of polygons called map units that may be composed of several soil components. Map units have defined spatial boundaries but components have discrete boundaries. Components have unique properties, interpretations, and productivity ratings that map units do not. Map unit properties are derived from aggregating component properties and can be different depending on the method of aggregation. STATSGO2 and SSURGO provide information about soil types, drainage classes, soil textures, and slope. The soil survey maps can be used to make management zones.

Analyzing Spatial Information

Management Zones
The management-zone approach separates fields into unique areas where it is assumed that a common management strategy can be implemented. Digital information obtained from the Web Soil Survey search engine is based on this concept. Within a management zone, it is assumed that a given problem is uniform and that a single treatment should be implemented across the zone. For example, in high-yield areas, corn will be seeded at a rate of 38,000 seeds/acre, whereas in low-yield areas corn will be planted at a rate of 29,000 seeds/acre. Preparing data for mapping is beyond the scope of this manual. There are multiple software packages available for this purpose. Making good management-zone maps with given data set requires a skilled agronomist.

Prescriptions Based on Contour Maps
For some information layers, continuous information was collected. Examples of this type of data are remote sensing, LiDAR elevation, and yield-monitor data. This data can be used to create application maps using geographic information systems (GIS) software.

Creating Prescription Maps
The resolution of the prescription maps is dependent on the operator, equipment used to implement the prescriptions, and the given field. A prescription map tells the system controller how much product to apply based on the location in the field. Each controller needs the data in a different structure. For example, a prescription map written for an Ag Leader PF3000 Pro requires the *.tgt format, and a Raven Viper can read the *.shp format. Most agricultural GIS packages can create prescription maps in multiple formats. The prescription is written to a compact flash (CF), PCMCIA card (depending on equipment selections), USB hard drive, or other type of data storage device, which is then uploaded to the computer within the machine cab. Wireless transfer of prescription and as-applied maps are also available in many newer systems.

Precision farming is in its infancy and the technologies are rapidly changing. Across the US, scientists are developing and testing algorithms that seek to improve yields and reduce costs. Software companies are making prescription maps easier. We believe that implementing precision farming next year will be easier than implementing it today, and today it is much easier than it was 10 years ago.

Figure 19.6 Soil EC map (left) taken by Veris Cart and sampling points for EC measurement (right). (Courtesy: SDSU)
References and Additional Information


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, USDA-AFRI Higher Education Program, and the South Dakota Corn Utilization Council.


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To optimize uptake of nitrogen (N) fertilizer efficiency and to minimize the adverse impact of N on the environment, we recommend that N be applied at the right time, in the right form, at the right place, and in the right amount. This chapter specifically addresses applying N at the right time. A corn plant takes up a large percentage of its N between the V6 (~10 inch tall) and R1 (silking) growth stages. During this period, newer hybrids require as much as 8 lbs/day to maintain maximum production. When N is applied earlier than it is needed by the plant, it can be lost through a variety of mechanisms including leaching and denitrification.

<table>
<thead>
<tr>
<th>N Timing</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>Equipment is available.</td>
<td>N loss off-field can be through several mechanisms.</td>
</tr>
<tr>
<td></td>
<td>Weather permitting, time is typically not a constraint.</td>
<td>Applied prior to crop demand. Often has lower efficiency than spring and split applications.</td>
</tr>
<tr>
<td>Preplant spring</td>
<td>Reduced N losses relative to fall.</td>
<td>If excessive spring rainfall, N loss off-field can still be significant.</td>
</tr>
<tr>
<td>At planting pop-up and starter fertilizer</td>
<td>Applied with or near the seed.</td>
<td>Salts and ammonium/ammonia in the fertilizer can inhibit germination.</td>
</tr>
<tr>
<td></td>
<td>For pop-up use, only low rates required.</td>
<td>Applied prior to crop demand.</td>
</tr>
<tr>
<td>Topdressed, applied to standing crop after emergence and when corn is &lt; 6 inches</td>
<td>Reduces losses relative to fall or preplant spring.</td>
<td>Volatilization losses may be high when surface broadcast.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rainfall required to move N into the soil when surface broadcast.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leaching/denitrification losses may be high following spring rainfalls, but inhibitors may help.</td>
</tr>
<tr>
<td>Sidedressed, applied when corn is &lt;12 inches tall</td>
<td>Applied when plant needs N.</td>
<td>Accounts for early spring rainfall, however, rainfall is required to move the N into the soil.</td>
</tr>
<tr>
<td></td>
<td>Accounts for rainfall.</td>
<td>Can be delayed by excessive rainfall conditions.</td>
</tr>
<tr>
<td></td>
<td>Improved N efficiency.</td>
<td>Time demands due to weed control requirements.</td>
</tr>
<tr>
<td>Combination of starter + sidedressed (Split)</td>
<td>Accounts for rainfall, can have high efficiency.</td>
<td>Time required to apply the sidedressed N.</td>
</tr>
</tbody>
</table>
The advantages and disadvantages associated with N fertilizer timing in corn production are summarized in Table 20.1. Corn producers need to consider weather, N fertilizer source, placement, and cultural practices such as tillage, pest, weed, and disease pressure. The ultimate goal of an N fertilization program is to supply N when it is most needed. While economic and logistic factors make fall N applications more convenient, the practice has risks that may not be worth the trade-offs. In years with a wet spring a significant amount of N may be lost, making spring and split N applications preferable. This chapter provides management guidelines for fall, spring, and split N applications.

**N Fertilizer Options**

With the high cost of N fertilizer and an awareness of adverse effects of N on the environment, there is an increased interest in adopting techniques that improve N fertilizer efficiency. Recent research has strengthened the case that in humid or irrigated environments, a split application is more effective at meeting corn N demands than a single application applied either in the fall or early spring. However, in rainfed corn production systems, delaying the N application increases the risk that surface-applied N will not be incorporated and available for uptake from crop roots. When this happens, the yield loss can also be substantial.

**Fall Broadcast Applications of Urea**

Broadcast-applied urea is most susceptible to environmental loss through volatilization. It is not recommended to fall apply N before the soil cools to less than 50°F or to sandy soil. Moreover, research from Montana found that application to snow-covered soil still maintained fairly high volatilization rates, particularly during periods of snowmelt. Additionally, application to soil with high pH, generally above 7.5, increases volatilization. Ammonia volatilization is reduced by incorporating the urea granular into the soil either by cultivation or rainfall.

**Starter and Pop-up Fertilizers**

Pop-up fertilizers are placed with the seed at planting, whereas starter fertilizer is applied near the seed. Salts contained within the fertilizer can reduce seed germination. For pop-up fertilizers, avoid the use of urea. For corn production in South Dakota, di-ammonium phosphate (DAP) or mono-ammonium phosphate (MAP) are recommended as a pop-up fertilizer. Both of these products contain a small amount of N. Generally, the K₂O + N rate applied with the seed should not exceed 10 lbs/acre, however this rate is dependent on row spacing and soil texture. A calculator to determine pop-up fertilizer rates is available from the International Plant Nutrition Institute, ipni.net/article/IPNI-3268.

Starter fertilizer is generally placed 2 inches to the side and 2 inches below the seed. By separating the fertilizer and seed, the risk of salt injury is reduced. However, this risk is not eliminated and it is recommended to apply less than 70 lbs of N + K₂O if the band is within 2 inches of the seed.

**Split-N Applications**

In a split-N application system, N is applied at multiple times during the season. It can be applied in the fall, with the seed as a starter, in a band next to the seed (2 inches deep by 2 inches to the side of the seed row), or between the rows as a sidedressed application. One of the greatest strengths with the split-N approach is that it allows the grower to account for early season N losses and changes in the grain yield potential. When a preseason nitrogen test shows adequate soil N, a producer may benefit economically by reducing preplant or starter N rates.

Research in South Dakota indicates that splitting N applications between preplant and V6 can increase corn grain yield over fall application of N. However, the amount of N to apply at V6 is dependent on the amount of nitrate-N contained in the soil. The pre-sidedress nitrate test (PSNT) is one tool that can be used to estimate the sidedress N application rate. For PSNT, randomly collect 16 to 24 soil cores from the surface 12 inches when the plants are between V3 to V5 (Magdoff et al., 1984). Sample collection and handling should follow good sampling protocols. Determine the N rate based on the NO₃-N concentration (Table 20.2).
One of the problems with applying N at the V6 growth stage is that rainfall is needed to move the fertilizer into the soil where it can be absorbed by the roots. This problem can be avoided by injecting the N into the soil. However, if the in-season N application is delayed due to high rainfall or logistical issues, recent research from Missouri suggests that “rescue N” applications can be applied as late as tasseling. However, growers must take precautions to minimize leaf burn.

**Summary of N Timing**

Nitrogen is typically lost through volatilization, leaching and/or denitrification. A single, fall application of N represents a gamble on whether N will be available in late June and early July when it is most needed by the crop. There are cases where it has been found acceptable (Bundy, 1986; Vetsch and Randall, 2004). However, fall applications on sandy soils are not recommended, and it is not recommended on other soils until temperatures decrease below 50°F.

The potential losses from early-applied N and the yield advantage from in-season application are well-defined. After accounting for N in the soil, a broader set of recommendations would include N application through a combination of applying some N (30-50 lbs/acre) early in the growing season, with the remainder being applied in the mid-vegetative stages. Protecting the N with urease and nitrification inhibitors can also prolong the time period when N is safe from loss. Where possible, adding N through irrigation water is an effective approach.

### Table 20.2 Relationship between the amount of in-season soil test N in the surface 12 inches and the sidedressed N rate. *(Modified from Blackmer et al., 1991; Reitsma et al., 2008)*

<table>
<thead>
<tr>
<th>In-season soil test NO₃-N ppm</th>
<th>Sidedressed N lbs N/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>80-120</td>
</tr>
<tr>
<td>11-15</td>
<td>50-90</td>
</tr>
<tr>
<td>16-20</td>
<td>30-60</td>
</tr>
<tr>
<td>21-25</td>
<td>0-40</td>
</tr>
<tr>
<td>&gt; 25</td>
<td>0</td>
</tr>
</tbody>
</table>

*Modified from Blackmer et al., 1991; Reitsma et al., 2008*
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In South Dakota, the N, P, and K fertilizer recommendations are adjusted based on the amount of each nutrient contained in the soil. However, soil-based recommendations are only as good as the sample collected. Precision soil-nutrient information can be collected using many different techniques, including grid-soil sampling, management-zone sampling, mapping-unit sampling, and grid-cell sampling. This chapter discusses soil sampling, laboratory accuracy, and submitting the soil samples to an appropriate soil testing laboratory.

**Collecting a Composite Soil Sample**

1. Soil sampling protocols are site, nutrient, and crop specific, and they can be collected following a wide variety of approaches, including grid cell, whole field, grid point, and management zone.
2. Soil sampling date can influence the soil test results. Soil test results are often lower following harvest than prior to seeding because of plant uptake during the growing season and mineralization of organic matter. However, sampling in the fall has the advantage of allowing more time to collect and interpret the results.
3. Early spring sampling provides time for moisture to replenish the soil profile, thus making sampling easier.
4. Soil samples can be collected with a soil probe or auger. Probes and buckets should be cleaned prior to use. Collecting representative samples is difficult if soil conditions are too wet or too dry.
5. The soil sampling strategy should consider how fertilizer was previously applied. 
   a. Sampling banded fields is much more difficult than sampling fields where fertilizers were broadcast-applied.
6. Sample areas where animals were confined separately from the rest of the field.
7. Avoid sampling:
a. Guess rows as they may contain 0 or 2 fertilizer bands.
b. Exclude field entrances, field discontinuities (eroded and low areas), headlands and boarders, old homesteads, and animal confinement areas from the bulk sample.

8. In reduced-tillage fields where the location of the fertilizers are known:
   a. Avoid old P bands, unless adequate samples are collected. For P recommendations, if the rows are spaced 30 inches apart, collect 1 core from the old fertilizer band for every 20 outside the band.
   b. If N was band-applied between the crop rows in the previous year, collect 15 to 30 cores halfway between the fertilizer band and crop row.

9. In tilled fields where N and P fertilizer were broadcast, randomly collect 15 to 30 cores from each sampling zone.

10. If the N and P band locations are unknown, collecting representative samples is difficult, and undersampling (taking fewer than 15-29 cores per sample) a field can result in misleading recommendations.

11. Soil from all cores should be crushed and thoroughly mixed before a subsample is removed for analysis.
   a. Typically, a pound of soil is adequate for most chemical analysis.
   b. The samples should be frozen or air-dried and submitted to the laboratory for analysis. However, drying soil samples can influence the soil test results. Drying and grinding soil samples can result in the release of trapped K that was not plant-available. When selecting a soil testing laboratory, consider the reliability of the results as well as the turnaround time.

Opportunities for Precision Nutrient Management
In South Dakota, the primary soil nutrients that limit corn yields are nitrogen (N) and phosphorus (P). However, fundamental differences between N and P make it difficult to manage these nutrients using a common solution. One difference is that P stays where it is placed since it is chemically attached (sorbed) to the soil solids. Alternatively, applied nitrogen can be lost to denitrification (conversion of nitrate-N to N\textsubscript{2} gas), leaching (movement of nitrate N deeper in the soil profile), and volatilization (ammonia loss to the atmosphere). Chemical differences between N and P result in:

1. N being an annual cost, whereas P is a capital cost.
2. A portion of P applied 50 years ago still being available today.
3. N recommendations that are based on the amount of nitrate contained in the surface 2 feet, whereas P recommendations are based on the concentration of P in the surface 6 inches.
4. Different opportunities to capture a return on the sampling investment exist for N and P. For example:
   a. The greatest opportunity to increase profitability with precision P management occurs when the whole-field composite soil Bray-1 P concentrations range between 12 and 30 ppm, and prior manure applications may have increased nutrient variability. This opportunity exists because even though the field average value is greater than the optimum value (Olsen P > 16 ppm and Bray P > 21 ppm), 50% to 70% of field may have soil test values that are below this value (Kleinjan, 2002).
   b. The greatest opportunity for precision N management exists when the field has relatively high variability, prior manure applications increased variability, split N applications are an option, and there is a high likelihood that the soil contains a significant amount of NO\textsubscript{3}-N.
5. Whether you use traditional or precision soil sampling, soil sampling is a time-tested approach to increase profitability. If you are composite sampling and the year-to-year composite results have a significant amount of variability, this field is a good candidate for grid sampling.

Selecting a Sampling Protocol
A one-size-fits-all soil sampling protocol is not recommended and it is important to remember that the starting point for your fertilizer investment is the soil sample. The strengths and weaknesses of the different sampling approaches are summarized in Table 21.1.

**Whole-field Sampling**
In spite of soil sampling protocols that generally recommend that sampling areas should be less than 40
acres, many agronomists collect a single, composite sample from a quarter section (160 acres). If whole-field samples are collected follow good sampling protocols.

**Grid-cell Sampling**
In grid-cell sampling, the field is split into uniform cells where a single, composite soil sample is collected from each cell. Prior research has shown that recommendation errors are reduced by using a 10-acre or smaller grid cell (Chang et al., 2004). Cells generally are rectangular in shape and a composite soil sample is collected from each cell. These samples should be collected using “good” soil sampling protocols (Clay et al., 1997, 2002). Samples are then mixed to create a composite sample. If the field contains old homesteads or old animal confinement areas, these zones should be separated from the rest of the field. The zones can be any size and they can be changed to match the expected variability. This technique is easy to implement, well-suited for today’s equipment, and does not require extensive training.

**Grid-point Sampling**
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. A commonly used spacing density is 2.5 acres. The grid points should be offset and their locations should be marked with a differentially corrected GPS. Grid-point sampling is useful when several fields are combined and when manure has been extensively applied. At each grid point, 15 to 20 cores should be collected from an 8- to 10-foot radius surrounding the point. The major drawbacks to this approach are the labor and analysis costs. Grid-point sampling can be used as a baseline measurement.

**Soil-based Sampling**
In soil type-based sampling, composite soil samples should be collected from each soil mapping unit. Assessments of this sampling approach have been mixed (Fleming et al., 1999; Mount, 2001).

**Management-zone Sampling**
Management-zone sampling is where the field is split into zones based on soil and crop-yield variability. This approach has value if the data layers show consistent yield patterns over multiple years. Management zones can be developed based on apparent electrical conductivity, yield-monitor data sets, remote sensing, historical 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 (GIS) software

| Table 21.1 Sampling approach and the skill required to implement them. |
| --- | --- | --- | --- |
| Sampling approach | Protocols | Skill required | Fertilizer errors |
| | | Sampling | Interpretation | |
| Whole field | Follow “good” protocols for collecting samples. Do not collect composite samples from entrances or old homesteads. | Moderate to high | Low | High |
| Grid cell | Samples are randomly collected from predetermined cells. | Low | Low | Moderate to low |
| Grid point | 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. | Low | High | Moderate to low |
| Soil type | Composite soil samples collected from NRCS defined soil map. | Moderate to high | Moderate | High to moderate |
| Management zone | Soil samples collected from management zones. | Moderate | High | High to moderate |
| Prior management | Locate old homesteads on old USDA-NRCS photos and sample the homesteads separately from the rest of the field. | Moderate | Low | High to moderate |
| Best guess | No soil sample collected. | Low | Low | Extremely high |
is routinely used to process the data. Once a zone is identified, a single, composite sample, containing 15 to 20 individual cores, should be collected. This approach is not recommended for fields with recent manure application histories.

*Prior Management-based Sampling*

In this sampling approach, the field is split into different zones based on the prior management. For example, including a subsample from an old homestead in a whole-field sample increases the soil test P value and reduces the fertilizer recommendation. In this approach, areas previously enrolled in CRP, tile drained, and/or including animal confinement areas should be sampled separately from the rest of the field (Fig. 21.1). Management practices implemented 50 years ago can still impact soil test P values today (Kleinjan, 2002).

*Selecting a Reputable Laboratory*

When selecting a soil testing laboratory, you should consider the reliability of the results as well as the turnaround time. Precision and accuracy represent two different terms. Precision is a measure of repeatability, while accuracy represents whether the correct value was obtained. Laboratories can be precise and inaccurate as well as imprecise and inaccurate. Where possible, select laboratories that are precise and accurate. The Soil Science Society of America sponsors the North American Proficiency Testing (NAPT) program that provides a certification of laboratories. A list of certified laboratories is available at naptprogram.org. Ask your laboratory whether it participates in a sample exchange program.

*Submitting the Sample for Analysis*

Once the laboratory has been selected, follow its recommendations for submitting samples. Contact information for the different laboratories is available below. Many soil testing laboratories recommend that the samples be cooled and submitted for analysis as soon as possible. Do not leave moist samples in the truck. If they cannot be submitted within 24 hours, they should be air-dried or frozen after collection. Composite soil samples should be dried by spreading them out on a clean table for 2 or 3 days.

*Storing Data*

Once the analytical results are obtained the data should be archived for future reference. Choices for long-term storage include:

1. Printed hard copies of all data from a given field.
2. On-farm storage of the digital records. This is complicated by computer systems that routinely change.
3. Off-farm storage by a data management company.

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. Additional information for conducting an assessment is available in Chapter 29.

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 on investment depends on how well you use the information.
References and Additional Information


Acknowledgements
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1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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Remote sensing can provide useful information for a variety of problems. However, there is not a universal solution for all situations because each problem has unique data requirements. Different problems may have different data requirements. For example, the use of remote sensing to scout for pests has a different data requirement than developing an N recommendation. Remote sensing can provide a flexible structure for collecting information that can be analyzed using a variety of approaches. This chapter provides examples of matching remote-sensing information to problems.

**Remote-sensing Basics**

Remotely sensed images are composed of individual pixels that have a specified spatial resolution. For each information layer (band) that is monitored, a pixel has one value assigned to that spatial location. For a different information layer, a pixel will likely have a different value assigned to it. For example in a healthy plant, the relative pixel value for the blue band might be 7%, whereas in the near infrared (NIR) band, a healthy plant might reflect 60% of the incoming light (Fig. 22.1). An unhealthy plant may have very different reflectance characteristics.

The main advantages of remote sensing are:

1. Rapid analysis (an image can be analyzed in a relatively short period of time).
2. Assessment of a large area within a single image.
3. Easy identification of differences within an image.
4. Improved field scouting efficiency.
5. Up-to-date information.
6. Information from areas difficult to access.
7. Data that can be analyzed using a number of different analysis approaches.
9. Relatively inexpensive data collection that provides a permanent benchmark.
10. Ability to use sensors aboard a UAV (drone) to overcome problems associated with resolution, rapid
11. Potential ability to convert crop reflectance into variable-rate N application maps.

Disadvantages include:
1. Multiple stresses can have similar impacts on reflectance.
2. Adverse climatic conditions (e.g., clouds and rain) or temporal changes can influence interpretation of findings.
3. Spectral signature of a plant may be different for each plant growth stage.
4. Ground scouting may be required to confirm problem.
5. Different problems may require different spatial resolution (size of each pixel).
6. Pixel values are not acquired by direct measurement.
7. The spatial resolution may be inadequate.
8. Data analysis and collection need trained and experienced person.
9. Geometric and radiometric correction may be required.
10. Image data may be difficult to convert into variable-rate maps.

Application of Remote-sensing Technique to Farming
Application of remote sensing to precision farming can be separated into 4 unique steps (Fig. 22.2): 1) determine whether remote sensing can help, 2) develop a stress map, 3) identify the yield-limiting factors, and 4) develop a corrective management solution.

Remote-sensing data can be visualized and processed in a variety of ways. For example, a true color composite image can be made by displaying the blue, green, and red bands as blue, green, and red colors, respectively. However, a false color composite image is produced when the green, red, and NIR bands are displayed as blue, green and red colors, respectively. In a true color image, healthy plants appear green whereas in a false color image, a healthy plant appears bright red.

Images from satellites are useful for identifying problem areas that are not time-sensitive. For example, images of hail-damaged corn fields can be important for crop insurance and for estimating grain yields. Figure 22.3 shows normalized difference vegetation index (NDVI) images derived from Landsat data acquired before and after a hailstorm. The images are useful for identifying the damaged areas and calculating the acreage of the damage.

Grain yields can be reduced by nutrient deficiencies, water stress, weeds, insects, and diseases. Information
about the extent of problems can be identified by scouting the field from the air, scouting the field from the ground, or collecting satellite images (Fig. 22.4).

**Technical Note for Remote Sensing**

Remote-sensing indices have been used for making N fertilizer recommendations. The two most common indices are NDVI \([(\text{NIR} – \text{red})/(\text{NIR}+\text{red})]\) and GNDVI \([(\text{NIR}-\text{Green})/(\text{NIR}+\text{Green})]\). For NDVI calculations, reflectance in the near infrared and red bands must be collected, whereas reflectance information in the near infrared and green bands must be collected for GNDVI calculations. In some fields, GNDVI has a stronger relationship to N stress than NDVI. Either index can help a farmer switch from a single preplant N recommendation to a split N recommendation, which in turn can reduce fertilizer costs and improve profitability. Across the corn belt, research is being conducted in the development of N management N-based algorithms.

**Collecting Remote-sensing Information**

Remote-sensing imagery can be collected using various platforms, including handheld, manned aircraft, UAV (Unmanned Aerial Vehicle), and space-based (satellite). Each platform has different advantages and disadvantages (Table 22.1). Understanding the benefits and limitations of various platforms and sensors is critical for selecting the appropriate remote-sensing system. In a general sense, resolution is directly related to cost.

<table>
<thead>
<tr>
<th>Platform</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Hand or ground | - Can be used to identify the reflectance characteristics of an individual leaf, plant, or area.  
- Flexible availability.  
- Useful for real-time spraying applications. | - Collect the reflectance characteristic from a single point, not creating image. |
| UAV            | - Flexible availability.  
- Relatively low cost.  
- Very high spatial resolution.  
- Changeable sensors. | - Relatively unstable platform can create blurred images.  
- Geographic distortion.  
- May require certification to operate.  
- May be limited in height above ground.  
- Processing the data into field images may be prone to error. |
| Aircraft       | - Relatively flexible availability.  
- Relatively high spatial resolution.  
- Changeable sensors. | - High cost.  
- Availability depends on weather condition. |
| Satellite      | - Some free images.  
- Clear and stable images.  
- Large area within each image.  
- Good historical data. | - High cost for high spatial resolution images.  
- Clouds may hide ground features.  
- Fixed schedule.  
- Data may not be collected at critical times.  
- May need to sort through many images to obtain useful information. |

**Ground-based Sensors**

Nonimaging portable sensors such as CropScan, Greenseeker, and many others have been used to identify reflectance characteristics for a variety of problems. For example, these sensors have been used to develop a stress index of corn plants and to sense weeds between corn rows. Sensors mounted on a tractor are used for real-time, variable-rate fertilizer/herbicide applications.

**Aerial Sensors**

Aerial sensors can be mounted on manned and unmanned aerial platforms. The primary advantages of aerial sensors are that the high-resolution images are collected quickly and the data can be used for a variety of problems (Fig 22.4). However, the cost can be very high.

It may be possible to reduce sample collection costs by using a UAV, commonly known as a drone. UAVs
can fly any time and take images under cloudy conditions if there is no rain and the wind is under 25 mph. Currently restrictions are in place to prevent flying UAVs higher than 400 feet above ground level. Drone restrictions, however, are under review. The primary limitations of UAVs are vibrations, unstable attitude (roll, pitch, and yaw), and variable wind speeds and directions.

**Space-based Sensors**
A wide variety of satellite and sensor choices are available (Table 22.2). In general, each sensor collects data within different wavelength intervals and at different resolutions, and each satellite has different revisit times. The spatial resolution of the panchromatic band (black and white or pan band) is generally higher than the resolution for the multispectral (multi) bands. Spatial resolution is the ground area of each pixel within an image. For example, a resolution of 1.84 m means that the pixel has the dimensions of 1.84 by 1.84 m on the ground. Problems with space-based images are that clouds can prevent data collection, the atmosphere can distort reflectance values, and the platforms may have a long revisit time. The data cost can range from free to high.

<table>
<thead>
<tr>
<th>High Spatial Resolution Images</th>
<th>Spatial Resolution (m)</th>
<th>Multi-Spectral Bands</th>
<th>Temporal Revisit days</th>
<th>Relative Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeoEye-1</td>
<td>0.46</td>
<td>1.84</td>
<td>B, G, R, N</td>
<td>2.1 to 8.3</td>
</tr>
<tr>
<td>WorldView-1</td>
<td>0.55</td>
<td></td>
<td></td>
<td>1.7 to 5.9</td>
</tr>
<tr>
<td>WorldView-2</td>
<td>0.52</td>
<td>2.4</td>
<td>B, G, R, N, R-edge, 3 others</td>
<td>1.1 to 3.7</td>
</tr>
<tr>
<td>WorldView-3</td>
<td>0.34</td>
<td>1.38</td>
<td>B, G, R, N, R-edge, 23 others</td>
<td>1 to 4.5</td>
</tr>
<tr>
<td>Pleiades-1A</td>
<td>0.5</td>
<td>2</td>
<td>B, G, R, N</td>
<td>Daily</td>
</tr>
<tr>
<td>Pleiades-1B</td>
<td>0.5</td>
<td>2</td>
<td>B, G, R, N</td>
<td>Daily</td>
</tr>
<tr>
<td>QuickBird</td>
<td>0.73</td>
<td>2.9</td>
<td>B, G, R, N</td>
<td>1 to 3.5</td>
</tr>
<tr>
<td>IKONOS</td>
<td>1</td>
<td>4</td>
<td>B, G, R, N</td>
<td>3</td>
</tr>
<tr>
<td>SPOT-6</td>
<td>1.5</td>
<td>6</td>
<td>B, G, R, N</td>
<td>1 to 5</td>
</tr>
<tr>
<td>SPOT-7</td>
<td>1.5</td>
<td>6</td>
<td>B, G, R, N</td>
<td>1 to 5</td>
</tr>
<tr>
<td>RapidEye</td>
<td>5</td>
<td></td>
<td>B, G, R, N, R-edge</td>
<td>1 to 6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Moderate Spatial Res. Images</th>
<th>Spatial Resolution (m)</th>
<th>Multi-Spectral Bands</th>
<th>Temporal Revisit days</th>
<th>Relative Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sentinel-2</td>
<td>10</td>
<td>B, G, R, N, R-edge, 5 others</td>
<td>5 to 10</td>
<td>Free</td>
</tr>
<tr>
<td>SPOT-5</td>
<td>5</td>
<td>G, R, N, Shortwave IR</td>
<td>2 to 3</td>
<td>Free</td>
</tr>
<tr>
<td>LANDSAT 7 ETM+</td>
<td>15</td>
<td>B, G, R, N, 3 others</td>
<td>16</td>
<td>Free</td>
</tr>
<tr>
<td>LANDSAT 8 OLI</td>
<td>15</td>
<td>B, G, R, N, 6 others</td>
<td>16</td>
<td>Free</td>
</tr>
</tbody>
</table>

B: Blue; G: Green; R: Red; N: NIR; R-edge: Red-edge; IR: Infrared
References and Additional Information


Acknowledgements
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(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov;

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South Dakota nitrogen, phosphorus, and potassium fertilizer recommendations are based on soil test results, yield goals, and other credits. Directions for converting yield estimates and soil test results to nitrogen (N), phosphorus (P), and potassium (K) recommendations are provided below. The purpose of this chapter is to provide guidance on applying N, P, K, Fe, and Zn fertilizers. Recommendations for lime, sulfur, starter fertilizers, and band-applying fertilizer are provided in Chapters 25, 26, and 27.

**Table 23.1 General guidelines for estimating corn yield goals should consider that:**

- Corn yields in South Dakota over the past 20 years have been increasing at an annual rate of ≈2.0 bu/acre/year.
- For example, 140 bu/acre + (10 years)×(2 bu/year) = 160 bu/acre today.
- When estimating the yield goal, it is not recommended to consider more than 10 years of data.
- Abnormally high or low yield values should be excluded from yield goal estimates.
- Managing for an optimistic, yet realistic, yield goal is important. Underestimating the yield can contribute to a gradual yield decline.
- Achieving full yield potential depends on management, climate, soil, and will vary from field to field and year to year.

### Fertilizer Recommendation Yield Goals

In South Dakota, fertilizer recommendations for nitrogen (N), phosphorus (P), and potassium (K) are based on the expected yield or “yield goal.” Calculating yield goals should include adjustments for annual yields that have been increasing at a rate of 2 bu/(acre× year). Guidelines for calculating yield goals are provided in Tables 23.1 and 23.2. There are many different approaches used to estimate the yield goal. One approach uses field records to calculate the field’s historical average yield followed by using the soil moisture content at planting to adjust the goal, other methods include removing unusually low or high values. Low yields could result from droughts, floods, hail, uncontrollable pest infestation, late harvest, or other extraordinary events, whereas unusually high yields can result from ideal growing conditions that are unlikely to regularly occur.

### Nitrogen Recommendations

#### N Transformations

Nitrogen (N) applied to soil undergoes many transformations facilitated by soil microbes and chemical reactions (Fig. 23.1). These reactions influence how much is lost, retained in the soil, or utilized by the target plants. Nitrogen can be lost by volatilization, leaching, denitrification, and runoff. Nitrogen lost
through these mechanisms increases costs and can reduce yields. Volatilization is the loss of ammonia gas (NH$_3$) from soil, fertilizer, and manure. Research reports that up to 100% of the ammonia-N contained in manure can be lost through volatilization if the manure is left on the soil surface (Lauer et al., 1975), whereas over 30% of the urea-N can be lost to volatilization when urea is left on the soil surface (Clay et al., 1990).

Denitrification is a microbial conversion of nitrate (NO$_3$-) to nitrous oxide (N$_2$O) or nitrogen (N$_2$) gas, and it is the highest when the soils are warm and wet. If the soil is well-drained denitrification losses are relatively low. Denitrification can be reduced by treating the fertilizer with a nitrification inhibitor or splitting the N rate.

Nitrate leaching occurs because both the NO$_3$- molecule and soil have a negative charge. Nitrate losses can be high following a heavy rain and it is more rapid in sandy soil than in medium- and fine-textured soils. Nitrate leaching losses can be reduced by splitting the N application. Immobilization is the conversion of inorganic N into organic N by plants and soil microbes. Immobilization reduces the amount of inorganic N available to the crop and it can lead to early season N deficiencies. N immobilization is highest when crop residues with high carbon to nitrogen (C/N) ratio are left in the field. Immobilized N becomes available to the plant as microbes themselves die and decay. Reduced-tillage and no-tillage systems often have high immobilization.

Nitrogen fixation is the conversion of atmospheric N (N$_2$) to plant available N by bacteria. Common South Dakota rotations include soybeans and alfalfa where N fixation can provide up to 40 and 150 lbs N/acre, respectively, for the following corn crop (Gerwing and Gelderman, 2005). Nitrogen mineralization is the biological conversion of organic N to inorganic N, whereas nitrification is the biological oxidation of ammonia or ammonium to nitrite followed by the oxidation of the nitrite to nitrate. Nitrification inhibitors slow the conversion of ammonia to nitrate and they can reduce N losses in sandy soils from leaching and denitrification losses in high clay soils (Franzen, 2013). If a substantial amount of N has been lost, the plants may have N deficiencies. Under these conditions, it may be possible to add additional N as a split application or in the irrigation.

**N Plant Uptake and Movement**

In the soil, both nitrate and ammonia can be utilized up by the corn plant. These ions move to the root in the water transpiration stream and by diffusion. Once in the plant, N is mobile and will move from older parts of the plant to newer growth (translocation). Translocation results in deficiency symptoms appearing as yellow V-shaped patterns on lower leaves (Fig. 23.2). If crop growth stage allows, soil sampling and an injected sidedress application according to soil test results is recommended. In some states, active-optical sensor algorithms have been developed to direct in-season N application to corn (Franzen, 2014). Algorithms from other states should be used as a starting algorithm, with modifications from local grower field sensing and yield

**Figure 23.1 Important N transformations in agricultural soils. (Courtesy of IPNI)**

**Figure 23.2 Nitrogen deficiency in corn. Note the V-shaped chlorosis in older leaves and that the lowest leaves (oldest leaves on the plant) are dead. (Umesh M. Rangappa, University of Agricultural Sciences, Raichur, courtesy IPNI, Notes: The photo was taken at 67 days after planting. The soil was a sandy clay loam)**
correlation considered as more local data is acquired. In irrigated systems, fertigation according to yield goal and soil test results is a viable option.

**N Recommendation Model**
The South Dakota N recommendation for grain and silage are:

- N grain rec. (lbs/acre) = yield goal × 1.2 – soil NO$_3$-N - manure N + no-till adjustment
- N silage rec. (lbs/acre) = (10.4 lbs N/ton silage) – soil NO$_3$-N - manure N + no-till adjustment

The South Dakota whole field N recommendation (1.2 lbs N/bu grain yield goal) was recently tested (Kim et al., 2013). This assessment showed that prior to 2012 the model was reasonably accurate. The multiplier (1.2 lbs/acre) used to determine the N recommendation is currently being assessed. Preliminary analysis suggests that the multiplier could be reduced to 1 lb N/bu. An example for determining the yield goal is below (Table 23.2).

### Table 23.2 Estimating the corn grain yield goal:

<table>
<thead>
<tr>
<th>Year</th>
<th>#Standardized yield (bu/A)</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>136</td>
<td>Average</td>
</tr>
<tr>
<td>2</td>
<td>133</td>
<td>Average</td>
</tr>
<tr>
<td>3</td>
<td>126</td>
<td>Average</td>
</tr>
<tr>
<td>4</td>
<td>128</td>
<td>Average</td>
</tr>
<tr>
<td>5</td>
<td>126</td>
<td>Average</td>
</tr>
<tr>
<td>6</td>
<td>145</td>
<td>Average</td>
</tr>
<tr>
<td>7</td>
<td>*171</td>
<td>Excellent</td>
</tr>
<tr>
<td>8</td>
<td>163</td>
<td>Excellent</td>
</tr>
<tr>
<td>9</td>
<td>*112</td>
<td>Poor</td>
</tr>
<tr>
<td>10</td>
<td>129</td>
<td>Average</td>
</tr>
</tbody>
</table>

Base yield goal = 136
Recommendation = 136 bu + 10%*136 = 149.6 ~ 150 bu

### Estimating N Fertilizer Credits

#### Soil NO$_3$-N
Residual soil NO$_3$-N is estimated by analyzing a 0- to 24-inch soil sample collected in the spring. Additional information for collecting soil samples is available in Chapter 21. To obtain accurate soil test results, the sampling technique should consider prior management, and should involve separately sampling areas such as wet spots, old homesteads, old fence lines, field entry points, hay piles, turnrows, or salt-affected patches. If a soil sample is not available, residual-soil N can be estimated using the long-term soil test average of 55 lbs/acre. If the field was summer fallowed the previous year and if a soil sample is not available, 100 lbs/N acre can be used to estimate residual nitrate-N. Soil testing for residual nitrate is most important for continuous corn and where manure is routinely applied (Fig. 23.3). In sensitive areas, such as over shallow aquifers, an additional sample from the 24- to 48-inch depth should be collected. If the soil test N exceeds 30 lbs nitrate-N/acre in the 24- to 48-inch depth, 80% of that amount of N should be added to the residual N credit (Gerwing and Gelderman, 2005).
Manure N

Manure N credit estimates are best determined from a laboratory analysis of a sample of the manure. Samples should be representative of the source and should be collected after the manure has been well-mixed. If the manure is not sampled, N content can be estimated using values in Table 23.3.

Legume N Credit

Legume crops, which form symbiotic relationships with bacteria, can provide a significant amount of N to the following crop. In situations where corn follows soybeans, a credit of 40 lbs N/acre is recommended. Credits for other legume crops are provided in Table 23.4 (Reitsma et al., 2008).

| Table 23.3 Estimated nitrogen content of liquid and solid manure. (Modified from Lorimor and Powers, 2004) |
|---|---|---|---|---|---|
| Type of Livestock | Liquid Manure | Solid Manure |  |
|  | Nitrogen (N) lbs/1000 gal | Nitrogen (N) lbs/ton | \(N_{\text{ORGANIC}}\) | \(N_{\text{INORGANIC}}\) | \(N_{\text{ORGANIC}}\) | \(N_{\text{INORGANIC}}\) |
| Swine |  |
| Farrowing | 7 | 8 | 11 | 3 |
| Nursery | 11 | 14 | 8 | 5 |
| Grow-Finish | - | - | 10 | 6 |
| Grow-Finish(deep pit) | 17 | 33 | - | - |
| Grow-Finish(wet/dry feeder) | 21 | 39 | - | - |
| Grow-Finish(earthen pit) | 8 | 24 | - | - |
| Breeding-Gestation | 13 | 12 | 4 | 5 |
| Farrow-Finish | 12 | 16 | 8 | 6 |
| Farrow-Feeder | 10 | 11 | 5 | 5 |
| Dairy |  |
| Cow | 25 | 6 | 8 | 2 |
| Heifer | 26 | 6 | 8 | 2 |
| Calf | 22 | 5 | 8 | 2 |
| Veal calf | 26 | 21 | 4 | 5 |
| Herd | 25 | 6 | 7 | 2 |
| Beef |  |
| Beef cows | 13 | 7 | 4 | 3 |
| Feeder calves | 19 | 8 | 6 | 3 |
| Finishing cattle | 21 | 8 | 7 | 4 |
| Poultry |  |
| Broilers | 50 | 13 | 34 | 12 |
| Pullets | 48 | 12 | 39 | 9 |
| Layers | 20 | 37 | 22 | 12 |
| Tom turkeys | 37 | 16 | 32 | 8 |
| Hen turkeys | 40 | 20 | 32 | 8 |
| Ducks | 17 | 5 | 13 | 4 |

These values should not be used in place of a regular manure analysis as true nutrient content varies drastically depending on feeding and manure storage and handling practices. Use only for planning purposes.

| Table 23.4 Nitrogen credits from previous legume crop. (Gerwing and Gelderman, 2005) |
|---|---|---|
| Crop | Population (Plants/ft²) | \(\text{\&}N\text{ Credit (lbs N/Acre)}\) |
| Alfalfa or Legume | 1-2 | 50 |
| Green Manure | 3-5 | 100 |
| >5 | 150 |
| Soybeans, edible beans, peas, lentils and other annual legumes | | 40 |

1 No-till corn into alfalfa or green manure crop: use half credit first year. Other tillage systems: use full credit.
2 For second year following alfalfa and green manure crops: use half credit.
3 Includes sweet clover, red clover, and other similar legumes.
**Tillage Adjustment**

If no-tillage has been followed for less than 5 years, then the N rate should be increased 30 lbs N/acre. For fields that have been in no-tillage for more than 5 years, the adjustment should be zero. Examples are below.

**Example 23.1 Example for estimating N requirement.**

**Field A:** Estimate the corn grain N recommendation if the yield goal is 200 bu/acre, prior soybean yields was 60 bu/acre, and the nitrate-N amount in the surface 2 feet is 60 lbs/acre. The field is chisel plowed.

\[ \text{N recommendation} = 200 \times 1.2 - \text{residual N credit} - \text{soybean credit} \]

Residual N credit is 60 lbs N/acre and the soybean credit is 40 lbs N/acre (Table 23.4)

\[ \text{N recommendation} = 240 \text{ lbs N/acre} - 60 \text{ lbs N/acre} - 40 \text{ lbs N/acre} = 140 \text{ lbs N/acre} \]

**Field B:** No-tillage for 7 years, yield goal is 200 bu/acre, nitrate-N is 60 lbs/acre, and the previous crop was corn. For this field the recommendation is as follows:

\[ \text{Nitrogen recommendation} = 1.2 \times 200 - 60 = 180 \text{ lbs N/acre} \]

The field had been in no-tillage for 7 years and therefore a tillage adjustment is not used.

**Field C:** No-tillage for 3 years, yield goal 200 bu/acre, nitrate-N is 60 lbs/acre and soybeans was the previous crop.

\[ \text{Nitrogen recommendation} = 1.2 \times 200 - 60 + 30 = 170 \text{ lbs N/acre} \]

---

**Phosphorus Recommendation**

Phosphorus (P) exists in soil solution, mineral, and organic forms (Fig. 23.4). About 1% of P is in solution (plant available), 85% is in mineral form, and 14% is in organic form. It is not recommended to apply P to production fields if Olsen or Bray soil test P exceeds 100 ppm. Off-site movement of P generally occurs with runoff and erosion, as P is strongly attached to soil. The transport of P from production fields to streams and lakes can result in algal blooms, which impact fisheries and other wildlife. Transport is minimized when conservation-tillage practices are adopted.

Concentrations of P in runoff waters can be reduced by:

1. Minimizing the exposure of manure and fertilizer to runoff water.
2. Only applying P where it is needed.
3. Maintain a buffer between “fertilized” and surface water or drainage.
4. Consider developing and maintaining “grassed” or “wooded” buffers or filter strip.
5. Avoid application of manure on frozen or snow-covered ground.
6. Maintain crop residues above 30% to reduce erosion and incorporate the P when possible.

The optimal pH value for P availability is about 6.8, and increasing or decreasing the soil pH values from this value reduces its plant availability. Clay soils in the western part of the state often have high soil calcium (Ca\(^{2+}\)) and magnesium (Mg\(^{2+}\)) levels that reduce soil test P levels. Irrespective of the soil test P values, these high clay soils may not respond to P fertilizer.

The soil test categories are an index that is correlated to a probability of a yield response from added fertilizer (Table 23.5). Soil samples analyzed during 2010 at the SDSU Plant Science Soil Testing Laboratory showed that 50% of the samples were in the medium or below soil test P categories (Gelderman and Ulvestad, 2010).

Phosphorus-deficiency symptoms appear in corn as “purpling” of leaves, most commonly seen during
early growth stages (Fig. 23.5). New leaves may not show coloration and P-deficient plants are shorter. The symptoms may disappear as the plant matures. Some hybrids will not show coloration, even when limiting. Symptoms may appear even though soil test phosphorous (P) levels are high. Deficiency symptoms can result from cool or dry soil conditions, compacted soils, and root systems that have been reduced by tillage, cultivation, and insects.

In soils that test high for P, banding 30 lbs P₂O₅/acre at planting may increase early growth but may not increase yield. In soils with low to medium soil test levels, banded P application at planting usually increases yields. Banding P is most effective when the yield is > 150 bu/acre, when < 40 lbs P₂O₅/acre is applied, and the soil test P level is < 10 ppm. Additional details on starter, pop-up, banding P is available in Chapter 26. A bushel of corn removes about 0.38 lbs of P₂O₅. Based on this estimate, a 150 bu/acre corn crop removes 57 lbs of P₂O₅.

Phosphorus recommendations are based on yield goals and laboratory results from a 0- to 6-inch soil sample (Table 23.5). In South Dakota, P fertilizer recommendations can be calculated from either the Bray-1 or Olsen P methods. The University of Minnesota soil-testing laboratory used the Bray-1 (B-P1) if the pH < 7.4 and the Olsen (O-P) method if the soil pH > 7.4. Findings from Iowa suggest that Olsen P can replace Bray P if the soil pH < 7.4 (Sawyer, Iowa State). However, at pH values < 5.5, the Olsen P test can overestimate P availability (http://www.soiltech.co.nz/articles/article13.pdf). Results from Mehlich III (MIII) soil tests are often similar to those obtained from the Bray-1 method, but in high pH soils, it cannot substitute for the Olsen test. Sample calculations are shown in Example 23.2. When calculating P fertilizer rates, assume that 100% of the fertilizer P is available and 90% of manure P is available.

**Potassium Recommendation**

Potassium-deficiency symptoms appear as leaf yellowing and burning that begins at the tip of older leaves and, unlike N deficiency symptoms, cause yellowing at the leaf margins first before intensifying later in the season to include the mid-rib (Fig. 23.7). These symptoms are often observed in: 1) plants where root growth is limited by adverse soil/soil moisture conditions; 2) sandy soils and organic soils; and 3) fields where the crop residues were harvested. Potassium deficiencies start in older tissues and may progress up the plant. Lodged corn plants (not root lodged) may be K deficient. About 0.27 lbs. of K₂O are removed by each bushel of corn grain. The amount of K₂O removed with each ton of silage averages about 7.3 lbs/ton, and the K₂O removed when harvesting the amount of stover that produced 1 bushel of grain is about 1.1 lbs of K₂O per bushel of grain.

<table>
<thead>
<tr>
<th>Soil Test Method</th>
<th>Soil Test Level</th>
<th>Very Low</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olsen</td>
<td>0-3</td>
<td>4-7</td>
<td>8-11</td>
<td>12-15</td>
<td>16+</td>
<td></td>
</tr>
<tr>
<td>Bray-P1</td>
<td>0-5</td>
<td>6-10</td>
<td>11-15</td>
<td>16-20</td>
<td>21+</td>
<td></td>
</tr>
<tr>
<td>Probability of a yield response</td>
<td>80%</td>
<td>50-80%</td>
<td>20-50%</td>
<td>10-20%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 23.5 P-deficient corn symptoms appear as leaf “purpling” along leaf edges and slow and stunted growth. Symptoms most often appear early in the season, especially in low areas with high water tables (Courtesy: South Dakota State University). Phosphorus-deficient corn plants are always purple, but not all purple plants are P deficient, as the symptom can also be caused by anything interfering with early corn root development.
Example 23.2 Calculating the P\textsubscript{2}O\textsubscript{5} recommendation if the corn yield goal is 220 bu/acre, the soil contains 7 ppm Olsen-P, and 6 tons of solid beef manure are applied. In this equation, FPR is the fertilizer P recommendation in pounds of P\textsubscript{2}O\textsubscript{5}/acre, STP is the soil test P value, and RYG is realistic yield goal. The manure credit is estimated from data in Table 23.6.

\[
FPR = (0.7 - 0.044 \times \text{STP}) \times \text{RYG}
\]
\[
FPR = (0.7 - 0.044 \times 7) \times 220 = 86.2 \text{ lbs P}_2\text{O}_5/\text{acre}
\]

Manure credit
6 tons/acre \times 3 \text{ lbs P}_2\text{O}_5/\text{ton} \times 0.9 \text{ lbs available P/lbs of applied P} = 16.2 \text{ lbs P}_2\text{O}_5/\text{acre}

Recommendation = 86.2 - 16.2 = 70 \text{ lbs P}_2\text{O}_5/\text{acre}
FPR = fertilizer P\textsubscript{2}O\textsubscript{5}/acre recommended
RYG = realistic yield goal (bu/acre)
STP = the soil test Olsen P result (ppm)

This calculation assumes that 90% of the manure P is available to the plant.

<table>
<thead>
<tr>
<th>Table 23.6 Estimated phosphorus content of manure. (Modified from Lorimor and Powers, 2004) If an analysis of the manure is available, assume 90% of total P is available.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Livestock</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Swine</strong></td>
</tr>
<tr>
<td>Farrowing</td>
</tr>
<tr>
<td>Nursery</td>
</tr>
<tr>
<td>Grow-Finish(deep pit or solid)</td>
</tr>
<tr>
<td>Grow-Finish(wet/dry feeder)</td>
</tr>
<tr>
<td>Grow-Finish(earthen pit)</td>
</tr>
<tr>
<td>Breeding-Gestation</td>
</tr>
<tr>
<td>Farrow-Finish</td>
</tr>
<tr>
<td>Farrow-Feeder</td>
</tr>
<tr>
<td><strong>Dairy</strong></td>
</tr>
<tr>
<td>Dairy Cow</td>
</tr>
<tr>
<td>Heifer</td>
</tr>
<tr>
<td>Calf</td>
</tr>
<tr>
<td>Veal calf</td>
</tr>
<tr>
<td>Herd</td>
</tr>
<tr>
<td><strong>Beef</strong></td>
</tr>
<tr>
<td>Beef cows</td>
</tr>
<tr>
<td>Feeder calves</td>
</tr>
<tr>
<td>Finishing cattle</td>
</tr>
<tr>
<td><strong>Poultry</strong></td>
</tr>
<tr>
<td>Broilers</td>
</tr>
<tr>
<td>Pullets</td>
</tr>
<tr>
<td>Layers</td>
</tr>
<tr>
<td>Tom turkeys</td>
</tr>
<tr>
<td>Hen turkeys</td>
</tr>
<tr>
<td>Ducks</td>
</tr>
</tbody>
</table>

These values vary depending on feeding and manure storage and handling practices and are not likely representative of actual manure nutrient content. Use only for planning purposes. These values should not be used in place of a regular manure analysis.
The amount of K in stover is approximately four times greater than that observed in grain. Precipitation leaches K out of the stover left in the field. By removing the whole corn plant as silage or by baling corn stover after grain harvest, there is potential for most of the stalk K to be removed from the field before it has the opportunity to leach out of the stover. Based on these estimates, the grain from a 150 bu/acre corn crop contains 40.5 lbs of K\textsubscript{2}O, whereas the stover contains 165 lbs of K\textsubscript{2}O. These values suggest that stalk harvesting has the potential to reduce plant available K. The K contained in the stalks, at $0.50/lb of K\textsubscript{2}O, has a value of approximately $20 per ton of stalks.

Using stalks for one’s own livestock (feed or bedding) results in most of the stalk K being returned to the field as manure. Most agricultural soils in South Dakota have relatively high K levels. However, positive yield responses to K fertilizer applied as starter or broadcast have been observed. In South Dakota, K fertilizer recommendations are based on yield goals and the amount of K extracted from a 0- to 6-inch soil test value using the equations in Table 23.7. If manure is applied, K fertilizer may not be needed as manure usually has high amounts of K. Due to the risk of corn seed germination, and the low probability of K responses in high K soils, application of K as a pop-up fertilizer should be considered risky.

**Zinc and Iron Fertilizer Recommendations**

Micronutrient deficiencies usually result from environmental conditions and may be temporary. If micronutrient deficiencies are suspected, soil testing is recommended. Table 23.8 can be used to determine the Zn and Fe recommendations. In most situations, secondary (Ca, Mg, S) and micronutrients (B, Zn, Fe, Cu, Mo, Mn) have a limited impact on South Dakota corn yields. However, Zinc (Zn) deficiencies can be observed in coarse-textured soils, eroded soils, organic soils, or soils with high levels of P. Seasonal climate conditions may also affect Zn availability because Zn-deficiency symptoms, feathering and striping on the youngest leaves, are often observed in cool, wet soils. Zinc recommendations are in Table 23.8. As of 2015, the zinc recommendations are under revision. Initial analysis suggests that 2.5 lbs Zn/acre should be applied to soils in the high range.

Iron (Fe) deficiencies may be observed in leveled or eroded soil where the calcareous subsoils have been exposed. Iron-deficiency symptoms in corn are observed as yellowing with interveinal striping of younger

<table>
<thead>
<tr>
<th>Zinc soil test interpretation (ppm)</th>
<th>Zinc recommendations (lbs/acre)</th>
<th>Fe soil test (ppm)</th>
<th>Fe recommendation (lbs/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - .25 Very low</td>
<td>10</td>
<td>0.25 - 2.5 low</td>
<td>0.15</td>
</tr>
<tr>
<td>.26 - .50 Low</td>
<td>10</td>
<td>2.6 - 4.5</td>
<td>0.15</td>
</tr>
<tr>
<td>.51 - .75 Medium</td>
<td>5</td>
<td>&gt;4.5</td>
<td>0</td>
</tr>
<tr>
<td>.76 - 1.00 High</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.01 + Very high</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Based on inorganic products as source of zinc such as zinc sulfate*
leaves. Correcting for Fe deficiency can be difficult, and an effective approach to minimize yield losses is to apply manure or biosolids.

Considerations for No-tillage

No-tillage can result in slower early season growth. Use of residue managers to darken the soil at planting can help, but not completely overcome the slower start. Use of strip-tillage, with the strip-tillage conducted in the fall has resulted in similar corn growth patterns to conventional-till in several studies. Starter fertilizer applied with or near the seed can be used to enhance early season growth. If N or K is applied with the seed, the total amount added should not exceed 10 lbs of N + K₂O. If possible, N fertilizer should be subsurface band-applied. In no-tillage systems, it is recommended that the N rate be increased 30 lbs/acre if the field has been in continuous no-till for less than 5 years. Nitrogen is best applied in no-till/strip-till beneath the residue using a coulter or coulter-led shank. If N must be applied to the soil surface, banded urea ammonium nitrate (UAN) or broadcast urea with either NBPT (Agrotain) or Limus (NBPT+ NPPT) are better options than broadcast UAN. Use of urease inhibitors generally prevent ammonia volatilization from urea for about 10 days. Broadcasting urea onto residue-covered fields in the fall can result in a substantial amount of N loss and is not recommended. Winter application of urea to frozen soils is not recommended.

References and Additional Information

Websites

http://soiltest.cfans.umn.edu/understanding-your-report/agronomic-crops/

Papers


Sawyer, J.E. Differentiating and understanding the Mehlich 3, Bray, and Olsen soil phosphorus tests. Iowa State University.

Acknowledgements
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The preceding is presented for informational purposes only. SDSU does not endorse the services, methods or products described herein, and makes no representations or warranties of any kind regarding them.
Over the past 20 years the amount of corn residue produced has increased with grain yields. High yields require that these materials be carefully managed. In some situations, corn-residue harvesting can increase the yield of the following corn crop (reducing disease pressure and carbon accumulations). However, yield gains as a result of stover harvesting maybe short-lived. Stover harvesting reduces soil residue cover, which increases the risk of wind and water erosion, and, in the long term, may reduce organic matter, and soil health. In addition, a failure to account for harvesting costs and nutrient removal can further decrease short- and long-term monetary gains. This chapter discusses the short- and long-term consequences of corn stover harvesting.

Stover Harvesting Introduction

Stover Harvesting Ethanol and Livestock Feed

In the United States, there is an increased use of corn stover to provide livestock feed and bedding and to produce cellulosic ethanol (US Department of Energy estimates, 2010). The use of corn stover for bedding is definitely not new. The use of corn stover as a feed, which is protein deficient (5.4% on a dry matter basis) (Table 24.1), was not practical without the availability of an inexpensive high-protein source (distillers grain) from the ethanol industry. Details on creating distillers grain-enhanced diets are provided in Garcia and Kalscheur (2006) and Carlson et al. (2010). They suggested that stover harvesting, when combined with the application of livestock manure to the residue-harvested land, has many benefits.

Table 24.1 Nutrient content of various feed components. (Modified from Garcia and Kalscheur, 2006) In this table, CP is crude protein, ADF is acid detergent fiber, NDF is neutral detergent fiber, TDN is total digestible nutrients, Ca is calcium, P is phosphorus, and S is sulfur.

<table>
<thead>
<tr>
<th>Feed component</th>
<th>CP</th>
<th>ADF</th>
<th>NDF</th>
<th>Fat</th>
<th>TDN</th>
<th>Ca</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distillers grain</td>
<td>29.7</td>
<td>19.7</td>
<td>38.8</td>
<td>10</td>
<td>78.5</td>
<td>0.22</td>
<td>0.83</td>
<td>0.44</td>
</tr>
<tr>
<td>Soy hulls</td>
<td>13.9</td>
<td>44.6</td>
<td>60.3</td>
<td>2.7</td>
<td>67.3</td>
<td>0.63</td>
<td>0.17</td>
<td>0.12</td>
</tr>
<tr>
<td>Beet pulp</td>
<td>10</td>
<td>23.1</td>
<td>45.8</td>
<td>1.1</td>
<td>69.1</td>
<td>0.91</td>
<td>0.09</td>
<td>0.3</td>
</tr>
<tr>
<td>Corn silage</td>
<td>8.8</td>
<td>28.1</td>
<td>45</td>
<td>3.2</td>
<td>68.8</td>
<td>0.28</td>
<td>0.26</td>
<td>0.14</td>
</tr>
<tr>
<td>Corn stalks</td>
<td>5.4</td>
<td>46.5</td>
<td>77</td>
<td>1.1</td>
<td>54.1</td>
<td>0.35</td>
<td>1.16</td>
<td>0.1</td>
</tr>
<tr>
<td>Oat straw</td>
<td>4.4</td>
<td>47</td>
<td>70</td>
<td>2.2</td>
<td>50</td>
<td>0.24</td>
<td>0.06</td>
<td>0.23</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>4.8</td>
<td>49.4</td>
<td>73</td>
<td>1.6</td>
<td>47.5</td>
<td>0.31</td>
<td>0.1</td>
<td>0.11</td>
</tr>
</tbody>
</table>
**Maintaining Soil Organic Matter**

The harvesting of cornstalks for off-farm sale reduces the amount of plant material available to maintain soil organic matter (Clay et al., 2012, 2014, 2015). The amount of corn stover that can be sustainably removed is dependent on many factors, including rotations, the amount of organic matter in the soil, the amount of crop residue returned to the soil, slope, climate, and tillage (Clay et al., 2015). Tillage generally increases soil organic C mineralization and the associated soil organic C maintenance requirement. Research suggests that: 1) in a rotation that includes both corn and soybean, removing corn stover most likely will contribute to a gradual decrease in soil organic matter; 2) soil carbon loss is linked to the tillage intensity; and 3) from 1985 to 2010, South Dakota soil carbon contents in the surface 6 inches increased 24% (Clay et al., 2012, 2014). The increase in soil organic carbon was attributed to increasing corn yields, reduced tillage intensity, and improved corn genetics. Clay (2014) reported that 22%, 63%, and 36% of the yield increases in corn, soybean, and wheat, respectively, from 1974 to 2012 could be linked to improved soil health, providing a $1.1 billion impact on the South Dakota economy in 2012.

**Fertilizer Recommendations and Residue Harvesting**

South Dakota fertilizer recommendations do not account for corn-residue harvesting. A 200 bu/acre corn crop produces about 4.75 tons of stover per acre (Arora et al., 2011). The amount of N, P$_2$O$_5$, and K$_2$O contained in the grain of a 200 bu/acre corn crop is approximately 180, 76, and 54 lbs, respectively (Table 24.2). In contrast, N and P$_2$O$_5$ in residue is 16 and 5.8 lbs/ton, whereas, K$_2$O in residue is about 40 lbs/ton. This suggests that about 190 lbs of K$_2$O could be removed annually, if all corn residue is harvested. Over time, this removal can lead to K deficiencies.

**Stover Harvesting and Corn Pathogens**

Although several corn pathogens are residue borne, it is not recommended in South Dakota to harvest corn stover specifically for disease management. In South Dakota, rotations, tillage, hybrid selection, scouting, and foliar fungicides applied at V6 or tasseling, if warranted, are the recommended practices for disease management in corn.

<table>
<thead>
<tr>
<th>Table 24.2 The amount of nutrients (pounds/ton) contained in the grain and straw of plants routinely grown in South Dakota. The nitrogen (N), phosphorus (P$_2$O$_5$), potassium (K$_2$O), magnesium (Mg), and sulfur (S) removal rates for corn residue were based on a 0.5 harvest index (grain/(grain + residue)) and dry corn weighing 47.32 lbs/bu. (Modified from Clay et al., 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plant</strong></td>
</tr>
<tr>
<td>lbs/ton</td>
</tr>
<tr>
<td>Alfalfa</td>
</tr>
<tr>
<td>Barley straw</td>
</tr>
<tr>
<td>Corn residue</td>
</tr>
<tr>
<td>Oat straw</td>
</tr>
<tr>
<td>Soybean residue</td>
</tr>
<tr>
<td>Wheat straw</td>
</tr>
<tr>
<td>lbs/bu</td>
</tr>
<tr>
<td>Barley grain</td>
</tr>
<tr>
<td>Corn grain</td>
</tr>
<tr>
<td>oat grain</td>
</tr>
<tr>
<td>soybean grain</td>
</tr>
<tr>
<td>wheat grain</td>
</tr>
<tr>
<td>lbs/acre (200 bu/corn crop)</td>
</tr>
<tr>
<td>Corn grain</td>
</tr>
<tr>
<td>corn residue</td>
</tr>
</tbody>
</table>
6-Year Budget with Residue Harvesting

When harvesting stover in a continuous corn rotation, there are at least two extreme scenarios that can be envisioned. The first strategy is where stover is used as livestock bedding or feed and the manure is returned to the field. This management system represents a “closed loop,” with at least some nutrients and organic matter returned via manure application. The closed-loop question is considered in Carlson et al. (2010). The second system is where the stover is sold and leaves the farm with no returning nutrients or residue. This chapter addresses the second scenario.

Credits

Harvesting corn residue in continuous corn rotations may reduce yield losses often observed as corn is planted after corn (i.e. yield drag). This question was investigated in an experiment where 60% of the corn stover was harvested annually for 5 years (Table 24.3). This experiment showed that in a continuous corn rotation, residue harvesting can produce short-term yield increases (≤2 years) and (inconsistently) long-term yield losses (≥4 years). Based on this experiment, there was on average a 14 bu/acre yield gain for the first two years following stover harvesting, and based on a corn selling price of $3.50/bu, this represent a $49/(a×year) credit. However, in years 4 and 5, there was an 8 bu/acre decrease, which represents a $28/(a×year) loss. The second credit is the amount of money received for the residue. In this budget, it was estimated that 2.4 tons stover/acre was sold annually at a price of $44.87/ton (Edwards, 2014), or a gain of $107.

The value of the nutrients contained within the stover was $26.12/ton (Table 24.4). Others have reported slightly different values. For example, the USDA-NRCS estimated that the nutrient value of a ton of corn residue was $46.17/ton, whereas Mayer (2012) estimated that the nutrient value was $16.25. Edwards (2014) had slightly different values and reported that the nutrient value of stover was $49.62/ton. In Michigan, Pennington (2013) estimated that the nutrient content of stover was $31.25/ton. Differences between the studies are the result of different estimates of stover nutrient concentration and fertilizer selling price (Table 24.4). In this analysis, it was estimated that 2.4 tons of stover was harvested annually, and that the value of the nutrients in each ton was $26.12/ton.

Stover harvesting costs were based on reports from Iowa and Indiana. In Iowa, Edwards (2014) estimated that non-nutrient harvesting costs were $31.22/ton, whereas in Indiana, Thompson and Tyner (2011) had slightly lower values and estimated that the harvesting costs were $17.56/ton. They also estimated additional costs ($42.72) for transport, unloading, and storage. To provide a conservative estimate of harvesting costs, we used $17.56/ton. If the costs are higher, profitability will be reduced.
The five-year budget was based on annual loss of soil nutrients ($26.12/ton, Table 24.4), non-nutrient harvesting costs ($17.56/ton), changes in the yield, and a stover selling price of $44.87/ton. During the first two years, there was a net increase in return, and thereafter, there was a net loss. This analysis suggests that there is a short-term opportunity when the residues are sold off-farm. However, these returns may be short-lived.

<p>| Table 24.5 A net budget of residue harvesting on the economic returns over a 6-year period. |
|---------------------------------|-------------------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|</p>
<table>
<thead>
<tr>
<th>Investments</th>
<th>Years 1-5 Nutrient $/acre</th>
<th>Total $/acre</th>
<th>Year 6 Nutrient $/acre</th>
<th>Harvest $/acre</th>
<th>Total $/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient $/acre</td>
<td>310.18</td>
<td>208.53</td>
<td>518.71</td>
<td>62.04</td>
<td>41.71</td>
</tr>
<tr>
<td>Harvest $/acre</td>
<td>208.53</td>
<td>518.71</td>
<td>62.04</td>
<td>41.71</td>
<td>103.75</td>
</tr>
<tr>
<td>Credits</td>
<td>Yield</td>
<td>Selling</td>
<td>Yield</td>
<td>Selling</td>
<td>Total</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-------------------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Yield</td>
<td>84</td>
<td>532.85</td>
<td>616.85</td>
<td>-28</td>
<td>106.57</td>
</tr>
<tr>
<td>Selling</td>
<td>532.85</td>
<td>616.85</td>
<td>-28</td>
<td>106.57</td>
<td>78.57</td>
</tr>
<tr>
<td>Net change</td>
<td>98.14</td>
<td></td>
<td>-25.1795</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual profit</td>
<td>19.63</td>
<td></td>
<td></td>
<td>-25.1795</td>
<td></td>
</tr>
</tbody>
</table>

References and Additional Information


Pennington, D, 2013. What is corn stover worth?


USDA-NRCS, Harvesting crop residue, what is its worth.

Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, South Dakota Corn Utilization Council, and USDA-NRCS-CIG. Special thanks to Kyle Gustafson, Agronomist Winfield Solutions, for his critical review.


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(1) mail: U.S. Department of Agriculture
Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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Corn production can be limited by too low or too high soil pH values. The soil pH is a measure of the concentration of the H+ ion in the soil solution and it is reported on the logarithmic scale. It can range from 0 to 14 and a neutral solution has a pH value of 7. A pH change in one pH unit represents a 10-fold increase or decrease in acidity or alkalinity. Soil pH is highly variable and in many fields it can range from 6.0 in well-drained upper landscape positions to 8.0 in poorly drained lower landscape positions. Soil pH influences many soil properties, including nutrient availability and toxicities, plant growth, nutrient transformation, and herbicide effectiveness. The purpose of this chapter is to discuss liming requirements and the implications of soil pH on the soil chemical and biological properties.

Why Soil pH is Important

Soil pH influences crop productivity and it is a measure of soil acidity (pH<7) and alkalinity (pH>7). Soil pH requirements vary for different crops. For example, legumes typically require a higher soil pH than grasses or cereals. Herbicide effectiveness can also be influenced by soil pH. For example, Hitbold and Buchanan (1977) reported that atrazine persistence increases with pH, whereas imazaquin (Scepter), imazethapyr (Pursuit), and atrazine effectiveness are decreased with decreasing soil pH (Franzen et al., 2004; Franzen and Zollinger, 1997). Soil phosphorus is generally most available at pH values between 6.5 and 7.0. At low soil pH values (<6) the microbial process that converts ammonium (NH₄-N) to nitrate (NO₃-N) can be slowed.

Soils have varying abilities to moderate pH changes resulting from the addition of acids and bases. This ability to moderate pH is called buffering capacity. As a rule of thumb, soils with high clay and organic matter contents have higher buffering capacities than low organic matter, sandy soils.

One of the primary factors contributing to reductions in the soil pH (soil acidification) is the transformation of ammonium (NH₄) based fertilizers (urea, urea ammonium nitrate solution (28%),
anhydrous ammonia) to nitrate (NO₃⁻) (Tables 25.1, 25.2). This transformation process acidifies soil by producing hydrogen ions when the ammonium ion is nitrified to nitrate.

In South Dakota fields with low soil pH values, yields can be increased by applying lime (Fig. 25.2). Research conducted between 1999 and 2013 showed that corn yields were reduced 10% to 20% when the soil pH value was less than 5.8 (Fig. 25.2; Table 25.2), and that applying lime minimized these yield reductions. The amount of lime required is dependent on both the soil pH and soil buffering capacity. Low pH soils are most often observed in the eastern side of South Dakota (Table 25.3).

**South Dakota Lime Recommendation**

South Dakota lime (CaCO₃) recommendations are based on the buffer pH (BpH) index method (Gerwing and Gelderman, 2005; Table 25.4). In this method, a soil extractant is used to measure the reserve alkalinity. Lime requirements may be different for different problems (Mallarino et al., 2013) and the rates should be adjusted based on the lime composition, purity, and fineness (Clay et al., 2011).

In the past, lime has not been widely used in South Dakota, and available liming materials may include agricultural lime, pelleted agricultural lime, or municipal water-treatment lime (Kaiser et al., 2011; Mullins et al., 2009). South Dakota research showed that: 1) pelleted lime and municipal water-treatment lime have similar impacts on soil pH (Table 25.5); 2) there are differences between conventional and no-tillage systems (Table 25.5); and 3) the lime effectiveness was higher when tilled into the soil because lime is not mobile in the soil.

---

### Table 25.1

<table>
<thead>
<tr>
<th>Fertilizer source</th>
<th>Chemical composition</th>
<th>% N</th>
<th>Lbs lime/lb fertilizer</th>
<th>Lbs lime/lb of N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anhydrous ammonia</td>
<td>NH₃</td>
<td>82</td>
<td>1.48</td>
<td>1.80</td>
</tr>
<tr>
<td>Urea</td>
<td>CO(NH₂)₂</td>
<td>46</td>
<td>0.84</td>
<td>1.83</td>
</tr>
<tr>
<td>Ammonium sulfate</td>
<td>(NH₄)₂SO₄</td>
<td>21</td>
<td>1.12</td>
<td>5.33</td>
</tr>
</tbody>
</table>

---

### Table 25.2

<table>
<thead>
<tr>
<th>Nitrogen treatment</th>
<th>N Rate</th>
<th>pH (0-6 inch)</th>
<th>-log[H+]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check – no nitrogen</td>
<td>0</td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td>Spring – recommended N rate</td>
<td>110</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Split – recommended N rate</td>
<td>110</td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>Fall – recommended N rate</td>
<td>110</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Spring 200</td>
<td>200</td>
<td>5.5</td>
<td></td>
</tr>
<tr>
<td>Spring 400</td>
<td>400</td>
<td>5.0</td>
<td></td>
</tr>
</tbody>
</table>
Table 25.3 The influence of South Dakota NASS region [northeast, NE; southeast, SE; north-central, NC; south-central SC; and western regions, WR (northwest, west, southwest)] on the pH value of soil samples submitted to the SDSU Soil Testing Laboratory.

<table>
<thead>
<tr>
<th>South Dakota Region</th>
<th>Average pH</th>
<th>pH range</th>
<th>pH range</th>
<th>pH range</th>
<th>pH range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt;6.1</td>
<td>6.1-6.5</td>
<td>6.6-7.0</td>
<td>7.1-7.5</td>
</tr>
<tr>
<td>NE</td>
<td>6.61</td>
<td>21</td>
<td>27</td>
<td>27</td>
<td>17</td>
</tr>
<tr>
<td>SE</td>
<td>6.37</td>
<td>32</td>
<td>30</td>
<td>23</td>
<td>11</td>
</tr>
<tr>
<td>NC</td>
<td>6.49</td>
<td>26</td>
<td>30</td>
<td>25</td>
<td>14</td>
</tr>
<tr>
<td>SC</td>
<td>6.78</td>
<td>6</td>
<td>24</td>
<td>43</td>
<td>22</td>
</tr>
<tr>
<td>WR</td>
<td>6.98</td>
<td>8</td>
<td>25</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>Overall</td>
<td>6.54</td>
<td>24</td>
<td>28</td>
<td>26</td>
<td>15</td>
</tr>
</tbody>
</table>

A samples analyzed by the SDSU Soil Testing Laboratory
B NE=northeast, SE=southeast, NC=north-central, SC=south-central, WR=west river

Table 25.4 The amount of lime in South Dakota needed to raise the soil pH to 6.0. (Gerwing and Gelderman, 2005) Lime rates were based on the CaCO₃ equivalent of 90% and total effectiveness of 70%. One ton of pure CaCO₃ is equivalent to 1.6 tons of material.

<table>
<thead>
<tr>
<th>Buffer Index</th>
<th>Lime required for 0-6 inch soil depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffer pH</td>
<td>Lime (tons/acre)</td>
</tr>
<tr>
<td>&gt;6.5</td>
<td>0</td>
</tr>
<tr>
<td>6.2 – 6.5</td>
<td>2.0</td>
</tr>
<tr>
<td>5.9 – 6.2</td>
<td>2.5</td>
</tr>
<tr>
<td>5.6 – 5.9</td>
<td>3.0</td>
</tr>
<tr>
<td>&lt;5.6</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Table 25.5 The influence of the dry weight of different liming products and tillage on soil pH. Lime sludge was applied in 2005 and it was obtained from the Brookings Municipal Water Treatment Plant, while the Super Cal was obtained from Calcium Products Inc., located in Gilmore City, IA. Within a column, pH values with different letters are significantly different. The LSD is the least significant difference between treatment means, NS means not significantly different.

<table>
<thead>
<tr>
<th>Lime</th>
<th>Conventional-tillage</th>
<th>No-till</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Rate</td>
<td>0-2”</td>
<td>2-4”</td>
<td>4-6”</td>
<td>0-6”</td>
<td>0-2”</td>
</tr>
<tr>
<td></td>
<td>tons/a</td>
<td>pH</td>
<td>pH</td>
<td>pH</td>
<td>pH</td>
<td>pH</td>
</tr>
<tr>
<td>Check</td>
<td>0</td>
<td>5.3 b</td>
<td>5.5 b</td>
<td>5.6 b</td>
<td>5.4 b</td>
<td>5.2 b</td>
</tr>
<tr>
<td>Lime sludge applied in 2005</td>
<td>1</td>
<td>7.6 a</td>
<td>7.4 a</td>
<td>6.3 a</td>
<td>7.1 a</td>
<td>7.3 a</td>
</tr>
<tr>
<td>Super Cal applied between 1998 and 2005</td>
<td>1</td>
<td>7.4 a</td>
<td>7.2 a</td>
<td>6.2 a</td>
<td>7.0 a</td>
<td>7.3 a</td>
</tr>
<tr>
<td>Super Cal applied in 1998 and 2002</td>
<td>4</td>
<td>7.5 a</td>
<td>7.5 a</td>
<td>6.3 a</td>
<td>7.1 a</td>
<td>7.4 a</td>
</tr>
<tr>
<td>LSD(.10)</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.4</td>
<td>0.2</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Summary
Field research suggests that corn yields can be increased by lime in soils with pH values <5.8 (Bly and Gelderman, 2015). Relatively low pH values are attributed to acidity produced during nitrification of applied N. Lime effectiveness is determined by CaCO$_3$ content and fineness of the material. Pelletized and water-treatment lime appear to be equally effective in changing soil pH. Soil pH changes from lime application was less effective at subsurface depths with no-till compared with conventional-tillage, however, grain yields were comparable. Corn grain yield improvement can be expected from lime applications if buffer pH is ≤6.4 and when the soil pH is ≤5.8. Examples for determining lime requirements are available in Clay et al. (2011) and US USDA-NRCS (1999).
References and Additional Information


Acknowledgements
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(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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The phosphorus (P) application methods used in corn production fields can impact yield and net profitability. The primary benefit from banding P is that it concentrates the P in a small zone near the plant, which can improve P availability. The objectives of this chapter are to: 1) discuss different P application methods, 2) summarize research comparing P application methods, 3) review the effect of band distance from the seed, 4) discuss safe amounts of P-containing fertilizers that can be placed with the seed, and 5) consider strengths and weaknesses of the application methods.

Introduction

Plant-available P moves slowly through the soil by diffusion to the root. Diffusion is the movement of ions from an area with high concentration to an area with low concentration. Factors that influence P diffusion are soil texture, water content, bulk density, pH, temperature and the distance between higher soil P concentrations zones such as bands and the root. P diffusion rates are higher for finer textured soil (clay), higher soil water content, lower soil bulk density, soil pH between 5.0 and 6.0, higher soil temperatures, and shorter distances from root to soil zones with higher P concentration (Bhadoria et al., 1991; Grierson et al., 1999; Olsen and Watanabe, 1963; Schachtman et al., 1998). Crops with finer root systems or those that have been colonized by arbuscular mycorrhizal fungi (AMF) may have higher P uptake efficiencies (Bittman et al, 2006). Adopting no-till practices that encourage fungi growth and development can encourage AMF colonization.

Figure 26.1 P applied as a broadcast or banded application. (Courtesy of Colorado State University, Clay et al., 2009)
Phosphorus fertilizer application methods include broadcast, banded, or band-applied with the seed (Fig. 26.1). Liquid or dry fertilizers are used with any of these placement options. Starter fertilizers, placed at planting, can be located to the side of the row or with the seed (pop-up). Usually, only a portion of the total recommended P rate for optimum corn yield is placed as a starter, unless the recommended P rate is low enough to enable full rate application. The balance of the P recommendation that is not applied as a starter needs to be applied with another method.

Concentrating fertilizer P in a band often improves P availability as there is less opportunity for the fertilizer P to be tied up in the soil, especially at very low or high soil pH. Rates can sometimes be reduced by one-third or more for band-applied P. However, reducing rates can result in a decline of soil test P over time, which can reduce yield potential (Chapters 23 and 29).

Phosphorus can be applied in a variety of forms ranging from liquid to solid products (Chapter 28) and the application technique will depend on your goals, your soil test value, and tillage and equipment options. Tillage system and equipment availability play an important role in determining what choice a corn grower makes when considering P placement. Equipping a very large planter with fertilizer application equipment can be less than desirable because the added weight can lead to higher soil compaction. Frequently asked questions regarding P placement for corn:

1. What P application method returns the greatest economic return?
2. What distance from the corn row should P bands be placed?
3. How much fertilizer can be placed with the seed at planting?

**P Application Method Comparisons (band vs. broadcast)**

Choosing the most appropriate P application method is complicated by the many factors that influence plant P uptake efficiency. Placing the P in a band near the seed may increase plant P uptake efficiency because it concentrates P in a zone easily reached by early root growth. In addition, P diffusion from the band to the root is high due to a large concentration gradient when compared with broadcast P application. However, when the bulk soil test P is high, the benefits of banded P are reduced. Therefore, knowing soil test P level is important when determining placement options. The optimal balance between P banding and broadcast application is difficult to achieve (Barber, 1974, 1985).

Soil fertility researchers conducted research studies at several land-grant universities between 1970 and 2015 that compared banded and broadcast P applications (Fig. 26.2).

This research suggested that the benefit from banding P increased with yield potential. For example, at yield less than 100 bu/acre banding and broadcasting P had similar yields, whereas at 200 bu/acre, banding P had a 7.4 bu/acre yield advantage over broadcasting P. When the P rate was considered, the yield advantage from banding was higher when the P application rate was ≤ 40 lbs P\(\text{O}_5\)/acre (Fig. 26.3). Based on these findings, banding is recommended when yields are greater than 150 bu/acre, P rates < 40 lbs P\(\text{O}_5\)/acre, and soil test P is
at or below the medium category.

These recommendations are contrary to findings from Iowa, where banded and broadcast treatments had similar yields (Mallarino et al., 1999; 2004). Differences between South Dakota and Iowa may be attributed to differences in rainfall, length of growing season, and tillage.

Could higher soil moisture conditions in South Dakota no-till cornfields result in similar conclusions between banded and broadcast P? Phosphorus placement research projects were conducted in South Dakota between 1998 and 1999 at nine sites located in corn grower no-till fields. Phosphorus fertilizer was either placed as starter (2x2 band) or broadcast at 40 lbs P₂O₅/acre. Statistical comparison between the two treatments showed that site year was significant, which is indicative of a wide range of yield environments used in the project. The banded P treatment (134.1 bu/acre) grain yield average was greater than broadcast (130.8 bu/acre), but not statistically significant. A relative grain yield comparison of broadcast and banded P across Olsen P soil test levels showed that banded P resulted in greater yield at the 4-6 ppm soil test range and similar yields when the soil test value was ≥ 10 ppm (Fig. 26.4).

**Distance of P Band from the Seed**
Phosphorus band distance from the crop root is another factor influencing P uptake efficiency. Few research studies have investigated the optimal P band distance because it requires specialized research equipment. Research conducted in 2004 and 2005 near Beresford, SD, and Brookings, SD, evaluated the effect of P band distance from the seed furrow on grain yield. This research showed that the greatest yield increase occurred when the P band was located 2 inches from the seed (Fig. 26.5).

**Seed-placed Phosphorus**
In some situation, placing the P fertilizer with the seed can improve P uptake efficiency. Triple super phosphate (0-46-0) was a very common P fertilizer material in the past and was very safe for seed application. However, for various reasons, this material is not produced to a great extent by the plant food industry. More recently developed P sources containing nitrogen include ammonium polyphosphate (10-34-0), monoammonium phosphate (MAP, 11-52-0), and diammonium phosphate (DAP, 18-46-0). A number of liquid P sources containing N, P, and K have been developed such as 7-21-7, 4-10-10, 3-18-18 and 9-18-9. In addition, numerous mixed fertilizers have been developed containing secondary and micronutrients as well. A pop-up fertilizer calculator has been developed for determining safe pop-up

<table>
<thead>
<tr>
<th>Table 26.1 Allowable rates of 10-34-0 (ammonium polyphosphate) fertilizer applied with corn seed at planting for 30-inch rows and 5% germination reduction. (Based on <a href="http://www.ipni.net">www.ipni.net</a> calculator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Texture</td>
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<tr>
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<tr>
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<tr>
<td>Fine/Medium</td>
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<tr>
<td>Coarse</td>
</tr>
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</table>
fertilizer rates (Gelderman, 2007). This calculator considers the fertilizer source, soil texture, soil moisture, row width, and risk adversity. The calculator was developed using laboratory method results that were well-correlated to field study data.

This calculator is available from the International Plant Nutrition Institute, www.ipni.net (search for Seed-placed Fertilizer Decision Aid). Table 26.1 was developed from this tool and shows the allowable rates of ammonium polyphosphate fertilizer (APP) with differing soil moisture and textures that can be applied with the corn seed planted in 30-inch rows using a 5% maximum seed germination reduction risk.

Summary
There are many different techniques that can be used to apply P to soils. Each application approach has strengths and weaknesses (Table 26.2). South Dakota has a frigid, semi-arid environment that may influence plant responses to P compared with other corn growing regions. In our soils and climatic conditions, management practices that encourage early growth may result in higher corn yields. Different outcomes may be found in more temperate environments. This paper contains several key summaries including:

1. Understanding soil phosphorus, the meaning of soil P test levels, and the factors influencing P movement (diffusion) to plant roots are very important for optimal P placement.
2. At lower $P_{2}O_{5}$ application rates (< 40 lbs/acre), band-placement grain yields were higher than broadcast and generally occurred at research sites with soil test P below the medium level.
3. In South Dakota no-till corn research, corn grain yield from fertilizer band (2x2) applications were higher than broadcast applications at soil test (Olsen) P levels less than 10 ppm.
4. P bands placed 4 inches or less from the seed furrow returned the highest grain yield.
5. P placement with the seed is a good management practice. However, special attention needs to be taken to understand how different fertilizer materials may reduce seed germination. The seed-placed fertilizer calculator, www.ipni.net, is a good tool to determine pop-up fertilizer limits.

| Table 26.2 Strengths and weaknesses of P application methods. |
|-----------|-----------------|-----------------|
| Strengths | Weaknesses       |                 |
| Pop-up    | • Promotes early growth. | • Can reduce germination if the rate is too high. |
|           | • Can increase yields if soil test values are low. | • Ammonia contained in the fertilizer can reduce germination. |
|           | • Increases P uptake efficiency when soil test P is lower. | • Extra equipment for planter to carry. |
|           |                 | • Some liquids are more corrosive and can damage equipment over time. |
|           |                 | • Additional P fertilizer may have to be applied to get recommended P rate. |
| Broadcast | • Can be easily applied. | • May be less effective than banding for low P rates. |
|           | • Will increase the bulk soil P level. | • May be less effective when soil test P levels are low. |
|           | • Will increase corn yields. |                 |
|           | • Could be as effective when compared with banding when rates > 40 lbs $P_{2}O_{5}$/acre. |                 |
| Banded   | • In high-yield environment can increase yields. | • May not be effective for low-yield potentials. |
|           | • Most effective if the soil P level is in the low to medium level. | • May not be practical for high P rates. |
|           | • Bands should be placed less than 5 inches from the seed. | • Extra equipment for planter to carry. |
|           | • Increases P uptake efficiency when soil test P is lower. | • Some liquids are more corrosive and can damage equipment over time. |
|           |                 | • Additional P fertilizer may have to be applied to get the recommended rate. |
References and Additional Information


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, South Dakota Corn Utilization Council and International Plant Nutrition Institute (IPNI).


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(1) mail: U.S. Department of Agriculture
Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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Corn sulfur (S) deficiency symptoms include leaf yellowing and/or striping or interveinal chlorosis of new leaves (Fig. 27.1). Corn yield responses to S addition were more likely in sandy no-tillage fields where the surface 2 feet of soil contains < 40 lbs of SO\(_4\)-S/acre. Sulfur deficiency can be minimized by applying sulfur-containing fertilizers or manure. This chapter provides information needed to make informed decisions concerning sulfur fertilizer applications.

**A Growing Problem**
Sulfur (S) is an essential nutrient for crop production that in the past was largely supplied through atmospheric deposition. However, improvements in air quality have reduced S depositions. For example, from 1972 to 1980, SO\(_2\) emissions decreased in the United States from 32 million to 26 million tons, which was further reduced to 6.5 million tons in 2011 (Tisdale et al., 1985; Furiness et al., 1998; Jeschke and Diedrick, 2010; US-EPA, 2014). Decreasing sulfate depositions have been accompanied by increased applications of sulfur-containing fertilizers. In South Dakota from 2002 to 2010, the use of sulfur-containing fertilizers increased from 18,318 tons to 51,592 tons (USDA-NASS, 2012).

**Sulfur in the Soil**
Soil contains between 200 and 1000 lbs of S/acre, which can exist as inorganic SO\(_4\)-S\(^2-\), gypsum (CaSO\(_4\)), reduced sulfide (S\(^2-\)), and organic-S. Plant requirements for S can be obtained from the mineralization of organic matter, the oxidation of sulfide, the solubilization of gypsum, and/or from atmospheric depositions. Sulfate (SO\(_4\)-S\(^2-\)) is an important form of S in the soil. This negatively charge anion can leach with percolating water. Sulfur mineralization converts organic-S to hydrogen sulfide (H\(_2\)S), which is then oxidized to sulfate. Processes that influence microbial activity, such as tillage, will impact sulfur mineralization.

**Plant S Deficiencies**
Due to relatively slow mobilization from older leaves to younger leaves, S deficiency generally includes
yellowing as well as leaf striping of younger leaves (Fig. 27.1). Nitrogen (N) has similar symptoms in corn. However, yellowing is most observed in older leaves. Sulfur deficiency symptoms are most observed in low-organic-matter, no-till corn. Research conducted at 130 locations in South Dakota between 1990 and 2014 indicates that corn responds to S if: 1) the amount of sulfate in the surface 2 feet is < 40 lbs SO$_4$-S/acre, 2) no-tillage is used at the site; and 3) the soil texture is relatively coarse (Fig. 27.2). The S source used in these studies was ammonium sulfate and grain yields were adjusted to 15% grain moisture.

Causes of S deficiency may include reduced mineralization resulting from low organic matter contents, cool temperatures, the adoption of reduced-tillage systems where soil organic matter is sequestered, and/or the loss of sulfate with leaching water.

**Collecting and Analyzing Soil Samples**

Sulfate-S (SO$_4$$_2$) is a negatively charged ion that is not strongly held in South Dakota’s negatively charged soils. Because SO$_4$$_2$ can move with water percolating through the soil, samples collected from the surface 2 feet for N recommendations can be used for S recommendations. The soil samples should be kept cool and submitted to your soil testing laboratory as soon as possible. The samples can be analyzed for SO$_4$-S using Combs et al. (1998). Because the sulfate test is not always accurate, soil sulfate analysis should be used as a starting point for determining a sulfur recommendation. Consider the soil organic matter, soil texture, SO$_4$-S, and tillage practices when making a recommendation (Table 27.1).

There are a number of fertilizers that can be used to reduce S deficiencies including manure (Chapter 28). For example, ammonium thiosulfate (12-0-0-26) can be mixed with UAN or ammonium sulfate (21-0-0-24) can be mixed with urea (46-0-0). However, the S contained in Elemental S (0-0-0-90) is not readily available because it requires oxidation prior to plant uptake. Manure from animals that used distillers grains in their rations may contain relatively high concentrations of S.

Because both N and S are needed to produce plant proteins, the ratio between these nutrients can range from 8:1 to 10:1. Typically, if crop requirements for nitrogen are 100 lbs N/acre, then the sulfur requirements will be 7 to 13 lbs S/acre. Approximately 25 lbs of S are harvested in a 15-ton silage crop (Schulte and Kelling, 1992), and cereal grain crops have the highest S requirements while soybeans have the lowest.

<table>
<thead>
<tr>
<th>Sulfur Soil Test</th>
<th>Relative S Soil Level</th>
<th>Coarse Tilled$^a$</th>
<th>Coarse Strip or no-till</th>
<th>Medium/Fine Tilled$^a$</th>
<th>Medium/Fine Strip or no-till</th>
</tr>
</thead>
<tbody>
<tr>
<td>lbs/a (0-2ft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-9</td>
<td>Very Low</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>10-1</td>
<td>Low</td>
<td>25</td>
<td>25</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>20-29</td>
<td>Medium</td>
<td>15</td>
<td>25</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>30-39</td>
<td>High</td>
<td>15</td>
<td>15</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>&gt;=40</td>
<td>Very High</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

$^a$ conventional-tillage
References and Additional Information


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, South Dakota Corn Utilization Council and International Plant Nutrition Institute (IPNI).


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Many South Dakota farmers spend $170/acre per year on fertilizers. Reducing these costs requires an understanding of the available products. Fertilizer can be solid, liquid, and gas, each with unique strengths and weaknesses. This chapter discusses the different commercially available fertilizers and provides examples on how to determine the cost of nutrients contained within the fertilizer.

**Fertilizer Salt Index**
The salting effect of the fertilizer is most important when developing recommendations for pop-up and starter fertilizers. A pop-up fertilizer calculator is available at [http://www.ipni.net/article/IPNI-3268](http://www.ipni.net/article/IPNI-3268). A salt index is used to estimate the seed-germination risk, and generally, Na+ and K+ fertilizers have higher salt index values than P fertilizers.

**Microbial Inhibitors**
Nitrogen can be lost through three major mechanisms: leaching, volatilization, and denitrification. Different inhibitors are needed for each mechanism. Nitrification inhibitors can be used to reduce leaching and nitrification losses, whereas urea hydrolysis inhibitors can be used to reduce ammonia volatilization losses. Nitrification inhibitors slow the conversion of ammonium to nitrate. Nitrate, which is a negatively charged ion can be leached (move with percolating water) through negatively charged soil. Denitrification is the conversion of nitrate to N gas. In corn production, leaching and denitrification losses are highest when soil water content is high.

A commercially available nitrification inhibitor, Nitrapyrin, can be purchased as N-Serve® or Instinct™, whereas Docyandiamide (DCD) can be purchased in SuperU®. Nitrification inhibitors generally are not recommended when the fertilizer is applied as a sidedressed application. Urea hydrolysis inhibitors slow the conversion of urea to ammonium, which in turn slow volatilization losses (Clay et al., 1990). Urea inhibitors include NBPT and Agrotain®.

**Nitrogen Fertilizers**

*Slow-release N Fertilizer*
Slow-release fertilizers release only a portion of the fertilizer immediately. Commercially available products include ureaform (38-0-0), which is a combination of urea with formaldehyde; sulfur-coated urea (36-0-0); isobutylidene diurea (IBDU); and polymer-coated urea (ESN®, Polyon®, and Nutricote®). The higher cost of these materials may warrant their use for high-value crops such as vegetables, fruits,
and ornamentals. Slow-release N fertilizers are used: 1) to improve fertilizer efficiencies where N losses (leaching or denitrification) are high, 2) to overcome the need for multiple application dates, or 3) in crops where delayed nutrient release is desirable. Additional information on slow- and controlled-release fertilizer is provided by Lui et al. (2014).

**Ammonium Nitrate**
This product may have limited availability, and it is the only commonly used solid fertilizer that contains N in the NO\textsubscript{3}⁻ form. The chemical formula for ammonium nitrate (AN) is NH\textsubscript{4}NO\textsubscript{3}. Ammonium nitrate is a hazardous material because it can become combustible if it comes in contact with petroleum, diesel fuel, herbicides, pesticides, elemental S, or powdered metals. Because ammonium nitrate absorbs water from the air, it should be stored carefully. Products such as urea ammonium nitrate (UAN) contain AN but are considered safe for widespread use.

**Urea**
Urea is a commonly purchased, dry, granular fertilizer with a grade of 46-0-0. Urea is an uncharged compound that can be moved into the soil with percolating water. After application, urea is hydrolyzed with water (i.e., undergoes a chemical breakdown due to a reaction with water) into ammonia (NH\textsubscript{3}) and CO\textsubscript{2}. The application of urea to soil can lower the pH and ammonia can be lost through volatilization if the urea is not incorporated into the soil. The application of urea with the seed (pop-up) can reduce germination. A calculator for determining pop-up fertilizer rates is available from the International Plant Nutrition Institute (www.ipni.net or http://www.ipni.net/article/IPNI-3268). Starter fertilizer is generally placed 2 inches to the side and 2 inches below the seed. By separating the fertilizer and seeds, the risk of salt injury is reduced. However, this risk is not eliminated. Traditionally, it has been recommended to keep the 2-inch by 2-inch application rate below 70 lbs of product/acre. Additional information on fertilizer placement is available in Jones and Jacobsen (2009). Urea can be blended with monoammonium phosphate (MAP) or diammonium phosphate (DAP), but it should not be blended with superphosphate or ammonium nitrate.

**Ammonium Sulfate**
Ammonium sulfate has a lower risk of volatilization than urea and is a good product in high pH soil. Ammonium sulfate will lower the soil pH faster than urea and it can be used to provide S in sulfur-deficient soils. The primary disadvantage is that it requires more lime to neutralize the acidity produced during nitrification than other N fertilizers. Its cost per unit of N is generally higher than urea. The main benefit of AMS is using it to supply the crop’s sulfur requirements while receiving a nitrogen credit.

**N Solutions**
These are liquid fertilizers with grades that range from 28-0-0 to 32-0-0. These solutions are mixtures of urea and ammonium nitrate. Because the risk of precipitation decreases with increasing 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 onto the soil surface. The UAN solution, 28-0-0, is nonflammable, nontoxic, and therefore is relatively safe and easy to handle, ship, and store. However, these fertilizers can be corrosive to some metals. UAN is well-suited for in-season N application, and the density is used to convert gallons to pounds. A rule of thumb for UAN (28-0-0) is that one gallon of fertilizer contains 3 lbs of N. Example: (10.8 lbs/gal*.28=3.024 lbs N/gal).

When applied to the soil, volatilization losses are highest when applied to warm, high pH soils. When applied to soils with high residue, some of the N will likely be immobilized by the residue. To reduce this risk, broadcast applications are not recommended in high-residue soils. Immobilization can be reduced in high-residue soils by surface or subsurface banding.

**Gas N Fertilizers**
In the manufacturing of N fertilizers, atmospheric N is combined with H⁺ to form anhydrous ammonia (NH\textsubscript{3}). NH\textsubscript{3} is a colorless gas with a grade of 82-0-0. Anhydrous ammonia (NH\textsubscript{3}) is typically the most...
inexpensive, commercially available N fertilizer. To assure stability in the soil, injection is required for this N source. When applied to soil, it is rapidly converted to NH$_4$$^+$\textsuperscript{+}. 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.

**Phosphorus Fertilizers**

The production of most commercial phosphate fertilizers begins with the conversion of rock phosphates to phosphoric acid. Ammonia is then added to superphosphoric acid to create the liquid, 10-34-0. Liquid ammonium phosphate (10-34-0), can be mixed with a finely ground potash (0-0-62), water, and UAN solution (28-0-0) to form many different grades of fertilizer.

The addition of ammonia with phosphoric acid produces a slurry that is solidified to produce monoammonium phosphate (11-52-0 or 10-50-0) or diammonium phosphate (18-46-0). It is important to consider that P fertilizers are produced from rock phosphate, which is mined. These resources, like oil, are limited. Table 28.3 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 nonwater-solubilized P that is solubilized when placed in citrate. Fertilizer can also contain polyphosphate and orthophosphate forms. Polyphosphate (P$_2$O$_5$) is produced by heating orthophosphate (H$_3$PO$_4$) to remove the water. This process converts 40% to 60% of the ortho-P to poly-P.

**Monoammonium Phosphate (MAP)**

MAP fertilizer grades range from 11% to 13% N and 48% to 55% for P$_2$O$_5$. If pure, MAP [(NH$_4$)$_2$HPO$_4$] would have a fertilizer grade of 12.2-61.7-0. MAP contains less ammonia than DAP, making it a preferred pop-up fertilizer. Depending on the manufacturing process, it may contain some sulfur. MAP is water-soluble and when added to soil, NH$_4^+$ and H$_2$PO$_4^-$ ions are formed. The acidity of this product reduces the risk of ammonia volatilization. Map is a good fertilizer to use as a pop-up. It should not be mixed with calcium (Ca) and magnesium (Mg) fertilizer when applied with irrigation water. Clumping and caking can be reduced by using chemical conditioners. Purified products may be used as a feed additive, and it may be found in dry chemical fire extinguishers.

**Diammonium Phosphate (DAP)**

The fertilizer grade of DAP can range from 18% to 21% N and 46% to 53% P$_2$O$_5$. If pure, DAP [(NH$_4$)$_2$HPO$_4$] would have a grade of 21.2% N and 53.8% P$_2$O$_5$. Depending on the manufacturing process, it may also contain some sulfur. DAP is water-soluble and when added to soil, the NH$_4^+$ and H$_2$PO$_4^-$ ions are formed. The area surrounding the dissolving fertilizer granule is slightly alkaline. The impact of DAP on seed germination is greater in basic than acid soils. Ammonia volatilization risk with this product is minimal.

**Nitrophosphates**

This material is produced by reacting phosphate rock with nitric acid. The products are phosphoric acid and calcium nitrate. Depending on the requirement, a range of products is available. These products attract moisture, so they should be stored carefully to prevent caking.

**Polyphosphates**

Polyphosphates contain orthophosphate and polyphosphate. Two common ammonium polyphosphate fertilizers have an N-P$_2$O$_5$-K$_2$O composition of 10-34-0 or 11-37-0. This is a liquid fertilizer that does not require special handling and storage. However, it can be corrosive, so storage and handling equipment should be made of resistant materials. With time, polyphosphate splits apart. A general guideline is to minimize storage time and avoid storage over summer. Aqua or Anhydrous Ammonia is not compatible with 10-34-0. Polyphosphates (10-34-0) can be sprayed on to the soil surface and incorporated into the
soil. The salting-out temperatures, where precipitation can occur, for 10-34-0 and 11-37-0 are 0°F and 32ºF, respectively. Rules of thumb for P fertilizers include that:

1. MAP and DAP are soluble in water.
2. Manure can add a significant amount of P to the soil. Generally, P from organic sources is slightly less available when compared with dry or liquid fertilizers. In the year following manure applications, 60% to 80% of the P is typically available to the plant.
3. Orthophosphate or polyphosphate fertilizers are produced by removing the water from phosphoric acid.
   a. The resulting products contain approximately 40% to 60% orthophosphate with the remaining portion in the polyphosphate form.
   b. Examples of fertilizers containing orthophosphates (H₃PO₄) are MAP and DAP.
   c. Polyphosphates have the chemical formula H₄P₂O₁₀ and fertilizer grade of approximately 10-34-0.
   d. The P in orthophosphates and polyphosphates is generally considered plant available.

**Potassium Fertilizers**

**Potassium Chloride**

Potassium chloride (60% to 62% K₂O) is often referred to as potash. The color of potash can vary from pink or red to white. White potash is often higher in K analysis. One of the advantages of potash is that it often provides chlorine, which may provide disease resistance. Potassium chloride is approximately 47% chloride. Other fertilizers providing Cl⁻ are ammonium chloride (NH₄Cl), calcium chloride (CaCl₂), magnesium chloride (MgCl₂), and sodium chloride (NaCl).

This material should be stored in a dry location. Heat or cold will have little effect on this fertilizer, and KCl can be blended with a variety of N and P fertilizers 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.

**Potassium Sulfate**

Potassium sulfate (K₂SO₄) 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. K₂SO₄ can be used in sulfur-deficient soils. More information is available from the International Plant Nutrition Institute, www.ipni.net.

**Micronutrients**

**Sulfur**

A range of different S products are available. The most concentrated fertilizer is elemental sulfur. To make it available to the plant, it must be oxidized:

\[ S + 1.5O_2 + H_2O \rightarrow 2H^+ + SO_4^- + \text{energy} \]

Elemental S is often used in sodic (high Na) soil remediation. Other solid S sources are gypsum (CaSO₄), ammonium sulfate (21-0-0-24), and potassium sulfate (0-0-50-18). Two liquid S fertilizer products are ammonium polysulfide and ammonium thiosulfate. Ammonium polysulfide is a dark-red solution that contains about 20% N and 40% S. Ammonium polysulfide has a density of 9.4 lbs/gal and can be mixed with 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 this fertilizer is mixed with UAN, the rate that the urea is hydrolyzed (urea-N \( \rightarrow \) NH₄⁺) may be slowed, which in turn can reduce N losses.

**Chlorine**

Chlorine can be applied with potassium chloride (0-0-60), which is 47% chloride, ammonium chloride (NH₄Cl), calcium chloride (CaCl₂), and magnesium chloride (MgCl₂). In many situations, compound fertilizers are applied to soils. These fertilizers can provide macronutrients and micronutrients.
**Blended Fertilizers**
Many custom blends of N-P$_2$O$_5$-K$_2$O 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.

**Compound Fertilizers**
A compound fertilizer is typically a solid product that contains multiple nutrients within each granule. These fertilizers differ from blends, where the fertilizers were mixed together. Compound fertilizers are often more expensive than blended fertilizers.

**Manure**
Manure is an excellent source of nutrients in agricultural systems. Different livestock handling systems are more efficient than others at returning nutrients to the soil. Average amounts of N and P$_2$O$_5$ contained in different manures are shown in Table 28.3. Manure can be used to provide the plant nutrient requirements in organic agriculture. Manure has the added benefit of adding organic matter to soil, which should improve soil health and water-holding capacity. Manure should be incorporated into the soil to minimize nutrient losses.

**Determining the Lowest Cost Fertilizer Mixture**
There are many different fertilizer formulations commercially available. The question is, which is least expensive?

Example 1. Urea (46-0-0) cost $450/ton, what is the price per pound of N.

\[
\frac{\$450}{2000 \text{ lbs}} \times \frac{1 \text{ pound}}{0.46 \text{ lbs N}} = \$0.489/\text{lb N}
\]


Solution a. Assume the S does not have a value.

\[
\frac{\$375}{2000} \times \frac{1 \text{ pound}}{0.21 \text{ lbs N}} = \$0.89/\text{lb N}
\]

Solution b. Assume each lb S has a value of $0.25.

Calculate the value of the S

\[
2000 \text{ lbs fertilizer} \times \frac{0.21 \text{ lb S}}{1 \text{ pound}} \times \frac{\$0.25}{1 \text{ lb S}} = 105
\]

Subtract value of S from the cost of the fertilizer and calculate cost of N

\[
\$375 - 105 = $270/\text{ton}
\]

\[
\frac{\$270}{2000 \text{ lbs}} \times \frac{1 \text{ lb pound}}{0.21 \text{ lbs N}} = \$0.64/\text{lb N}
\]

Additional examples of calculations for determining the lowest-cost material are available in Clay et al. (2011).
References and Additional Information


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, South Dakota Corn Utilization Council, and the International Plant Nutrition Institute (IPNI).


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To assess whether the fertilizer investment is adequate, it is important to conduct a periodic assessment of your corn soil fertility program (Table 29.1). This assessment could consider changes in the soil nutrient level or the amount of nutrients harvested by the crop. This chapter discusses and provides examples on how to conduct P, K, and N assessments.

**Preparing to Conduct N and P Fertility Assessments**

1. **Soil Sample Collection**
   - The goal for a nutrient assessment is to provide information for a valid comparison over time. This requires that the samples be collected in the same location and relative date (Chapter 21). Due to plant uptake during the growing season, N, P, and K soil test results are often lower in following harvest than prior to planting. To the best of our knowledge, an appropriate sampling time for

### Table 29.1 Steps for improving a fertilizer program:

1. Collect soil samples from your field following appropriate protocols.
2. Conduct a visual scouting of the production field.
   a. Consider collecting plant samples and soil samples from problematic areas. Have these samples been analyzed for the nutrients in question? Compare your nutrient concentration with optimum plant nutrient concentrations. If the sample nutrient concentration is below the critical level, this does not necessarily mean that your plants are nutrient-limited. The critical levels were defined many years ago and they should be used only as a benchmark for comparison. Plant nutrient concentrations should be compared with soil test results and previous yields.
3. Assess the N rate by measuring stalk nitrate and the residual N content at the end of the growing season.
4. Calculate changes in soil N by converting soil organic matter contents to organic N.
5. Track changes in soil P and K over the past several years. How do your soil P and K nutrient levels compare with the optimum soil nutrient levels?
6. Develop a P and K budget. In this calculation, consider removal and additions.
7. Based on your results, revise the N, P, and K recommendations.

---

**Figure 29.1 An aerial image and field soil test P contour map. Very high P levels can be found in old homestead sites. (Courtesy of authors)**
long-term fertilizer assessments has not been reported. Our recommendation is to use either spring or fall samples for assessments, not both.

Sample Preparation for Shipping

After the samples are collected they should be prepared for shipping to an appropriate laboratory. When selecting a soil testing laboratory, consider the reliability of the results as well as the turnaround time. Selection of a precise and accurate laboratory is essential in terms of data quality and reliability. Precision and accuracy represent two different terms. Precision is a measure of repeatability, while accuracy is a measure of correctness of the reported value. Laboratories can be precise and inaccurate as well as imprecise and inaccurate. Where possible, select laboratories that are precise and accurate. The Soil Science Society of America sponsors the North American Proficiency Testing (NAPT) program that provides a certification of laboratories. A list of certified laboratories is available online at naptprogram.org. Ask your laboratory if it participates in a sample exchange program. Once a laboratory is selected, follow its recommendations for submitting samples. Many soil testing laboratories recommend that the samples be cooled and submitted for analysis as soon as possible. Do not leave moist soil samples in the truck for several days or in direct sunlight. Check with the laboratory about its recommendations for sample preparation.

2. Scouting fields

When scouting the field, it is important to note the date, determine the plant growth stage, visually inspect the plants for nutrient deficiencies (Table 29.1), measure the plant population, and travel beyond the field boarders (Fig. 29.2). Different protocols may be adopted for N, K, and P assessments, and in many situations, problems can be remediated only in next year’s crop.

Once the analytical and scouting results are obtained, the data should be stored for future reference. To facilitate this analysis, yield data, associated cultural practices, images, pest problems, personal notes, sampling dates, sampling protocols, and soil test results should be placed into long-term storage. Choices for long-term storage include:

- Printed hard copies of all data from a given field.
- On-farm storage of digital records. This is complicated by computer systems that routinely change.
- Off-farm storage by a data management company.
- Routinely update data to current data storage formats.

3. Tissue Sampling

Tissue sampling can be used for in-season assessment of nutrient shortages. Tissue samples collected from a prescribed location and different protocols are used for different plants and crop growth stages. For example, in soybeans at the seedling growth stage, collect the entire plant, whereas for plants between the R1 to R3 growth stages, collect 30 to 50 of the most recently mature trifoliates (Kaiser et al., 2013).

For corn at the seedling growth stage, 15 to 20 whole plants should be collected, whereas for plants between 12 inches tall (30 cm) to tasseling, 15 to 20 of the first fully developed leaves from the top of the plant should be collected. For plants between tasseling and silking, collect 12 to 20 of the leaves directly below the ear (Kaiser et al., 2013). Again, care should be followed to make sure the plants do not mold. The expected ranges for selected nutrients are provided in Tables 29.3 and 29.4.
### Table 29.2 General plant deficiency symptoms that can be observed when scouting a field.

<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>In legume, treat seed with Bradyrhizobium or apply N fertilizer.</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 (see Chapter 23).</td>
<td>Older parts first.</td>
<td>Apply K fertilizer, check soil K levels.</td>
</tr>
<tr>
<td>Sulfur</td>
<td>General yellowing (see Chapter 27).</td>
<td>Younger leaves first.</td>
<td>Apply S fertilizer, 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.</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>

### Table 29.3 Expected ranges for soybean trifoliates collected between R1 and R3. (Kaiser et al., 2013)

<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 29.4 Expected ranges of selected nutrients for corn collected at three growth stages. Images of corn growth stages are available in Chapter 5.

<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>
Conducting an N Assessment
Assessing the effectiveness of the N fertilizer rate is more difficult than assessing the phosphorus fertilizer program. The differences between the nitrogen and phosphorus assessment approaches are that nitrate is rapidly lost from soil, whereas phosphate is retained by soil. Annual N fertilizer assessments can be conducted by using a stalk nitrate test to determine the amount of nitrate-N contained in stalks 2 or 3 weeks prior to black layer.

4. Stalk Nitrate Test – Annual Assessment
The cornstalk nitrate test has been used as an end-of-season tool to assess the N program. However, it is important to point out that many external values may influence the interpretation. For example, a drought can result in elevated values (Sawyer, 2010). In this test, 2 or 3 weeks prior to black layer, the section of the plant between 6 and 14 inches above the ground collected and analyzed (Camberato and Nielsen, 2014). Previous research has shown that high nitrate concentration is the result of N availability exceeding the plant requirement. Research conducted in Indiana suggests that a concentration < 450 ppm represents low availability, between 450 and 2000 ppm represents optimal availability, and > 2000 ppm excessive availability (Camberato and Nielsen, 2014). Slightly different values are suggested for Minnesota, where the adequate levels are defined between 700 and 2000 ppm (Kaiser et al., 2013). Stalk nitrate-N concentrations for South Dakota have not been defined.

5. Changes in Soil C and N – Long-term Assessment
Long-term changes in the soil organic C and N can be used to assess temporal changes in soil health and the N supplying power. Increases in soil organic matter have been linked to increased plant-available water and N mineralization. Sample calculations are provided in Example 29.1. This assessment shows that 488 lbs of organic N/acre have been added to the soil. There have been numerous attempts to develop a soil chemical test that will predict how much of the organic N will be available to the growing crop in the next growing season. In spite of these efforts, a simple chemical test is not available. Different states have integrated soil organic matter into the N recommendation differently. For example, in Nebraska soil organic matter is integrated into the calculation. However, in South Dakota soil organic matter is not integrated into the calculation. Nitrogen contained in the soil organic matter can be made available to the plant only through N mineralization.

Example 29.1 If your soil organic matter in the surface 6 inches (15 cm) has increased from 2% to 2.5%, how much additional C and N is stored in the soil? In this calculation, assume that the surface 6 inches contains 1,673,000 lbs of soil/acre, and the C/N ratio is 10. This soil has a bulk density of 1.25 g/cm³.

Step 1. Determine the amount of soil organic matter (SOC) in the soil. In this calculation, it was assumed that 1 acre of soil 6 inches deep contained 1.68 million lbs soil.

\[
\frac{(0.025-0.02 \text{ lb})}{\text{lb soil}} \times \frac{1,680,000 \text{ lbs soil}}{\text{acre}} = 8,400 \text{ lbs SOM/acre}
\]

Step 2. Convert SOM to organic C

\[
\frac{8400 \text{ lbs SOM}}{\text{acre}} \times \frac{0.58 \text{ lbs C}}{1 \text{ lb organic matter}} = 4870 \text{ lbs C/acre}
\]

Step 3. Calculate change in soil N

\[
\frac{4870 \text{ lbs C}}{\text{acre}} \times \frac{0.1 \text{ lbs N}}{1 \text{ lb C}} = 488 \text{ lbs N/acre}
\]

Determining P and K Removal
6. Temporal Changes in Soil Nutrients
Nutrient assessments are based on comparing changes in the soil test value with fertilizer additions and the amount of nutrient removed in harvested crops. Factors that influence the effectiveness of these
calculations include:
1. That soil test values are often lower in the fall following harvest than the spring. Temporal differences resulting from overwinter recharge increase soil nutrient concentrations.
2. Field-moist samples often have lower K concentrations than dried and ground samples.
3. Soil test P can increase under anaerobic conditions and decrease under aerobic conditions. This change is attributed to changes in the oxygen concentration and associated changes in the relative amounts of Fe$^{+2}$ (anaerobic) and Fe$^{+3}$ (aerobic) contained in the soil solution.

**Determine P Removal**

Yield monitor data, when combined with average nutrient levels in grain and tissue samples, can be used to track P removal. The basic approach for converting yield monitor data to nutrient removal maps is to use data in Table 29.5. Because the yield monitor data contains erroneous information, it must be cleaned prior to analysis. Several approaches for cleaning yield monitor data are provided in Pierce and Clay (2007).

When developing a P budget, all crops used in the rotation must be considered. Removal rates for selected crops are provided in Table 29.5. The amount of nutrient removed from a field is determined by summing the amount of nutrients removed over several years, while additions are determined by summing the nutrient additions, including manure (Example 29.1). Removal can be converted from P to P$_2$O$_5$ by dividing the removal value by 0.436 and K can be converted to K$_2$O by dividing the removal value by 0.83.

### Table 29.5 Estimates of nutrient removal of N, P$_2$O$_5$, K$_2$O, Mg, and S by major South Dakota crops. (Clay et al., 2011)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Plant Part</th>
<th>Unit</th>
<th>N</th>
<th>P$_2$O$_5$</th>
<th>K$_2$O</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/mt</td>
<td>14</td>
<td>3.3</td>
<td>24</td>
<td>2</td>
<td>2.8</td>
</tr>
</tbody>
</table>

**7: Determine Nutrient Inputs**

Nutrient inputs are determined by summing all of the nutrients contained in the fertilizer and the manure. For example, if 100 lbs/a of diammonium phosphate (DAP) is applied every other year, then over a 6-year period 300 lbs of DAP will be applied. Based on a fertilizer grade of 18-48-0 (N, P$_2$O$_5$, K$_2$O), 144 lbs of P$_2$O$_5$/a or 62.9 lbs P/acre have been applied. If 115 lbs P$_2$O$_5$ are removed annually then more P is removed than added. Under these conditions, the soil test value should decrease. An additional example is provided below (Example 29.4).

If analysis suggests that mining has occurred (outputs>inputs) and soil test values have decreased below the critical nutrient level, consider increasing the fertilizer rate (Fig. 29.3). If the soil value is much higher than the critical level, consider reducing the fertilizer rate. In some situations, environmental considerations necessitate decreasing or eliminating additional P applications. The potential impact of increasing or decreasing the fertilizer rate can be tested by placing side-by-side fertilizer strips in the field.

**Meeting Environmental and Production Goals**

In the past, fertilizer recommendations were based on the plants economic responses to specific nutrients. Agronomists are now asked to consider both production and environmental goals simultaneously. Achieving this goal may require that fertilizer Best Management Practices become aligned with the 4-R program (Fixen, 2007). The 4-R program is the application of fertilizers using the right source, at the
Example 29.2 Estimating crop P and K removal in a corn and soybean rotation.

1. Calculate the amount of $P_2O_5$ and $K_2O$ removed by 60 bu/acre soybean crop and 200 bu/acre corn crop.

Pounds of $P_2O_5$/acre removed by a 60 bu/a soybean crop

$$\text{Pounds of } P_2O_5/\text{acre} = \frac{60 \text{ bu}}{\text{acre}} \times \frac{0.84 \text{ lbs } P_2O_5}{\text{bu}} = 50.4 \text{ lbs. } P_2O_5/\text{acre}$$

Pounds of $P_2O_5$/acre removed by a 200 bu/acre corn crop

$$\text{Pounds of } P_2O_5/\text{acre} = \frac{200 \text{ bu}}{\text{acre}} \times \frac{0.38 \text{ lbs } P_2O_5}{\text{bu}} = 76 \text{ lbs. } P_2O_5/\text{acre}$$

Total removal is 126 pounds of $P_2O_5$/acre

Pounds of $K_2O$/acre removed by a 60 bu/a soybean crop

$$\text{Pounds of } K_2O/\text{acre} = \frac{60 \text{ bu}}{\text{acre}} \times \frac{1.3 \text{ lbs } K_2O}{\text{bu}} = 78 \text{ lbs. } K_2O/\text{acre}$$

Pounds of $K_2O$/acre removed by a 200 bu/acre corn crop

$$\text{Pounds of } K_2O/\text{acre} = \frac{200 \text{ bu}}{\text{acre}} \times \frac{0.27 \text{ lbs } K_2O}{\text{bu}} = 54 \text{ lbs. } K_2O/\text{acre}$$

Example 29.3 Determine the amount of N and $P_2O_5$ harvested in a 200 bu/acre corn crop. A 200 bu corn crop produces approximately 9464 lbs of dry stover [(200 bu/acre)×(47.32 lbs dry grain/bu grain)×(1 lb stover/lb dry grain)]. This calculation assumes a harvest index [HI= dry grain/(grain + stover)] = 0.50

N and $P_2O_5$ in the grain + stover

$$\text{Corn } N = \frac{200 \text{ bu}}{\text{a}} \times \frac{0.9 \text{ lbs } N}{\text{bu}} + \frac{9464 \text{ lbs. stover}}{\text{a}} \times \frac{16 \text{ lbs}}{2000 \text{ lbs}} \times \frac{1 \text{ ton}}{1 \text{ ton}} = 256 \text{ lbs } N/\text{a}$$

$$\text{Corn } P_2O_5 = \frac{200 \text{ bu}}{\text{a}} \times \frac{0.38 \text{ lbs } P_2O_5}{\text{bu}} + \frac{9464 \text{ lbs. stover}}{\text{a}} \times \frac{5.8 \text{ lbs}}{2000 \text{ lbs}} \times \frac{1 \text{ ton}}{1 \text{ ton}} = 103 \text{ lbs } P_2O_5/\text{a}$$

Example 29.4 Calculate the amount of $P_2O_5$ added to a soil if 50 gal/acre of ammonium polyphosphate (10-34-0, density = 11.7 lbs/gal) are applied annually for 3 years.

$$3 \text{ years} \times \frac{50 \text{ gal}}{\text{acre}} \times \frac{11.7 \text{ lbs}}{1 \text{ gal}} \times \frac{34 \text{ lbs. } P_2O_5}{100 \text{ lbs fert}} = 597 \text{ lbs } P_2O_5/\text{a}$$

Determine the amount of $K_2O$ that has been applied if 125 lbs of potassium chloride (0-0-62) is applied annually for 3 years.

$$3 \text{ years} \times \frac{125 \text{ lbs}}{\text{acre}} \times \frac{62 \text{ lbs. } K_2O}{100 \text{ lbs fert}} = 232 \text{ lbs } K_2O/\text{a}$$
right rate, at the right time, and at the right place. This basic concept is designed to increase yields while having a minimal impact on the environment. Worldwide research is being conducted to achieve this goal. To further improve fertilizer recommendations, new knowledge, new diagnostic techniques, routing scouting, and improved record keeping needs to be integrated into our assessment and recommendation protocols. A critical component of improving fertilizer efficiency may include changing our conceptual understanding of fertilizer response and converting static fertilizer algorithms to dynamic algorithms that consider changes in climatic conditions.

References and Additional Information


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Support for this document was provided by South Dakota State University, SDSU Extension, South Dakota Corn Utilization Council, USDA-AFRI, and USDA-NRCS.


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Poorly drained areas frequently require drainage to optimize crop growth. In these areas, high water content can drown crops, delay seeding, increase N fertilizer loss, increase crop disease, and slow seed germination. These areas often are small depressional zones in large, relatively flat fields or lower elevational areas in fields with rolling topographies. Individualized drainage systems need to be developed based on a field’s topography. In addition, many poorly drained fields have high salt concentrations. This chapter addresses high water table management.

**Lowering High Water Tables with Subsurface Drainage**

Approximately 25% of the farmable acres in the U.S. have some form of artificial drainage. Subsurface (tile) drainage is used to remove excess soil water and salts using drainage pipes or tiles installed below the soil surface (Fig. 30.1). 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 typically are installed below the root zone at depths ranging from 2.5-to 4-feet. The drain line outlets generally are streams or open ditches.

Subsurface drainage is used to enable timely 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 for extended periods from excess precipitation.

By removing excess water from the root zone (Fig. 30.2), salts are flushed from the root zone, and the risk of soil compaction from field operations is reduced. Since soils with subsurface drainage 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 systems.

Along with improved yield, subsurface drainage tends to reduce surface runoff and peak flows by
encouraging increased water infiltration into soil. Zucker and Brown (1998) reported that subsurface drainage reduced surface runoff from 29% to 65%, and peak flows were reduced from 15% to 30%.

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 phosphorous losses may be reduced up to 45% (Zucker and Brown, 1998). However, subsurface drainage can increase nitrate export. The nitrate concentration in drainage water frequently exceeds the drinking water standard (10 mg/L). There are several emerging practices designed to maintain the benefits of drainage, while reducing negative environmental impacts (Chapter 31).

South Dakota drainage law currently (2016) delegates regulatory authority of drainage to the county level. Therefore, a first step in any drainage project is to consult with the county drainage board (in many counties, the board of county commissioners is also the drainage board) about permitting requirements. Note that 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 also 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 guidelines from neighboring states (e.g., Minnesota and Iowa).

**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 cost of the drainage system over its lifetime. Although the actual lifetime of a well-designed drainage system may be 50 to 100 years, its economic lifetime often is 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 provide 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 corn yields by 20 to 30 bushels per acre (Zucker and Brown, 1998), and data based on 20 years of yield records from Ontario showed yield increases of 26 bushels per acre (29% increase) on average for corn (Irwin, 1999). Additional information is available in Hofstrand (2010).

**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 vegetation. 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 whether 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 also must meet all legal and regulatory requirements for drainage outlets. In general, the drainage should occur through a natural or established watercourse and should not alter substantially 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 often are 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 traditionally have been used to remove ponded water from closed depressions or potholes through a subsurface drainage system. By providing a direct connection to water at the surface, however, these intakes serve as a shortcut for sediment, nutrients, or other pollutants to travel to downstream surface water bodies. Several alternative practices exist for removing ponded surface water that can eliminate the need for traditional surface intakes. Often a more intense set of closely spaced laterals or a buried coil of tile in the low spot will drain water quickly enough that a surface intake is not needed. A rock or “blind” inlet is another option that eliminates the need for a riser and filters out sediment before it enters the drain. Open intakes that are flush with the soil surface, in particular, should be avoided because they provide no protection from sediment entering the system. Commercial low-velocity inlets with wicks are available that filter out sediment before it enters the drainage system. More traditional slotted or perforated risers allow for some settling of sediments before water enters the intake. A permanent grass buffer should be established around the riser to trap sediment and other pollutants before they reach the intake.

If surface intakes are added to a subsurface drainage system, the system should be large enough to accommodate the concentrated flow entering from the surface. Surface intakes can be a source of weakness in the drainage system because hitting an intake with farm implements can damage the connecting line. Offsetting the intake on a short lateral line helps protect the main line.

**Drainage Coefficient**

The drainage system should be designed to remove excess water from the active root zone within 24 to 48 hours of excess precipitation to prevent crop damage. The rate at which the drainage system removes water from the soil is commonly called the drainage coefficient and is a measure of the system capacity. The drainage coefficient typically is expressed as the depth of water removed in a 24-hour period (inches/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.

<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>Mineral Soils</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field crops</td>
<td>¼ – ½</td>
<td>½ – ¾</td>
<td>½ – 1</td>
</tr>
<tr>
<td>High value crops</td>
<td>½ – ¾</td>
<td>¾ – 1</td>
<td>1 – 1½</td>
</tr>
<tr>
<td>Organic Soils</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field crops</td>
<td>½ – ¾</td>
<td>¾ – 1</td>
<td>1 – 1½</td>
</tr>
<tr>
<td>High value crops</td>
<td>¾ – 1 ½</td>
<td>1 ½ – 2</td>
<td>2 – 4</td>
</tr>
</tbody>
</table>

Typical drainage coefficients for humid regions are shown in Table 30.1. Skaggs (2007) developed
equations for estimating a drainage coefficient to maximize profit based on growing-season rainfall. Based on these equations, design drainage coefficients for eastern South Dakota range from 1/6 to ½ inches per day (greatest in the far southeast and decreasing to the north and west). In addition to this guidance, the choice of an appropriate drainage coefficient should be made based on local conditions, experience, and judgment. 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.

**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 30.2, 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 farther apart, whereas shallower drains need to be closer together to achieve the same drainage coefficient. Table 30.2 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 iGrow Drainage Calculators (http://www.igrowdrainage.org) include a drain-spacing calculator that can help with these decisions.

Drains typically are 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 with 3- to 6-inch diameter pipes and 2.5 feet for mains with pipes 8-inches or more in diameter. 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. 30.3). Main lines are run through natural low areas toward the outlet, and lateral lines may be added to provide drainage for larger wet areas. 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.

### Table 30.2 Typical drain spacing and depths for parallel drains for various soils. *(ASABE EP260.5 standard)*

<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 (⅛ inch/day)</td>
<td>Good Drainage (⅜ 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>
For any layout pattern, a general guideline to follow when laying out the system is to align lateral lines along the field contours to the extent possible. This allows the lateral lines to act as interceptors of water as it moves down the slope. Collectors or main lines are then placed on steeper grades or in swales to allow for a more uniform lateral grade line.

**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 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 30.3 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. Humps or dips in the pipe from reversals in grade must always be avoided.

**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 material (e.g., corrugated plastic or smooth-wall, plastic or concrete). 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 3/8-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.

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 (e.g., http://www.igrowdrainage.org).
- Drainage contractors and engineers.

**Installation Considerations**

In addition to a good design, the quality of installation also is important in determining how well a drainage system will perform. Once a drainage system is installed, correcting problems is difficult and expensive. To ensure that the drainage installation is done on grade and is of high quality an experienced and reliable contractor should be selected. 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 critical. 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 drainage system. Problems to watch for following installation include wet spots in the field where drains were installed, sedimentation at the outlet, outlet blockages, and erosion damage around the outlet.

**Saline Seeps**

Drainage can be used to help manage high salt concentrations (Chapter 32). In South Dakota, excess water can result in a gradual buildup of salts in the surface soil. 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. If a crop in the recharge area does not use the water, 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 (see Chapter 31 for additional information).

**References and Additional Information**


Acknowledgements

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(1) mail: U.S. Department of Agriculture
Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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Subsurface (tile) drainage removes excess water; improves trafficability; reduces excess water stress, soil compaction, surface runoff, erosion, and phosphorous transport; enhances soil aeration; encourages root development; removes excess salts; and leads to greater and more consistent yields. In spite of these numerous benefits, tile drainage can also increase the transport of nitrate from the field to nontarget areas. Nitrate is transported from surface soil to nontarget areas with percolating water because it is not attached to the soil particles. The goal of this chapter is to discuss in-field and edge-of-field practices that reduce nitrate transport through tile-drained systems (Fig. 31.1).

The Nitrate Problem
Nitrate-N concentrations in drainage water are highly variable and often exceed the EPA drinking water standard of 10 ppm (mg/L). Reducing high nitrate concentrations to levels at or below the EPA drinking water standard can be expensive and may require expanding urban and rural water treatment facilities. For example, the Des Moines Water Works installed expensive nitrate-removing treatment facilities to clean river water that receives tile-drainage waters from upstream sources. To recover these costs, it filed a lawsuit against three Iowa counties where tile drainage is prevalent. In South Dakota, nitrate-N concentration in ground and surface waters is highly variable, ranging from near zero to much higher than 10 ppm. Generally, however, nitrate-N concentrations in South Dakota rivers are less than 10 ppm.

On a broader scale, nitrate-N derived from drained croplands in the Upper Midwest is a major contributor
to hypoxia in the Gulf of Mexico (Alexander et al., 2008; US EPA, 2007). The hypoxic zone results from nitrogen and phosphorous stimulating microbial growth in the Gulf of Mexico. The dissolved oxygen in the water decreases when the microbial organisms die and are decomposed, which reduces oxygen availability to desirable species. Hypoxia has environmental and economic consequences because the amounts of harvestable fish and shellfish from the affected regions are reduced. To reduce hypoxia, states along the Mississippi River, not including South Dakota, have been tasked with reducing nutrient loading to streams and tributaries that feed the Mississippi River (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2008). The strategy to achieve this goal is the adoption of nutrient Best Management Practices (BMPs). The feasibility and potential impacts of nutrient BMPs on nitrate loading in Iowa is available in IDALS (2014) from the Iowa Department of Agriculture and Land Stewardship. In South Dakota, cost share may be available for implementing BMPs from the USDA NRCS. As public scrutiny about drainage and water quality increases, the potential exists for increased regulation. One way for farmers to be proactive about water quality is to voluntarily adopt practices that reduce off-site nitrate deposition. This chapter describes some of the most promising practices currently available.

**In-field Practices**

**Cropping and Management Strategies**

*Improved nitrogen management.* Applying N in excess of plant requirements increases the risk of nitrate leaching. Nitrate-N concentrations in drainage water can be reduced by multiple practices, including adopting N management strategies that improve N-fertilizer efficiency. These practices include reducing fall N applications, splitting the N application into two or more applications to target plant uptake requirements, and adopting cropping systems that enhance nutrient cycling (Fig. 31.1). Optimizing nitrogen application rates, timing, and using nitrification inhibitors can limit nitrate losses and improve N efficiency. Additional information about alternative in-field techniques is available in Chapters 20 and 29.

*Cover crops.* Cover crops reduce nitrate losses by utilizing NO$_3$-N that otherwise would be lost through leaching (Chapter 15). In South Dakota, integrating cover crops into corn and soybean rotations is complicated by the region’s short growing season. Research is being conducted to overcome this limitation. In Iowa, it was estimated that cover crops have the potential to reduce nitrate loading by 31% (IDALS, 2014), whereas in Minnesota, it was estimated that cover crops have the potential to reduce nitrate loading by 20% (State of Minnesota, 2014). Similar estimates are not available for South Dakota.

*Perennial crops.* Including perennial plants, such as alfalfa or native grasses, in a cropping rotation, has the benefit of reducing N fertilizer additions and nitrate losses while providing habitat for wildlife and insect pollinators. In Iowa, it was estimated that adopting a crop rotation that consists of two years of alfalfa, followed by three years of annual crops, could reduce nitrate loading 42% (IDALS, 2014).

**Drainage System Modifications**

*Controlled drainage.* Controlled drainage (or drainage-water management) uses flow-control structures to manage the timing and amount of drain flow by controlling the outlet elevation (Fig. 31.2). Many controlled drainage systems raise the outlet elevation during the late fall and winter. Reducing drain flow by raising the outlet elevation reduces total nitrate transport. In the spring and perhaps during harvest the outlet

![Figure 31.2 Controlled drainage (or drainage-water management) uses control structures to raise and lower the outlet elevation. The outlet is raised at times when drainage is not needed (the nongrowing season) or after spring field operations to store water in the soil for later availability for the crop. By reducing drain flow, controlled drainage also reduces nitrate losses from the drainage system. (Courtesy of Christianson et al., 2015)](image-url)
is lowered and the system operates like a conventional drainage system. Water for the growing crop is increased by raising the outlet following spring operations. It is important to note that controlled drainage only manages the outlet elevation and that the actual water-table level is a function of precipitation, evapotranspiration and other water losses. In drainage systems requiring a lift station, this often is accomplished by turning off the pump.

Controlled drainage is best suited to relatively flat fields (< 0.5% slope). Typical recommendations are to install a control structure for each 1- to 2-foot change in field elevation. For fields with slopes greater than 1%, more control structures are required, which increases the cost. Aligning the drainage laterals with the field contours minimizes costs and maximizes the area served by each control structure. In some situations, traditional drainage systems can be retrofitted with control structures. However, if this option was not considered during the drainage design process, retrofitting may be impractical on all but the flattest of fields. Producers can receive technical and financial assistance through the USDA NRCS to help with the installation of a controlled drainage system.

Controlled drainage has little effect on actual nitrate concentrations in the water. Instead, nitrate load reductions are achieved by reducing the amount of drain flow. In a review of controlled drainage studies, Skaggs et al. (2012) found that controlled drainage reduced nitrate loading 18% to 79%. In Iowa, it was estimated that controlled drainage reduced nitrate loading 33% (IDALS, 2014). The costs of installing controlled drainage can be partially recovered by higher yields (Skaggs et al., 2012).

Shallow drainage. In shallow drainage systems, the tile lines are installed 2.5- to 3-feet deep in the soil as opposed to > 3.5 feet (Fig. 31.3). Placing the tile lines at shallower depths reduces the total amount of water drained from the soil, which reduces nitrate losses. However, shallow drainage, when compared with deep drainage, requires more tile lines, which increases cost. By not lowering the water table as deeply, more water is stored in the soil, which may contribute to higher yields.

Like controlled drainage, shallow drainage reduces nitrate losses by reducing drain flow. However, unlike controlled drainage, shallow drainage does not have any topographic limitations. In Iowa, it was estimated that shallow drainage could reduce nitrate loading 32% (IDALS, 2014). Similar estimates for South Dakota are not available.

Recycling drainage water. In drainage-water recycling, captured drainage water is stored in a holding pond or reservoir, and used to irrigate the crop in the summer (Fig. 31.4). The benefits of this approach include increased yields and recycled nutrients. Although the practice of drainage-water recycling is attractive, it is limited by topographic requirements, the availability of a storage reservoir, unknown economic returns,
and, if high in other salts, could result in soils with greater salinity problems (Chapter 32).

**Edge-of-field Practices**  
**Denitrification Bioreactors**
A denitrification bioreactor is a trench filled with a carbon source, typically wood chips. Drainage water is diverted through the bioreactor by a control structure (Figs. 31.5 and 31.6). During periods of high flow, a portion of the drainage water is allowed to bypass the bioreactor so that drainage in the field is not affected. In the drainage water that passes through the bioreactor, a portion of the nitrate is transformed to benign nitrogen gas through the microbial respiration process of denitrification. The bioreactor is designed to enhance this process by providing food (the woodchips) and minimizing dissolved oxygen in the water. Since denitrification is a biological process, the nitrate reduction depends on the temperature and the water flow rate. Water that does not flow through the bioreactor receives no treatment.

Bioreactors can be retrofitted to wide variety of drainage systems, and they can generally fit within the edge-of-field buffer areas. Bioreactors are best suited for fields < 80 acres and they should function for 10 to 15 years before the woodchips need replacement.

**Testing Bioreactors in South Dakota**
Four bioreactors have been installed and monitored for performance in South Dakota. Findings from these reactors suggest that their efficiency decreases with increasing flow rate. During periods of high flow, nitrate concentrations can be reduced 30% to 40%, whereas during periods of low flow, nitrate concentrations can be reduced > 90%. In Iowa, it was estimated that bioreactors reduced nitrate concentrations 43% (IDALS, 2014). The estimated cost (2016) for installing a bioreactor in South Dakota is approximately $10,000. Unfortunately, bioreactors provide no real benefit to the farmer; the benefits are all downstream. Cost-share assistance is available through the USDA NRCS.

**Wetlands**
By routing drainage water through a wetland, the nitrate concentration can be reduced, while simultaneously providing habitat for wildlife, pollinators, and a variety of other benefits. The nutrient reduction results from the combination of plant nutrient uptake, microbial immobilization, and denitrification. An analysis of Iowa wetlands showed that on average nitrate concentrations were reduced 52% (Helmers et al., 2008). Compared to bioreactors, wetlands require a much greater land area, making
them better suited for the capture of water from multiple fields.

**Saturated Buffers**

Vegetated buffers between the edge of the field and the surface water are a long-established practice to reduce sediment and nutrient losses from surface runoff. However, in fields with subsurface drainage, the drainage water has no chance for it to interact with the buffer since it’s confined to the pipe. Saturated buffers work by using a control structure to divert drainage water through the buffer area’s soil (Fig. 31.7). By reconnecting the drainage water with the soil in the buffer, nitrate concentration in the water is reduced. Saturated buffers are relatively new, so limited information is available about their long-term effectiveness. However, in an Iowa study, most of the nitrate was removed from water diverted into the buffer (Jaynes and Isenhart, 2014). The major drawback to this practice is that there is generally insufficient buffer area to handle all of the drainage water during high flows, so a bypass may be required. The bypass water receives no treatment, so the nitrate removal efficiency of the saturated buffer is a function of how much water can be diverted through the buffer. In Iowa, it was estimated that saturated buffers have the potential to reduce nitrate loading 50% (IDALS, 2014).

**Summary**

Subsurface drainage, or tiling, provides a number of economic production benefits to corn producers. However, impacts of drainage on the environment are mixed. Drainage can reduce sediment and phosphorous losses but increase nitrate-N losses compared with undrained croplands. There is increasing pressure to reduce nitrogen losses from subsurface drained land because of concerns over the Gulf of Mexico hypoxic zone from excess nutrients and public health concerns over elevated nitrate levels. A number of practices are emerging to maintain the production benefits of drainage while reducing the nitrate-nitrogen lost from these systems. A few of these practices offer the potential of added yield benefits to the producer, but many do not. There are, however, cost-share incentives in place to assist with implementing many of these practices. Adopting one or more of these practices is a proactive way for agricultural producers to demonstrate a commitment to water quality. Even if a practice won’t be implemented immediately, evaluating and planning for practices that could be implemented within a producers cropping and drainage system will make it much easier for future adoption if financial or regulatory incentives change.

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*Figure 31.6 Photo of a partially completed bioreactor near Baltic, SD, showing the woodchips, plastic liner, geotextile cover, and soil cap. (Courtesy of C. Hay)*

*Figure 31.7 Saturated buffers use a control structure to divert water laterally in the buffer through perforated distribution pipes that release the water into the soil in the buffer. The water flows through the soil in the buffer, where it has a chance to interact with the vegetation and bacteria in the buffer for additional nitrate removal, before it discharges into the receiving water. (Courtesy of Christianson et al., 2015)*
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IDALS, Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, and Iowa State University College of Agriculture and Life Sciences. 2014. Iowa Nutrient Reduction Strategy: A science and technology-based framework to assess and reduce nutrients to Iowa waters and the Gulf of Mexico. Des Moines, IA. Available online at: http://www.nutrientstrategy.iastate.edu (accessed 5 November 2015)


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Salt-affected soil is a serious problem in the northern Great Plains. If high salt concentrations exist, then the problem’s type and magnitude must be accurately diagnosed. The objective of this chapter is to discuss diagnosis and remediation of South Dakota’s saline and saline/sodic soils. Key terms used in this chapter are provided at the end of the chapter. Clay dispersion can occur when the soil electrical conductivity (EC) is less than 2 dS/m and % sodium on the exchange sites is greater than 4%.

**Basic Information**

Due to increased rainfall, changing land uses, and that many of South Dakota’s soils were developed over marine sediments, the amount of land impacted by high salt concentrations has been increasing. High salt concentrations have a staggering impact on crop yields. For example, the NRCS reported that in Beadle, Brown, and Spink counties, high soil salt concentrations have resulted in an annual economic loss of over $26 million.

South Dakota soils affected by saline and sodium (Na⁺) are separated into three groups: saline (high total salts), saline/sodic (high total salts and Na⁺), and sodic (high Na⁺). The classification of a salt-affected soil into one of these groups is based on the soil electrical conductivity (EC, reported as dS/m) and the amount of Na⁺ on the cation exchange sites. The soil cation exchange capacity (CEC) is the capacity of the soil to retain positively charged cations. Common cations include Ca²⁺, Mg²⁺, NH₄⁺, K⁺, Fe³⁺, and Na⁺. The CEC helps the soil retain these nutrients from one year to the next. Because anions (negatively charged ions), such as nitrate (NO₃⁻), chloride (Cl⁻) or sulfate (SO₄²⁻) are repelled by the soil’s negative charges, anions are more rapidly lost with water percolating through the soil than cations.

Sodic soils have high Na⁺ concentrations, which can result in soil dispersion, decreased water infiltration, and increased erosion. Saline/sodic soils have high EC and high Na⁺ concentrations. Yields in these soils are reduced by the combined impact of high salt and Na⁺ concentrations. In South Dakota, soil clay dispersion (Fig. 32.1) can occur when drainage is placed under soils with an EC value < 2 dS/m and when the percentage of Na on the cation exchange sites is greater than 4.
Saline Soils

Diagnosis of Saline Soils

Climatic records indicate that spring temperatures and rainfall have increased in the northern Great Plains (Hatfield et al., 2011; Schrag, 2011), and these land use changes have resulted in higher water tables and the subsequent transport of subsurface salts to the soil surface.

Soils with salt problems can result from the natural weathering of soil and geologic parent materials, management, or a combination of both. Throughout South Dakota there are landscapes and geographic locations with naturally occurring high soil salinity levels. Within a field, salts have the potential to accumulate in some areas and not others. Generally, poorly drained footslope areas have higher salt contents than well-drained areas (Fig. 32.2). Problems often occur when the water table rises. In many South Dakota fields, salt accumulation is not a problem if irrigation water is not applied or if the water table is at least 6 feet below the soil surface.

To interpret the reported values from a soil testing laboratory, the test results and remediation techniques must be based on a standard analysis method. Many soil testing laboratories report EC values based on a 1:1 soil-to-water solution ratio, whereas the historical remediation techniques were based on the EC value measured using a saturated paste technique. Unfortunately, EC values from the two techniques are NOT equivalent, with the 1:1 method having a much lower value than the saturated paste method, thus underestimating the problem. Therefore, EC values from a 1:1 technique need to be converted to the saturated paste equivalent value, with the 1:1 values multiplied by 2.14, the relationship shown in Figure 32.3.
High salt areas can be identified by conducting a visual survey of the area, conducting an apparent electrical conductivity (EC$_a$) survey using a Geonics EM 38 (Mississauga, Ontario, Canada) or the Veris Soil EC Mapping System manufactured by Veris technologies (Salina, Kansas), tracking changes in yield over multiple years, and collecting and analyzing soil samples for electrical conductivity (EC).

### Remediation of Saline Soils

#### Managing High Salts

In saline soils, the high concentrations of soluble cations (Ca$^{2+}$, Mg$^{2+}$, Na$^{+}$, K$^{+}$) and anions (SO$_4^{2-}$, NO$_3^{-}$, Cl$^{-}$) reduce seed germination and plant growth. One of the first steps in remediating a salt problem is seeding salt-tolerant (preferably, perennial) plants in the saline and adjacent areas (Table 32.1). For example, alfalfa grown in adjacent areas may help lower the water table, which helps prevent the expansion of the affected soil. If the saturated paste soil EC1:1 is less than 0.5 dS/m, corn can be seeded (Fig. 32.4).

### Table 32.1 Sensitive, moderately sensitive, moderately tolerant, and tolerant plants. The 1:1 values were based on relationship shown in Figure 32.2. The units dS/m are identical to mmhos/cm. (Modified from the Food and Agriculture Organization of the United Nations, http://www.fao.org/DOCREP/005/Y4263E/y4263e0e.htm, accessed 6/1/2016)

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Max. EC without loss</th>
<th>% loss above crit. value</th>
<th>Max. EC without loss</th>
<th>% loss above crit. value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitive plants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:1 Sat. paste</td>
<td>dS/m</td>
<td>%loss/ dS/m</td>
<td>%loss/ dS/m</td>
<td></td>
</tr>
<tr>
<td>Beans</td>
<td>0.47</td>
<td>38.5</td>
<td>19</td>
<td>Turnip</td>
</tr>
<tr>
<td>Carrot</td>
<td>0.47</td>
<td>30.0</td>
<td>14</td>
<td>Radish</td>
</tr>
<tr>
<td>Strawberry</td>
<td>0.67</td>
<td>70.6</td>
<td>33</td>
<td>Lettuce</td>
</tr>
<tr>
<td>Onion</td>
<td>0.56</td>
<td>34.2</td>
<td>16</td>
<td>Clover</td>
</tr>
<tr>
<td>Rice</td>
<td>1.4</td>
<td>25.7</td>
<td>12</td>
<td>Foxtail</td>
</tr>
<tr>
<td>Corn (sweet)</td>
<td>0.79</td>
<td>27.8</td>
<td>13</td>
<td>Orchard grass</td>
</tr>
<tr>
<td>Timothy</td>
<td>0.93</td>
<td>36.4</td>
<td>17</td>
<td>Corn (field)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flax</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Potato</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Alfalfa</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cucumber</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tomato</td>
</tr>
<tr>
<td>Mod Tol. Plants</td>
<td>dS/m</td>
<td>%loss/ dS/m</td>
<td></td>
<td>Oat</td>
</tr>
<tr>
<td>Wild rye</td>
<td>1.26</td>
<td>12.8</td>
<td>6</td>
<td>Sorghum</td>
</tr>
<tr>
<td>Sudan grass</td>
<td>1.31</td>
<td>9.2</td>
<td>4.3</td>
<td>Tolerant Plants</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Canola or rapeseed</td>
</tr>
<tr>
<td>Crested wheatgrass</td>
<td>1.64</td>
<td>8.6</td>
<td>4</td>
<td>Tall wheatgrass</td>
</tr>
<tr>
<td>Fescue, tall</td>
<td>1.82</td>
<td>11.3</td>
<td>5.3</td>
<td>Barley</td>
</tr>
<tr>
<td>Soybean</td>
<td>2.34</td>
<td>42.8</td>
<td>20</td>
<td>Canola or rapeseed</td>
</tr>
<tr>
<td>Birds foot trefoil</td>
<td>2.34</td>
<td>31.4</td>
<td>10</td>
<td>Cotton</td>
</tr>
<tr>
<td>Perennial ryegrass</td>
<td>2.62</td>
<td>16.3</td>
<td>7.6</td>
<td>Durum wheat</td>
</tr>
<tr>
<td>Durum wheat</td>
<td>2.66</td>
<td>11.6</td>
<td>5.4</td>
<td>Durum wheat</td>
</tr>
<tr>
<td>Forage barley</td>
<td>2.80</td>
<td>15.2</td>
<td>7.1</td>
<td>Sugar beet</td>
</tr>
<tr>
<td>Wheat</td>
<td>2.80</td>
<td>15.2</td>
<td>7.1</td>
<td>Crested wheat grass</td>
</tr>
<tr>
<td>Asparagus</td>
<td>1.92</td>
<td>4.3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
Over winter, salts can be transported out of the surface soil with percolating water. Tillage will bring these salts back to the soil surface, and in many situations dormant seeding is effective because the lowest EC values are observed in the spring following snowmelt.

A partial list of techniques to reduce salt problems is provided in Table 32.2. Once a high salt area is identified, an interceptor or tile drainage can be used to lower the water table (Note: Tiling should be done ONLY if sodium is NOT a problem in the soil). See Chapter 30 for details.

Table 32.2 Do's and Don'ts when managing saline soils:

**Things to do**
1. Identify the problem and map its extent. High salinity is often a symptom of a high water table, and soil layers with low water permeability.
2. Drainage reduces salinity risks. On average, the soil EC value will decrease 0.5 dS/m for every 6 inches of water that percolates through the soil. Drainage details are in Chapter 30.
3. Prevent expansion of the problem. Expansion can be slowed by establishing deep-rooted, salt-tolerant (preferably, perennial) vegetation within the saline area.
   a. If the area is poorly drained, dormant seeding tall wheatgrass into frozen soil can be used to establish a crop in the area.
   b. Alfalfa directly adjacent and above the salt-affected area can intercept water moving into the saline area.
   c. Cover crops seeded in the fall may reduce water flow into the affected area. Lowering the water table reduces capillary rise and provides the opportunity to leach salts deeper in the profile.
   d. Techniques that reduce surface-soil evaporation, such as no-till and minimum till may be useful.

**Things not to do**
1. Deep tillage, ripping, and spring tillage should be used with caution because tillage can bring salts back to the soil surface. No-till seeding has been used to overcome this risk.
2. For sodic or saline/sodic soil (soils with high sodium content), tile drainage can worsen the problem.

Over winter, salts can be transported out of the surface soil with percolating water. Tillage will bring these salts back to the soil surface, and in many situations dormant seeding is effective because the lowest EC values are observed in the spring following snowmelt.

A partial list of techniques to reduce salt problems is provided in Table 32.2. Once a high salt area is identified, an interceptor or tile drainage can be used to lower the water table (Note: Tiling should be done ONLY if sodium is NOT a problem in the soil). See Chapter 30 for details.

**Sodium and Saline/Sodic Soils**

**Diagnosis of Saline/Sodic soils**
The common Na-containing salts with South Dakota's soils are sodium sulfate (Na₂SO₄) and sodium carbonate (Na₂CO₃). Managing for Na is important because the sodium cation disperses soil aggregates, slows water infiltration, and increases erosion (Fig. 32.1). High Na can also result in high soil pH, which can reduce the availability of some nutrients (N, P, Fe, Mn, Cu, and Zn).

If tile drainage is installed the EC can decrease gradually until the tipping point is reached and the soil disperses (Fig. 32.5). As demonstrated in Figure 32.5, a flocculated soil may have > 4% of the bases extracted being Na if the EC is high. However, as the EC decreases the risk of soil dispersion increases. In northern Great Plains dryland agriculture, tile drainage of soils with % Na extracted with ammonium acetate greater than 4 can result in problems.

Diagnosis involves collecting and analyzing soil samples from the problem areas. The sampling depth depends on the magnitude of the problem. If the goal is to install tile drainage, the soil sample should be collected from the soil surface for a salt

![Figure 32.5 The influence of drainage on the relative amount Na extracted with ammonium acetate. Drainage results in a decrease in the soil EC and the concentrations of calcium, magnesium, and sodium (Na). However, the percentage of Na as a function of all cations increases, which results in soil dispersion.](image-url)
assessment and from the surface 3 feet for a drainage assessment. Each sample should contain at least 3 pounds of moist soil collected with a soil probe from at least 10 areas within the problem area. These soil samples should be sent to a laboratory to determine the EC and percent Na extracted by ammonium acetate. Examples for determining sodium risks are provided in Examples 32.1 and 32.2.

In soil testing reports, the sodium risk is the ratio between amount of Na in the soil and the sum of the cations extracted by the ammonium acetate solution (Table 32.3). [It is important to note that some laboratories refer to the sum of the cations as the cation exchange capacity (CEC)]. The percent sodium extracted with ammonium acetate is 100 times the ratio between Na and the sum of the cations (Table 32.3).

If the soil has a Na risk, the long-term goal should be to prevent further degradation. In South Dakota, installing drainage systems in saline/sodic soils can result in serious problems within a few years.

### Example 32.1 Sample calculations for determining the percent of Na extracted with ammonium acetate.

A soil sample is sent off for laboratory analysis. In this analysis, ammonium acetate is used to extract Na, Ca, Mg, and K. The sample contains 2136 ppm Na$^{+}$, 2181 ppm Mg$^{2+}$, 3198 ppm Ca$^{2+}$, and 200 ppm K$^{+}$. Calculate the % Na extracted by ammonium acetate. In this calculation 1ppm = 1 mg/kg.

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. In addition, the molecular weight of each cation is needed. Na = 23 mg/mmol; Mg = 24.3 mg/mmol; Ca = 40 mg/mmol; and K = 39 mg/mmol. The valances and molecular weights are used to convert mmol to mmolc.

Step 1. Convert ppm for each cation to mmolc/kg. For this conversion 1ppm = 1 mg/L

\[
\begin{align*}
2136 \text{ mg Na} & \times \frac{\text{mmol Na}}{23 \text{ mg Na}} \times \frac{1 \text{ cmol Na}}{10 \text{ mmol Na}} = 9.29 \text{ cmol Na} \\
2181 \text{ mg Mg} & \times \frac{\text{mmol Mg}}{24.3 \text{ mg Mg}} \times \frac{1 \text{ cmol Mg}}{10 \text{ mmol Mg}} = 18.0 \text{ cmol Mg} \\
3198 \text{ mg Ca} & \times \frac{\text{mmol Ca}}{40 \text{ mg Ca}} \times \frac{1 \text{ cmol Ca}}{10 \text{ mmol Ca}} = 16 \text{ cmol Ca} \\
200 \text{ mg K} & \times \frac{\text{mmol K}}{39 \text{ mg K}} \times \frac{0.5 \text{ cmol K}}{10 \text{ mmol K}} = 0.5 \text{ cmol K}
\end{align*}
\]

The sum of cations (sometimes called bases) is (9.29+18.0+16+0.5) = 43.8 cmol/kg.

The % sodium extracted by ammonium acetate = 100 x [total cmol Na/total sum of cations] or for this problem:

\[
100 \times \frac{9.29}{43.8} = 21.2\%
\]

Based on this analysis, the soil contains a high relative amount of Na$^{+}$ compared to the total cations in the soil. Therefore, tile drainage of this soil would NOT be recommended, as tiling may result in soil aggregate dispersion and an associated loss of productivity.
### Example 32.2 Estimating % sodium extracted by ammonium acetate.

The sum of bases or cations can be calculated using the following steps. First, use ammonium acetate to extract the soil cations. Determine the concentrations of Na\(^{+1}\), Ca\(^{2+}\), Mg\(^{2+}\), and K\(^{+}\) in the soil and the sum of the cations. In this example, the sum of the cations is 26 cmolc/kg or 26 meq/100 g and Na is 692 ppm.

Note: The sum of cations and the Na value are given in different units. Therefore, the common unit of cmol/kg (or meq/100 g) must be determined for the Na value to determine the % Na in the soil. For this calculation 1 ppm = 1 mg/kg.

On the soil testing laboratory reports, Na\(^{+1}\) is listed as ammonium acetate extractable and the units are ppm. For these calculations ppm must be converted to meq/100 g or cmol/kg.

Convert Na in ppm to cmol/kg.

\[
\frac{692 \text{ mg Na}}{\text{kg}} \cdot \frac{\text{mmol Na}}{23 \text{ mg Na}} \cdot \frac{1 \text{ cmol Na}}{10 \text{ mmol Na}} = \frac{3 \text{ cmol Na}}{\text{kg soil}}
\]

The sum of the bases (provided in above example) is \(\frac{26 \text{ cmolc}}{\text{kg}}\)

then

\[
\frac{3 \text{ cmolc}}{\text{kg soil}} \cdot \frac{\text{kg soil}}{26 \text{ cmolc}} \cdot 100\% = 11.5\%
\]

This analysis indicates that 11.5% of the ammonium acetate extractable bases are Na\(^{+1}\). This soil has a very high Na concentration. Caution should be used in this soil’s management.

### Adding Organic Matter

A relatively inexpensive approach to improve the soil structure is to apply low Na-containing manure or apply crop residues to problem 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 to meet animal nutritional requirements may not be desirable for soil applications.

### Reseeding to Perennial Plants

Returning saline and sodic soils to deep-rooted, salt-tolerant perennial plants and grasses appears to reduce salt problems. These perennial plants can lower the water table and provide the roots needed to stabilize the soil aggregates.

### Adding Chemical Amendments

Another Na remediation approach is to replace the sodium on the soil exchange sites with calcium. In most situations, the least expensive amendments are either gypsum or elemental sulfur. The oxidation of sulfur reduces soil pH and, if free lime is present, Ca can be released. If the soil contains high sulfate or gypsum concentrations, then the addition of gypsum may not be effective (Skarie et al., 1987). In soils containing high sulfate or gypsum, elemental S may be more effective than gypsum. However, for elemental S to work, the soil must contain free lime. To increase the effectiveness of elemental S, the appropriate amount should be mixed into the soil. Theoretically, 1 ton of gypsum is replaced by 380 lbs of elemental S (0.19 \(\times\) 2000 lb/ton = 380 lbs Sulfur).

### Mitigating Sodium Risks with Tile Drainage

If % sodium extracted by ammonium acetate is greater than 4 (example calculations shown above), installing tile drainage can result in soil dispersion and the loss of productivity if the water percolating through the soil is rainwater. This dispersion is the direct result of a gradual decrease in the soil EC. Chemical remediation can be used to reduce this risk. The amount of chemical to apply depends on the
Example 32.3 Determine how much gypsum is needed. In this calculation, remember that 1 mmol/100 g = 1 cmol/kg in this soil, the soil sum of bases (cations) is 20 cmol/kg soil or 20 mmolc/100 grams, and the % Na$^{+}$ extracted by ammonium acetate was 15%. The goal is to reduce the surface 6 inches % Na extracted to 5%. In this calculation assume that the weight of the soil in the surface 6 inches is 1,850,000 lbs.

1. Calculate the amount of Na that must be exchanged to reduce from 15% to 5%.

\[
15\% = 100 \times \frac{\text{Na}}{\text{CEC}}
\]

in this example CEC is estimated to be 20 mmol/100 grams.

\[
0.15 \times \frac{20 \text{ mmol}}{100 \text{ g}} = \text{Na} = 3 \text{ mmolc/100g}
\]

at 5% Na, the amount of Na on the exchange sites is 1 mmolc/100 g (i.e. 0.05*20)

To reduce Na from 3 to 1 mmolc/100g, then 2 mmolc/100g of Na must be replaced with Ca$^{2+}$.

2. Determine the amount of gypsum to apply. This calculation assumes that 1 mole of gypsum will replace 2 moles of Na. Gypsum is used in this calculation because it contains Ca$^{2+}$ which replaces Na$^{+}$ on the exchange sites. This assumption is based on Ca having a 2+ valance and Na having a 1+ valance and gypsum having a molecular weight of 172.2 g.

\[
\frac{1,850,000 \text{ lbs soil}}{\text{acre}} \times \frac{2 \text{ mmol Na}}{100 \text{ g}} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ kg}}{2.20 \text{ lbs}} \times \frac{1 \text{ mole CaSO}_4 \cdot 2\text{HO}}{1000 \text{ mmol}} \times \frac{1 \text{ mole}}{2 \text{ moles Na}} = 1.59 \text{ tons of gypsum}
\]

Based on this calculation 1.59 tons of gypsum are needed if the surface 6 inches/acre weighs 1.85 million pounds. If the soil weighs 2 million pounds, then 1.72 tons of gypsum are needed [e.g. (2 million/1.85 million) x 1.59 tons] (Table 32.6).

Example 32.4 The soil test reports that the sample contains 2273 ppm Na$^{+}$, 1037 ppm K$^{+}$, 236 ppm Mg$^{2+}$, and 2273 ppm Ca$^{2+}$. Convert these ppm values to meq/100 g soil.

**Solution**

Note: When doing this calculation, it is important to know that K has a valance of 1+, Na has a valance of 1+, Ca has a valance of 2+, and Mg has a valance of 2+. Note: In these calculations, the answer has the units meq/100 g. The 100 g in the denominator by dividing by 10 g not 1000 g.

\[
\begin{align*}
\text{2273 mg Na} & \quad \times \frac{23 \text{ mg Na}}{1 \text{ mmol Na}} \times \frac{1 \text{ meq Na}}{1 \text{ mmol Na}} \times \frac{1 \text{ kg soil}}{100 \times 10 \text{ g}} = 9.88 \text{ meq Na} \\
\text{1037 mg K} & \quad \times \frac{39 \text{ mg K}}{1 \text{ mmol K}} \times \frac{1 \text{ meq K}}{1 \text{ mmol K}} \times \frac{1 \text{ kg soil}}{100 \times 10 \text{ g}} = 2.66 \text{ meq K} \\
\text{236 mg Mg} & \quad \times \frac{24.3 \text{ mg Mg}}{1 \text{ mmol Mg}} \times \frac{2 \text{ meq Mg}}{1 \text{ mmol Mg}} \times \frac{1 \text{ kg soil}}{100 \times 10 \text{ g}} = 1.94 \text{ meq Mg} \\
\text{2273 mg Ca} & \quad \times \frac{40 \text{ mg Ca}}{1 \text{ mmol Ca}} \times \frac{2 \text{ meq Ca}}{1 \text{ mmol Ca}} \times \frac{1 \text{ kg soil}}{100 \times 10 \text{ g}} = 11.4 \text{ meq Ca}
\end{align*}
\]

2. Determine the sum of cations

\[
= (9.88+2.66+1.94+11.4) \text{ meq/(100 g soil)} = 25.85 \text{ meq/100 g soil}
\]

3. Determine the % Na extracted with ammonium acetate

\[
\% \text{Na} = 100\% \times \frac{9.88}{25.85} = 38.2\%
\]

Based on this value 38% of the total cations extracted were Na.
incorporation of the selected chemical. For example, if no-tillage is used in the field, then treating the top 2 inches may be necessary, whereas if the soil is plowed then an 8-inch profile should be treated. Tables 32.4, 32.5, 32.6, and 32.7 can be used to simplify these calculations.

**Mixing Chemical Treatments with Soil**

When applying an amendment, incorporate the amendment with a tillage operation (even in no-till). Chemical treatments are most effective when they are incorporated into the soil. If the subsoil contains gypsum, tillage can be used to transport subsurface gypsum to the surface (Sandoval and Jacober, 1977).

**Economic Analysis**

The costs of different chemical treatments are provided in Table 32.7. Before selecting a product, check with a local provider about availability and cost.

**Summary**

In the northern Great Plains saline and sodic soils are serious problems. The management of salt-affected soils includes diagnosis, prevention, and remediation. Diagnosis involves collecting a soil sample from the problem area, which must be correctly interpreted. Many soil testing laboratories use different methods to determine the soil EC and sodium risk. For example, Midwest Laboratories Inc. and Ward Laboratories Inc. report the EC of 1:1 solution to soil ratios, whereas the historical technique was to determine the EC using a saturated paste. The EC value of a 1:1 is converted to EC of a saturated paste by multiplying the value by 2.14.

Even though many soil testing laboratories report sodium and cation exchange capacity (CEC) values, they may not be labeled as such. For example, in the Ward Laboratories report and Table 32.2, CEC is listed as Sum of Cations, while on the Midwest Laboratories report, CEC is listed as CEC. AgLab Express, located in Sioux Falls, SD, reports CEC and ESP, while Agvise reports CEC and % base saturation. A more complete listing of soils laboratories is available in Chapter 21. In this document, these values are reported as % Na extracted by ammonium acetate.

Prevention and remediation involve planting something at the site. In sodic soils, a common remediation approach is to add Ca \([\text{elemental S; solubilizes } \text{CaCO}_3 \text{ to release Ca; gypsum, and CaSO}_4]\). Gypsum additions may not be effective if the soil contains high concentrations of gypsum or SO\(_4\)-S. Under these conditions, elemental sulfur may be useful.

**Table 32.4** The approximate amount of gypsum in tons/acre required to convert the soil surface 6 inches with a specified % Na extracted with ammonium acetate to a soil with a % Na of 5. The soil's cation exchange capacities are shown on the y-axis. This calculation assumes that the surface soil weighs 2 million pounds/acre. However, many soils weigh slightly less than this value. The weight of soil for 1 acre that is 6 inches deep is approximately \(1.7 \times 10^4\) if it has a bulk density of \(1.25 \text{ g/cm}^3\). If the bulk density is \(1.45 \text{ g/cm}^3\), then the weight is approximately 2 million pounds. To convert from 2 million to 1.7 million pounds multiply the gypsum needed by 0.85 (1.7 million pounds/2 million pounds).

<table>
<thead>
<tr>
<th>Sum of bases</th>
<th>Initial % Na</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Tons gypsum/acre</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>15</td>
<td>0.75</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>1.25</td>
</tr>
<tr>
<td>30</td>
<td>1.5</td>
</tr>
<tr>
<td>35</td>
<td>1.75</td>
</tr>
</tbody>
</table>
Table 32.5 The relationship between tons of gypsum and lbs of elemental sulfur required for the surface 6 inches as influenced by desired change in Na\(^{+}\). This calculation assumes that the surface soil weighs 2 million pounds/acre. If less than the 6 inches is treated, use the appropriate ratio. For example, if only 2 inches are treated divide the tons of gypsum by 3.

<table>
<thead>
<tr>
<th>Desired change in %Na meq/100g</th>
<th>Tons gypsum 6 inches</th>
<th>Lbs of elemental S 6 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.43</td>
<td>190</td>
</tr>
<tr>
<td>1.0</td>
<td>0.86</td>
<td>380</td>
</tr>
<tr>
<td>1.5</td>
<td>1.29</td>
<td>570</td>
</tr>
<tr>
<td>2.0</td>
<td>1.72</td>
<td>760</td>
</tr>
<tr>
<td>2.5</td>
<td>2.15</td>
<td>950</td>
</tr>
<tr>
<td>3.0</td>
<td>2.58</td>
<td>1,140</td>
</tr>
<tr>
<td>3.5</td>
<td>3.01</td>
<td>1,330</td>
</tr>
<tr>
<td>4.0</td>
<td>3.44</td>
<td>1,520</td>
</tr>
</tbody>
</table>

Table 32.6 The relationship between different chemical treatments and amount of gypsum needed.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Chemical formula</th>
<th>Ton equivalent to 1 ton of gypsum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum</td>
<td>CaSO(_4) \cdot 2\text{H}_2\text{O}</td>
<td>1.0</td>
</tr>
<tr>
<td>Elemental S</td>
<td>S</td>
<td>0.19</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>H(_2)\text{SO}_4</td>
<td>0.57</td>
</tr>
<tr>
<td>Calcium Chloride</td>
<td>CaCl(_2) \cdot 2\text{H}_2\text{O}</td>
<td>0.86</td>
</tr>
<tr>
<td>Limestone</td>
<td>CaCO(_3)</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Table 32.7 2015 estimated costs for Na-affected soil remediation with chemical additives:

Cost of the chemical additives

- Elemental S at $720/ton
- Calcium chloride (CaCl\(_2\) \cdot 2\text{H}_2\text{O}) at $740/ton
- Gypsum (CaSO\(_4\) \cdot 2\text{H}_2\text{O}) at $240/ton

To reclaim a soil needing 1 ton equivalent gypsum

- Gypsum: 1 ton × $240/ton = $240
- CaCl\(_2\): 0.86 ton × $740/ton = $636
- Elemental S: 0.19 ton × $720/ton = $137

Table 32.8 Key terms used in this chapter.

<table>
<thead>
<tr>
<th>Key terms</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC</td>
<td>Cation exchange capacity, number of exchangeable cations that the soil is</td>
<td>meq/100 g = cmol /kg</td>
</tr>
<tr>
<td></td>
<td>capable of holding.</td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>Electrical conductivity, used to measure salts.</td>
<td>dS/m = mmol/cm</td>
</tr>
<tr>
<td>Sum of bases</td>
<td>Value reported on soil test results= CEC, may be identical to sum of cations.</td>
<td>meq/100 g = cmol /kg</td>
</tr>
<tr>
<td>Sum of cations</td>
<td>Value reported on soil test results= CEC, may be identical to sum of bases.</td>
<td>meq/100 g = cmol /kg</td>
</tr>
<tr>
<td>mmhos/cm</td>
<td>units used to measure salts.</td>
<td>identical to dS/m</td>
</tr>
<tr>
<td>dS/m</td>
<td>units used to measure salts.</td>
<td>identical to mmhos/cm</td>
</tr>
<tr>
<td>ESP</td>
<td>Exchangeable sodium percent.</td>
<td>% Na/CEC</td>
</tr>
<tr>
<td>SAR</td>
<td>Sodium adsorption ratio.</td>
<td>(=\text{Na}^{+}/(0.5 \times (\text{Ca}^{2+} + \text{Mg}^{2+}))^{0.5})</td>
</tr>
<tr>
<td>Saline soil</td>
<td>Soil containing high salt concentration, based on EC.</td>
<td>Historically EC &gt; 4 dS/m</td>
</tr>
<tr>
<td>Sodic soil</td>
<td>Soil containing high sodium concentrations,</td>
<td></td>
</tr>
<tr>
<td>Based %Na/CEC.</td>
<td>Track when ESP &gt; 4</td>
<td></td>
</tr>
<tr>
<td>ppm</td>
<td>The number of parts per million</td>
<td></td>
</tr>
<tr>
<td>meq/100 g</td>
<td>The millequivalents per 100 grams of soil</td>
<td>meq/100 g = cmol /kg</td>
</tr>
<tr>
<td>cmol /kg</td>
<td>The centamole of charge of an ion per kg of soil</td>
<td></td>
</tr>
</tbody>
</table>
References and Additional Information


USDA. 1954. Diagnosis and improvement of saline and alkali soils. Agric. Handbook. no. 60. United States Salinity Laboratory, Riverside, CA.
Acknowledgements
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(1) mail: U.S. Department of Agriculture
   Office of the Assistant Secretary for Civil Rights
   1400 Independence Avenue, SW
   Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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In South Dakota, average annual precipitation decreases from east to west across the state (Fig. 33.1). However, plants in all regions can experience water stress, and irrigation can reduce yield losses. This chapter discusses when and how much irrigation water to apply.

**Soil-Water-Plant Relationships**

If you are planning a new or expanding an existing irrigation system, equipment and management options should be discussed with your local advisor and you will need to obtain a permit from the South Dakota Department of Environment and Natural Resources (DENR). Once you obtain a receipt of the application, you will receive a report and recommendation along with a public notice to be submitted to your local newspaper. If your application is not contested, it takes at least two months to process the permit. If the application is contested, then it will be considered by the state Water Management Board. For additional permit requirements, contact the DENR. Information about South Dakota aquifers is available in Iles (2008).

Figure 33.1 Average annual precipitation (in inches) in South Dakota from 1981 to 2010 and irrigating a corn field (Courtesy K. Reitsma and G.W. Buchleiter, Bugwood.org)
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. 33.2). Soil water-holding properties 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. When the saturated sponge is removed from the bucket, some of the water freely drains out of the sponge. When this free-water drainage stops, the soil is at field capacity (FC). In field soil, this drainage occurs over several days after a precipitation event that saturates the soil. Water content can continue to decrease through plant uptake and evaporation until the permanent wilting point (PWP) is reached. The permanent wilting point is the point where plants will no longer recover when water is added. Water held by the soil between FC and PWP is called plant available water (PAW) and varies by soil texture (Example 33.1). Plant available water ranges from 0.9 inches of water/foot of soil in fine sands to 2.3 inches/foot in silt loams. Because soils vary by depth, the total amount of PAW needs to be calculated by soil texture for each depth and summed to estimate the PAW throughout the whole root zone.

As soil dries, the remaining water becomes increasingly more difficult for the plant roots to absorb (Fig. 33.2). When 30% to 70% of the plant available water has been depleted, the plant starts to experience water stress. The percentage of plant available water that the soil is allowed to reach before triggering irrigation is the management allowable depletion (MAD). The water held in the soil above the MAD is called the readily available water (RAW). The RAW can be calculated as the PAW multiplied by the MAD. The MAD value is dependent on the drought tolerance of the plant. A common MAD value used in corn production is 50%.

To be most effective, water must be applied to and stored in the zone containing a majority of the corn roots. Early in the growing season, the roots may be concentrated in the surface 12 inches. As the season progresses, roots can extend down to 5 feet. Most of the roots, however, are found in the surface 3 feet. A general guideline is to schedule irrigations based on the amount of PAW in the surface 2 feet prior to R1 (silk) and 3 feet thereafter.

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. Applying more water than the amount needed to bring the soil to field capacity can result in runoff, erosion, and deep
Example 33.1 Determine the amount of PAW in the surface 36 inches of soil. The soil textures at the site by depth are silt loam (0-6 inches), clay (6-18 inches), and sandy loam (18 to 36 inches). Use the following table to determine plant available water.

Step 1. Calculate the PAW for each soil layer and total plant available water in the root zone (to a depth of 36 inches).

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Plant Available Water (inch/ft 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>Loam</td>
<td>1.8-2.5</td>
</tr>
<tr>
<td>Silt loam</td>
<td>1.8-2.6</td>
</tr>
<tr>
<td>Clay loam</td>
<td>1.8-2.5</td>
</tr>
<tr>
<td>Clay</td>
<td>1.8-2.4</td>
</tr>
</tbody>
</table>

Calculate the PAW by soil texture. The upper and lower values for the range of PAW are added and the divided by 2 (to get the average amount).

\[
\text{silt loam} = \frac{1.8+2.6}{2} = \frac{2.2}{2} \text{ inches} \\
\text{Plant available water: clay} = \frac{1.8+2.4}{2} = \frac{2.1}{2} \text{ inches} \\
\text{Plant available water: sandy loam} = \frac{1.3+1.8}{2} = \frac{1.55}{2} \text{ inches}
\]

Step 2. Calculate the amount of water in the surface 36 inches. Note that each texture has a different depth, which can vary from less than 1 ft to more than a foot. Therefore, the amount of water held has to be corrected for the depth of the soil texture.

\[
\text{Depth 1:} \quad \frac{2.2}{\text{ft soil}} \times \frac{1 \text{ foot soil}}{12 \text{ inches}} \times \frac{6 \text{ inches}}{1 \text{ inch}} = 1.1 \text{ inch water} \\
\text{Depth 2:} \quad \frac{2.1}{\text{ft soil}} \times \frac{1 \text{ foot soil}}{12 \text{ inches}} \times \frac{12 \text{ inches}}{1 \text{ inch}} = 2.1 \text{ inch water} \\
\text{Depth 3:} \quad \frac{1.55}{\text{ft soil}} \times \frac{1 \text{ foot soil}}{12 \text{ inches}} \times \frac{18 \text{ inches}}{1 \text{ inch}} = 2.32 \text{ inch water}
\]

Step 3. Calculate the total PAW

Total is 1.1 + 2.1 + 2.32 = 5.52 inches of water

The amount of water lost to transpiration (water lost from plants to air) and evaporation (water lost from soil to air) is called evapotranspiration (ET). Early in the growing season (after planting), evaporation is the most important water-loss mechanism, but as the corn develops and reaches full canopy, transpiration becomes more important. Weather data (temperature, solar radiation, wind, and relative humidity) are used to calculate a reference ET (ETref) value, using either alfalfa (ETr) or grass (ETo) as the reference surface. Crop-specific information is used to adjust the ETref value by a coefficient specific to the crop (Kc) that changes depending on the plant growth stage (Fig. 33.3). For example, between 0 and about 720 growing-degree days, the Kc for corn ranges from 0.1 (early in the season) to 0.9 of the ETref. When corn is going from vegetative to reproductive phases, the Kc is > 1, indicating that corn is using more water than the reference crop during that time. The amount of water used by corn decreases as the plant matures in the fall. A map of SD showing average daily ET in July can be seen in Figure 33.4. Daily values of corn ET
Irrigation Scheduling

The amount and timing of each irrigation are a function of irrigator preference, the amount of water contained in the soil, soil and plant characteristics, and equipment capacity. When scheduling irrigation, it is important to realize that heavy irrigations (refilling the profile to at least the top 2 feet of soil) are typically more effective than light, more frequent irrigations. Wetting the soil to deeper depths promotes deeper root development, which can reduce lodging and enhance nutrient efficiency. Soils with lower water infiltration rates, however, may require shallow and more frequent irrigations to prevent runoff. To minimize yield losses due to water stress in sandy soils, frequent irrigations maybe required during grain filling and critical crop stages.

The Checkbook Approach for Estimating Soil Water

A commonly used irrigation scheduling method is called the Checkbook Approach (Werner, 1993) (Table 33.1). Whether using the Checkbook Approach or another method, soil water content should be measured occasionally to make sure the calculated value is accurate.

The Checkbook Approach often is called the Water Balance Method. This method adds water received from rainfall and irrigation to the water balance and subtracts ET. To maximize productivity, the field should be irrigated before readily available water has been depleted. This can be seen graphically in Figure 33.5. As the crop consumptive water use reduces the plant available water, irrigations can be timed to stay above the management allowable depletion (MAD) for corn. Greater irrigation amounts will allow for additional time between irrigations, but be careful not to raise the stored water content higher than the field capacity or runoff, leaching, flood stress of the roots, or increased disease incidence may occur. The Checkbook Approach utilizes the following tools:

- A rain gauge to measure rainfall and irrigation.
- Estimated ET values.
- Soil moisture balance worksheets (Table 33.1).
- Soil water content measurements (to validate checkbook balances).

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

<table>
<thead>
<tr>
<th>Date</th>
<th>Corn Stage</th>
<th>Notes</th>
<th>Max Temp</th>
<th>ET (-)</th>
<th>Irrigation (Net) (+)</th>
<th>Rain (+)</th>
<th>PAW = 7.1”** Stored Water</th>
<th>% of PAW Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/22/2014</td>
<td>R1</td>
<td>Partly Cloudy, 10-15 mph Wind</td>
<td>86</td>
<td>0.37</td>
<td>0</td>
<td>5.21</td>
<td>73%</td>
<td></td>
</tr>
<tr>
<td>7/23/2014</td>
<td>R1</td>
<td>Sunny, 5 mph Wind</td>
<td>82</td>
<td>0.25</td>
<td>0</td>
<td>4.93</td>
<td>69%</td>
<td></td>
</tr>
<tr>
<td>7/24/2014</td>
<td>R1</td>
<td>Cloudy, 10 mph Wind</td>
<td>76</td>
<td>0.21</td>
<td>0.27</td>
<td>4.99</td>
<td>70%</td>
<td></td>
</tr>
<tr>
<td>7/25/2014</td>
<td>R2</td>
<td>Sunny, Calm</td>
<td>85</td>
<td>0.31</td>
<td>1.2</td>
<td>5.5</td>
<td>78%</td>
<td></td>
</tr>
<tr>
<td>7/26/2014</td>
<td>R2</td>
<td>Sunny Calm</td>
<td>89</td>
<td>0.33</td>
<td>5.20</td>
<td>73%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7/27/2014</td>
<td>R2</td>
<td>Sunny Calm</td>
<td>90</td>
<td>0.35</td>
<td></td>
<td>5.20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*See Example 33.1 for calculation of total PAW (total plant available water) in the profile.
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. Due to runoff, effective rainfall is usually less than the measured rainfall. One approach to estimate effective precipitation is to include all rainfall up to 0.2 inch, and then 80% of any rainfall greater than 0.2 inch. If the crop is at full canopy cover, a small amount (up to 0.05 inch for corn) may be subtracted for water intercepted and retained by the leaves (Example 33.2). Additional details for estimating effective precipitation can be found in Cahoon et al. (1992).

### 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.

#### The Hand-feel Method
This is a fast and inexpensive method and it involves estimating the soil water content using your thumb and forefinger. In this method, the hand should be calibrated for different soil textures and moisture contents. Hand-feeling is the least accurate method and should be used only to get a rough idea of water status.

#### Gravimetric Water Content
Gravimetric water content is measured by collecting samples and calculating the weight difference between wet and oven-dried samples. Samples can be dried in a microwave oven using procedures detailed in Schneekloth et al. (2007). Drying with a microwave oven is much quicker than drying with a conventional oven and can provide moisture percentage estimates within an hour of collecting the sample. For the microwave method:

1. Collect 5 to 10 soil cores from a given soil depth and management zone with a soil probe. Note the location of samples and store and seal in a plastic bag.
2. Mix the sample.
3. Weigh a plate and place around 25 g gram (approximately 1 ounce) on the plate and re-weigh. The wet weight of the sample is \( W_{s_{\text{wet}}} \).
4. Place in a microwave for 10 minutes. Weigh, and put in the microwave for an additional 5 minutes. Repeat the process until the weight is constant. The weight of this dry sample is \( W_{s_{\text{dry}}} \).
5. Calculate the gravimetric water content using the equation:
   \[
   \% \text{ moisture} = \left( \frac{W_{s_{\text{wet}}}}{W_{s_{\text{dry}}}} - 1 \right) \times 100\%
   \]
   An example of this calculation is shown in Example 33.3.

#### Soil Water Sensors
The soil water content or status can also be measured with sensors placed in the soil. For irrigation scheduling, sensors should be placed at multiple depths (such as 6”, 18”, and 30” to represent the top 3 feet of soil) near both the start and endpoint of the irrigation system. When installing a soil water sensor such as a gypsum block or granular matrix block, insert the sensor into a PVC pipe sleeve. This can help you be more accurate with your depth and helps to protect the wire from rodents. Make the hole as

---

**Example 33.2 Determine the effective rainfall for a 3-inch rain. The corn crop is full canopy cover and runoff is not detected.**

\[
\text{Effective rainfall} = 0.2 + [0.8 \times (3 - 0.2)] - 0.05 = 2.39 \text{ inches}
\]

In this calculation all rainfall < 0.2 inches counts, 80% of the rainfall > 0.2 inches, and 0.05 inches is subtracted for plant interception.
tight as possible to the diameter of the sensor to assure that the measurements are as representative as possible.

Soils are variable so multiple stations of sensors can be useful to understand the variation of water availability within the field. A balance must be struck between cost and labor requirements for installation of multiple stations and the increased knowledge and understanding of the field that will be gained from the added stations. To install, use a soil probe as close in diameter as possible to the soil sensor to create the hole, and insert the sensor. There should be a tight fit between the sensor and the soil (Air between the soil and the sensor will affect the readings). If a tight fit isn't achieved, it may be necessary to make a soil-water slurry, pour the slurry into the hole, and place the sensor into the slurry. The slurry will have properties that differ from the surrounding soil so the sensor readings may be affected but to a lesser extent than air pockets. The sensor may not read accurately right after installation. With wetting and drying cycles, the measurements should become more accurate.

The greatest value from soil water sensors can be gained by monitoring them for long periods of time. The accuracy of any single water content measurement may be suspect but changes over time reveal trends that can be useful for managing irrigation water. It is important to monitor and maintain the sensors, so they operate accurately. Practice and skill are required to obtain accurate measurements and information.

Soil water tension can be measured with sensors such as gypsum blocks (Werner, 2002), granular matrix blocks (e.g., Watermark®, Figure 33.6 Watermark® Granular Matrix sensor. (Irrometer, Co., Riverside, CA). (Courtesy of Todd Trooien, South Dakota State University), Figure 33.7. ECH2O EC-5 soil water content sensor (Decagon Devices, Pullman, WA, Decagon.com). Note the RD-45 connector at the end of the cable for easy connection to a data logger. (Courtesy of Todd Trooien, South Dakota State University)

---

**Example 33.3** Calculate the amount of plant available water remaining in the surface 12 inches for a silt loam soil when $W_{s_{w_{w}}}$ is 25 g and $W_{s_{d}}$ is 20 g. In this problem, the bulk density for the soil is 1.3 g cm$^{-3}$ and the percentage of soil water at the permanent wilting point (PWP) is 9%.

Step 1. Determine the gravimetric water content:

$$\% \text{ moisture} = \frac{(25-20)}{20} \times 100\% = 25\%$$

This value represents the gravimetric water content. To convert this value to inches of plant available water remaining in the soil, the value needs to be converted to a volumetric basis (Step 2).

Step 2. Determine the amount of plant available water (PAW) remaining in the soil:

$$\text{PAW} = (\text{sample depth}) \times (\text{bulk density}) \times \left(\frac{\% \text{ moisture} - \% \text{ moisture at PWP}}{100}\right)$$

$$\text{PAW} = 12 \text{ inches} \times \left(\frac{1.3 \text{ g}}{\text{cm}^3}\right) \times \left(\frac{(25-9)}{100}\right) = 2.5 \text{ inches}$$

Note: These calculations convert gravimetric values to volumetric values. Weight-based (gravimetric) values are reported as g/g whereas volumetric values are reported as g/volume. Some instruments measure volumetric values and some measure volumetric values. Only convert gravimetric values to volumetric values.
Fig. 33.6, Irmak et al., 2014) or tensiometers (Kranz et al., 1989). These sensors measure the soil water tension, the energy with which the water is held in the soil, rather than soil water content. All of these sensors have been used for irrigation management for many years and are readily available at relatively low cost.

Soil water content is often measured with sensors that fall into one of two measurement categories: capacitive sensors or time domain reflectometry (also called transmissivity). Various capacitive soil water content sensors are available, including the ECH\textsubscript{2}O (Fig. 33.7, Decagon.com), and the Enviroscan probes (Sentek.com). The ECH\textsubscript{2}O sensors are placed at a single depth in a single location. The Enviroscan probe contains a series of sensors located on a single instrument so multiple depths (an entire profile) can be measured at the same time. Research results with capacitive probes have been mixed. Profile capacitive methods such as the Enviroscan have been shown to be unreliable for irrigation management purposes (Evett et al., 2012). But other research has shown that capacitive sensors provide useful information if they are calibrated for local conditions (Rudnick et al., 2015).

Time domain transmissivity (TDT) methods have been shown to be more accurate for use in irrigation management (Evett et al., 2012). Some readily available TDT sensors include: Acclima (Acclima.com) and Gro Point (Esica.com, Evett et al., 2015).

Soil water measurements can improve irrigation management by providing data for making current and future decisions. Storing the data can be done on personal computers, hard drives, or in the cloud. Cloud-based storage will most likely be managed by commercial irrigation management services. If you purchase these services, data is uploaded to the internet and stored on commercial servers. This is beneficial because the information can be accessed by multiple devices. These cloud services typically include decision support software that provides irrigation guidance. There are many systems or packages available.

**Critical Plant Growth Stages**

The two most critical periods for irrigation of corn are seed germination and from V8 (3 weeks prior to tasseling) to a week after silking (R3). Adequate soil moisture near the soil surface is needed for germination. If the surface soil layer is dry, irrigation may be needed to improve germination and seedling vigor. Adequate water in the root zone is needed for root development.

Between V8 and R3, meeting the high water demand will require planning (Werner, 1993). After R3 corn is less susceptible to water stress than between V8 and R3. From R3 to R6 soil water levels should be allowed to approach 70% maximum allowable depletion. Terminating irrigation before R6 does not promote early maturing and dry-down of the grain (Werner, 1993). Many soils contain 2 to 4 inches of water in the root zone when they reach 60% to 70% maximum allowable depletion. Depleting soil water at the end of the season minimizes nutrient leaching and provides an opportunity for the surface soil to dry prior to harvest.

**Irrigation Systems**

**Surface Irrigation**

Surface irrigation has been used for millennia. Surface irrigation is inherently nonuniform because the soil surface is used for water conveyance and water storage. 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 reduce the difference of infiltration time between the top and bottom of the field, improving 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, thus reducing the difference in infiltration time. Other methods for increasing uniformity include surge irrigation, cutback irrigation, and furrow packing (usually for the first irrigation). Polyacrylamide (PAM) soil amendments are often used to reduce soil erosion when the irrigated soils are particularly erodible.
**Center Pivot**

Center pivot irrigation is the most popular irrigation method in South Dakota. Center pivot systems can reduce labor requirements (compared with surface irrigation), increase distribution uniformity and irrigation efficiency, and allow the effective application of fertilizer or pesticides with the irrigation water. With center-pivot systems, nozzles can be placed above, at the top of the canopy, or within the corn canopy. Historically, high-pressure systems used high impact, widely spaced sprinklers that were mounted on the pipe. These systems were effective but had high energy requirements. To reduce energy requirements, operating pressures have decreased. Drop hoses or pipes can be used to lower the nozzles to just above or even into the crop canopy. This is known as mid-elevation spray application (MESA). Where water supplies are greatly diminished and irrigation systems have limited capacity, nozzles have been installed as low as 2 feet above the soil surface. This is known as low-elevation spray application (LESA). The LESA system requires many additional nozzles compared with MESA because the lower pressure creates a smaller wetted diameter from the nozzle. This raises the initial cost of the system but will save money in energy over the long term. In some cases, the sprinkler is covered with a sock that drags on the ground so that water is applied directly to the soil surface. This is called low-energy precision application (LEPA). The greatest danger of using low nozzle elevations is that runoff can occur. If you are considering installing nozzles near the soil surface, be sure that your soils have high infiltration rates (> 0.25 inch/hr).

The most-used system is MESA because wind drift and evaporation are reduced compared with the high-pressure system, nozzles are kept out of the crop canopy most of the time, and wetted diameters can be larger than low-pressure systems, which reduces risk of runoff and requires fewer nozzles.

Pressure regulators are an important consideration for sprinkler irrigation systems. When the elevation of a sprinkler changes, the pressure changes. This change of pressure results in a change of water flow rate through the sprinkler. If the irrigation system must go up and down hills, pressure regulators should be used. A pressure regulator will reduce the pressure when the sprinkler is at a low elevation. This keeps the pressure and the flow rate constant when the sprinkler changes elevations. This is important to keep water application uniform across the field. In general, pressure regulators should be installed when the sprinkler flow rate variation exceeds 10%. NRCS recommends the use of pressure regulators when the variation of pressure exceeds 20% (which corresponds to a flow rate variation of 10%). Increasing the pumping pressure will have little to no effect on the nozzle flow rate with pressure regulators. The pressure increase will affect only the flow rate and distance of the spray at the end gun, if installed.

**Subsurface Drip Irrigation**

Subsurface drip irrigation (SDI, Fig. 33.8) is a microirrigation system. SDI systems have high water-use efficiencies and they have been used to irrigate corn in the central and southern Great Plains. A disadvantage with this system is the high installation cost. Drip lines are normally buried in the soil across the field every 5 feet (60") for 30-inch rows. This allows every row to be within 15” of a drip line. Even though SDI is expensive, it does offer some additional benefits. Low amounts of nitrogen can be added to the water through the system at any crop growth stage (spoon-fed). SDI systems have the highest potential application efficiency with little to no evaporation. SDI allows for lower pump capacities than a pivot, it will fit into oddly shaped fields, and it covers the whole area. Pressure-compensating emitters can handle some field topography but may still be limited. Maintenance of these systems includes periodic flushing of the lines and chemical injection into the water to provide pH or biological control to help keep the emitters from plugging. Rodents can also pose a threat to these systems, as the plastic tape can be easily punctured. Leaks are often determined by troubleshooting system pressures and by finding excess water at the ground surface.

![Figure 33.8 Subsurface drip irrigation (SDI). Water is added to the field near the plant roots with no exposure to the soil surface. (Courtesy of Dr. F.R. Lamm, Kansas State University)](image-url)
Managing Saline (salts) and Sodium Problems
This section concentrates on salt problems associated with irrigation systems. Additional information on saline and sodic soil management is available in Chapter 32. Salt problems often occur when the irrigation water contains high salt concentration and when the soil has 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 an 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 accumulate and cause problems. In poorly drained situations, select salt-tolerant crops and/or install artificial drainage to remove excess water and salts from permeable soils (see Chapter 32 as tiling is not suitable for some 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 to leach salts is referred to as the “leaching requirement” (LR).

\[
LR = \frac{\text{Irrigation Water EC (dS/m)}}{\text{Acceptable Deep Drainage EC (dS/m)}}
\]

LR is determined by measuring the electrical conductivity (EC) of irrigation water and acceptable deep drainage water and then placing those values into the equation above. EC of irrigation water is commonly reported in units of decisiemens per meter (dS/m). A sample calculation is provided in Example 33.4.

**Example 33.4** Determine the leaching requirement if the irrigation water EC is 2 dS/m and the acceptable deep drainage EC value is 6 dS/m.

\[
LR = \frac{2}{6} = 0.33
\]

A leaching requirement of 0.33 means that 33% more water (over the plant’s requirements) is needed to leach salts from the upper profile. For example, if the plant requires 3 inches of water, then the amount of water needed to meet the needs of the plant and to wash excess salts out of the profile is 4 inches \(4 = 3 + [3 \times 0.33]\). More information for managing saline soils is provided in Bischoff and Werner (1999).

**Toxic Ions (Na and B) Contained in Irrigation Water**
Irrigation water can contain ions that are toxic to corn. In South Dakota, two ions of concern are boron (B) and sodium (Na). B can reduce yields when its concentration exceeds 1 mg/L. Many South Dakota aquifers with high concentrations of B also have high concentrations of Na. To determine the B and Na concentrations of your irrigation water, collect a representative pint of water and send it to an appropriate laboratory for analysis. Contact your regional extension center for help in locating a water quality testing lab.

Extreme care must be used in soils with high Na contents or when using water with high Na concentration. Na destroys soils by dispersing soil colloids and destroying soil structure. In addition, high Na reduces water infiltration and permeability. Irrigating with water that has high Na concentrations has rendered some land in South Dakota useless. Na-affected soils often have very poor drainage, and Na-sensitive plants experience reduced growth. Nutrient-deficiency symptoms (resulting from high pH) and poor soil physical conditions are often observed in high-Na situations. If a Na problem is suspected, contact your local Extension educator or crop consultant for advice. Suspected Na problems can be confirmed by testing soil and irrigation water for Na, calcium (Ca), and magnesium (Mg) content. Additional information about saline and sodic soil problems is provided in Chapter 32.
If Na is a problem, the long-term goal should be to prevent further degradation and reduce further addition of Na. Some options for managing sodic soils include planting Na-tolerant plants, improving drainage, and adding low-Na manure or gypsum or other sources of calcium. Elemental sulfur (S) is sometimes recommended to lower soil pH values. Recent South Dakota research is showing that application of S is an effective amendment to reclaim sodic soils. If gypsum (CaSO$_4$•2H$_2$O) is present at deeper soil depths, deep tillage may help bring the gypsum to the soil surface. If drainage and soil amendments are not possible, consider an alternative land use, such as pastureland planted with salt- and Na-tolerant grasses.

**Chemigation**

An irrigation system with the proper additional equipment can apply fertilizers or pesticides with the water. This practice is commonly referred to as chemigation. Chemigation is well-suited for center pivot systems. However, chemigation is not well-suited for large-volume irrigation guns because of drift and uniformity problems. Advantages of chemigation include: 1) reduced soil compaction, 2) less labor and reduced costs, 3) rapidly applied treatments; and 4) less mixing. The disadvantages include: 1) high initial equipment costs, 2) need for specialized equipment, and 3) some products are not approved for chemigation.

Fertilizer applied through an irrigation system must remain soluble in the irrigation water. If it is not water-soluble, precipitates will form and nozzles, emitters, and fittings can become clogged. If you are unsure of solubility of a fertilizer:

- Fill a clear jar with irrigation water.
- Add the fertilizer at the concentration you will apply to the field.
- Look for precipitates at the bottom of the jar.
- If precipitates form, you should not use that material for chemigation.

After fertilizer application, a small irrigation may be applied to wash the fertilizer off the plant and reduce the possibility of fertilizer burn. When using chemigation to apply liquid nitrogen or other chemicals, you may not need water at the time you want to apply the chemicals. If that is the case, apply the chemicals in a timely fashion but use the least amount of water possible. High-capacity injection equipment and an irrigation system that can cover the field in the shortest period of time are desirable for chemigation.

When chemigating you must also protect the water supply and environment. Backflow of the chemical into a well or other water supply or leakage of the chemical can have serious consequences. State law requires the use of an anti-backflow device when chemigating (SDCL §34A-2A-3). In South Dakota, requirements include an irrigation pipeline check valve, a vacuum relief valve, an automatic low pressure drain, a chemical injection line check valve, interconnect of the injection pump and irrigation pump, and an inspection port. Table 33.2 shows various backflow prevention options. Additionally, standard professional practices for chemigation and water supply protection have been developed (ASAE, 1989).

If applying a pesticide with the irrigation system, the pesticide must be labeled both for corn and for application with the irrigation system. Chemigation is not recommended for use with volume guns (big guns) because of poor application uniformity and wind drift problems. Always read and follow the

<table>
<thead>
<tr>
<th></th>
<th>Reduced Pressure Principal Assembly</th>
<th>Double Check Valve Assembly</th>
<th>Pressure Vacuum Breaker Assembly</th>
<th>Air Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Pressure</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Possible Back Pressure</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Possible Back Siphonage</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nontoxic</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Toxic (Chemicals and Pathogens)</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Table 33.2 Backflow prevention options for site-specific risks. (NRCS MT NEM)
instructions on the product label and take precautions to protect yourself and others from chemical exposure.

In summary, properly managed irrigation can pay dividends by reducing stress caused by lack of water and thereby increasing crop yields. Irrigated lands should be managed for high yields and high returns to maximize the return on the irrigation investment. Such management might include increasing plant population to best capitalize on investment in irrigation equipment. Irrigation research in Nebraska has shown economic optimum seeding rates for corn might be increased from 26,000 up to 34,000 seeds/acre on irrigated croplands (Barr et al., 2013).

<table>
<thead>
<tr>
<th>Water term</th>
<th>Definition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation point</td>
<td>All pores are filled with water.</td>
<td>0 bars</td>
</tr>
<tr>
<td>Field capacity</td>
<td>Water in the soil after free drainage.</td>
<td>-1/3 bars</td>
</tr>
<tr>
<td>Plant available water</td>
<td>The total amount of water in the soil that the plant can use.</td>
<td>Between -1/3 and -15 bars</td>
</tr>
<tr>
<td>Maximum allowable depletion</td>
<td>Point where the irrigation should be turned on.</td>
<td></td>
</tr>
<tr>
<td>Readily available water</td>
<td>Between 30% to 70% of the plant available water.</td>
<td></td>
</tr>
<tr>
<td>Permanent wilting point</td>
<td>Plant will not recover from the water stress.</td>
<td>-15 bars</td>
</tr>
<tr>
<td>Evapotranspiration (ET)</td>
<td>Water lost through evaporation and transpiration.</td>
<td></td>
</tr>
</tbody>
</table>
References and Additional Information


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.


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(1) mail: U.S. Department of Agriculture
Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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The ability to nurture the planted seed to a mature plant depends on many factors, including the seed germination rate and seedling emergence. Both of these factors depend the effectiveness of the seeding process. Seedling emergence is used to calculate the seeding rate and to assess the effectiveness of the planting system. These calculations require that the row spacing and plants per row be estimated. The purpose of this chapter is to discuss guidelines for determining the seeding rate and measuring seed emergence.

Calculating the Corn Seeding Rate
An important consideration in achieving the yield goal requires that the appropriate number of seeds be planted in the soil. A very coarse rule of thumb is to seed 10% more seeds than your target population. However, this rate can be fine-tuned by considering the seed germination rate and the number of germinated seeds that survive to harvest. Information on germination is provided by the seed dealer and found on the seed bag or box label. Expected survival, which is impacted by diseases, insects, weather events, and seedbed characteristics, is harder to estimate. The survival of germinated seeds to harvest can be calculated by measuring seed emergence and the harvested plant population.

Seedling Rate
The seeding rate is calculated with the equations:

\[
\text{Seedling rate (seeds/acre)} = \frac{\text{Desired population at harvest (plants/acre)}}{\text{\% emergence of planted seeds}}
\]

In this equation, the % emergence of planted seeds can be estimated based on seed germination rate and prior records. Common estimated values for % emergence of planted seeds range from 90% to 95%, and it can be calculated using the equation:
The % germinated seeds can be estimated using the germination rate provided by the seed seller and the % of germinated seeds that emerged from the soil (Fig 34.1). Unfortunately, the % of germinated seeds that emerged from the soil is not known and therefore it must be estimated. This value is important because it can reveal planter problems. Sample calculations for these values are provided in Examples 34.1, 34.2, and 34.3.

**Seed Emergence**
Calculating the % seed emergence requires a measurement of the plant population (Fig. 34.1). The percent seed emergence is influenced by many factors, including seedbed preparation, crusting, and diseases, and it is calculated with the equation:

\[
\% \text{ Seed emergence} = 100\% \times \frac{\text{Plant population after emergence}}{\text{Seeding rate}}
\]

**Calculating Plant Population**
The plant population in a cornfield is determined by counting the number of plants in 1/1000 of an acre (Table 34.1). Based on data in Table 34.1, for a 30-inch row, the length of the row for 1/1000 of an acre is 17 feet and 5.1 inches.

**Determining Stand Uniformity**
Corn plants that are too close can act as a weed to the adjacent plant. The newest of planters, if accurately calibrated, have the capacity to reduce this variability to near zero. Stand uniformity can be determined by calculating the standard deviation of the distances between adjacent corn plants. The field variability can be determined by placing a 20-foot tape measure next to a row of corn plants, as shown in Figure 34.2.

Record the location of each plant within the row in inches. Use a tape measure that documents inches rather than feet and inches. Repeat the process at 4 or 5 separate locations within the field. Type these numbers into a spreadsheet and use the spreadsheet to calculate the distance, the average distance, and standard deviation of the distances (Table 34.2).

Optimum yields are obtained by minimizing the spacing variability. The standard deviation provides an index of the ability of the seeder to plant a uniform stand (Note that there may also be agronomic problems, such as clods or a crust that reduces seedling emergence). Most agronomists believe that yield is

<table>
<thead>
<tr>
<th>Distance (inches)</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>10</th>
<th>14</th>
<th>15</th>
<th>20</th>
<th>21</th>
<th>28</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feet</td>
<td>87</td>
<td>74</td>
<td>65</td>
<td>52</td>
<td>37</td>
<td>34</td>
<td>26</td>
<td>24</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>Inches</td>
<td>1.4</td>
<td>7.1</td>
<td>4.1</td>
<td>3.3</td>
<td>4</td>
<td>10.2</td>
<td>1.6</td>
<td>10.7</td>
<td>8</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Table 34.1 The distance along a row representing 1/1000 of an acre. On the row, the number of plants should be counted. The plant population is 1000 times the number of plants in 1/1000 of an acre.

**Figure 34.2** The number of corn plants along a transect within a single row. In this example, corn plants are located at 2, 5, 19, 25, 37, 42, 46, 55, and 57 inches.
Example 34.1 Determine the emergence of germinated seeds (EGS). If the seed container label germination rate is 90%, the seeding rate is 35,000 seeds/acre, and the post-emergence counted plant population is 30,000 plants per acre, what is the % emergence of germinated seeds?

\[
\% \text{EGS} = \frac{\% \text{seed emergence}}{100} = \frac{30,000 \text{ plts/acre}}{35,000 \text{ plts/acre} \times 0.90} = 0.952
\]

This calculation suggests that 95.2% of the germinated seeds emerged from the soil.

Example 34.2 If the seedling plant population is 32,000 plants/acre and the plant population at harvest is 31,000 plants/acre, what is the survival of seedlings to harvest?

\[
\% \text{ survival} = \frac{31,000}{32,000} = 96.9\%
\]

Example 34.3. If the % germination is 96%, the expected survival of germinated seed to harvest is 92.2%, and the target plant population is 34,000 seed/acre what is the seeding rate?

Seeding rate = \( \frac{\% \text{seed germination rate}}{100} \times \frac{30,000 \text{ plts/acre}}{35,000 \text{ plts/acre}} \)

Seeding rate = \( \frac{34,000/\text{acre}}{0.96 \times 0.922} = 38,413 \text{ plants/acre} \)

Example 34.4 Determine the seed emergence rate if the seeding rate is 38,000 plants/acre.

Measure the row width, and if your row width is 30 inches, count the number of plants in a row that is 17 feet and 5.1 inches long. If 35 corn plants are contained in the row, then your plant population is 35,000 plants/acre (35×1000).

Seed emergence = 100% \( \times \frac{35,000}{38,000} = 92.1\% \)

In a second example, you plant corn in 15-inch rows, what is the length of row to produce 1/1000th of an acre? Based on data in Table 34.1, count the number of plants in a row that is 34 feet and 10.2 inches long.

Table 34.2 Sample spreadsheet showing how to calculate plants/acre and yield losses due to variable seeding. The tables below show the locations on a tape measure. In the table on the right, the equations behind the values in column B are shown. The value in column C is the row spacing.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured location of each corn plant</td>
<td>Spacing distance between each pair of plants</td>
<td>30</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>17</td>
<td>16</td>
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<td>4</td>
<td>33</td>
<td>5</td>
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<td>1</td>
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<td>5</td>
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<td>8</td>
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<td>8</td>
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<td>60</td>
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</tr>
<tr>
<td>11</td>
<td>66</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>Average</td>
<td>6.6</td>
</tr>
<tr>
<td>13</td>
<td>Standard deviation</td>
<td>5.12</td>
</tr>
<tr>
<td>14</td>
<td>Bu/acre in estimated yield loss</td>
<td>12.5</td>
</tr>
<tr>
<td>15</td>
<td>Plants/acre</td>
<td>30,750</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equations</td>
<td></td>
</tr>
<tr>
<td>=A2-A1</td>
<td></td>
</tr>
<tr>
<td>=A3-A2</td>
<td></td>
</tr>
<tr>
<td>=A4-A3</td>
<td></td>
</tr>
<tr>
<td>=A5-A4</td>
<td></td>
</tr>
<tr>
<td>=A6-A5</td>
<td></td>
</tr>
<tr>
<td>=A7-A6</td>
<td></td>
</tr>
<tr>
<td>=A8-A7</td>
<td></td>
</tr>
<tr>
<td>=A9-A8</td>
<td></td>
</tr>
<tr>
<td>=A10-A9</td>
<td></td>
</tr>
<tr>
<td>=A11-A10</td>
<td></td>
</tr>
<tr>
<td>average(B2:B11)</td>
<td></td>
</tr>
<tr>
<td>=stdev(B2:B11)</td>
<td></td>
</tr>
<tr>
<td>=(B13-2)*4</td>
<td></td>
</tr>
<tr>
<td>=(1/(C1*B12))<em>144</em>43,560</td>
<td></td>
</tr>
</tbody>
</table>
optimized by a standard spacing distance (low standard deviation) between the plants. Research suggests that a standard deviation of 2 inches is excellent. There is about a 4 bu/acre yield loss per inch for standard deviations greater than 2 inches.

<table>
<thead>
<tr>
<th>Table 34.3 Definition of terms used in this chapter.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Terms</td>
</tr>
<tr>
<td>Definition</td>
</tr>
<tr>
<td>Seed germination</td>
</tr>
<tr>
<td>The germination rate of the seed. Specified by the</td>
</tr>
<tr>
<td>seller.</td>
</tr>
<tr>
<td>Seedling emergence</td>
</tr>
<tr>
<td>The emergence of the seedlings from the soil.</td>
</tr>
<tr>
<td>Seeding rate</td>
</tr>
<tr>
<td>The number of seeds/acre planted in the soil.</td>
</tr>
<tr>
<td>Plant population</td>
</tr>
<tr>
<td>The plant population following emergence.</td>
</tr>
<tr>
<td>% emergence of germinated seeds</td>
</tr>
<tr>
<td>Difficult to measure, can be estimated based on the</td>
</tr>
<tr>
<td>seed germination rate.</td>
</tr>
<tr>
<td>Standard deviation of the stand uniformity</td>
</tr>
<tr>
<td>The standard deviations (variability) in the distances between adjacent corn plants.</td>
</tr>
</tbody>
</table>

References and Additional Information


Nielsen, R.I. 1993. Stand establishment variability in corn AGRY-91-1(rev 1997). Department of Agronomy, Purdue University, W. Lafayette, IN.
Acknowledgements
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In the United States, corn is marketed in bushels, which are measured in units of mass rather than units of volume. For example, the industry standard for #1 yellow corn is 56 lbs per bushel, but may be bought and sold at many different % moisture contents (e.g., 15.5%, 13.0%). Grain drying from higher to lower moisture content shrinks as water is lost. Grain moisture shrinkage is an important concept in grain marketing as this impacts the buying price and discounts. To optimize economic returns, understanding shrinkage and drying costs calculations are critical. This chapter provides examples of how to determine the impact of variable grain moisture contents on grain mass. Key facts about grain moisture content are provided in Table 35.1.

Table 35.1 Key facts about grain moisture content:
1. For long-term storage, grain moisture should be 13.1% to reduce disease and insect losses.
2. Grain buyers post drying and shrink charges. Know the product delivery specifications for these two factors.
   a. Drying cost and shrink factors should be considered when deciding where to sell your corn.
   b. Handling losses > 1% may be excessive.
3. Grain moisture content is considered on a wet-weight basis, below are standard moisture contents for different grains.
   a. A bushel of corn at any moisture level weighs 56 lbs.
   i. A bushel of corn at 15.5% moisture contains 47.32 lbs of dry (0.0% moisture) corn and 8.68 lbs of water.
   ii. A bushel of corn at 13% moisture contains 48.72 lbs of dry corn and 7.28 lbs of water.
   b. A bushel of wheat at 13.5% moisture weighs 60 lbs.
   c. A bushel of soybeans at 13% moisture weighs 60 lbs.

Understanding Shrinkage
Why is the Term Shrinkage Used for Grain?
Our forefathers developed the method for buying and selling grain. Before large-scale weighing capability was available, grain was sold by volume (thus, the bushel became the basic unit of grain commerce). The inside dimensions of a grain wagon were measured to determine its width, length, and height (Fig. 35.1). A bushel United States dry measure equals 2150.42 cubic inches (CRC handbook). A standard bushel...
of corn weighs 56 lbs at 15.5% final moisture content. However, some grain buyers want to purchase
even drier grain (less water content) and have a discount based on the % difference between the seller’s
grain moisture content and their posted moisture content. The weight loss by drying is referred to as
shrinkage. When wet corn greater than the posted moisture content is purchased by the buyer and dried,
the grain loses volume as water evaporates from the grain. The grain test weight increases depending on
the beginning and ending % moisture content, with a range of 0.25 to 0.50 lb/bushel-%point. Thus, the
term shrinkage was used to describe the phenomena of less volume due to moisture loss in a load of corn.
Today, volume (bu) is not measured and grain transactions are based upon weight. However, due to grain-
selling history before scales, the word shrinkage is still associated with moisture loss.

**Economic Implications of Grain Moisture**

Grain discounts often consider shrinkage, handling losses, and drying costs. Shrinkage is the loss of weight
(water) when grain dries. Handling losses are loss of weight due to grain respiration (carbon), loss of oils
during drying, and the loss of materials when grain is transported or moved from one location to another.
Drying costs result from the amount of energy needed to dry corn to a storable moisture percentage to
maintain quality.

To optimize the grain selling price, the farmer must understand the buyer’s delivery specifications
regarding: 1) shrinkage, 2) drying charges, and 3) final moisture content based on grain sale date. In
corn production, buyer discounts can substantially reduce the return. For example, the buyer may have
discounts for grain that has moisture contents different than their specifications. Understanding these
discounts can help farmers make sound economic decisions.

Grain moisture is measured with a sensor that usually requires, at the very least, annual calibration.
There are many companies that produce moisture sensors for grain, including real-time in line sensors
for combines, sensors for bulk grain, and moisture probes. When grain moisture content is measured, a
sample is collected and analyzed. As with all measurements, the analysis is only as good as the sample.
Accurate assessments require that a “good representative” sample be collected and that the sensor be
precise and accurate. To achieve a representative moisture value for grain from the field or in an on-farm
bin, read and follow the instructions provided by the sensor manufacturer regarding sample collection.
Note that on-farm grain moisture sensors can be impacted by temperature of the grain. Grain moisture
meter errors typically increase once the temperature is less than 40°F.

**Grain Moisture Calculations**

Bushels of corn based on corn weight:

\[
Bu = \text{Amount of corn in wagon (lb)} \times \frac{1}{56 \text{ lbs}} \tag{1}
\]

This equation does not take into account the moisture content of the grain. Grain moisture equation:

\[
MC\% = 100 \times \frac{ww}{ww + wdc} \tag{2}
\]

Where

- \(ww\) = weight of water
- \(wc\) = weight of wet corn
- \(wdc\) = weight of dry corn
- \(MC\%\) = moisture content as a decimal

The amount of water in wet grain is determined by the equation:

\[
ww = MC\% \times wc \tag{3}
\]

The grain moisture equation can be algebraically manipulated to determine the amount of water in grain
based on the grain's dry weight:

\[
ww = \frac{MC \times wdc}{1-MC} \tag{4}
\]
Equation [4] can be algebraically manipulated to determine the dry grain based on the wet weight of corn (wc), the % moisture of the wet corn (MC), and the % moisture of the dry corn (dry).

\[
\text{grain weight at 'dry' moisture %} = \frac{wc \times (100\%-MC)}{100\%-\text{dry}} \tag{5}
\]

Dry weight of corn (grain) can also be calculated using this equation:

\[
\text{WDC} = WC - WW \tag{6}
\]

When grain is dried, it loses moisture to the atmosphere. The amount of loss is the shrink. **Moisture shrink (%)** is determined with the equation:

\[
\% \text{Moisture shrink} = 100 \times \frac{\text{original moisture content} \%-\text{final moisture} \%}{100-\text{final moisture} \%}
\]

This definition of shrinkage does not consider the amount of grain can also be lost at an elevator through dust and removal of foreign materials. Typically, handling losses are 0.25 to 0.5%.

---

**Example 35.1**

A farmer has delivered 16,954 lbs of 20% moisture corn to the elevator. The elevator docks for shrinkage of delivered corn to 13% moisture content. Elevator-posted prices are $3.50/bushel corn with a 1.2%/moisture point (1.2%/pt.) shrinkage discount. How many bushels of corn at 13% moisture are delivered and how much water is contained in the grain.

**Method 1**

An alternative technique to solve this problem is to use equation 5:

\[
= 16954 \times \left(\frac{100-20}{100-13}\right) = 15,590
\]

Finally, determine the number of bu of corn at 13% moisture, using equation [1]:

\[
\text{Bushel corn}_{13}\% = \frac{15,590 \text{ lbs}}{56} = 278.4 \text{ bushels}_{13}\%
\]

Based on these calculations, the amount of corn that the elevator will pay for is 278.4 bu.

Shrinkage is calculated by subtracting the initial weight from the final weight

\[
= 16,954-15,590 = 1,364 \text{ lbs}
\]

The percent shrinkage is 100\% \times \frac{1364}{16954} = 8.045\%, and the shrinkage per percent of moisture loss is 1.01493\% (8.045\%/7\%). See Table 35.2.

The per bushel shrinkage is \frac{1364}{302.75} \text{ bushels} = 4.505 \text{ lbs/bushel}, and the shrinkage per bushel per each change in moisture percent is

\[
= \frac{4.505 \text{ lbs/(bushel} \times(20-13\% \text{ moisture})}{= 0.644 \text{ lbs)/(bushel} \times\text{point moisture}}.
\]

This value is similar to Table 35.2

**Method 2**

This problem can also be solved by using Table 35.2. In this table, the beginning and end moisture values are determined, and the water shrink factor value is multiplied by the difference. For example, if the wet corn delivered has a % moisture content of 20% and the elevator docks for shrinkage at 13%, then 20-13 = 7% and the value for 1.149 from the table is multiplied by 7.

In this example, the elevator is using a grain moisture % of 13%. In Table 35.2, the shrinkage value to 13% moisture is 1.149.

**Step 1.** Determine the number of points difference from the wet grain delivered to the acceptable moisture content (points are the change in the moisture content based on percentage).

**Answer:**

The difference between the initial moisture content (20%) and final (13%) is 7%. This difference is the
number of moisture points.

**Step 2.** Percent water shrink is determined by:
(moisture points) x the water shrink factor (Table 35.2).

From Table 35.2,
1.149%/pt is the water shrink factor associated with the final moisture content of 13%.

Answer:

\[
7 \text{ pts} \times \frac{1.149\%}{\text{pt}} = 8.0435 \text{ water shrinkage}
\]

**Step 3.** The bushels lost due to water weight are calculated by multiplying the bushels at 20% moisture times the water shrink factor. The water shrink factor is converted from a percent (8.043%) to a decimal (0.08043) by dividing the percent by 100.

First, bushels delivered at 20% moisture are calculated

\[
16,954 \text{ lbs/(56 lbs/bu)} = 303 \text{ bu at 20% moisture}
\]

Answer:

\[
303 \text{ bu}_{20\%} \times 0.0804 = 24 \text{ bushel shrink}
\]

**Step 4.** Bushels at final moisture content = 13% is:

\[
303 \text{ bu}_{20\%} - 24 \text{ bu shrink} = 279 \text{ bu}_{13\%}
\]

The same answer is achieved using both methods. If you have access to a table with values, the calculations may take less time. However, if the values for the water shrink factor are not available, the first method can be used.

**What is the final $/bu paid to the farmer based on shrink discount?**

If the corn had been delivered at 13% moisture and corn has a test weight of 56 lbs/bu, the paid amount would be: the number of bushels delivered x $/bushel. In this example:

\[
303 \text{ bu}_{13\%} \times \frac{$3.50}{\text{bu}} = $1060.50
\]

However, the corn was delivered at 20% moisture and the amount of corn delivered at 13% is only 278 bu. At $3.50/bu this is worth $973 (278 bu\_{13\%} \times \frac{$3.50}{\text{bu}} = $973).

It is important to note that this example DID NOT include drying costs, which may be an additional $0.04 - $0.06/moisture point.

**Comparing Farm vs. Elevator Drying Costs**

The elevator often charges for drying costs for grain that is delivered too wet to the elevator. These charges are often expressed as a $ amount per point of moisture content between the wet (delivered) and dry (acceptable). The farmer must decide whether the drying cost is reasonable. To calculate the on-farm drying costs, the fuel, capital, and labor costs must be considered.

**Capital costs to own the dryer**

In this example, a 20 ft. axial plenum grain dryer system costs approximately $77,000. This system can dry corn up to about 750 bu/hour at full heat from 20% to 15% moisture. The interest rate at the bank is 5% and depreciation is 8%. The farm averages 750 acres of corn. The average yield is 170 bu/acre. The producer starts to harvest grain at 21% moisture desires a final dry moisture content of 15.5%.

---

**Table 35.2 Relationship between the final moisture content, water shrink factor, and lbs water/bu-pt.**

<table>
<thead>
<tr>
<th>Final moisture Content (%)</th>
<th>Water shrink factor (%/pt)</th>
<th>lbs water/Bu-pt</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.0</td>
<td>1.190</td>
<td>0.66666</td>
</tr>
<tr>
<td>15.5</td>
<td>1.183</td>
<td>0.66272</td>
</tr>
<tr>
<td>15.0</td>
<td>1.176</td>
<td>0.65882</td>
</tr>
<tr>
<td>14.5</td>
<td>1.170</td>
<td>0.65497</td>
</tr>
<tr>
<td>14.0</td>
<td>1.163</td>
<td>0.65116</td>
</tr>
<tr>
<td>13.5</td>
<td>1.156</td>
<td>0.64739</td>
</tr>
<tr>
<td>13.0</td>
<td>1.149</td>
<td>0.64468</td>
</tr>
<tr>
<td>12.5</td>
<td>1.143</td>
<td>0.64000</td>
</tr>
<tr>
<td>12.0</td>
<td>1.136</td>
<td>0.63630</td>
</tr>
</tbody>
</table>
Example 35.2 One thousand (1000) lbs of grain at 22% moisture content are delivered to an elevator. If the buyer’s final moisture content is 13% moisture, determine shrinkage and the amount of grain at 13% moisture.

Method 1
Using equation 5, grain weight at ‘dry’ moisture % = WC x \(\frac{100\%-\text{MC}}{100\%-\text{dry%}}\)

\[
= 1000 \times \frac{100-22}{100-13} = 897 \text{ lbs}
\]

Shrinkage was 1000-897 = 103 lbs.

The load contains 16 bushels.

Method 2
An alternative method of calculation is to use Table 35.2 to estimate water shrinkage. Using Table 35.2 when the final moisture content = 13%, the corresponding shrink factor is 1.149%/pt. The points change in this example from wet to dry is:

\[
9 \text{ pts} \times \frac{1.149\%}{\text{pt}} = 10.341\% \text{ shrink}
\]

There were 17.86 bu corn at 22% moisture:

Therefore:

\[
17.86 \text{ bu} \times 0.101341 = 1.85 \text{ bu shrink}
\]

\[
17.86 \text{ bu} - 1.85 \text{ bu} = 16 \text{ bu}_{13%}
\]

Example 35.3 An elevator’s posted cash price and final moisture is $3.29/bu at 15.5%. The corn delivered by the farmer is 13% moisture, less than the posted moisture. If the farmer sells the corn to this elevator, what is the value of the grain?

Step 1. First, the shrink value associated with the final moisture content of 15.5% must be determined. Using Table 35.2:

<table>
<thead>
<tr>
<th>Final moisture Content (%)</th>
<th>Water shrink factor (%/pt)</th>
<th>Lbs water/Bu-pt</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.5</td>
<td>1.183</td>
<td>0.66272</td>
</tr>
</tbody>
</table>

If the base price is $3.29 and the grain is aerated with high humidity air, the corn moisture content may potentially increase from 13% to 15.5%.

Water weight has been added to the grain to increase the moisture. The resulting increase in grain price will be:

\[
(15.5-13.0 \text{ pts}) \times \frac{0.01183}{\text{pt}} \times \frac{$3.29}{\text{bu}} = \frac{$0.097}{\text{bu}}
\]

An additional $0.097 or ~ $0.10/bu is added to the selling price, $3.29/bu, to increase the price to $3.39/bu.

Example 35.4 The elevator will dry each bushel of the 22% moisture corn to 13% moisture. At delivery the corn had a moisture content of 22%. For each bu of 56 lbs/bu 22% moisture corn dried, calculate is the lbs of dry corn at 13%.

Equation [5] is used to calculate the dry grain at the lower moisture content:

Dry grain weight = wet grain weight \(\times \frac{(100\%-\text{wet%})}{(100\%-\text{dry%})}\)

Substituting in the delivery moisture content (22%) and the moisture content desired by the elevator (13%), the dry grain weight is calculated:

\[
\text{Grain weight at 13%} = 56 \times \frac{100-22}{100-13} = 50.21 \text{ dry corn}
\]

The elevator’s actual shrinkage was from 56 lbs to 50.21 lbs, which is a loss of: 56-50.21 = 5.79 lbs water.
Example 35.5 Determine the costs for an on-farm system with the following specifications. The dryer energy efficiency for heat is 3000 BTU/lb-water and for electricity is 0.03 kWh/lb-water. Propane is $1.45/gal and the electric rate is $0.09/kWh.

In this example the final corn moisture % is 15.5%. At 15.5% final moisture content, a bushel point is 0.6627 pounds of water (0.67 lbs water/bu-pt) (see Table 35.2):

<table>
<thead>
<tr>
<th>Final moisture Content (%)</th>
<th>Water shrink factor (%/pt)</th>
<th>Lbs water/ Bu-pt</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.5</td>
<td>1.183</td>
<td>0.6627</td>
</tr>
</tbody>
</table>

1. **Propane cost, amount needed per % point**

\[
\frac{0.6627 \text{ lbs water}}{\text{bu-pt}} \times \frac{3000 \text{ BTU}}{\text{lb-water}} \times \frac{1 \text{ gal propane}}{92,000 \text{ BTU}} \times \frac{$1.45}{1 \text{ gal propane}} = $0.0315 \text{ bu-pt}
\]

2. **Electricity cost for drying system and fans, amount needed per % point**

\[
\frac{0.6627 \text{ lbs water}}{\text{bu-pt}} \times \frac{0.03 \text{ kWh}}{\text{lb-water}} \times \frac{$0.09}{1 \text{ kWh}} = $0.0018 \text{ bu-pt}
\]

3. **Total cost on farm drying cost, energy**

\[
\frac{$0.0315 \text{ propane}}{\text{bu-pt}} + \frac{$0.0018 \text{ electricity}}{\text{bu-pt}} = $0.0333 \text{ bu-pt}
\]

a. **Cost to own dryer per year (does not consider capital investment to purchase the dryer)**

\[
\frac{(5\%+8\%)}{100} \times $77,000 = $10,010
\]

b. **Bushel points to dry:**

\[
750 \text{ a} \times \frac{170 \text{ bu}}{\text{a}} \times (21-15.5 \text{ pts}) = 701,250 \text{ bu-pts}
\]

c. **Cost to own on-farm dryer system**

\[
\frac{$10,010}{701,250 \text{ bu-pts}} = $0.01427 \text{ bu-pt}
\]

The total cost to dry grain on the farm considering energy, and interest and depreciation to own the systems is:

\[
\frac{$0.0333}{\text{bu-pt}} + \frac{$0.01427}{\text{bu-pt}} = $0.04757 \text{ bu-pt}
\]

Labor costs to operate the on-farm drying system were not included. If hired labor is used, this must be considered into the on-farm drying costs as well. Therefore, if the cost of drying at the elevator is $0.03/bu- pt then it is cheaper to use the elevator.

**Important Related Information**

**How fast does corn dry?**

Typically in South Dakota it takes 15 to 30 growing-degree days (base 50°F) to reduce the corn moisture content from 30% to 29% (1 percentage point). After November 1, very little in-field drying occurs.

**How efficient is your dryer?**

Dryer efficiencies can range from as low as 0.005 gal/bu-pt to as high as 0.03 gal/bu-pt or more. At $1.60/ gal for propane, this translates to $0.008/bu-pt to $0.048/bu- pt. For drying corn from 24% to 15% moisture, this calculates to a cost of between $0.072/bu to $0.432/bu. In addition, capital costs (the cost of owning a dryer) can amount to an additional cost of $0.06/bu-pt.
Compare drying system costs of using (1) air and heat vs. (2) air only to dry crops. Air-only drying will require a shorter bin fill (usually less than 20 ft) and a significantly greater amount of air (usually more than 1.00 to 1.25 cubic ft per min/bu). Drying with air will require bins that are dedicated only to drying single load for most of the fall drying season. The air-drying systems typically will use no propane and require an electric energy input range of from 0.1 to 0.6 kWh/bu-pt. At $0.07/(kWh), this translates to a cost of between $0.007 to $0.042/bu-pt. Capital costs must also be considered. Note that the lowest cost will typically occur early in the drying season when ambient air temperature is the highest. Unfortunately, this normally is when the highest moisture percentage may be observed in corn.

Harvest Corn or Leave in the Field?
The cost of field drying is frequently viewed as being free; however, field drying has risks. The longer corn is left in the field, the greater the potential for ear drop caused by wind, precipitation, or wildlife. Drier corn (15%) has been shown to exhibit greater combine harvest loss (both ear drop and kernel shelling) than wetter corn (24% moisture).

To make the best decision for your operation, evaluate the costs of (1) on-farm drying vs. (2) local elevator drying charges. The local elevator may be using natural gas rather than propane and this may result in both profit for the elevator and cost savings for the producer.

References and Additional Information
Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.


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   Office of the Assistant Secretary for Civil Rights
   1400 Independence Avenue, SW
   Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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If the combine is not adjusted correctly, profits can be left in the field. Yield losses are unavoidable, but through careful management they can be minimized. The first step in minimizing combine yield losses is determining the source. This involves identifying where the loss occurred, followed by making appropriate adjustments. The combine should be adjusted to minimize ear and kernel losses, while also managing cracked or broken kernels and foreign matter in the grain. This chapter is devoted to the measurement of corn harvest losses, and then linking those losses to where the loss occurred.

Introduction
Producers are anxious to begin harvest, and once started, reluctant to stop or delay. However, counting some kernels on the ground and determining the losses from various machine systems can be time very well-spent and easily pay for itself, especially if problems are corrected early. The quick-count methods discussed in Table 36.1 provide information that can be used to determine whether combine header settings need adjustment to improve harvest efficiency. Every 1% loss of a 200 bu/acre yield at $4/bushel is $8/acre of reduced net income. Losses from a machine that is not properly adjusted for the harvest conditions can easily be 4% to 5% of the grain in the field. Without measuring losses, it is not possible to know whether they are high or low. Without analyzing where the losses are occurring, it is difficult to know which combine adjustments to make. Routine checks will help minimize preventable losses.

Table 36.1 Determining harvest loss when combining by quick-count methods:

Step 1. KERNEL LOSS: Count kernels on the ground inside a simple frame of known area (e.g., ft²) in a harvested area. Determine the number of loose kernels per square foot. To calculate the loss in bushels per acre due to kernel loss, divide the number of counted kernels/ft² by 2. The percent harvest loss to kernel loss can be calculated by dividing the kernel bu/acre losses (determined above) into your measured yield per acre, and multiplying by 100%.

Step 2. EAR LOSS: Pick a row behind your combine and count any ears on the ground within 87 feet (approximately 30 paces) of the back of the combine. One ear on the ground in 30 paces between rows with 30” spacing is approximately 1 bushel per acre of harvest loss from ears. Therefore, the number of ears counted is equal to the bushel per acre ear loss. The percent loss due to ear loss is determined by dividing the ear loss/acre into your measured yield per acre and multiplying by 100%.

These quick measurements help in observing “normal” and excessive losses, providing a check for combine header settings, and improving harvest efficiency.
In this chapter, we present the concept of using a simple frame that encloses a known area to measure kernel loss. The other measurement is done by counting ears along a length of 87 feet (about 30 paces) behind the combine. These measurements may be done while waiting for a truck or wagon. Yield loss in bu/acre can be quickly assessed using these methods. Two kernels/ft\(^2\) is 1 bu/acre, and each ear in 30 paces along a 30” row is 1 bu/acre. If total losses exceed 1% of the yield, combine adjustments may be required.

**Detailed Analysis of Loss Calculations**

**Example 36.1** What is the estimated corn yield loss if 6 kernels are found in a 1-ft\(^2\) area?

**Answer:**

\[
\text{Answer: } \frac{6 \text{ kernels}}{\text{ft}^2} \times \frac{43560 \text{ ft}^2}{\text{acre}} \times \frac{\text{bu}}{90,000 \text{ kernel}} = \frac{2.9 \text{ bu}}{\text{acre}} = \frac{3 \text{ bu}}{\text{acre}}
\]

Solving this problem shows why yield loss can be estimated by dividing kernels/ft\(^2\) by 2. The assumption of 90,000 kernels/bu may need to be adjusted if corn kernels are large (decrease the number kernels per bushel) or small (increase the number kernels per bushel). See Table 36.2 for details.

<table>
<thead>
<tr>
<th>Kernels/lb</th>
<th>Kernels/bushel</th>
<th>Kernels/ft(^2) equivalent to 1 bushel/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large kernels</td>
<td>56 lbs</td>
<td>70,000</td>
</tr>
<tr>
<td>Medium kernels</td>
<td>56 lbs</td>
<td>90,000</td>
</tr>
<tr>
<td>Small kernels</td>
<td>56 lbs</td>
<td>110,000</td>
</tr>
</tbody>
</table>

General Formula: Kernels/ft\(^2\) = Kernels/lb x 56 lbs/bu x 1 acre/43560 ft\(^2\)

**Example 36.2** Assume corn kernel size is large, and the number of kernels lost is 6/ft\(^2\). What is the estimated corn yield loss in bu/acre? According to Table 36.2, the number of kernels/bu is 70,000. Therefore:

**Answer:**

\[
\text{Answer: } \frac{6 \text{ kernels}}{\text{ft}^2} \times \frac{43560 \text{ ft}^2}{\text{acre}} \times \frac{\text{bu}}{70,000 \text{ kernel}} = \frac{3.7 \text{ bu}}{\text{acre}} = \frac{4 \text{ bu}}{\text{acre}}
\]

This example illustrates that the size of kernels and assumptions about kernels/bu influence the estimates of % yield loss.

**Example 36.3** What is the yield loss if one ear is found along a distance of 87 feet between two 30” corn rows? In addition, each ear contains approximately 0.28 lbs of shelled corn.

**Answer:** For many people, 30 paces is approximately 87 ft and therefore, a rectangle that is 2.5 ft by 87 ft is an area of 217 ft\(^2\).

\[
\text{1 ear} \times \frac{43560 \text{ ft}^2}{\text{acre}} \times \frac{0.28 \text{ lb corn}}{1 \text{ ear}} \times \frac{\text{bushel}}{56 \text{ lbs corn}} = 1.003 \text{ bushel/acre}
\]

\[
\approx \frac{1 \text{ bushel}}{\text{acre}}
\]

The amount of grain on an ear may be more or less than 0.28 lbs. The lbs/ear number in the equation can be modified if the ear is larger.

**Example 36.4** What is the yield loss if one ear is found along a distance of 87 feet between two 30” corn rows? In addition, each ear contains about 0.4 lbs of shelled corn.

**Answer:** For many people, 30 paces is approximately 87 ft and therefore, a rectangle that is 2.5 ft by 87 ft is an area of 217 ft\(^2\).

\[
\text{1 ear} \times \frac{43560 \text{ ft}^2}{\text{acre}} \times \frac{0.4 \text{ lb corn}}{1 \text{ ear}} \times \frac{\text{bushel}}{56 \text{ lbs corn}} = 1.43 \text{ bushel/acre}
\]

\[
\approx \frac{1.4 \text{ bushel}}{\text{acre}}
\]
Sources of Harvesting Losses
Determining the overall harvest loss will not tell you where the loss is occurring or how to reduce it. The combine harvester performs a series of operations on the crop, each of which can contribute to grain losses. Identifying the source of lost grain is critical to making appropriate machine adjustments.

Preharvest Loss
Some crop losses are caused by lodging or ear drop and appear as whole ear losses. These losses increase as the season progresses and are not preventable through combine adjustments. Average preharvest losses should be less than 1% of total crop yield. These losses can be much higher in diseased or insect-damaged crops, or if there is a delay in harvest and/or exposure to weathering and high winds. Preharvest ear drop has been greatly reduced among some corn varieties, such as Bt (Bacillus thuringiensis), which reduces stalk damage caused by European corn borer. Preharvest ear losses are measured in unharvested areas, such as the area marked “P” in Figure 36.1.

Header Ear Loss
Header ear loss occurs as the harvester gathers the crop and strips the ears from the stalk. An improperly adjusted head, or poor operator management of the header height, ground speed, and steering can cause losses of whole or broken ears that are missed or bounce out of the head. Losses can reach 3% to 4% of the total crop yield but can be held to 1% or less with proper machine operation and adjustment.

Header Kernel Loss
Some kernels are shelled out and lost at the header as ears make contact with gathering snouts, snapping bars, snapping rolls, and the cross auger. These losses typically average about 0.6%. With proper adjustment of gathering chains and machine speed, these losses can be as low as 0.4%.

Combine Separation and Cleaning Loss
The internal systems of the combine are collectively called the separator. Total separator losses include those from threshing, separation of grain from straw, and cleaning of chaff from grain. Separation losses occur as some kernels pass through the combine embedded in the stalk and husk residue and are not retained. Cleaning-system losses occur when kernels flow over the sieves with chaff and cob pieces and pass out of the combine. These losses can be held to 0.1% of the total crop yield by adjusting the fan, rotor speeds, and sieve openings.

Combine Cylinder or Threshing Loss
Insufficient shelling action causes some kernels to remain on cobs as they pass through the machine. With correct rotor or cylinder speed, and correct concave clearance adjustment, this loss should not exceed 0.3% of yield. Correct adjustment is observed when there is a minimum of broken cobs and no kernels attached to the cobs. Overly aggressive threshing results in low threshing losses but increased kernel damage as well as fragmented cobs.

Leakage Loss
Leakage losses occur when part of the combine has an opening large enough for grain to escape. This can occur when a cleanout trap door or access port is left open or not fully secured. It can also occur because of wear to or damage of sheet-metal parts. Unlike other loss types, leakage loss has little to do with machine settings and everything to do with careful inspection and maintenance.
Measuring Combine Losses
Loss determinations should not be made near the edge of a field. Effects of headlands and entry of the machine into the crop can create losses that are not typical of the rest of the field. Measurements should be taken at least 300 feet from the field border. If the combine is equipped with a calibrated yield monitor, an observation of the yield should be made while operating at a constant speed. This yield will be used to determine percentage losses from combine operations. If the chaff-spreader system is controllable from the combine cab, turning the system off a short distance before conducting a loss analysis can be advantageous. This concentrates the separator losses behind the combine and simplifies sampling. It is not necessary to disengage the chaff spreader if it distributes the residue across the full swath width. The combine should be stopped and the separator disengaged at the point where machine losses are to be determined. The machine is then backed up a short distance to allow access to the area below the combine (Table 36.3).

Preharvest Ear Losses ($E_P$)
To measure preharvest ear losses, step off a distance of 87 feet, or typically 30 paces, in an adjacent row of the standing crop. See the strip marked “P” in Figure 36.1. Count any ears found on the ground in this section of row. Each ear represents a bushel/acre of loss. Determine the preharvest loss from ear drop. This process is easy and quick to repeat if there are any doubts as to whether a chosen row section was representative of the field (or field area). While it is not possible to alter the preharvest loss, the value will be subtracted from the total ear loss to determine losses from the header operation and harvest loss during combining. If the crop has been stressed by disease, insects, or weather, the ear drop may be substantial and should be measured.

Header Ear Losses ($E_A$)
To determine the loss of ears at the header, repeat the ear count process in an area that already has been harvested in one or more rows, such as that marked “A” in Figure 36.1. Note that the chaff areas in these already harvested areas are avoided for this determination. Count ears in 30 paces of that row and convert the result to bushels per acre as in the preharvest loss calculation. Header ear loss (EL) is then determined by subtracting the preharvest ear loss “P” from the total ear loss determined in area “A” ($E_A - E_P$). The EL can then be used to calculate Header ear loss percent = (EL/measured yield) x 100%. With an optimally adjusted machine, the header ear loss (EL%) should average less than 1 bu/acre.

Kernel Losses ($K_{p}$, $K_{c}$, and $K_{cob}$)
Assessing the combine’s performance for kernel loss requires taking measurements at several different locations around the machine. The number of kernels found in these locations will reveal where the losses are occurring.

It will be necessary to have a tool to help count kernels from a known area on the ground. Select an approach that is convenient enough so that you will use it. Devise a frame of known area that can easily be stored in the combine cab or hung on a post or hook where it is available. One approach is to use a circular hoop made from a piece of stiff wire. A length of 42.5 inches fashioned into a circle will enclose 1 square foot and will be about 13.5 inches in diameter. A circular hoop that encloses 2 ft$^2$ would require a length of wire 60.25 inches fastened end to end, and would be 19.2 inches in diameter. Another practical approach is to make a frame of PVC pipe with 90-degree bends. The frame can be

Figure 36.2 A PVC rectangular frame or cylinder that includes a known dimension can be used to measure yield losses. This PVC frame has bungee cords inside the tubes so it can be easily stored and assembled. Keep the frame in the combine cab and use it periodically to count lost kernels to help determine combine efficiency and areas that need adjustment for improvement.
### Table 36.3 Example of harvest loss calculator worksheet.

#### Corn Harvest Loss Calculation Worksheet

<table>
<thead>
<tr>
<th>Step, Measurement, or Calculation</th>
<th>Calculated As</th>
<th>Label</th>
<th>Value &amp; Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combine Head Width (ft)</td>
<td>HW</td>
<td>20</td>
<td>ft</td>
</tr>
<tr>
<td>Discharge Pattern Width (ft)</td>
<td>DW</td>
<td>4.0</td>
<td>ft</td>
</tr>
<tr>
<td>Length of a 30&quot; row to check for Preharvest and header ear loss. Equivalent to 1/200th acre.</td>
<td></td>
<td></td>
<td>87.12 ft</td>
</tr>
<tr>
<td>Area of your sample collection frame (ft²)</td>
<td>S</td>
<td>5</td>
<td>ft²</td>
</tr>
<tr>
<td>Kernels representing 1 bu/acre</td>
<td>N</td>
<td>2</td>
<td>#</td>
</tr>
<tr>
<td>Indicated yield prior to stopping (bu/acre)</td>
<td>Y</td>
<td>186</td>
<td>bu/acre</td>
</tr>
<tr>
<td>0.28 lb ears, or equivalent in area marked &quot;A&quot;</td>
<td>E&lt;sub&gt;A&lt;/sub&gt;</td>
<td>6</td>
<td>#</td>
</tr>
<tr>
<td>0.28 lb ears, or equivalent, counted in unharvested area “P”</td>
<td>E&lt;sub&gt;P&lt;/sub&gt;</td>
<td>1</td>
<td>#</td>
</tr>
<tr>
<td>Preharvest losses due to ear drop (bu/acre)</td>
<td>EL</td>
<td>5</td>
<td>bu/acre</td>
</tr>
<tr>
<td>Header ear loss (bu/acre)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Header ear loss percent</td>
<td>EL%</td>
<td>2.7</td>
<td>%</td>
</tr>
<tr>
<td>Average kernel counts inside test frame in locations marked “B” (header kernel loss)</td>
<td>K&lt;sub&gt;B&lt;/sub&gt;</td>
<td>19</td>
<td>#</td>
</tr>
<tr>
<td>Average kernel counts inside test frame in locations marked “C” (include kernels on cobs)</td>
<td>K&lt;sub&gt;C&lt;/sub&gt;</td>
<td>39</td>
<td>#</td>
</tr>
<tr>
<td>Average kernel count inside frame at locations “C” found attached to cobs only</td>
<td>K&lt;sub&gt;Cobs&lt;/sub&gt;</td>
<td>13</td>
<td>#</td>
</tr>
<tr>
<td>Average kernel count from the separator</td>
<td>K&lt;sub&gt;S&lt;/sub&gt;</td>
<td>4.00</td>
<td>#</td>
</tr>
<tr>
<td>Kernels/ft² found in locations marked &quot;B&quot;</td>
<td>K&lt;sub&gt;B&lt;/sub&gt;/S</td>
<td>3.80</td>
<td>#</td>
</tr>
<tr>
<td>Kernels/ft² separator loss</td>
<td>K&lt;sub&gt;S&lt;/sub&gt;</td>
<td>0.80</td>
<td>#</td>
</tr>
<tr>
<td>Kernels/ft² on cobs</td>
<td>K&lt;sub&gt;Cobs&lt;/sub&gt;/S</td>
<td>0.52</td>
<td>#</td>
</tr>
<tr>
<td>Bu/acre loss from shelling at the header</td>
<td>H&lt;sub&gt;L&lt;/sub&gt;</td>
<td>1.90</td>
<td>bu/acre</td>
</tr>
<tr>
<td>Bu/acre loss at through the separator</td>
<td>S&lt;sub&gt;L&lt;/sub&gt;</td>
<td>0.40</td>
<td>bu/acre</td>
</tr>
<tr>
<td>Bu/acre loss from threshing</td>
<td>T&lt;sub&gt;L&lt;/sub&gt;</td>
<td>0.26</td>
<td>bu/acre</td>
</tr>
<tr>
<td>Total bu/acre kernel losses from all sources</td>
<td>T&lt;sub&gt;KL&lt;/sub&gt;</td>
<td>2.30</td>
<td>bu/acre</td>
</tr>
<tr>
<td>Header kernel shelling loss %</td>
<td>HL%</td>
<td>1.02</td>
<td>%</td>
</tr>
<tr>
<td>Separator loss %</td>
<td>SL%</td>
<td>0.22</td>
<td>%</td>
</tr>
<tr>
<td>Threshing loss %</td>
<td>TL%</td>
<td>0.14</td>
<td>%</td>
</tr>
</tbody>
</table>
made to enclose 5 ft² 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. Two bungee cords threaded through the two end pieces and elbows and fixed with a knot will allow the frame to be broken down but kept as a unit so that it is always handy (Fig. 36.2). Larger areas provide more accurate counts, whereas smaller areas are quicker to count.

Count kernels in the frame at several specific locations in the field around the combine to conduct a complete harvest loss analysis. This should be done at several locations, especially if using a small area, such as the 1-ft² hoop. The average number of kernels per square foot is determined from these counts. Then the bushel per acre loss (based on kernel size) can be determined by dividing kernels/ft² by the appropriate value in the right-hand column in Table 36.1.

Kernels located in areas “B” (Fig. 36.1) represent kernel losses from the header and any preharvest kernel loss (K_B). Kernels at locations “C” represent losses from the header, preharvest losses, and losses during threshing, separation, and cleaning (K_C). The width of the chaff discharge pattern must be considered here. Modern combines often have very wide heads and the width of the discharge pattern (DW) may not be as wide as the head, even with chaff spreaders operating. Because of this, the kernel counts must be adjusted to the width of the head (HW) (see calculations provided in Table 36.3).

If the chaff spreader is not easily turned off, the width of the chaff pattern can be estimated by observing how far the spreaders throw cobs. To determine the losses from the threshing, separation, and cleaning systems, the kernel counts in the chaff pattern (areas C) will first have the counts from areas B subtracted. The difference is then multiplied by the chaff pattern width and divided by the header width. This effectively distributes the internal machine losses across the full width of the cut swath. If the chaff spreaders evenly distribute the residue across the full header swath width, the measurement locations marked C in Figure 36.1 can be made anywhere behind the combine and no adjustment for chaff pattern width is required. Information in Table 36.3 can be used to estimate total harvest losses as well as to separate the total loss into header kernel shelling loss, separator Loss, and threshing loss.

**Loss Calculation Example using a Worksheet**

Loss calculations can be made easier with a worksheet to act as an aid in recording and calculating the types of losses from the machine. A sample yield loss calculator form is provided in Table 36.3. It is a good practice to keep copies of this form in the combine cab with the check frame. The calculation for losses can be separated into several steps.

**Step 1.** Enter the width of the combine head (HW) that is being used. For example, the combine has an eight-row head and the row spacing is 30 inches, or 2.5 feet. The head covers 20 feet of width (30”/12”/ft ×8 rows), and this number is entered next to the label HW. With a planted row spacing of 30 inches, 87 feet (or 30 paces) (L) of a single row represents 1/200th of an acre for measuring ear losses. (Note: If row spacing is 20 inches, this length will need to be adjusted.)

**Step 2.** Enter the discharge pattern width of the harvester (DW). In this example, the combine has a 4-ft discharge width.

**Step 3.** Enter the area of the frame or hoop you are using to determine kernel losses. In this example, a 5-ft² PVC frame is used. Enter 5 next to the label S for the area of this frame.

**Step 4.** Enter the number of kernels that represent 1 bu/acre loss per ft² (N). In this example, assume that the kernels are of medium size, so that 90,000 kernels represent 1 bu (Table 36.1). This means that 2 kernels/ft² represent 1 bu/acre loss.

**Step 5.** Enter the yield on the yield monitor when the combine is stopped (Y). In this example, 186 bu/acre
is entered. If a yield monitor is not available, enter a yield estimate.

**Step 6.** Walk 30 paces in the area labeled “A” in the diagram (area that has been harvested). Over this area, 6 corn ears are found lying on the soil. Enter this value in the table next to $E_A$. Assuming each ear represents 1 bu/a (see Examples 36.3 and 36.4), we have about 6 bu/a of ear losses. This number can be modified if the ear contains more or less than 0.28 lb grain/ear.

**Step 7.** The ear losses measured in Step 6 seem large, so repeat this measurement in the standing crop to quantify preharvest ear losses ($E_P$). Stepping off 30 paces in the unharvested corn, we look for ears on the ground and locate 1 dropped ear. We enter this on the table next to $E_P$ and conclude that the preharvest ear drop is roughly 1 bu/a.

The header ear loss (EL) can now be calculated. The combine header was producing an ear loss of about 5 bushels per acre (6 bushel total minus 1 bushel of preharvest loss). The header ear loss percent (EL%) is determined in the worksheet using the formula provided for “Header ear loss percent.” It calculates to 2.7%. This value is high enough to be a source of improvement as we later consider adjusting the machine.

**Step 8.** Determine kernel losses. The PVC frame in Figure 36.3 encloses 5 ft$^2$ and is used to measure kernel losses at 3 points marked “B”. If you are using a smaller frame, such as the 1-ft$^2$ hoop, you may wish to take additional counts. The 5-ft$^2$ frame, in this case, produced counts of 15, 17, and 25 loose kernels at each of the three locations. The average loss is 19 kernels per frame $\left(\frac{15+17+25}{3}\right)$ and this value entered next to $K_B$ in the table. These losses are from shatter at the header operation, and include any preharvest shatter.

**Step 9.** Determine kernel losses at area C in the worksheet. These losses are in the discharge pattern where separator losses are now concentrated. While making these counts, we count how many kernels are in each frame ($K_C$) and make note of how many are still attached to a cob ($K_{Cobs}$). Final total kernel counts for this example are 35, 40, and 42 (note that this includes single kernels, as well as kernels still attached to the cob) for an average of 39 kernels within the frame. This average count is entered next to the label $K_C$ in the table. The number of kernels found attached to cobs within these frames was also noted at 11, 13, and 15. The average of 13 is entered next to the label $K_{Cobs}$.

**Step 10.** Calculate yield losses using the equations provided in Table 36.3. The balance of the table is completed using the formulas given for each step. Counts taken in the chaff discharge pattern are adjusted using the chaff pattern and header widths to redistribute the losses over the full swath width.

1. The adjusted kernel counts are then converted to kernels/ft$^2$ using the area of the sample frame, which is 5 ft$^2$ in the example (the formulas that use #/S to calculate on the ft$^2$ basis)
2. The values of kernels/ft$^2$ are converted to bu/acre by dividing by 2 (#/N) for each loss.
3. The bu/a losses are combined ($HL_{bu/a} + SL_{bu/a}$) and divided by the measured yield (Y) to calculate the percentage yield loss from the head (HL%), the separator (SL%), and the threshing system (TL%).
4. Overall, the results of the loss evaluation indicate that we are losing 5 bu/a or 2.7% of the harvested yield due to ears not captured by the header.
5. The check further indicates that 2.3 bu/a or 1.23% of the harvested yield is being lost as loose kernels. By counting kernels ahead of the chaff pattern, we determine that 1.02% of the harvested yield was lost as shatter at the head.
6. Additional kernels found behind the combine indicate a total separator loss of 0.22%, and keeping track of kernels attached to cobs as a part of that loss indicated a 0.14% loss from the threshing system.
7. The losses from the header, both as whole ears, and as loose kernels, suggest a review of header adjustments operation. The separator loss is small, although the threshing loss may also indicate
possible adjustments to systems to reduce the number of kernels lost with the cobs. Adjustments that can potentially reduce these losses are addressed in Chapter 37.

The blank form below can be printed and used as a tool to aid in quickly calculating harvest losses and to guide the process of adjusting the combine. Areas that are shaded tan in the worksheet can be entered for your combine and variety, and may not change often. Rows that are shaded gold indicate areas where to measure losses. An app can be used to simplify this process. Frequently checking losses using these tools will help you to better understand the combine and how it responds to the varying conditions (wet plants, lodged areas, very dry plants) that it faces during harvest. The benefits in terms of additional recovered crop can be disproportionately large compared to the modest time that it takes to count kernels.

**References and Additional Information**


Acknowledgements
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   Office of the Assistant Secretary for Civil Rights
   1400 Independence Avenue, SW
   Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov;

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# Corn Harvest Loss Calculation Worksheet

**Field:**
**Date:**
**Variety:**
**Operator:**
**Combine:**

<table>
<thead>
<tr>
<th>Step, Measurement, or Calculation</th>
<th>Calculated As</th>
<th>Label</th>
<th>Value &amp; Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combine Head Width (ft)</td>
<td></td>
<td>HW</td>
<td>ft</td>
</tr>
<tr>
<td>Discharge Pattern Width (ft)</td>
<td></td>
<td>DW</td>
<td>ft</td>
</tr>
<tr>
<td>Length of a 30” row to check for Preharvest and header ear loss. Equivalent to 1/200th acre.</td>
<td>217.8/Row width(ft)</td>
<td>L</td>
<td>ft</td>
</tr>
<tr>
<td>Area of your sample collection frame (ft²)</td>
<td></td>
<td>S</td>
<td>ft²</td>
</tr>
<tr>
<td>Kernels representing 1 bu/acre</td>
<td>Kernels in 1 lb x 56/43,560</td>
<td>N</td>
<td>2 #</td>
</tr>
<tr>
<td>Indicated yield prior to stopping (bu/acre)</td>
<td></td>
<td>Y</td>
<td>bu/a</td>
</tr>
<tr>
<td>0.28 lb ears, or equivalent in area marked “A”</td>
<td></td>
<td>Eₐ</td>
<td>#</td>
</tr>
<tr>
<td>0.28 lb ears, or equivalent, counted in unharvested area “P”</td>
<td></td>
<td>Eₚ</td>
<td>#</td>
</tr>
<tr>
<td>Preharvest losses due to ear drop (bu/acre)</td>
<td>Eₚ</td>
<td>bu/a</td>
<td></td>
</tr>
<tr>
<td>Header ear loss (bu/acre)</td>
<td>Eₐ - Eₚ</td>
<td>ELₚ</td>
<td>bu/a</td>
</tr>
<tr>
<td><strong>Header ear loss percent</strong></td>
<td>($(Eₐ - Eₚ)/Y) \times 100%$</td>
<td>ELₚ</td>
<td>%</td>
</tr>
<tr>
<td>Average kernel counts inside test frame in locations marked “B” (header kernel loss)</td>
<td>Kₐ</td>
<td>#</td>
<td></td>
</tr>
<tr>
<td>Average kernel counts inside test frame in locations marked “C” (include kernels on cobs)</td>
<td>Kₐ</td>
<td>#</td>
<td></td>
</tr>
<tr>
<td>Average kernel count inside frame at locations “C” <em>found attached to cobs only</em></td>
<td>K_Cobs</td>
<td>#</td>
<td></td>
</tr>
<tr>
<td>Average kernel count from the separator</td>
<td>$(Kₐ - Kₚ) \times (DW/HW)$</td>
<td>Kₚ</td>
<td>#</td>
</tr>
<tr>
<td>Kernels/ft² found in locations marked “B”</td>
<td>Kₐ/S</td>
<td>KSFₐ</td>
<td>#</td>
</tr>
<tr>
<td>Kernels/ft² separator loss</td>
<td>Kₚ/S</td>
<td>KSFₚ</td>
<td>#</td>
</tr>
<tr>
<td>Kernels/ft² on cobs</td>
<td>$(K_{Cobs}/S) \times (DW/HW)$</td>
<td>KSF_Cobs</td>
<td>#</td>
</tr>
<tr>
<td>Bu/acre loss from shelling at the header</td>
<td>KSFₐ/₂</td>
<td>HLₐ</td>
<td>bu/a</td>
</tr>
<tr>
<td>Bu/acre loss at through the separator</td>
<td>KSFₚ/₂</td>
<td>SLₚ</td>
<td>bu/a</td>
</tr>
<tr>
<td>Bu/acre loss from threshing</td>
<td>KSF_Cobs/₂</td>
<td>TL_Cobs</td>
<td>bu/a</td>
</tr>
<tr>
<td><strong>Total bu/acre kernel losses from all sources</strong></td>
<td>HLₐ + SLₚ</td>
<td>TKL</td>
<td>bu/a</td>
</tr>
<tr>
<td><strong>Header kernel shelling loss %</strong></td>
<td>HLₐ/Y \times 100%</td>
<td>HLₐ%</td>
<td>%</td>
</tr>
<tr>
<td><strong>Separator loss %</strong></td>
<td>SLₚ/Y \times 100%</td>
<td>SLₚ%</td>
<td>%</td>
</tr>
<tr>
<td><strong>Threshing loss %</strong></td>
<td>TL_Cobs/Y \times 100%</td>
<td>TL_Cobs%</td>
<td>%</td>
</tr>
</tbody>
</table>
Grain yield losses can be classified as: 1) preharvest ear losses, 2) ear losses from the header, 3) kernel shatter loss from the header, 4) threshing losses, and 5) separation and cleaning losses. Chapter 36 provided directions and calculations to determine the magnitude of these losses during harvest. This chapter provides a discussion of combine adjustments and settings that can be made to reduce losses that occur as the combine gathers and processes the crop.

**Sources for Yield Losses**
The header is the first contact point with the crop and, very often, the largest source of grain loss. In the header, the stalks are gathered and pulled downward into the header mechanisms, and the ears are snapped from the cornstalk and transported rearward onto the header pan and eventually, the combine feederhouse. Each of these steps will produce some losses. Understanding the process and knowing how adjustments affect the performance can help minimize losses. Directions for identifying where the losses are occurring and the magnitude of the loss are available in Chapter 36.

**Ear Losses**
Loss of whole ears most often occurs in the process of gathering the crop into the header. Crop conditions can have a pronounced effect on these losses. Since adjustments for lodged or down corn may be different, they will be addressed separately. In healthy, standing corn, the objective for the header system is to gently restrain the plant stalk with the gathering chain and allow the stalk rolls to pull the stem straight down until the ear is stripped from the stem. Ideally, the stalk should not be pushed forward, pulled backward or displaced sideways, and the ear should encounter the deck plates and be broken free about 2/3 of the way to the upper end of the deck plates. Most of the adjustments made to the header attempt to achieve this action. The settings suggested in the owner’s manual are a good starting point to minimize the loss of whole ears.

**Gathering Chain Speed**
The relationship between forward machine speed and the rearward speed of the gathering chains (Fig. 37.1) influences the flow of the crop into the header system. If the rearward speed of the chain links is the same as the forward combine speed, the stalks entering between the flights or lugs on the chain will be restrained, but neither pushed forward or pulled rearward. In a combine model that has variable speed control of header functions, it may be possible to automatically maintain this condition at varying ground
speeds. Increasing the forward machine speed would cause a matching increase in the speed of the gathering chains. While the trend in combine design is toward more automatic controls, most combines do not manage this speed ratio automatically. In this case, the operator is responsible for managing this important parameter. Increasing the ground speed without correspondingly increasing the gathering chain speed results in stalks being pushed forward by the chain lugs.

The chains pull the stalks toward the platform when operating at too low a ground speed. Either action can contribute to ear loss as the stalk is violently displaced and ears are flung forward or backward. Poor matching of gathering chain speed to ground speed can also cause stalks to be broken off or pulled from the ground, resulting in additional stem and leaf material passing through the harvester. If the speed of the header functions, including gathering chain speed, is adjustable, then this should be adjusted so that stalks appear to move smoothly into the head. If the chain speed is not adjustable, then the forward combine speed should be adjusted to minimize disturbance of the stalks as they proceed into the head.

**Header and Row Alignment**

Smooth feeding of the stalks into the header mechanism is difficult to achieve if the row widths do not accurately match the head row spacing. Adjust the head to match any variation in planter row spacing and make every attempt to keep the combine in sync with the planter. Harvesting with a match row of varying width in the swath will cause some stalks to enter the row unit off-center. Losses can increase if the stalks are displaced as the snouts force them into the gathering chains. Header size can impact this loss. Careful planting and auto-steer technologies can help minimize stalk disturbance. Auto-steer technology also can reduce steering errors. Auto-steer can be GPS driven but can also be driven by sensors that detect cornstalks and cause steering corrections to minimize error from a target row. Some systems use both approaches.

**Lodged Corn**

Corn plants lodged because of weather, disease, or insect damage are more difficult to gather without ear losses. Since crop conditions can greatly vary, there isn’t a lone solution for gathering lodged corn. However, there are adjustments that can reduce losses.

1. Lodged corn should be harvested as soon as possible to avoid further lodging, as well as damage to lodged ears from moisture and close proximity to the ground.
2. Lower speeds are generally required to allow downed stalks to be pulled up and over header snouts without losing the ear, so plan to slow down significantly.
3. If the crop is lying in the direction of the rows, it is usually more effective to harvest against the direction the stalks are pointing. This will require deadheading the combine to one end of the field prior to each pass.
4. Lowering the head as much as possible, without taking in rocks or dirt, will also capture more of the crop.
5. Increasing the angle of the head by loosening it on its mount and shifting the rear upward can make the gathering chains somewhat more aggressive. With the front of the head lower and the rear higher, the lugs on the gathering chains will reach down and lift stalks as they reverse direction.
6. Gathering chains can also be repositioned on their sprockets to position the lugs or flights to be directly across from each other. This will provide a more positive capture of stalks.
7. Aftermarket attachments in the form of a “reel” to gather downed material or powered cones to lift crop material over the end snouts of the head are available if lodged acreage is large.

8. It may be advantageous to open the spacing between ear savers to minimize any resistance to ears on down stalks as they are pulled in by gathering chains.

9. When adjusting for adverse conditions such as lodged corn, it is important to use the loss checks outlined in Chapter 36 to know whether a technique is reducing the losses or not. Check losses frequently and adjust when needed.

**Shelling Losses at the Head**

Kernel shelling losses at the head occur when ears impact hard surfaces and dislodge kernels that bounce out of the head or filter through the stripper plates. Many of the adjustments recommended above to lower whole ear losses also reduce losses caused by shelling because impact forces are lowered.

**Deck Plates**

Ideally deck plates should be positioned so that the space between them is centered above the space between the snap rolls underneath (Fig. 37.2). Stalks then are pulled straight down between the plates. Some heads require manual spacing of the deck plates. Others have hydraulically adjustable plate spacing. The lower spacing, where stalks enter, is recommended to be slightly narrower than the upper spacing. Many combine manuals suggest an initial spacing of 1 1/8” at the bottom and 1 1/4” at the top. With the trend to higher plant populations and smaller ears, it may be advantageous to narrow this spacing. Many producers use a pair of sockets as a handy way of spacing plates (for example, using a 1” diameter socket at the bottom and a 1 1/8” diameter socket at the top).

Sizes should be selected to accommodate your crop and conditions. Setting the spacing too narrow will require more power and will break some stalks, taking in more material through the combine. Setting the spacing too wide will increase “butt shelling,” which occurs when the butt end of the ear contacts the stalk rolls, and kernel loss. Hydraulically adjustable deck plates allow changes in plate spacing to accommodate local conditions in the field. Dryland producers who experience a wide variability in crop conditions with regard to terrain or spatial location may particularly benefit from this option. If adjusting on the go, the narrowest spacing that allows for free flow of the stalks between the deck plates will reduce shelling losses. Be sure to occasionally check to determine that this convenient option is working as intended. It is quite possible for the sliding mechanism to stick, rust, or seize as the machine ages. Checking for uniform plate spacing between rows will help prevent losses from a malfunction.

**Gathering Chains**

Manuals recommend that the gathering chain lugs extend into the gap between the deck plates by ¼”. This will vary if deck plates are adjusted on the go. Chain lugs can be staggered or timed so that they move up the plates across from each other. Staggered lugs will be less aggressive and pull in fewer leaves. This may be preferable in wetter crop conditions. In a very dry crop, additional leaf material stripped by timed opposing lugs may help sweep kernels from butt shelling up and into the head. Timed chain lugs can also be more aggressive in lodged fields.

**Cross Auger Position**

Two clearance adjustments are common on the cross auger that delivers the crop to the center of the head where it enters the feederhouse. One adjustment is the spacing between the auger flighting and the
stripper bar (Fig. 37.3). Begin with the combine manual’s recommendation and adjust this space to minimize any wrapping of stalks or plant parts around the auger. A second clearance is the space under the auger to the pan on the head. Again, the manufacturer’s recommendation is a starting place, but a spacing of 1¾” is common. Smaller spaces may increase the shearing of ears by the flighting, while too large a space may inhibit the steady flow of material along the pan.

It is also desirable to keep the cross auger close to the feederhouse drum where the feederhouse chain takes over from the auger. Reducing this space may minimize the accumulation of crop as it enters the feederhouse and help prevent backfeeding that can cause losses. Some combine designs have an overlap of the auger flighting from the right and left sides at the center, whereas others do not. An extension of the flighting to create this overlap can be added and may help propel the ears smoothly into the feederhouse.

**Feederhouse Adjustments**

A traffic jam of ears waiting at the center of the cross auger to enter the feederhouse can cause both ears and kernels to be lost. Minimizing the space between the feederhouse chain and the auger can reduce this buildup. If the chain tensioning system will allow it, the addition of a link or half-link to the feederhouse chain will extend the drum forward, which may reduce the space between the auger and the feederhouse drum. Running the feederhouse at a fast speed will also reduce buildup of crop transitioning from the cross auger to the feederhouse.

**Losses from the Combine Separator**

The designs of newer combines are very forgiving with regard to their ability to thresh, separate, and clean the grain. In many cases, the losses from these internal systems may be less than 1% of the standing yield in the field. As indicated above, it is most common for the losses from the header to be the major source of machine losses.

**Threshing Losses**

Threshing losses occur when kernels fail to break free of the cob as it passes between the cylinder or rotor and the concave. Factors influencing this process include:

1. Crop conditions, such as moisture and variety, will affect how easily kernels thresh.
2. Speed of the cylinder or rotor.
3. Concave gap between the cylinder or rotor and the concave.
4. Concave type and style.
5. Guide vanes that determine the dwell time of the crop in the threshing system of some machines.
6. Rasp bar or rotor tine styles and condition.
7. Feed rate of the crop into the threshing system.
8. Material other than grain (MOG) rate through the threshing system.
9. Cleaning system settings that determine how much material enters the return threshing system.

Threshing losses are typically very low. However, if the losses are > 0.3% of the yield, adjustments may be warranted. Increasing the rotor or cylinder speed will generally decrease threshing losses, but may also cause an increase in kernel damage, particularly if the crop moisture content is very high or very low. Increasing speed will generally require more power.
Decreasing the concave gap forces the material through a smaller space and generally reduces threshing kernel loss. This can also cause kernel damage and cob breakup, which may cause an increase in returns and potentially more foreign matter in the grain sample. Tightening the concave gap will also increase power requirements.

Concave type or style can affect threshing. If corn is the predominant crop for a particular machine, it may be appropriate to select concave types that are specifically designed for corn.

Rotary or axial-flow threshing systems can have guide vanes that affect crop flow. The crop follows a helical path around the rotor, and guide vanes can change this path to a tighter helix, such that the crop makes more trips around the rotor before moving on.

Rasp bars and rotor tines will affect threshing performance. These can be changed or replaced as the combine is serviced prior to harvest but are not easily adjusted for changes in crop conditions. If you have chronic problems with threshing losses, then exploring hardware options for the rotor or cylinder for the following season may be appropriate.

The operator controls the feed rate of material using forward speed. The threshing system is most effective with a constant flow of material. Threshing is gentler when much of the rubbing action is from crop-to-crop contact rather than contact between the crop and the rotor or the concave. Keeping the concave gap filled aids threshing but also cushions the kernels so that damage is lower. Changing ground speed can help maintain constant flow through the threshing system. However, this should be balanced against the effects of changing speed upon header performance. In many cases, the combine’s separator is more forgiving than the header.

The flow of material other than grain (MOG) through the combine affects performance of all internal systems in the separator. MOG in the form of stalks, leaves, and cobs is affected by the crop conditions and header settings. Most internal functions perform better with less MOG, so adjusting header functions to take in less MOG is generally desirable. Adjustment of stripper plate spacing, gathering chain speed and machine forward speed will affect MOG intake.

Some threshing losses are prevented by the combine’s return, or tailings, system. That system is adjusted to capture cob fragments that may still contain kernels before they can be expelled and return them to a threshing system a second time. Opening the tailings trap at the back end of the cleaning shoe can make it easier to capture cob fragments that have attached kernels and return them for additional threshing. This system should be adjusted to prevent losses of poorly threshed cobs, but should not be the primary system to keep threshing losses low. Often the volume of tailings or returns can indicate that changes should be made in the first pass at the threshing system.

**Separation Losses**

Separation losses occur when kernels pass out of the back of the combine while embedded in stalk and leaf residue. Distinguishing separation loss from cleaning system loss is difficult because both appear as loose kernels on the ground behind the combine. In corn, harvest separation losses should be very low, with values of 0.1% loss common. It is not very difficult for the machine to separate corn kernels from the modest amount of stalk and leaf material that should enter the machine. Factors that affect separation efficiency include:

1. Material other than grain (MOG) feed rate.
2. Crop moisture content.
3. Rotor speed.
5. Guide vanes on the concave.
6. Crop feed rate.

Separation losses can increase if lodging or other conditions cause a large volume of MOG to enter
the combine. Wet grain and wet MOG do not slide easily next to each other and can cause separation problems. Much of the separation process occurs in the threshing system when kernels drop through the concave. Remaining separation occurs on the straw walkers or on the aft part of the rotor. Many adjustments that increase threshing may also increase separation. Increasing rotor speed increases the centripetal forces that cause separation in a rotary combine. Adjusting feed vanes that increase the dwell time of the crop on the rotor will increase separation efficiency and decrease losses. Decreasing the feed rate, and particularly the MOG feed rate, will increase separation efficiency and reduce these losses. In wet corn, it is even more important to limit the MOG intake.

Cleaning System Losses
The combine cleaning system is designed to separate clean grain from small-fragment MOG such as bee's wings chaff, leaf and stalk fragments, and small cob fragments. Cleaning system losses should also be very small and are hard to distinguish from separation losses. If the loose kernel losses from cleaning and separation exceed a few tenths of a percent, then adjustments are warranted. Cleaning losses occur when grain flows out of the back of the combine, passing over the chaffer and cleaning sieves. Factors that can affect cleaning system losses include:
1. Fan speed and baffle direction.
2. Sieve opening size.
3. Feed rate onto the sieves.
4. MOG feed rate.
5. Cylinder and concave settings that break up MOG and load the cleaning system.
6. Crop moisture content.
7. Distribution patterns on the sieves.
8. Crop test weight.

Cleaning grain is a balance between gravity and aerodynamic forces. The grain is allowed to fall through the sieve openings into the airstream while the chaff and lighter MOG float on the airstream upward and to the rear. The oscillation of the shoe helps to move larger heavier material to the rear. A low fan speed and full sieve openings would prevent any cleaning losses, but would allow much of the chaff to pass with clean grain into the tank. A high fan speed will clean the grain, but can potentially cause some kernels to float or bounce out of the rear of the combine. Baffles in the airstream can control where the airstream passes through the sieve openings and how evenly the air is distributed along the shoe. Opening the sieves (Fig. 37.4) can allow grain to more easily fall through, even with high airspeeds. The balance of cleaning losses and foreign matter in the grain can be affected by the feed rate of material onto the shoe. It is possible to overwhelm the airflow if the flow of material onto the shoe is not even. Adjustments of individual combine designs that promote the even distribution of grain and chaff onto the shoe will reduce losses and keep the grain clean. Consult the operator's manual for the adjustments specific to your machine.

Not all adjustments are initially intuitive. For example, you could find excessive loose kernels on the ground behind the combine. The operator's manual may suggest that increasing the fan speed can reduce losses. This would seem counter to logic and might be expected to expel more grain. However, if the losses are occurring because a heavy layer of grain and chaff on the sieves is preventing grain from moving down, increasing the airflow can disperse the pile of material and allow the grain to filter down and the
chaff to float off. Your operator’s manual is the best source of information about your combine’s specific systems. The manufacturer often provides a prioritized checklist to help find appropriate adjustments for a particular kind of loss.

A procedure called a “kill stall” can be used to check deposition patterns onto the shoe if cleaning system losses are excessive. The procedure, recommended by the combine manufacturer, involves rapidly stalling the combine engine by cutting throttle and simultaneously braking and pushing hydrostat ahead. After the engine stalls, the separator is disengaged and the engine is restarted to allow it to cool and shut down. Rapidly stopping the separator during the stall has the effect of freezing the process in place so that it is possible to open the side panels and view the loading of the separator system. If grain is piled disproportionately on one side or part of the shoe, the owner’s manual can be studied to find appropriate adjustments to spread the grain more evenly on the shoe and improve cleaning. These problems will exist most clearly in high-yielding grain and with the combine separator systems heavily loaded.

More MOG means more work for the cleaning system. High rotor speeds, tight concave spacings, and a dry crop can result in lots of broken up MOG and a cleaning system that is overloaded. Managing one system within the machine often affects another. If cleaning system losses are high or if excessive cob fragments are found in the grain sample, it may be necessary to revisit the threshing system settings. Nearly every adjustment that is made on the threshing or cleaning system will affect other aspects of the machine’s performance. Manuals recommend adjusting one thing at a time, and then checking the losses and clean grain quality before making any further adjustments.

Crop conditions also affect cleaning. High-moisture corn and MOG have more friction, and do not spread and flow as easily as dry grain. For example, if moving into a field that has higher moisture content, the losses from the separator should be determined and the grain sample examined. Opening sieves and increasing fan speed may be required to compensate for the increased friction from moisture. Other crop conditions, such as test weight, also can affect cleaning losses. Grain that failed to mature normally and has a resulting low test weight can blow out of the combine more easily with the chaff. Air and sieve openings can be adjusted again to retain more of the grain while keeping a clean sample.

Adjusting a combine to yield minimal grain losses involves a multitude of potential adjustments to accommodate the conditions that change from year to year and field to field. Manufacturers have incorporated ever-improving systems on combines to make the process easier and more robust. Even with these systems, however, the operator still must check for losses from the header and the separator and make appropriate adjustments to compensate for and reduce those losses. In corn harvest, the header will continue to be the area where the operator’s skill at adjusting the machine and operating it in a way that accommodates local conditions has a huge impact on the amount of grain – and profit – that is left in the field.

References and Additional Information
http://extension.agron.iastate.edu/soybean/production_combineset.html (accessed 6 June 2016)


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Corn yield estimates can be used for a variety of purposes including: marketing; planning storage requirements; organizing harvest equipment; and making decisions about pests. The purpose of this chapter is to provide guidance and examples on how to convert field measurements into estimated corn yields.

**Table 38.1 Basic steps to estimate yields:**

1. Yield estimates start with tracking seed germination, assessing planter effectiveness, and determining your plant density. Many of these measurements can occur shortly after seedling emergence.

2. As you approach plant maturity, grain yields can be estimated by assessing the number of kernels/ear and kernel weight. The basic steps include:
   a. Estimating the ears/acre.
   b. Estimating the kernels/ear.
   c. Calculating kernels/acre = (ears/a × kernels/ear).
   e. Calculating bu/acre = [(kernels/a)/(kernels/bu)].

**Estimating Yield after Emergence**

As the corn plant grows, it is important to identify problems that could reduce yields. This requires that the fields be routinely scouted (by ground or through aerial imagery) and calculations conducted to convert point measurements to common yield units, usually bushels/acre. To estimate yield following emergence, you need to make many assumptions, which include:

1. The number of rows of kernels on an ear.
2. The number kernels in each of the rows.
3. The number of kernels per bushel (weight/kernel).

Example 38.1 provides steps for determining yield estimates. These estimates are based on plant population and do not consider how yield may be reduced due to planting date, or pest or nutrient stresses. For example, Carter et al. (1989) and Nafziger et al. (1989) reported that a 1.5-week delay from the “normal” planting date decreased yield 5% and that a 3-week delay reduced yield 12%.
Yield Estimates During the Early Reproductive Stages of Corn Growth (R1–R3)
As the season progresses, the yield estimates become more accurate. The R1 growth stage occurs when silks are visible outside the husk (Chapter 5). At this growth stage, the silks catch the falling pollen grains and fertilization occurs after the pollen moves down the silk to the ovule. Each ovule has the capacity to become a kernel. Yield is estimated by measuring the plant population and then estimating the number of kernels per ear. An approach similar to Example 38.1 can also be used to estimate yield.

Step 1. Determine the number of ears per acre. Measure off 1/1000 of an acre (Table 38.1). A tape measure is the most accurate way of measuring off the indicated length of row. A faster way, but less accurate method, is to step off the row length. With practice and calibration, it is possible to step off the indicated length with an accuracy of plus or minus a few inches. As an example, if you are working in 30-inch rows, the plants are counted along a length of row measuring 17 feet, 5 inches (Table 38.1). Then, estimate the plant population per acre by multiplying the number of plants per row length by 1000. Note: Across a field, you may want to take several estimates and average them, or if population is variable by area, each area may need its own estimate. These estimates would then be averaged based on the percent area that is expected to have a similar population.

Step 2. Determine the number of kernels/ear by counting the number of kernels/row and the number of rows/ear. If the ear size in the field appears

Yield Estimates from R4–R6 Growth Stages
The R4 growth stage is called the dent growth stage and the R6 stage is physiological maturity (black layer) (Chapter 5). At these growth stages, yield estimates become more accurate.

### Table 38.1 The length of row to count for 1/1000 of an acre depending on row width (in inches)

<table>
<thead>
<tr>
<th>Row width</th>
<th>Row length</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>feet</td>
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<tr>
<td>22</td>
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</tr>
<tr>
<td>26</td>
<td>20</td>
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<td>30</td>
<td>17</td>
</tr>
<tr>
<td>34</td>
<td>15</td>
</tr>
<tr>
<td>38</td>
<td>13</td>
</tr>
</tbody>
</table>

Figure 38.1 Example of an ear used to calculate the number of kernels per row. Only fully filled kernels along fully filled rows should be counted. The lines indicate the kernels that should be included in the count. This ear contains ~34 rows of kernels.
uniform, select 4 or 5 “average ears” and count the number of kernels/row. Include only the kernels and rows that are fully filled (see Figure 38.1 and count only the kernels inside of the marked lines). This ear contains ~36 kernels/row.

Count the number of rows/ear. For this step break the ear in half, which makes it easier to count rows (Fig. 38.2). The count for the ear below is ~18 rows/ear. The rows/ear will almost always be an even number. The number of kernels/ear can be calculated or determined using Table 38.2. If the number of kernels/row is highly variable, we suggest that at least 10 ears be counted from each area.

\[
\text{Kernels/ear} = \frac{36 \text{ kernels}}{\text{row}} \times \frac{18 \text{ rows}}{\text{ear}} = 648 \text{ kernels/ear}
\]

**Step 3.** Calculate the kernels/acre from the data collected in Steps 1 & 2. To determine the number of kernels/acre, the calculations are shown below. Assume that the number of plants counted along the 17’5” length = 35 plants. Therefore, 35 x 1000 = 35,000 plants (ears) per acre.

\[
\frac{\text{ears}}{\text{acre}} \times \frac{\text{Kernels}}{\text{plant}} = \frac{\text{Kernels}}{\text{acre}}
\]

\[
35,000 \text{ Ears} \times \frac{648 \text{ Kernels}}{\text{ear}} = 22,680,000 \text{ Kernels/acre}
\]

**Step 4.** Estimate the number of kernels/bu. The mass/kernel of corn varies greatly (see Chapter 36, Table 36.2). The number of kernels/bu can range from 70,000 kernels/bu to 105,000 kernels/bu (assume a bushel to be 56 lbs at 15.5% moisture). The kernel weight is very sensitive to climatic conditions between August and September. During wet conditions, a bushel may contain 70,000 kernels, whereas if August and September are hot.

**Example 38.2** Based on a plant population of 35,500 plants/acre, estimate your yield at the tasseling (R1) stage of development.

**Step 1.** Estimate your plant population by:
1. Counting the number of plants in 1/1000 of an acre.
2. Multiplying your count by 1000.

**Step 2.** Estimate the yield by multiplying your plant population by the estimated weight of grain per ear, and dividing the lbs grain/acre by 56 lbs/bu. This example assumes that each ear weighs 0.4 lbs.

\[
\frac{35,500 \text{ ears}}{\text{acre}} \times \frac{0.4 \text{ lbs}}{1 \text{ ear}} \times \frac{bu}{56 \text{ lbs}} = 254 \text{ bu/acre}
\]

Note: Reduce your estimate if you know the crop has been stressed. For example, weeds present during the weed-free period can reduce yield from 5% to 100% depending on species present and density. Similar yield reduction calculations can be conducted for nutrient deficiencies, or insect and disease damage. Examples for estimating yield losses are available in Clay et al. (2011). At the early reproductive growth stages, yield estimates are not accurate and typically overestimate actual yield. As the crop matures, kernel-based assessments become more accurate.

**Figure 38.2 Count the number of rows. On this ear, there are ~20 kernels per row (Courtesy authors).**

**Table 38.2** A table for estimating the number of kernels/ear. In the above example, the number of kernels/row was 36 and number of rows/ear was 18. Using this table, the value would be estimated to be 630 kernels/ear, whereas the calculated value was 648. Because there was 1 kernel/row extra (36 vs. 35) = 630 + 18 = 648.

<table>
<thead>
<tr>
<th>Rows/ear</th>
<th>20</th>
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<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
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<td>Kernels/ear</td>
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<td>360</td>
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<td>420</td>
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<td>560</td>
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<td>720</td>
<td>840</td>
<td>960</td>
<td>1080</td>
</tr>
<tr>
<td>24</td>
<td>520</td>
<td>650</td>
<td>780</td>
<td>910</td>
<td>1040</td>
<td>1170</td>
</tr>
<tr>
<td>26</td>
<td>560</td>
<td>700</td>
<td>840</td>
<td>980</td>
<td>1120</td>
<td>1260</td>
</tr>
</tbody>
</table>
and dry, a bushel may contain 105,000 kernels. The producer’s management (variety, plant population, fertility, tillage system, etc.) also impacts the number of kernels/bu. The kernel weight per bushel can be estimated by weighing a known number of kernels that are representative of the kernels (see Example 38.3)

Step 5. Calculate the bu/acre.
The estimated yield per acre can be determined by calculating the bu/a (see below) or by using a Table 38.3.

\[
\text{bu/acre} = \frac{\text{bu}}{\text{kernel}} \times \frac{\text{kernel}}{\text{acre}}
\]

\[
\frac{22,680,000 \text{ kernels}}{\text{acre}} \times \frac{\text{bu}}{90,000 \text{ kernels}} = 252 \text{ bu/acre}
\]

Using Table 38.3, the information needed includes: 35,000 plants/acre and 648 kernels/ear. At 650 kernels/ear and 35,000 plants/a, the value from Table 38.3 is 253 bu/a.
Table 38.3 Table for converting kernels/ear and ears/acre to corn yield in bu/a. In this calculation, it was assumed that a bushel contains 90,000 kernels.

<table>
<thead>
<tr>
<th>Ears/acre</th>
<th>Kernel/ear 250</th>
<th>300</th>
<th>350</th>
<th>400</th>
<th>450</th>
<th>500</th>
<th>550</th>
<th>600</th>
<th>650</th>
<th>700</th>
<th>750</th>
<th>800</th>
<th>bu/acre</th>
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<tr>
<td>*1000</td>
<td>42</td>
<td>50</td>
<td>58</td>
<td>67</td>
<td>75</td>
<td>83</td>
<td>92</td>
<td>100</td>
<td>108</td>
<td>117</td>
<td>125</td>
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<td>267</td>
<td>288</td>
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<td>329</td>
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References and Additional Information
Carter, P. R., E. D. Nafziger, and J. G. Lauer, 1989, Uneven Emergence in Corn, North Central Extension Publication No. 344


Acknowledgements
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(1) mail: U.S. Department of Agriculture  
Office of the Assistant Secretary for Civil Rights  
1400 Independence Avenue, SW  
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

USDA is an equal opportunity provider, employer, and lender.
Weeds typically are defined as plants out of place. Based on this definition, any plant can be considered a weed when it interferes with a desired plant. However, in natural areas, these same plants may provide food for animals and insects, and ground cover to protect the soil. For a sustainable system, the need to produce food must be balanced with the need to maintain and sustain our ecosystem. The goal of this chapter is to provide information about crop loss (when available), herbicide resistance (if any), management strategies, tips for identifying broadleaf weeds, and images of South Dakota noxious weeds. Up-to-date chemical management for weeds can be found at online at iGrow.org, http://igrow.org/agronomy.

**Table 39.1 Relative competitiveness of common South Dakota weeds.**

Yield loss due to weeds varies by species, weed density, and time of emergence. Weeds that emerge early tend to cause more yield loss than those that emerge after crop establishment. All weeds have the potential to cause 100% yield loss, however, some are relatively more competitive with corn than others. This table gives a relative rating of different weed species and their ability to cause a 5% yield loss.

<table>
<thead>
<tr>
<th>Highly competitive weeds (one or fewer plant/foot row results in 5% yield loss)</th>
<th>Common cocklebur</th>
<th>Common sunflower</th>
<th>Common waterhemp</th>
<th>Giant ragweed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common cocklebur</td>
<td>Field bindweed</td>
<td>Switch grass</td>
<td>Giant ragweed</td>
<td></td>
</tr>
<tr>
<td>Common sunflower</td>
<td>Horseweed</td>
<td>Volunteer corn</td>
<td>Giant foxtail</td>
<td></td>
</tr>
<tr>
<td>Common waterhemp</td>
<td>Wooly cupgrass</td>
<td>Redroot pigweed</td>
<td>Russian thistle</td>
<td></td>
</tr>
<tr>
<td>Giant ragweed</td>
<td>Wild proso millet</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Moderately competitive weeds (5-10 plants needed per foot of row to result in 5% yield loss)</th>
<th>Canada thistle</th>
<th>Hedge bindweed</th>
<th>Common lambsquarters</th>
<th>Kochia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada thistle</td>
<td>Field bindweed</td>
<td>Switch grass</td>
<td>Giant foxtail</td>
<td></td>
</tr>
<tr>
<td>Hedge bindweed</td>
<td>Horseweed</td>
<td>Volunteer corn</td>
<td>Russian thistle</td>
<td></td>
</tr>
<tr>
<td>Common lambsquarters</td>
<td>Wooly cupgrass</td>
<td>Redroot pigweed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kochia</td>
<td>Wild proso millet</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low competitive weeds (&gt; 10 needed per foot of row to result in 5% yield loss)</th>
<th>Wild buckwheat</th>
<th>Green foxtail</th>
<th>Yellow foxtail</th>
<th>Longspine sandbur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wild buckwheat</td>
<td>Green foxtail</td>
<td>Yellow foxtail</td>
<td>Longspine sandbur</td>
<td></td>
</tr>
<tr>
<td>Large crabgrass</td>
<td>Witchgrass</td>
<td>Venice mallow</td>
<td>Barnyardgrass</td>
<td></td>
</tr>
</tbody>
</table>

**Corn Yield Losses (Critical Weed-Free Period)**

Weeds present in the field from V2 to V8 can irreversibly reduce corn yields. This period is often called the weed-free period. This loss often occurs before the weeds compete with the corn plant for water, nutrients, and light. The factor(s) responsible for this loss is unknown, although light quality, volatile compounds, and/or other mechanisms have been examined. Different weed species have different emergence and
growth rates. In general, weeds that emerge early in the growing season have greater impact on corn yields than weeds that emerge later.

**Perennial Weeds**

Perennial plants can germinate from seed, or may produce new shoots from buds on roots, rhizomes (horizontal, below-ground structure that sends up shoots), stolons (prostrate stem above ground that produces new plants from tips or nodes), crowns, etc. (i.e., perennating structures). The new shoots can emerge very early in the spring and grow quickly because of carbohydrate storage in the perennating structures. These plants are often found to prosper in no-till or minimum-tillage systems due to the lack of disturbance to the perennating structures. In most cases, tillage **should not be used** as the major control mechanism because structures with the buds may be moved to new areas to form new infestations.

Examples of perennials include: Canada thistle, field bindweed, hedge bindweed, dandelion, and Jerusalem artichoke. In addition, all seven South Dakota Noxious Weeds are perennials, with descriptions included at the end of this chapter.

Herbicide applications should be timed for summer just before flowering to kill flowers and potential seed, and fall after the first light frost (or in late September even if no frost has occurred) to move herbicide to the plant’s roots. Frequent mowing or plant disruption without herbicides is needed to keep the plant from flowering and producing seed. In addition, frequent disturbance can help deplete carbohydrates in the roots, rhizomes, etc., which can weaken the plant. Unfortunately, if new shoots form from buds, the leaves can begin sending carbohydrates to the roots soon after emergence, so nonchemical weed control can be a long-term task.

**Biennial weeds**

These plants germinate from seed in the spring and form a rosette that, if undisturbed during the first season, overwinters. The second year, the plant produces flowers and seeds. Examples of biennial weeds include: musk thistle, bull thistle, biennial wormwood, and common mallow. Chemical and nonchemical control can be effective against biennial weeds. Nonchemical control approaches for biennial weeds include: tillage, high-quality seed corn, crop rotations, mulches, and cover crops. The chemical control of the rosette form of biennial weeds is often very effective in the fall. Herbicide effectiveness generally increases with temperature. Daytime temperatures of 50°F or higher are desirable.

**Annual Weeds**

Annual weeds are those that germinate from seed every year and live only for a single season. Annual weeds can germinate at different time periods. **Winter annuals** will germinate and emerge in fall or very early spring and flower early, usually before corn planting. Winter annual weeds include: field pennycress, horseweed or marestail, and evening primrose. Winter annuals can be more of a problem in no-till systems as the undisturbed residues provide overwinter protection for the germinated weeds. In addition, these weeds may set seed even before any spring field operations occur.

Early emerging spring annual weeds (days or weeks prior to corn planting) include: common sunflower, Pennsylvania smartweed and ladysthumb, common lambsquarters, and giant ragweed. Early emerging spring annual weeds may be controlled with preplant burndown applications of herbicides. These plants cause interference and the greatest yield losses if they remain undisturbed because they are already growing before corn emergence.

Weeds that emerge at or soon after corn planting include: common ragweed, velvetleaf, Russian thistle, redroot pigweed, common cocklebur, wild mustard, black nightshade, Venice mallow, wild buckwheat, and kochia. These weeds are targeted with a pre-emergence herbicide application. Weeds that emerge after corn emergence and into midsummer include: common waterhemp, biennial wormwood, Palmer amaranth, and buffalobur. Weeds not controlled by pre-emergence applications are typically the targets of postemergence control operations.
Perennial Broadleaf Plants

Canada thistle (Cirsium arvense)

Canada thistle (Figure 39.1) is a South Dakota Noxious Weed and it typically emerges before or at corn planting.

**Plant Description:** This perennial has a deep, extensive root systems and spreads by seeds or pieces of root transported from one location to another. The emerging plants are very small and the leaves are opposite. The plants are very dark green, and leaves have a crinkled appearance with sharp spines on the leaf margins and stem. The stems are erect, may have green or red stripes, and can grow to almost 6 ft tall under certain conditions. Flowers are imperfect, with colonies of male and female plants.

**Areas of Infestation and Yield Loss Potential:** This weed is often found in disturbed sites and may thrive in no-till systems. Canada thistle can produce a 30% yield reduction with 4 shoots or more per ft$^2$. Tillage, in mature stands, will spread rhizomes and increase areas of infestation. 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.

**Herbicide Resistance:** Biotypes of Canada thistle have been reported to be resistant to synthetic auxin herbicides (WSSA Group 4).

Perennial sowthistle (Sonchus arvensis)

Perennial sowthistle (Figure 39.2) is a South Dakota Noxious Weed that typically emerges early from rhizomes, whereas young plants can start from creeping roots almost any time during the year. Seeds can germinate throughout the season if moisture is adequate.

**Plant Description:** This perennial reproduces by seeds and regrows from tap and creeping roots. This plant has a dandelionlike rosette and produces a flower stalk that has yellow, dandelionlike flowers. The plant has a smooth stem with milky juice, and it has long, lobed leaves with spiny edges. The leaves have a whitish coating on the leaf surface.

**Areas of Infestation and Yield Loss Potential:** This weed generally escapes from roadside areas, and infestations often start at field margins. Perennial sowthistle is a problem in no-till and minimum-till fields. This plant can form dense colonies, however, little research has been done to examine harvest losses.

**Herbicide Resistance:** To date, herbicide resistance has not been reported in perennial sowthistle, but other species of sowthistle have been reported to be...
resistant to ALS-inhibitor herbicides (WSSA Group 2).

**Wild four o’clock (Mirabilis nyctaginea)**
Wild four o’clock (Figure 39.3) typically emerges before or at corn planting, and this perennial plant reproduces primarily from seed and shoots that arise from the taproot.

**Plant Description:** The leaves are opposite, ovate with no or few hairs, and the stems are erect. Inflorescence is an umbel with pink or red-purple sepals. Flowers open late in the afternoon, hence the name four o’clock.

**Areas of Infestation and Yield Loss Potential:** This plant often grows in sandy, dry soils. If growing in more fertile sites, it usually has poor growth because of other plant competition. It has a large taproot and it is not aggressive. It rarely is observed at densities high enough to produce significant yield losses.

**Herbicide Resistance:** As of 2015, herbicide resistance has not been reported, although the plant is tolerant to 2,4-D (synthetic auxin herbicides) (WSSA Group 4).

**Curly dock (Rumex crispus)**
Curly dock (Figure 39.4) typically emerges before or at corn planting. This perennial plant reproduces mainly by seed, but once established, new rosettes form at the top of the taproot in late fall or early spring.

**Plant Description:** Curly dock, a member of the buckwheat (Polygonum) family, is erect and grows from 2- to 5-ft tall. It has an ocrea (membranous sheath) at the leaf base. Leaves are hairless, and stems are often unbranched below the flower head. Leaves are alternate along the stem. The fruits and stems turn rusty brown at the end of the season.

**Areas of Infestation and Yield Loss Potential:** This plant is often found in wet areas of the field. This plant is not aggressive and rarely observed in densities high enough to produce large yield losses. However, yield loss may occur due to wet soil conditions.

**Herbicide Resistance:** As of 2015, herbicide resistance has not been reported. However, plants in the Polygonum family are tolerant of synthetic auxin herbicides (WSSA Group 4).

**Swamp smartweed (Polygonum coccineum P. amphibium)**
Swamp smartweed (Figure 39.5) typically emerges before or at corn planting. This perennial plant reproduces primarily from seed, but once established, shoots arise from rhizomes, stolons, and rooting stems.

**Plant Description:** Swamp smartweed is erect and grows from 1- to 3-ft tall. It is a member of the
buckwheat (Polygonum) family. This plant has an ocrea (membranous sheath) at the leaf base. Leaves are oblong and alternate along the stem. The inflorescence is spike with pink- or rose-colored flowers.

**Areas of Infestation and Yield Loss Potential:** This plant is often found in low-lying, wet areas of the field. This plant can be observed in high densities in wet soils and yield losses may be due to poor corn growing conditions.

**Herbicide Resistance:** As of 2015, herbicide resistance has not been reported. However, plants in the Polygonum family are tolerant of synthetic auxin herbicides (WSSA Group 4).

**Common milkweed (Asclepias syriaca)**

Common milkweed (Figure 39.6) typically emerges before or at corn planting, and this perennial plant reproduces from seed, root buds, and crown buds. Several stems can arise from a single crown. This plant is being reintroduced in many areas due to its importance to the larvae of the monarch butterfly.

**Plant Description:** This plant has an erect plant habit that grows from 2- to 6-ft tall. Leaves are opposite, oblong and hairy. Stems are hairy and contain milky sap. The flowers are arranged in umbellate cyme and flowers have pink- to rose-colored petals.

**Areas of Infestation and Yield Loss Potential:** Common milkweed prefers dry, open sites. This plant can be aggressive with densities high enough to result in significant yield loss. Harvest problems may occur if high densities are present because of the sticky sap from cut stems.

**Herbicide Resistance:** This plant has always been tolerant of glyphosate (WSSA Group 9) due to sticky sap in the plant.

**Hemp dogbane (Apocynum cannabinum)**

Hemp dogbane (Figure 39.7) typically emerges before or at corn planting but new shoots can emerge throughout the season. This perennial plant reproduces from seeds and a spreading root system.

**Plant Description:** It has an erect plant habit, but unlike milkweed, often is bushy with many stems. Plants can grow up to 3 ft tall. Leaves are opposite, oblong, and the upper leaf surfaces typically are hairless. Stems contain milky sap. The flowers are arranged in a cyme and have white to white-green petals.
Areas of Infestation and Yield Loss Potential: Hemp dogbane prefers dry, open sites and is an aggressive plant that is difficult to control. Crop rotations with a hay crop for several years with several cuttings per year help reduce infestations.

Herbicide Resistance: This plant is tolerant to glyphosate (WSSA Group 9).

**Ground cherry (Physalis sp.)**

Ground cherry (Figure 39.8) typically emerges before or at corn planting, but new shoots can emerge throughout the season. This perennial plant reproduces from seed and it develops a thick, underground root system.

**Plant Description:** Ground cherry has an erect habit but often becomes bushy with many stems. Plants can grow up to 3 ft tall. Leaves are alternate, oval with a toothed margin. Leaf surfaces have glandular hairs, and single yellow-green flowers develop papery, conical seedpods (Japanese lanterns).

Areas of Infestation and Yield Loss Potential: This aggressive plant prefers dry, open sites and can be difficult to control. Sticky seeds can adhere to crop seeds during harvest if corn is cut short.

Herbicide Resistance: As of 2015, herbicide resistance has not been reported.

**Jerusalem artichoke (Helianthus tuberosus)**

Jerusalem artichoke (Figure 39.9) typically emerges early from tubers with many plants appearing in a small area. This perennial plant reproduces from seed, tubers, and rhizomes.

**Plant Description:** Jerusalem artichoke has a sunflowerlike rosette and the leaves are opposite. The plant has pale yellow, disk flowers, and it can grow up to 10 ft tall.

Areas of Infestation and Yield Loss Potential: High populations can be found in wet sites and in no-till or minimum-till fields. This plant can be extremely aggressive due to its tall stature, and corn yield losses of almost 100% have been reported.

Herbicide Resistance: Herbicide resistance has not been reported.

**Field bindweed (Convolvulus arvensis)**

Field bindweed (Figure 39.10) emerges in late spring to early summer.

**Plant Description:** This perennial plant can grow from rhizomes or seed and it has arrow-shaped leaves on a twining stem. The root system can be extensive and deep-rooted. Flowers are white to pink and bell- or trumpet-shaped.
Areas of Infestation and Yield Loss Potential: This plant grows well in dry soils and it can produce a 50% yield reduction in corn. In addition, the vining nature of the plant can cause problems with harvest equipment.

Herbicide Resistance: This plant is tolerant of glyphosate (WSSA Group 9), and biotypes are resistant to cell-membrane disruptor (paraquat) (WSSA Group 22) herbicides.

**Hedge bindweed (Calystegia sepium)**
Hedge bindweed (Figure 39.11) typically emerges before or at corn planting. This perennial, vining plant reproduces by seed and rhizomes.

Plant Description: Hedge bindweed can be confused with field bindweed (Figure 39.10). However, the leaves have a long petiole and a pointed tip. The flowers are large, funnel-shaped, and white to pink in color.

Areas of Infestation and Yield Loss Potential: Found in disturbed sites. This plant is not as aggressive as field bindweed, although the vines may cause problems during harvest.

Herbicide Resistance: As of 2015, herbicide resistance has not been reported.

**Dandelion (Taraxacum officinale)**
Dandelion (Figure 39.12) typically emerges early, before corn planting, and the seeds can germinate throughout the season if moisture is adequate. This perennial reproduces by seeds and regrows from the taproots.

Plant Description: Dandelion has a basal rosette with long, lanceolate, lobed leaves. Milky juice can be found throughout the plant and exudes when cut. Bright yellow inflorescence with flowers arranged in heads.

Areas of Infestation and Yield Loss Potential: Dandelions can be a problem in no-till and minimum-till fields. This plant is not as aggressive as other perennials due to the low growing rosettes.

Herbicide Resistance: As of 2015, herbicide resistance has not been reported, although some are tolerant to synthetic auxin herbicides (WSSA Group 4).
**Biennial Plants**

*Common Mallow (or Roundleaf mallow) (Malva neglecta)*

Common mallow (Figure 39.13) generally is a biennial plant that reproduces from seeds. However, it can behave as an annual, winter annual, biennial, or short-lived perennial if winters are mild or it is located in a protected site. Seedlings emerge in several flushes throughout the season.

**Plant Description:** The leaves are alternate and oval-to kidney-shaped with wavy, lobed edges. The plant is prostrate to the ground, rarely getting taller than 1.5 ft but may have long vines. Leaf surface is hairy. Fruit is disk-shaped and flattened with a cheese-wheel appearance.

**Areas of Infestation and Yield Loss Potential:** Dense infestations are rarely observed in cultivated fields, but they may occur. The plant has a deep taproot that can help it survive drought and cold temperatures. Common mallow may not reduce corn yields, however, it can cause problems during harvest.

**Herbicide Resistance:** As of 2015 herbicide resistance has not been reported, although it is tolerant to glyphosate (WSSA Group 9).

*Bull thistle (Cirsium vulgare)*

Bull thistle (Figure 39.14) is a biennial plant that reproduces from seeds with a rosette (basal whorl of leaves) formed in the first year. In the second year – if the plant is not disturbed – it bolts and sends out many erect stems with flowers starting to form in July. This plant is the symbol of Scotland, as it saved the country from invaders.

**Plant Description:** The rosette leaves are elliptical to ovate in shape covered in cobweb-like hairs. Leaf margins can be unlobed (entire) to finely lobed but all are tipped with spines. Leaf surface is hairy. In the second year, stalks range from 3 to 6 ft in height with alternate, spiny leaves and spines on the stalk. Flower bolls are covered with spines and cobweb-like hairs.

**Areas of Infestation and Yield Loss Potential:** This plant prefers moist (not wet) sites but will grow on drier, sandy sites. In South Dakota, corn yield reductions have not been assessed.

**Herbicide Resistance:** As of 2015, herbicide resistant biotypes have not been reported, although it is tolerant of glyphosate (WSSA Group 9).

*Musk thistle (Carduus nutans)*

Musk thistle (Figures 39.15 and 39.16) reproduces from seeds with a rosette (basal whorl of leaves) formed the first year with emergence in the fall or early spring. In the second year, if not disturbed, the plant bolts and sends out many erect stems with flowers forming as early as May.
**Plant Description:** The rosette leaves are elliptical and smooth (without hair) with leaf margins deeply toothed to pinnately lobed. Leaf veins extend beyond the leaf margin to end as spines. Second-year stalks range from 2 to 4 ft in height, with alternate, spiny leaves and stalks with spiny wings. Flower color ranges from rose-purple to white. The inflorescences are disklike and nodding (Figure 39.15).

**Areas of Infestation and Yield Loss Potential:** This plant prefers moist (not wet) sites but will grow in drier, sandy sites. Musk thistle impact on corn yields is often not assessed, however, areas with heavy infestations may not be suitable for harvest.

**Herbicide Resistance:** This plant may be resistant to synthetic auxin herbicides (WSSA Group 4).

**Biennial wormwood (Artemisia biennis)**
Biennial wormwood (Figure 39.17) typically emerges in late-June to early July after corn planting and the plant may behave as an annual, flowering later in the first year of growth. Reproduction is from seed.

**Plant Description:** The first true leaves of seedlings are finely divided and often mistaken for common ragweed (compare Figures 39.17 and 39.40). Biennial wormwood has sharp leaf edges and leaves are hairless, whereas common ragweed has rounded leaf edges with hairs. Vegetative plants are rosettes. Flower stalks can grow up to 6 ft tall and a plant can produce over 400,000 seeds/plant.

**Areas of Infestation and Yield Loss Potential:** This plant grows well in disturbed, poorly drained soils and yield reduction can be up to 40% with 1 plant per ft². If the infestation is dense, areas may not be harvested because of the height of biennial wormwood, effectively reducing yield by 100% in these areas.

**Herbicide Resistance:** Herbicide applications must be done before the plant is 3” tall, as tolerance to all herbicides becomes an issue. As of 2015, herbicide resistant biotypes have not been reported.
Annuals Germinating in the Fall or Early Spring

**Eveningprimrose (Oenothera sp.)**

There are 20 species of eveningprimrose (Figure 39.18) in the Great Plains. These plants will emerge in the fall, overwinter as a rosette, or emerge in the early spring prior to planting. This biennial, winter annual, or early spring emergence plant reproduces only from seed.

**Plant Description:** The plant has numerous hairy leaves that are lancelike to oblong. Plants can grow up to 6 ft tall, and the flowers are yellow to reddish-yellow. The fruit is a cylindrical capsule tapering at the tip.

**Areas of Infestation and Yield Loss Potential:** High infestations can be found in reduced-tillage systems, and this plant is tolerant of drought conditions and sandy soil types. This plant is being explored as an alternative oil seed crop. Historically, the populations are less than the economic threshold.

**Herbicide Resistance:** As of 2015, herbicide resistance has not been reported, but the plant is difficult to control with herbicides typically used in corn.

**Prickly lettuce (Lactuca serriola)**

Prickly lettuce (Figure 39.19) is an annual or winter annual erect plant that reproduces from seeds germinating in fall or early spring.

**Plant Description:** The cotyledons (seed leaves) are oval or oblong with spiny margins and spines along the midrib of the leaf. The young plant is a basal rosette (growth habit resembling a dandelion) with stem elongation during flower development. The plant, when cut, exudes milky sap. Leaves on the elongated stem are alternate and leaf bases clasp the stem. Flowers are yellow in color and petals have a toothed margin.

**Areas of Infestation and Yield Loss Potential:** This plant is often found in disturbed sites. Its impact on corn yields is unknown.

**Herbicide Resistance:** Prickly lettuce biotypes in the United States have been reported to be resistant to ALS-inhibitor herbicides (WSSA Group 2) and synthetic auxin herbicides (WSSA Group 4).

**Flixweed (Descurainia sophia)**

Flixweed (Figure 39.20) is an introduced erect winter annual or biennial that germinates from seeds in the
fall or spring.

**Plant Description:** The leaves are finely divided and pinnately compound, grayish-blue in color. Juvenile plants have ovate-shaped leaves in a rosette arrangement, deeply lobed margins, and the leaves are covered in star-shaped hairs. Flower petals are very small and yellow or greenish-yellow. Flixweed is distinguished from other mustards because of its finely dissected leaves and very long, thin siliques (seed-holding capsules).

**Areas of Infestation and Yield Loss Potential:** This plant is often found in disturbed, dry sites. The impact of this plant on corn yields is unknown.

**Herbicide Resistance:** Flixweed biotypes in Kansas winter wheat fields have been reported to be resistant to ALS-inhibitor herbicides (WSSA Group 2).

**Tansy Mustard (Descurainia pinnata)**
Tansy mustard (Figure 39.21) is a native winter annual that germinates from seeds in the fall or spring.

**Plant Description:** The leaves are finely divided and pinnately compound, greener in color than flixweed. Juvenile plants have ovate-shaped leaves in a rosette arrangement, deeply lobed margins, and leaf surface has a gray to whitish pubescence. Flower petals are very small and yellow or greenish-yellow. It blooms earlier than flixweed. The fruits (pods) of tansy mustard are siliques. Tansy mustard and flixweed can be distinguished by examining the seed and seedpods. Tansy mustard seeds are ½-inch long and arranged in two rows along the pod, whereas flixweed seeds are 1- to 1½-inches long and are arranged in a single row.

**Areas of Infestation and Yield Loss Potential:** Dry, disturbed sites. Tansy mustard impact on corn yields is not known, and herbicides are most effective if they are applied prior to the plant bolting.

**Herbicide Resistance:** Herbicide resistance has not been reported.

**Shepherds Purse (Capsella bursa-pastoris)**
Shepherds Purse (Figure 39.22) is a winter annual that germinates from seeds in fall or spring.

**Plant Description:** The basal leaves are in a rosette and deeply lobed, and could be confused with dandelion. The seed stalk, when bolting, has narrow, alternate leaves that wrap around the stem and have irregular margins. The stem can be up to 1.5 ft tall with branches near the top. It has small white flowers and the seedpod is a silicle that is flat and triangular.

**Area of Infestation and Yield Loss Potential:** The
impact of sheperdspurse on corn yields is unknown and it can be controlled by a wide variety of herbicides if applied before bolting.

**Herbicide Resistance:** There are biotypes that are resistant to ALS-inhibitor herbicides (WSSA Group 2) and Photosystem II inhibitors (WSSA Group 5) (e.g., metribuzin) herbicides.

**Field pennycress (Thalaspis arvense)**
Field pennycress (Figure 39.23) is an erect winter annual that may germinate from seeds in the fall or spring.

**Plant Description:** The cotyledons are oval or oblong. The young plant is a basal rosette (growth habit resembling a dandelion), and stem elongation occurs during flower development. Young leaves are generally oval and without hair. Leaves on the elongated stem become more narrow and lancelike toward the top of the plant, but all have a toothed margin. Seeds are in silicles, which have the penny-shaped appearance, giving the plant its common name.

**Areas of Infestation and Yield Loss Potential:** This plant is often found in disturbed sites. This plant may not reduce yield but may cause problems during harvest or result in dockage due to off flavor of grain. This plant is being considered as an alternative oilseed crop, so fields are being planted to this species.

**Herbicide Resistance:** Biotypes have been found to be resistant to ALS-inhibitor herbicides (WSSA Group 2).

**Horseweed (Conyza canadensis)**
Horseweed (Figure 39.24) may overwinter as a rosette and bolt in the spring or emerge in the spring at or before corn planting.

**Plant Description:** This winter or summer annual reproduces from seed, and it has numerous linear, hairy (although some plants have few or no hairs) leaves crowded on the stem. The plant has numerous dotlike glands that secrete terpenes, releasing an unpleasant odor when the plant is crushed or cut. Typically the stem below the inflorescence is unbranched unless injured. Plants can grow up to 5 ft tall. The flowers are very small and are generally white. Seed is dispersed by wind with seeds having small white bristles (pappus). The plant can tolerate drought conditions.

**Areas of Infestation and Yield Loss Potential:** This plant generally has populations that are less than the economic threshold, however, high densities in row crops have been reported to cause > 80% yield loss.

**Herbicide Resistance:** There are biotypes resistant to Photosystem II inhibitors (WSSA Group 5) (atrazine), glyphosate (WSSA Group 9), ALS-inhibitors (WSSA Group 2), and cell-membrane disruptor (paraquat).
(WSSA Group 22) herbicides. Rotating herbicides or other control methods is necessary to minimize selection of herbicide resistant biotypes.

**Black medic (Medicago lupulina)**
Black medic (Figure 39.25) is a winter or summer annual that reproduces from seed.

**Plant Description:** This plant has a prostrate growth habit with multiple branches radiating from a central taproot forming a mat. The leaves are compound having 3 leaflets with sharply toothed margins and prominent veins. Small yellow flowers form dense heads at the stem ends. A single large seed develops in each flower. This weed seldom has a high enough density to warrant control and it has been suggested as a possible cover crop.

**Areas of Infestation and Yield Loss Potential:**
If uncontrolled early, moderate to high densities can result in significant yield loss. This plant can outcompete corn for nitrogen early in the season. This weed typically has been sparse in fields.

**Herbicide Resistance:** Biotypes have been reported that are resistant to Photosystem II inhibitors (atrazine) (WSSA Group 5), as well as, glyphosate (WSSA Group 9), ALS-inhibitors (WSSA Group 2), and cell-membrane disruptor (paraquat) (WSSA Group 22) herbicides. Rotating herbicides or other control methods is necessary to minimize selection of herbicide resistant biotypes.

**Low-growing or Vinelike Annual Broadleaf Weeds**

**Prostrate knotweed (Polygonum aviculare)**
Prostrate knotweed (Figure 39.26) is an annual plant reproducing from seeds that germinate early in the spring at or before corn planting.

**Plant Description:** Plants grow near flat to the ground and form a mat from a central taproot. Leaves are small, alternate and often covered with white mildew. Flowers are in the leaf axil, with 3 to 6 flowers per axil. This plant is a member of the buckwheat (Polygonum) family, so there is a papery brown or tan sheath (ocrea) at the nodes. There are other plants similar to prostrate knotweed, including erect knotweed (P. erectum), which tends to be more upright, and common knotweed (P. arenastrum), which as 1 to 3 flowers per leaf axil.

**Areas of Infestation and Yield Loss Potential:** This plant can grow in compacted, dry, salty soils. Historically, this weed has seldom been dense enough to warrant control. However, mats of the plant can cause problems.

**Herbicide Resistance:** There are European biotypes that are resistant to photosystem II inhibitors (atrazine) (WSSA Group 5). Plants in the Polygonum family are difficult to control with synthetic auxin herbicides (2,4-D) (WSSA Group 4).
**Spotted spurge (Euphorbia maculata)**
Spotted spurge (Figure 39.27) is an annual plant that germinates from seeds in the spring at or before corn planting.

**Plant Description:** Similar to knotweed, spotted spurge grows as a mat to cover the ground. Stems are pink and covered with hair and leaves are small and opposite, with some having a distinct purple spot in the leaf center. Flowers are in the leaf axil, and seeds are borne in a three-parted seedpod. This plant contains a sticky, milky white sap that is exuded when the stems are cut.

**Areas of Infestation and Yield Loss Potential:** This weed has seldom been dense enough to warrant control. However, mats of the plant can cause problems.

**Herbicide Resistance:** Herbicide resistance has not been reported, although due to the milky sap, glyphosate (WSSA Group 9) may provide poor control.

**Prostrate pigweed (Amaranthus blitoides)**
Prostrate pigweed (Figure 39.28) is annual plant that has seeds that germinate in early spring at or before corn planting.

**Plant Description:** Similar to knotweed and spotted spurge, it grows as a mat to cover the ground. This plant has pink stems that, unlike spotted spurge, do NOT contain milky juice. Stems are pink, sparsely hairy, and leaves are oblong and alternate. Small flower clusters are produced in the leaf axil. Shiny black seeds can be shaken from the plant.

**Areas of Infestation and Yield Loss Potential:** This weed has seldom been dense enough to warrant control. However, the plant mats can cause problems.

**Herbicide Resistance:** Biotypes of prostrate pigweed have been reported to be resistant to ALS-inhibitor (WSSA Group 2) and Photosystem II inhibitors (WSSA Group 5) herbicides.

**Common purslane (Portulaca oleracea)**
Common purslane (Figure 39.29) is an annual with seeds that germinate in the spring at or before corn planting.

**Plant Description:** Common purslane has pink stems that are fleshy and leaves are succulent. These plants are drought-resistant and grow best in hot, dry conditions. The plants can tolerate heavy metal stress and have been used in the past for phytoremediation of contaminated soils.

**Areas of Infestation and Yield Loss Potential:** Common purslane is considered a non-target weed that can grow in a variety of agricultural settings. It does not have a significant impact on crop yields when present in low densities. However, its presence can be managed by cultural practices such as early planting and crop rotation to reduce seed bank levels.
weather. These plants grow as a mat to cover the ground and can re-root from stems following disturbance. Stems are pink, leaves are oblong and alternate, but clustered at the ends of branched stems. Small yellow flowers are produced in the leaf axil. Very tiny, shiny black seeds can be shaken from the plant.

**Areas of Infestation and Yield Loss Potential:** This weed has seldom been dense enough to warrant control. However, mats of the plant can cause problems.

**Herbicide Resistance:** Biotypes of common purslane have been reported to be resistant Photosystem II inhibitors (WSSA Group 5).

**Wild buckwheat (Polygonum convolvulus)**
Wild buckwheat (Figure 39.30) is an annual vining broadleaf with seeds that germinate at or prior to corn seeding. However, depending on soil temperatures and moisture, seeds can also germinate later.

**Plant Description:** Wild buckwheat is a member of the buckwheat (Polygonum) family. This plant has an ocrea (white to brown sheath) that is located at the base of the leaf on the stem. This plant is often confused with the perennial field bindweed (Figure 39.10) and is known as black bindweed in some areas. Triangular seeds, the ocrea, very small flowers, leaf shape, and root structure all help distinguish wild buckwheat from field bindweed.

**Areas of Infestation and Yield Loss Potential:** Wet areas of fields are more likely to have infestations. At low densities, wild buckwheat may not reduce corn yields. However, at high densities, yield losses can be as high as 30%. The vines twining up cornstalks may become tangled in harvest equipment. If mixed with corn grain, the high water content of wild buckwheat seeds may cause spoilage in stored grain.

**Herbicide Resistance:** Biotypes can be resistant to ALS-inhibitor (WSSA Group 2) and Photosystem II inhibitors (WSSA Group 5), and it is difficult to control with either glyphosate (WSSA Group 9) or 2,4-D (synthetic auxin herbicides) (WSSA Group 4).

**Tall morning glory (Ipomoea purpurea)**
Tall morning glory (Figure 39.31) is an annual, vining plant that has seeds that germinate at or just after corn planting. This plant can also reproduce from rhizomes.

**Plant Description:** Tall morning glory has heart-shaped leaves with entire margins. The stems have erect hairs and can climb up a plant. The flowers are large, funnel-shaped, and can be purple, blue, white, or red. This plant has been used as an ornamental but can escape into crop fields.

**Areas of Infestation and Yield Loss Potential:** Tall morning glory grows best in moist places. Buried seed can stay viable for a long time. It is important to
control as a seedling before the plant twines up the crop. This plant is not as aggressive as field bindweed, although the vines can reach 16 ft in length and may cause problems during harvest.

**Herbicide Resistance:** To date, herbicide resistance has not been reported.

**Broadleaf Annuals with an Erect (upright) Growth Habit**

*Palmer amaranth (Amaranthus palmeri)*

In South Dakota, Palmer amaranth (Figures 39.32 and 39.33) is an annual plant that is a new invasive weed. It is thought that the seeds will germinate late in the season after corn emergence. HOWEVER, this is unsubstantiated.

**Plant Description:** The first true leaves of seedlings are more linear than cotyledons of waterhemp, and the leaf surfaces are not hairy. Palmer amaranth has male and female plants and can grow up to 10 ft tall. The inflorescence of the female plant (Figure 39.34) is more highly branched and has more spines than the male. The female plant has been reported to produce over 1 million shiny black seeds.

**Areas of Infestation and Yield Loss Potential:** This plant is often found in fertilized, disturbed areas. The impact of Palmer amaranth in South Dakota is unknown. However, it is VERY aggressive in Southern states with yield losses of 100% reported.

**Herbicide Resistance:** Biotypes of this plant have been reported to be resistant to 5 different herbicide types in Southern regions and may have multiple resistances to two or more herbicides in the same plant. These include ALS-inhibitor (WSSA Group 2) and Photosystem II inhibitors (WSSA Group 5), glyphosate (WSSA Group 9), and PPO type (WSSA Group 14) herbicides.

*Redroot pigweed (Amaranthus retroflexus)*

Redroot pigweed (Figure 39.35) is an annual plant with seeds that germinate at or during corn planting.

**Plant Description:** The cotyledons are thin and linear, and the leaves are lancelike with alternate arrangement. The lower surface is hairy. Stems are stout and the lower portion is reddish (hence the name redroot). The plant is monoecious, with a single plant having both male and female flowers present. Seeds are black, shiny, and numerous with a large plant producing over 800,000 seeds per plant. Plants may hybridize with other Amaranthus species.

**Areas of Infestation and Yield Loss Potential:** This plant typically is found in disturbed areas usually with high fertility. Depending on weed density, yield losses as high a 55% have been reported.
Herbicide Resistance: Redroot pigweed biotypes have been shown to be resistant to Photosystem II inhibitors (WSSA Group 5) and ALS-inhibitor (WSSA Group 2) herbicides.

**Common waterhemp (Amaranthus rudis)**
Common waterhemp (Figure 39.36) is an annual plant that has seeds that germinate late in the season after corn emergence.

**Plant Description:** The first true leaves of seedlings are more lancelike (narrow) than the oval (egg-shaped) leaves as 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. The female plant has been reported to produce over 1 million shiny black seeds.

**Areas of Infestation and Yield Loss Potential:** This plant is often found in disturbed areas with high fertility. Depending on density yield losses of up to 55% have been reported.

**Herbicide Resistance:** Biotypes of this plant have been reported to be resistant to ALS-inhibitor (WSSA Group 2) and Photosystem II inhibitors (WSSA Group 5), glyphosate (WSSA Group 9), and PPO (WSSA Group 14) type herbicides.

**Toothed Spurge (Euphorbia dentata)**
Toothed spurge (Figure 39.37) is an annual plant that has seeds that germinate after corn emergence.

**Plant Description:** The leaves are opposite, blades ovate or lancelike, leaf tip sharply pointed. Short hairs are on upper and lower leaf surfaces. Stems have short bristly hairs, erect, and when cut, exude sticky, milky juice. Flowers are in terminal clusters, green, with seeds borne in capsules.

**Areas of Infestation and Yield Loss Potential:** The yield loss potential is unknown, however, the milky sap can cause problems with harvest.

**Herbicide Resistance:** Herbicide resistance has not been reported at this time. Due to the milky sap in the plant, toothed spurge is not well controlled with glyphosate.

**Volunteer Soybean**
Volunteer soybean is an annual plant that has seeds that can germinate after corn emergence. The plants look like the crop soybean but are growing from seed from previous crops. High densities can reduce corn yields 20% to 30%.

**Herbicide Resistance:** The volunteer soybean herbicide resistance will depend on the stacked traits from previous plantings, including glyphosate (WSSA Group 9) and, when available, synthetic auxin herbicides.
(WSSA Group 4).

**Smartweed sp. (Pennsylvania smartweed and Ladysthumb)** (**Polygonum sp.**)

Smartweed sp. (Figure 39.38) is a native, annual plant that has seeds that germinate prior to seeding corn.

**Plant Description:** This plant has a linear- to oar-shaped cotyledon, and the leaves are alternate in arrangement with the leaf surface smooth to slightly hairy. Nodes on the stem are swollen (jointed) with a papery sheath at each node (ocrea). Flowers are pink and the inflorescence type is a raceme.

**Areas of Infestation and Yield Loss Potential:** This plant is adapted to the wetter areas of a field. Smartweeds can reduce yield 15% at high densities.

**Herbicide Resistance:** Smartweed biotypes have been reported to be resistant to Photosystem II inhibitors herbicides (WSSA Group 5).

**Giant Ragweed** (**Ambrosia trifida**)

Giant ragweed (Figure 39.39) is an annual plant with seeds that first germinate when corn is being planted. Germination can continue if the temperatures remain cool.

**Plant Description:** The cotyledons are spatulate (spoon-shaped) and the leaves are opposite and divided into 3 to 5 lobes. The stems are erect, branched, and can grow to almost 6 ft tall under favorable conditions. The flowers are nonshowy and without petals.

**Areas of Infestation and Yield Loss Potential:** Giant ragweed is often found in disturbed sites with moist soil. If not controlled, early emerging plants at densities of 0.5 plants/ft\(^2\) can reduce corn yield up to 40%.

**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.

**Common Ragweed** (**Ambrosia artemisiifolia**)

Common ragweed (Figure 39.40) is an annual plant with seeds that germinate when corn is seeded.
**Plant Description:** This plant has cotyledons that are spatulate (spoon-shaped), and leaves that are opposite in the lower stem and alternate on the upper stem. The leaves are finely divided. The stems are erect, branched, and grow to 1 to 2 ft. The flowers are nonshowy and without petals.

**Areas of Infestation and Yield Loss Potential:** This weed is typically found in disturbed sites. At moderate densities, it can reduce corn yields by 10%. At high densities yield losses can be severe (> 50%).

**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)**
Velvetleaf (Figure 39.41) is an annual plant with seeds that germinate shortly after corn seeding.

**Plant Description:** The seedlings have round cotyledons and alternate, heart-shaped leaves. Leaves are covered with soft hairs giving it a “velvet” feel. The plant can reach 6 ft in height.

**Areas of Infestation and Yield Loss Potential:** This plant is often found in crop production fields and roadsides. In moderate infestations (1-2 plants/ft²), 20% corn yield reductions have been reported.

**Herbicide Resistance:** Biotypes in Minnesota and other areas have been reported to be resistant to Photosystem II inhibitors (WSSA Group 5) herbicides.

**Black nightshade (Solanum ptychanthum)**
Black nightshade (Figure 39.42) is an annual plant with seeds that germinate when corn is emerging.

**Plant Description:** The 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. Leaves are often holey because of flea beetle feeding. Flowers are white to bluish. Seeds are in berries with 50 to 100 seeds per berry. The juice of the berry stains seeds and reduces crop value.

**Areas of Infestation and Yield Loss Potential:** This plant can often be found in disturbed sites. With high to moderate infestations (> 1 plant/ft²) yield losses can be 80%. Juice of berries also mixes with chaff and this combination can plug combines.
**Herbicide Resistance:** Black nightshade biotypes have been reported to be resistant to ALS-inhibitor (WSSA Group 2) and Photosystem II inhibitors (WSSA Group 5), as well as cell-membrane disruptor (paraquat) (WSSA Group 22) herbicides.

**Venice mallow (Hibiscus trionum)**

Venice mallow (Figure 39.43) is an annual plant with seeds that typically germinate after corn emergence.

**Plant Description:** The cotyledons of the seedlings are round and the leaves are alternate with 3 to 7 distinct lobes. The leaf surface has hairs and the flowers are white to pale yellow. Fruits are an inflated capsule.

**Areas of Infestation and Yield Loss Potential:** This plant can often be found in disturbed sites and it is drought-tolerant and can grow in gravelly and acid soils. Corn yield losses are generally < 5% with moderate infestations, although season-long competition can increase this loss.

**Herbicide Resistance:** As of 2015, herbicide resistance has not been reported.

**Buffalobur (Solanum rostratum)**

Buffalobur (Figure 39.44) is an annual plant where the seeds typically germinate after corn emergence.

**Plant Description:** The first true leaves of seedlings are lance-shaped and the leaves are many-lobed, and alternate along the stem. Leaf surfaces and stems are spiny with long yellow spines. Spiny capsules hold the fruit.

**Areas of Infestation and Yield Loss Potential:** Buffalobur thrives in well-drained, disturbed soils. Depending on density and emergence date, yield losses are generally low to moderate.

**Herbicide Resistance:** As of 2015, herbicide resistance has not been reported.

**Common sunflower (Helianthus annuus)**

Common sunflower (Figure 39.45) is an annual plant and has seeds that germinate during or shortly after corn planting.

**Plant Description:** The plant cotyledons are oval with toothed-shaped margins on alternating leaves. The stems become multi-branched and covered with stiff hairs as the plant matures, and also has characteristic yellow flowers. This plant may be confused with Jerusalem artichoke, a perennial (Figure 39.9).
Common sunflower will not have creeping rhizomes.

**Areas of Infestation and Yield Loss Potential:** Infestations typically occur in drier soils. At moderate densities, this plant can reduce corn yields 70%.

**Herbicide Resistance:** Some biotypes of common sunflower are resistant to ALS-inhibitor (WSSA Group 2) herbicides.

**Common Cocklebur (Xanthium strumarium)**
Common cocklebur (Figure 39.46) is an annual plant with seeds that germinate after corn seeding.

**Plant Description:** The cotyledons of the seedlings are linear, thick, and shiny green. Leaves are alternate and large with wavy margins. Seeds are in burs that stick to animal coats.

**Areas of Infestation and Yield Loss Potential:** This plant can often be found in wet, poorly drained soils. At high densities, it can reduce yields 70%.

**Herbicide Resistance:** Biotypes of cocklebur have been reported to be resistant to ALS-inhibitor (WSSA Group 2) herbicides in some Midwestern states.

**Russian thistle (Salsola tragus)**
Russian thistle (Figure 39.47) is an annual plant that typically emerges before or at corn planting.

**Plant Description:** The seedlings resemble small pine trees with threadlike leaves. Older plants become spikelike with the leaf surface from smooth to hairy with nonshowy flowers. The entire plant breaks off at the base and disperses seed as it tumbles in the wind.

**Areas of Infestation and Yield Loss Potential:** This very drought- and salt-tolerant plant can be found in many areas. Depending on density and time of emergence, this plant can reduce corn yields 50%. If Russian thistle comes up even 1 week after the crop, yield losses may not be measurable.

**Herbicide Resistance:** Biotypes have been reported to be resistant to ALS-inhibitor (WSSA Group 2) herbicides.

**Common lambsquarters (Chenopodium album)**
Common lambsquarters (Figure 39.48) is an annual plant and it has seeds that generally germinate at or slightly before corn planting.

**Plant Description:** Emerging plants are very small, and the 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 ft tall under certain conditions. The flowers are nonshowy and without petals.
Areas of Infestation and Yield Loss Potential: Found in disturbed sites. Depending on density yield losses can be 30%.

Herbicide Resistance: Biotypes of this plant have been reported to be resistant to ALS-inhibitor (WSSA Group 2) and Photosystem II inhibitors (WSSA Group 5). Reduced sensitivity to glyphosate (WSSA Group 9) has been reported in some populations.

**Kochia (Kochia scoparia)**

Kochia (Figure 39.49) is an annual plant that reproduces from seeds. Kochia emerges at or before corn planting.

Plant Description: Seedlings can be very small with over 1000 present in a 1-ft² area. Leaf margins are fringed with hair. Leaf surfaces range from being without hairs to very hairy. Wind-blown plants will disburse seed in the fall.

Areas of Infestation and Yield Loss Potential: Kochia is often found in disturbed sites. Depending on density, yield losses can be 40%.

Herbicide Resistance: Some kochia biotypes in South Dakota have been reported to be resistant to Photosystem II inhibitors (atrazine) (WSSA Group 5), ALS-inhibitors (WSSA Group 2), and synthetic auxin herbicides (WSSA Group 4).

**Wild Mustard (Sinapsis arvensis syn. Brassica kaber)**

Wild mustard (Figure 39.50) is an erect annual plant with seeds that germinate before or at corn planting.

Plant Description: The cotyledons are kidney-shaped, and the leaves are alternate with hairs on the bottom of the leaf. Lower leaves are deeply lobed, whereas upper leaves are coarsely toothed. Flowers are yellow and seeds are found in a thin pod, known as a silique.

Areas of Infestation and Yield Loss Potential: This plant is often found in disturbed sites. Yield losses are dependent on density. For example, 1 and 4 plants/ft² can reduce yield 10% and 50%, respectively.

Herbicide Resistance: Biotypes have been found to be resistant to ALS-inhibitor (WSSA Group 2) herbicides.
Other Weeds

South Dakota Noxious Weeds

There are seven weeds presently on the South Dakota Noxious Weed list, http://www.weedcenter.org/store/docs/outreach/sd-weeds.pdf. All seven weeds are perennial, non-native plants that are considered highly invasive and destructive to human or animal health, or agriculture. The South Dakota Noxious Weeds are listed below.

<table>
<thead>
<tr>
<th>Noxious Weeds of South Dakota (2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant</td>
</tr>
<tr>
<td>Canada thistle</td>
</tr>
<tr>
<td>Leafy spurge</td>
</tr>
<tr>
<td>Perennial sowthistle</td>
</tr>
<tr>
<td>Hoary cress</td>
</tr>
<tr>
<td>Purple loosestrife</td>
</tr>
<tr>
<td>Saltcedar</td>
</tr>
<tr>
<td>Russian knapweed</td>
</tr>
</tbody>
</table>

There are many weeds in the state that have been listed as Local (County) Noxious Weeds. These plants can be annual, biennial, or perennial. Before the plant can be placed on the local (county) noxious weed list, the county has to petition the South Dakota State Weed and Pest Board. If approved for listing, the plant remains on the list for a maximum of 5 years.

Saltcedar (Tamarix sp)

Saltcedar (Figure 39.51) was introduced into the United States in the 1820s for ornamental and windbreak purposes. This perennial shrub or small tree reproduces from seeds, root sprouts, and buried stems.

*Plant Description:* The leaves are alternate and scalelike, blue-green to gray-green. Stems are erect or bushy, and can be up to 20 ft tall. Flowers are pink arranged on a raceme inflorescence. Millions of seeds can be produced per plant. Flowering can start in early April and continue through September.

*Areas of Infestation:* Often found in wet, disturbed sites, with the first infestations seen along the outside of potholes or along riverbanks. When the plants continue to invade, the infestation can be found in drier sites in very dense stands. Saltcedar is difficult to control. This plant has been found in western and southern South Dakota along rivers and streams and a few eastern South Dakota sites along lakes shores.

Leafy Spurge (Euphorbia esula)

Leafy spurge (Figure 39.52) is a perennial, erect plant reproducing by seed, crown buds, and rhizomes.

*Plant Description:* The leaves are alternate and narrow. Stems are erect up to 2.5 ft tall, branched.
above and without hair. When cut, stems exude a milky latex. Creeping rhizomes can extend about 10 ft from the original plant and have many buds on the lateral root. Flowers are greenish-yellow in small clusters. Seeds are in capsules that can split when ripe and shoot seed up to 20 ft. Flowering can start in May and continue through September.

Areas of Infestation: Often found in disturbed sites in very dense stands and the plant is difficult to control. Pasture areas of eastern South Dakota both north and south have dense leafy spurge infestations. Scattered plants can be found along roadsides.

**Purple Loosestrife (Lythrum salicaria)**

Purple loosestrife (Figure 39.53) is a perennial, erect plant, reproducing by seed and rhizomes. This plant is an escaped ornamental.

Plant Description: The stems are erect, not highly branched, four-angled, and hairless. Leaves are opposite or in whorls. Leaf blades are lanceolate with sharply pointed tips. Leaves have no petioles (leaves are attached to the stem) and leaves are covered with hairs. Crown buds and short creeping rhizomes. Flowers are purple and arranged on spikes. Flowering can start in July and continue through September.

Areas of Infestation: Often infestations start in very wet sites, but can then invade drier areas. The stands are too dense for waterfowl nesting and wet areas go dry because of this infestation. It spreads rapidly and is aggressive. This plant can be found along the shores and sandbars in the Missouri River. The eastern South Dakota pothole region may be highly vulnerable to invasion. The plant is difficult to control even with biocontrol agents that have been released in some areas.

**Russian knapweed (Centaurea repens)**

Russian knapweed (Figure 39.54) is a perennial, erect plant, reproducing by seed and rhizomes. Do not hand-pull as plant contains toxins that cause problems. Horses that eat this plant may get “chewing disease” from toxins in the plant.

Plant Description: Russian knapweed stems are erect, sparsely hairy, forming dense colonies. The plant has creeping rhizomes that produce adventitious shoots. Leaves are alternate with lower leaves lobed and upper leaves linear. Inflorescence type is a head with flowers that are pink to purple and numerous. Flowering can start in June and continue through September.

Areas of Infestation: Often found in disturbed sites in very dense stands and the plant is difficult to control. This plant has the greatest acres of infestation in Hutchinson County with scattered reports in other eastern and western South Dakota counties.
Hoary cress (Cardaria draba) is a perennial, erect plant, reproducing by seed and rhizomes.

**Plant Description:** Hoary cress leaves, which clasp the stem, are alternate with lower leaves oblanceolate and upper leaves more lance-shaped. Stems are erect, sparsely hairy. Creeping rhizomes that can extend about 10 ft from the original plant. Flowers are white on corymbs of numerous racemes. Flowering can start in early April and continue through August.

**Areas of Infestation:** Often found in disturbed sites in very dense stands. The plant is difficult to control once established. The plant is found in scattered infestations throughout western South Dakota with the highest infested areas reported in Butte County.

**References and Additional Information**

**Figure 39.55 Hoary cress plants with rhizomes and infestation.** (Courtesy Steve Dewey, Utah State University, Bugwood.org)
Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.


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(1) mail: U.S. Department of Agriculture
    Office of the Assistant Secretary for Civil Rights
    1400 Independence Avenue, SW
    Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov;

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There are many grass or grasslike weeds that reduce corn yields. The purpose of this chapter is to provide estimates on how different weeds reduce corn yields, information on expected emergence time, and guidelines for identifying important grass or grasslike weeds. Selected characteristics of grass and grasslike weeds are provided in Table 40.1. Current chemical weed management options can be found online at iGrow.org, http://igrow.org/agronomy/.

**Herbicide Use Disclaimer**

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 not compliant 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 chemical accidents and spills, back siphoning, mixing, and applying away from water sources. Herbicide applicators are responsible for following all herbicide label directions and precautions.

**Volunteer corn (Zea mays)**

Volunteer corn is an annual plant that typically emerges just before or just after corn planting depending on soil temperature and moisture conditions. The plants are from seed or from previous crops.

Plant Description: Looks like hybrid corn but is outside the row or in clumps if corn ears are present. Problems are heightened by corn monoculture systems or when herbicide-resistant varieties were planted in previous years.

Areas of Infestation and Yield-loss Potential: Volunteer corn typically is scattered throughout past year’s cornfields. Volunteer corn actually increases corn yield if ears develop. If no ears develop, then 15% to 20% yield loss may occur. The problem is that corn grain from volunteer corn may be of poor quality or wetter than hybrid corn.

Cultural Management: Use techniques that minimize harvest loss discussed in Chapter 36. If a glyphosate-tolerant (WSSA Group 9) or glufosinate-tolerant (WSSA Group 10) variety was planted, rotate to a broadleaf crop and use a grass herbicide and cultivate interrow areas. If a sethoxydim-tolerant (ACCase inhibitor, WSSA Group 1) variety was planted, use glyphosate or glufosinate for control because ACCase inhibitors may not control these volunteer plants.
Table 40.1 Timing of weed emergence and yield-loss potential of the selected grass and grasslike weeds. Information on herbicide-resistant weeds is available in Chapter 43.

<table>
<thead>
<tr>
<th>Time of emergence</th>
<th>Weed</th>
<th>Yield-loss potential</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early season</td>
<td>Volunteer corn</td>
<td>Low to moderate</td>
<td>May be resistant to several herbicides depending on the hybrid used in past years.</td>
</tr>
<tr>
<td>Early to midseason</td>
<td>Woolly cupgrass</td>
<td>Moderate</td>
<td>Postemergence grass herbicide provides good control, and not controlled by most preemergent grass herbicides.</td>
</tr>
<tr>
<td>Early season</td>
<td>Jointed goatgrass</td>
<td>Unknown</td>
<td>Can be troublesome after wheat crop. May germinate as a winter annual in October.</td>
</tr>
<tr>
<td>Early season</td>
<td>Foxtail barley</td>
<td>Moderate</td>
<td>No resistance reported.</td>
</tr>
<tr>
<td>Early season</td>
<td>Downy brome</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Early season</td>
<td>Japanese brome</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Early season</td>
<td>Quackgrass</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Early season</td>
<td>Giant foxtail</td>
<td>Moderate</td>
<td>May be resistant to ACCase inhibitors (WSSA Group 1, e.g., sethoxydim), ALS inhibitors (WSSA Group 2, e.g., sulfonylureas/imidazolinones), microtubule assembly inhibitor (WSSA Group 3, e.g., trifluralin), and Photosystem II inhibitors (WSSA Group 5, e.g., atrazine).</td>
</tr>
<tr>
<td>Early season</td>
<td>Yellow foxtail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early season</td>
<td>Green foxtail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midseason</td>
<td>Robust green foxtail</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Midseason</td>
<td>Bristly foxtail</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Midseason</td>
<td>Yellow nutedge</td>
<td>Low</td>
<td>Found in wet areas but can spread to drier sites. Reproduces from nutlets that can be spread through cultivation.</td>
</tr>
<tr>
<td>Midseason</td>
<td>Stinkgrass</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Midseason</td>
<td>Shattercane</td>
<td>Unknown</td>
<td></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 ACCase inhibitors (WSSA Group 1, e.g., sethoxydim) and Photosystem II inhibitors (WSSA Group 5, e.g., atrazine).</td>
</tr>
<tr>
<td>Late season</td>
<td>Large crabgrass</td>
<td>Low</td>
<td>May be resistant to ACCase 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., atrazine).</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>Switchgrass</td>
<td>Unknown</td>
<td>Found in CRP fields or field edges that bordered CRP.</td>
</tr>
<tr>
<td>Late season</td>
<td>Scouring rush Field horsetail</td>
<td>Low</td>
<td>No resistance reported, although difficult to control; found in areas that may have been flooded or very wet.</td>
</tr>
</tbody>
</table>

aHigh yield-loss potential = > 5% yield loss with 1 plant or fewer per foot of row
Moderate yield-loss potential = > 5% yield loss when plant density is 5 to 10 plants per foot of row
Low yield-loss potential = > 5% yield loss when plant density is > 10 plants per foot of row
Herbicide Resistance: Hybrid dependent based on transgenic traits; glyphosate (Roundup Ready® varieties), glufosinate (LibertyLink® varieties), or sethoxydim (WSSA Group 1).

Woolly cupgrass (*Eriochloa villosa*)
Woolly cupgrass (Figure 40.1) is an annual that reproduces by seed and emerges before or just after corn planting. Germination may occur over an 8- to 10-week period from cold or warm soil, under dry or wet conditions, and due to large seeds, can germinate from up to 6” deep. While the seed does not need light to stimulate emergence, if the crop canopy is opened due to hail or other factors, woolly cupgrass will emerge if seed is present.

**Plant Description:** The cotyledon (seed leaf) and first true leaf are very wide. Leaves are covered in fine soft hair (hence the name woolly). One of the leaf margins on each leaf generally is crinkled. This plant is often confused with foxtail grass species, but typically does not tiller as much as a foxtail. The seed head of woolly cupgrass is a distinctive panicle with compressed rows of seed that are only on one side of the rachis (the stem of the plant that bears the flowers and seeds). The seeds are oval and vary in color from tan to brown to green. Seeds in the soil can remain viable for up to 5 years.

**Areas of Infestation and Yield-loss Potential:** Woolly cupgrass is found in fertile loam to clay loam soils. If uncontrolled, low to moderate densities can cause up to 50% yield loss in corn. However, due to glyphosate (WSSA Group 9) or glufosinate (WSSA Group 10) applications, woolly cupgrass has become less of a problem. Tillage or rotary hoeing corn can be an effective cultural control. Rotating to soybean or alfalfa (with multiple cuttings) can also help reduce the infestation.

Herbicide Resistance: None has been reported although preemergent grass herbicides that act to inhibit very long-chain fatty acid synthesis (WSSA Group 15, e.g., acetamides) often do not provide adequate control.

**Jointed goatgrass** (*Aegilops cylindrica*)
Jointed goatgrass (Figure 40.2) emerges as a winter annual or in the spring before corn planting.

**Plant Description:** Jointed goatgrass is an annual, reproducing by seeds. This plant lacks auricles (small projection at the base of the leaf that wraps...
around the stem) at the leaf opening. Leaf blades are flat without hair or with short hairs. Leaf margins have hairs near the blade base. The leaf ligule (the appendage projecting from the inner side of the leaf) is membranous. The inflorescence (arrangement of flowers) is a compact spike. Seeds are cylindrical and about the same size as wheat.

**Areas of Infestation and Yield-loss Potential:** Found in many different types of soil along the roads and in pastures. This weed is problematic in wheat crops, but at this time, no information on corn yield loss is available. Deep tillage to bury seed is often an effective method for control of jointed goatgrass.

**Herbicide Resistance:** No reported resistance.

**Foxtail barley (Hordeum jubatum)**
Foxtail barley (Figure 40.3) is a cool-season perennial grass that emerges early in the season. Overwintering plants can start growth very early in the growing season and will produce a seed head by late-May or early-June. It is a clump grass, that does not spread widely, but seed will start new infestations.

**Plant Description:** The vegetative stems of foxtail barley are round and hairless. 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 (1/2 to 3”) awns that are often purplish in color.

**Areas of Infestation and Yield-loss Potential:** 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. Due to soil problems, corn growth may be poor and yields low in the area where this weed is growing. However, the yield reductions may not be primarily due to foxtail barley interference. Soil management to decrease water and salt problems in infested areas may be warranted. The areas may be too saline to produce corn.

**Herbicide Resistance:** No known resistance.

**Downy brome (Bromus tectorum)**
Downy brome (Figure 40.4) is an annual plant, reproducing from seed that typically emerges in the fall or early spring.

**Plant Description:** Leaves and sheathes of downy brome plants have soft hairs. The ligule is a short membrane (~1/30” or 1 mm), rounded and may be toothed. The inflorescence is a drooping panicle with many branches. There are long awns on the seed. The plant dries early in the summer and can be a fire hazard. Typically occurs in localized areas.
Yield-loss Potential: Yield loss is undetermined for corn; however, this plant can cause high yield losses in wheat. Use cultural practices with crop rotation (if planting winter wheat, 3- to 4-year rotation before wheat is planted again is recommended), control preplant if possible using burn-down type applications prior to planting.

Herbicide Resistance: Biotypes in the U.S. have been reported to be resistant to ACCase inhibitors (WSSA Group 1), and ALS inhibitors (WSSA Group 2, e.g., imidazolizone and sulfonylurea). Around the world, other biotypes have been reported that are resistant to urea-type herbicides, and Photosystem II inhibitors (WSSA Group 5).

Japanese brome (Bromus japonicus)
Japanese brome (Figures 40.5 and 40.6) is a winter annual that germinates from seed in the late fall and remains vegetative until spring.

Plant Description: Leaf sheath is hairy while the blade is hairless. Short awns on the seed. More upright seed head than downy brome.

Areas of Infestation and Yield-loss Potential: Typically occurs in localized areas. Yield loss is undetermined in corn.

Herbicide Resistance: Biotypes in the U.S. have been found to be resistant to ALS inhibitors (WSSA Group 2).

Cheat (Rye Brome) (Bromus secalinus)
Cheat (Figure 40.7), an annual grass, typically emerges in the fall or early spring – before or just after corn planting depending on soil temperature and moisture conditions. Cheat initiates its reproductive growth in mid-March, flowers in May, and matures in early June.

Plant Description: The ligule of cheat is rounded and may be toothed. There are short awns on the seed. At the seedling stage, this plant is very similar in appearance to the closely related species downy brome, but cheat becomes less hairy as it matures.

Areas of Infestation and Yield-loss Potential: Typically occurs in localized areas, prefers dry soil conditions. Yield loss in corn is undetermined. Use cultural practices with crop rotation (if planting winter wheat, 3- to 4-year rotation is recommended before wheat is planted again). Control this plant using preplant herbicides if possible or use burn-down type applications.

Herbicide Resistance: Biotypes in the U.S. have been found to be resistant to herbicides with ALS inhibitor mode of action (WSSA Group 2).
Quackgrass (Elymus repens)
Quackgrass (Figure 40.8) is a perennial plant, which reproduces primarily through rhizomes and seed. It is a non-native, cool-season grass emerging before corn.

Plant Description: The leaf sheath is rough, flattened toward the collar without hair. The leaf blades are flat and either smooth without hairs or slightly hairy. The ligule is membranous and short (< 1/30” or 1mm), and auricles may be seen clasping the sheath. The seed head is slender. Rhizomes are extensive and sharply pointed.

Areas of Infestation and Yield-loss Potential: Found in moist soils. Yield losses are moderate, although if high densities occur with rhizomes present, yield losses can be high. Unfortunately, tillage will spread rhizomes and increase pockets of infestation.

Herbicide Resistance: No reported resistance.

Giant foxtail (Setaria faberii)
Giant foxtail (Figure 40.9), an annual reproducing by seed, emerges before or just at the time of corn planting when temperatures are warm. Seeds do not require a dormancy period and if seeds mature in midsummer, they can sprout in late summer or fall if temperatures and moisture are favorable.

Plant Description: Giant foxtail is infrequently found in South Dakota. The upper leaf surface is densely covered with short hairs and the plant has a hairy ligule. Giant foxtail has long (3 to 5”) nodding heads, whereas green, yellow, and bristly foxtails have straight panicles. Giant foxtail can grow up to 7 ft tall.

Areas of Infestation and Yield-loss Potential: Common in several soil types and in many climates. Yield losses are moderate to high. This foxtail is much more aggressive than green or yellow foxtails. Tillage and postemergence cultivation can be effective control measures. Solid-seeded legume or grass crops, or narrow-spaced row crops can provide an effective shade canopy to reduce giant foxtail growth.

Herbicide Resistance: Giant foxtail has been reported to be resistant to Photosystem II inhibitors (WSSA Group 5, e.g., atrazine), ALS inhibitors (WSSA Group 2, e.g., sulfonylureas and imidazolinones) and ACCCase inhibitors (WSSA Group 1, e.g., sethoxydim).

Yellow foxtail (Setaria pumila)
Yellow foxtail (Figures 40.10 and 40.11) is an annual plant, reproducing by seed, and emerges toward the end of corn planting.

Plant Description: Common in eastern South Dakota fields. Yellow foxtail has long yellow hairs near the
ligule, a flattened stem, and larger seeds than green or giant foxtails.

**Areas of Infestation and Yield-loss Potential:**
Common in several soil types and in many climates. Depending on density, corn yield losses can approach 50%. Tillage may control yellow foxtail.

**Herbicide Resistance:** Biotypes of these foxtails have shown resistance to a number of herbicides with different modes of action. Yellow foxtail has been reported to be resistant to ALS inhibitors (WSSA Group 2) and Photosystem II inhibitors, such as atrazine (WSSA Group 5). Yellow foxtail is more tolerant to labeled rates of atrazine when compared with giant or green foxtail.

**Green foxtail (Setaria viridis)**
Green foxtail (Figures 40.10 and 40.11) is an annual plant, reproducing from seed and emerging toward the end of corn planting. Typically, green foxtail will emerge before yellow foxtail.

**Plant Description:** Green foxtail has no or few hairs on the leaf blade, a round stem, and seeds are small.

**Areas of Infestation and Yield-loss Potential:**
Common in several soil types and many climatic regions. Depending on density, corn yield losses can approach 50%. Tillage, crop rotation, and postemergence cultivation may be effective control measures.

**Herbicide Resistance:** Biotypes of these foxtails have shown resistance to a number of herbicides with different modes of action. Green foxtail has been reported to be resistant to microtubule assembly inhibitors [dinitroanaline (trifluralin)] (WSSA Group 3), ALS inhibitors (WSSA Group 2), ACCase inhibitors (WSSA Group 1), very long-chain fatty acid inhibitors (acetamide) (WSSA Group 15) and Photosystem II inhibitors (WSSA Group 5).

**Bristly foxtail (Setaria verticillata)**
This warm-season annual grass emerges after corn emergence, usually at the same time as yellow foxtail.

**Plant Description:** Bristly foxtail (Figure 40.12) can have a height of 1 to 4 feet with branching stems that bend sharply upward and without hair. The ligule has a fringe of hairs from a membranous base. Inflorescence is panicle, cylindrical, and spikelike. Bristles within the inflorescence and seed adhere to animals and clothing and can be identified from other foxtails by firmly touching the inflorescence to determine whether it lightly sticks to the skin.

**Areas of Infestation and Yield-loss Potential:** Bristly foxtail is found in waste places, gardens, and cultivated fields in the central and eastern Great Plains. No yield-loss data for corn is available. Tillage, crop rotation, and postemergence cultivation may be effective control measures to reduce stand numbers.
**Herbicide Resistance:** No cases of resistance reported in North America.

**Yellow nutsedge (Cyperus esculentus)**

Yellow nutsedge (Figures 40.13 and 40.14) is a perennial plant that will emerge before or at planting.

**Plant Description:** Yellow nutsedge is a non-native plant that reproduces by seeds, rhizomes, and tubers (nutlets). This plant has erect, triangular stems without hair that appear waxy. The leaves are grasslike-looking blades, pale green without hair. The seed heads are compact.

**Areas of Infestation and Yield-loss Potential:** Found by streams and wet areas in fields. Yield-loss potential is low, however, because of the habitat; corn yield may be low due to wet conditions and not due to competition with yellow nutsedge. Adequate water drainage to wet parts of the field may reduce yellow nutsedge problems. Chemical control is limited, but glyphosate (WSSA Group 9) may provide control of emerged yellow nutsedge.

**Herbicide Resistance:** None reported at this time.

**Stinkgrass (Eragrostis cilianensis)**

Stinkgrass (Figure 40.15) is an annual reproducing from seed. It is a warm-season grass that emerges after corn planting.

**Plant Description:** The blade is flat with warty glands on margins and backsides. Stiff hairs may be present at the collar region. Ligule is a short fringe of hairs. If crushed, stinkgrass has an unpleasant odor.

**Areas of Infestation and Yield-loss Potential:** Roadside, fields, or heavily grazed pastures. Yield loss is undetermined in corn, but heavy infestations will reduce yields.

**Herbicide Resistance:** None reported.

**Shattercane (Sorghum bicolor)**

Shattercane (Figure 40.16) is an annual plant, reproducing by seed. It is a warm-season grass that emerges after corn.

**Plant Description:** Shattercane is an erect, “cornlike” plant with a jointed stem. The sheath is round. The ligule is membranous and ciliate that is rounded or blunt and rarely pointed. This plant has a panicle inflorescence that is loose and often droops to one side.
side at maturity. Mature seeds disperse from seed head easily, promoting the plant’s re-infestation in a field.

**Areas of Infestation and Yield-loss Potential:** Found in many crop fields such as corn, grain sorghum, and soybeans. Significant yield loss in corn occurs when shattercane is allowed to reach 12 inches in height, even though it is removed soon after that. This weed is difficult to control in corn. Tillage, crop rotation, and postemergence cultivation can be effective control measures to reduce stand numbers. Pre-emergent and postemergent grass herbicides typically used in corn can be used for control.

**Herbicide Resistance:** Resistance to certain ALS inhibitor herbicides (WSSA Group 2) have been reported in Nebraska, Kansas, Iowa (e.g., Primisulfuron-methyl, nicosulfuron, imazethapyr) as well as a few other states across the country.

**Longspine sandbur (Cenchrus longispinus)**

Longspine sandbur (Figure 40.17) is a non-native, warm-season grass, reproducing from seed and emerging after corn planting.

**Plant Description:** This annual plant has flattened stems that have hair, and 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. If it is sat on (accidentally), the spines will go through the heaviest denim.

**Areas of Infestation and Yield-loss Potential:** Found in sandy soils, although may be found in fertile loam to clay loam soils. Yield loss is often low. Nuisance plant due to sharp burs. Tillage may be effective when sandbur is small. Crop canopy closure provides competition with shading and reduces growth. Glyphosate is an adequate control measure for longspine sandbur.

**Herbicide Resistance:** None has been reported.

**Barnyardgrass (Echinochloa crus-galli)**

Barnyardgrass (Figure 40.18) is a warm-season, annual grass that reproduces by seed and emerges after corn planting.

**Plant Description:** This grass has flattened, smooth, and branched stems without an auricle or ligule. This grass has broad leaves and typically is reddish or purple at its base. Barnyardgrass size can vary from
2” tall with only 1 tiller to over 4 ft tall with 50 + tillers.

**Areas of Infestation and Yield-loss Potential:** Larger plants are found around field edges, in wet areas, or in areas with poor canopy cover. Yield loss is often low due to late emergence. Tillage may be effective when plants are small. Shade under a crop canopy reduces growth.

**Herbicide Resistance:** Biotypes have been reported to be resistant to Photosystem II inhibitors (WSSA Group 5, e.g., atrazine), ACCase inhibitors (WSSA Group 1, e.g., sethoxydim), and other chemicals.

**Large crabgrass** (*Digitaria sanguinalis*)

Large crabgrass (Figure 40.19) is an annual, warm-season grass, reproducing by seed and emerging after corn emergence.

**Plant Description:** Large crabgrass has hairs everywhere on plant, a flattened stem, membranous ligule, and the seed head appears to be fingerlike spikes. This grass can grow from 6” to 2 ft tall.

**Areas of Infestation and Yield-loss Potential:** No specific growing requirements. Yield losses are low, even at high densities. Tillage, crop rotation, and postemergence cultivation may be effective management tools to reduce stand numbers. This grass is often difficult to control postemergence and should be controlled with pre-emergence chemicals.

**Herbicide Resistance:** Herbicide resistance has been reported to ACCase inhibitors (WSSA Group 1, e.g., sethoxydim) in Wisconsin.

**Wild proso millet** (*Panicum miliaceum*)

Wild proso millet (Figure 40.20) is an annual grass, reproducing from seed, and emerges late in the season, after corn emergence.

**Plant Description:** This warm-season grass has a round stem with membranous ligule tipped with a fringe of hairs. 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 6 ft tall. Seeds are large and shiny. They vary in color and may be white, green-striped, olive-brown, or black. The seed often remains 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 4 years.

**Areas of Infestation and Yield-loss Potential:** Tolerates sandy, dry soils, and high temperatures. Yield loss is moderate to high. Tillage may be effective when plants are small. Shading by the crop canopy reduces growth. Sanitation of equipment is suggested to prevent spread.

---

Figure 40.19 Large crabgrass collar region and mature plant. (Photos courtesy of Michael Moechnig, SDSU)

Figure 40.20 Wild-proso millet seedling, ligule and seed head. (Photos 1 and 3 courtesy of Steve Dewey, Utah State University archived at Bugwood.org; Photo 2 courtesy of Weed Science Society of America)
Herbicide Resistance: None noted at this time.

**Witchgrass (Panicum capillare)**
Witchgrass (Figure 40.21) is a warm-season, annual grass, reproducing by seed, and emerges after corn emergence.

**Plant Description:** 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. The panicle may be 1/2 or 2/3 of the size of the whole plant. When mature, the panicle can break off and tumble along the ground.

**Areas of Infestation and Yield-loss Potential:** Witchgrass grows well in sandy, droughty soil. Due to late emergence, yield loss is low, even at high densities.

**Herbicide Resistance:** A biotype of witchgrass, resistant to Photosystem II inhibitor herbicides (WSSA Group 5, e.g., atrazine) has been reported in Canada.

**Fall panicum (Panicum dichotomiflorum)**
Fall panicum (Figure 40.22) is a warm-season, annual grass, reproducing by seed. Plants emerge late in the season, after corn has emerged.

**Plant Description:** Vegetative stems often are confused with witchgrass, although fall panicum has few hairs. Sheath is round. Leaves emerge from the nodes in an alternate fashion. Blade is hairless and midrib is usually white and prominent. Seeds are bigger than witchgrass seed, but not as large as proso millet seed.

**Areas of Infestation and Yield-loss Potential:** Fall panicum grows well in sandy or droughty soil types. Yield-loss potential is moderate.

**Herbicide Resistance:** Worldwide, only Spain has reported resistance to Photosystem II inhibitor herbicides (WSSA Group 5).

**Switchgrass (Panicum virgatum)**
Switchgrass (Figure 40.23) warm-season, perennial grass emerges late in the season from seed and rhizomes after corn has emerged.

**Plant Description:** The plant often escapes from waterways or other areas, where it may be grown for soil stabilization. Vegetative stems are sometimes confused with witchgrass. There is a V-shaped patch

Figure 40.21 Images of witchgrass (Photos courtesy Steve Dewey, Utah State University, Bugwood.org and Robert Videki, Doronicum Kft, Bugwood.org).

Figure 40.22 Fall panicum collar region, inflorescence emerging, and mature inflorescence. (Photos courtesy Joseph M. DiTomasso, University of California - Davis, Bugwood.org ; (2) Bruce Ackley, The Ohio State University, Bugwood.org and (3) Lynn Sosnoskie, University of Georgia, bugwood.org)

Figure 40.23 Image of switchgrass head. (Photo courtesy James H. Miller, USDA Forest Service, Bugwood.org, and Howard Schwartz, at Bugwood.org)
of hair on the upper leaf surface near the stem. Bands of white hairs are located on the ligules, and the stem has dark-colored, swollen nodes. Plants can grow up to 6 ft tall. Switchgrass is grown in stands for biofuel but escaped plants can be problematic.

Areas of Infestation and Yield-loss Potential: Switchgrass grows well in sandy or droughty soil types, but is used in waterways for stabilization. Yield-loss potential is moderate. Pre-emergence grass herbicides other than atrazine may provide acceptable control.

Herbicide Resistance: Escaped plants can be difficult to control and are tolerant of atrazine (WSSA Group 5).

**Scouringrush (Equisetum hyemale) and Field horsetail (Equisetum arvense)**

These warm-season, grasslike plants are perennials that reproduce from rhizomes and spores and are slow to establish. Plants usually emerge after corn emergence.

**Plant Description:** Both scouring rush and field horsetail have hollow stems. Scouring rush (Figure 40.24) stems are erect, green, and unbranched. Most field horsetail (Figure 40.25) plants have many branches that occur in whorls at the stem joints. Stems of both plants contain silica and were used to scrub pans.

Areas of Infestation and Yield-loss Potential: Commonly found in wet roadside ditch areas. These plants encroach into field edges but are often slow to spread. Corn will not grow well in the wet soils where high infestations of these plants are found. Therefore, these infestations appear to be highly competitive with corn. In drier soils, these plants can establish, but at this time, no specific yield-loss data is available. Due to the perennial rhizomes of these weeds, tillage may spread the problem, but repeated mowing may exhaust the rhizome carbohydrate supply.

Herbicide Resistance: None reported.

**References and Additional Information**

Center for invasive species and ecosystem health available at http://bugwood.org/


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.


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(1) mail: U.S. Department of Agriculture
Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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The purpose of this chapter is to discuss chemical application and calibration. Applying pesticides at labeled rates is the legal obligation of the user. If too little is applied, you may not control the targeted pest. If too much is applied, your chemical costs increase, you may be in violation of the law, and there may be negative effects on the crop, humans, livestock, and the environment. Calibration doesn’t need to be complicated but should be done frequently to ensure correct rates and provide optimum efficacy for target pests. Rate controllers have automated calibration, however, they contain mechanical sensors that can wear or become sticky, so they also need to be checked to ensure that they function properly.

**Sprayer Calibration and Maintenance**

Well-maintained equipment that applies treatments at the prescribed rate optimizes control and reduces application errors. A small investment of time and money for the replacement of worn-out or faulty parts can be minimal compared to loss of product or crop yield. Details on equipment calibration is outlined in FS 933 “Calibration of Pesticide Spraying Equipment” available online at Wilson (2006).

In South Dakota, anyone who applies pesticides (including herbicides) to an agricultural commodity that has a value greater than $1,000 is required to be a certified applicator. There are two categories of certification: private applicators and commercial applicators. Contact your local Extension educator or the South Dakota Department of Agriculture for more information on certification.

Certified applicators who handle and apply any pesticide are required by rule to have a written “pesticide handling and discharge response plan.” A template for developing this plan is available from your local Extension educator or the SD Department of Agriculture and is available online at http://www.state.sd.us/doa/das/hp-pest.htm. The plan can serve as a reference for action in the event of an emergency.

Pesticides are a regulated material and must be stored, handled and applied in compliance with federal and state law. Some general safety tips for transport, storage and pesticide mixing are presented in Table 41.1. Questions regarding regulatory compliance should be directed to the SD Department of Agriculture, Office of Agronomy Services (605) 773-4432.
Safety and Worker Protection

Table 41.1 Safety tips for transport, storage, and mixing of pesticides:

<table>
<thead>
<tr>
<th>Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Place small containers (2.5 gallons or less) in water-tight totes.</td>
</tr>
<tr>
<td>✓ Do not exceed weight limits of trailers.</td>
</tr>
<tr>
<td>✓ Tie down tanks with load straps strong enough to secure the load.</td>
</tr>
<tr>
<td>✓ Avoid transportation on vehicles or trailers where the load can cause a rollover.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Store herbicides away from sensitive areas such as wells, populated buildings, animal feed, etc.</td>
</tr>
<tr>
<td>✓ Avoid storing herbicides in unheated storage over the winter, freezing may break containers or compromise the integrity of the product.</td>
</tr>
<tr>
<td>✓ Avoid storing or transporting near direct heat (e.g., furnaces or exhaust).</td>
</tr>
<tr>
<td>✓ Triple rinse, store in appropriate locations, and dispose of containers as labels direct.</td>
</tr>
<tr>
<td>✓ Lock doors to avoid accidental opening or vandalism.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Use and Mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Secure hoses, containers and pumps.</td>
</tr>
<tr>
<td>✓ Lock valves to avoid accidental opening or vandalism.</td>
</tr>
<tr>
<td>✓ Load and mix herbicides 150 ft from wells, lakes, or wetlands.</td>
</tr>
<tr>
<td>✓ Have an anti-back siphon device when filling equipment.</td>
</tr>
</tbody>
</table>

Record Keeping

The 1990 Farm Bill initiated the Pesticide Recordkeeping Program (PRP) and requires certified private applicators to keep records of all applications of federally restricted-use pesticides (RUP). Essentially, producers are required to record what, when, where, and to what crop a RUP was applied. Instructions and record-keeping forms are available by contacting county Extension educators, the SD Department of Agriculture, or the USDA Agricultural Marketing Service (http://www.ams.usda.gov/science/prb/Prbforms.htm). More information is provided in Chapter 4.

Personal Protective Equipment

When working with agricultural chemicals, it is important to wear the appropriate protective clothing. Manufacturers must provide information about the type of personal protective equipment (PPE) that must be worn when mixing, loading, handling, and applying pesticides. This information has to be on the pesticide label. There are different types of equipment needed (gloves, eye protection, and coveralls made of different materials to protect your skin) based on the solvents used in the pesticide formulation and the length of time you will be exposed to the chemical. Read and follow label directions to handle pesticides safely.

Sprayer Calibration

Before spraying a field, it is important to check the machine to see whether it is in good order. Walk around the sprayer to make sure booms are straight, level, and not bent or kinked; braces and springs are intact; shields are in place; and hoses, pumps, and gauges are operational and do not leak. If something failed at the last job, fix it. If you need to do welding, rinse off the sprayer prior to the operation. After repairing or replacing worn and broken parts, clean the strainer, nozzle screens, and nozzles with water mixed with ammonia or tank cleaner, based on label recommendations. Use a nozzle brush or a toothbrush to clean the nozzles. Do not use a wire or knife blade because they can damage the screens and nozzles. Once you determine that the sprayer is in good working order, you are ready to calibrate the sprayer. Directions for calibrating sprayers are available at Wilson (2006).

How Much Pesticide and Adjuvant per Tank?

If the carrier application rate is 5 gallons/acre and you want to apply 16 fluid ounces of product/acre, then you need to put 16 fluid ounces of product for each 5 gallons of water. If you have a 100-acre field, then you need 500 gallons of water (100 × 5), and you will need 12.5 gallons of product (16 fluid ounces ×100
acres = 1,600 ounces/128 ounces per gallon = 12.5 gallons). These values can be scaled up or down as needed.

Carefully read the label to determine whether and what type of adjuvants or surfactants should be included in the spray mix. Adjuvants may be recommended as an amount in volume/volume of the gallons in a sprayer OR as an amount per acre. If the amount is given as a volume/volume, then know how much of the herbicide mix is in a tank and then determine the amount to add. For example, if you have a full 500-gallon tankload and the adjuvant is suggested at 2% v/v, then:

\[(500 \text{ gal } \times 2/100) = 10 \text{ gallons of surfactant should be included. If the 500-gallon tank has only 300 gallons then } (300 \text{ gal } \times 2/100) = 6 \text{ gallons.}\]

If instead, the adjuvant is suggested on an acre basis, then the number of acres that will be treated with the sprayer load needs to be estimated and the amount of adjuvant calculated. For example, if the adjuvant should be applied at 1 quart/acre, the tank has 500 gallons of pesticide mix, and the output is 10 gal/a, the amount of adjuvant that should be added would be:

\[500 \text{ gal}/(10 \text{ gal/a}) = 50 \text{ a/tank;}\]
\[1 \text{ quart/a } \times 50 \text{ a/tank} = 50 \text{ quarts/tank; 1 gallon = 4 quarts so}\]
\[50 \text{ quarts/tank } \times 1 \text{ gallon/4 quarts} = 12.5 \text{ gallons}\]

Always double-check calculations, as this is easier and cheaper than making a mixing error. Read and follow label instructions for minimum carrier application rates. In some cases, 15 or 20 gallons of carrier per acre is needed to optimize spray coverage, especially for contact-type chemicals. Also add any recommended surfactants or spray additives at the correct rate. Label instructions will also provide the correct order for mixing chemicals in the tank. When applying a tank-mix of chemicals, make sure that the highest minimum rate of carrier is used for the application.

**Simple Technique to Calibrate a Sprayer**

1. Measure the width covered by one nozzle. This is the center of one nozzle to the center of the next nozzle along the boom.
2. Measure the amount of time to travel 1/128th of an acre (Table 41.2).
3. Using an ounce-delineated measuring container, with your sprayer loaded, collect spray from one nozzle for the time required to drive 1/128th of an acre.
4. If your nozzles are 18 inches apart and the sprayer is traveling at 5 mph collect spray for 30.8 seconds. Each ounce equals 1 gal/acre.

Also, make sure the spray pattern across the boom and from individual nozzles is correct. If more or less flow is needed across the boom, adjust the pressure (lower pressure to decrease the output, higher pressure to increase the output) or adjust the rate controller as needed.

Nozzle wear will affect the output and pattern of the nozzle. The material of the nozzle and type of formulation used will influence the wear. For example, abrasive materials will cause the nozzle orifice to open, causing greater output and less

#### Table 41.2 The relationship between swath width of a spray nozzle, distance, and length of time required to collect the spray. The number of ounces collected is equal to gal/acre. (Modified from Clay et al., 2011)

<table>
<thead>
<tr>
<th>Nozzle width</th>
<th>Distance for 1/128th a</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>inch</td>
<td>feet</td>
<td>sec</td>
<td>sec</td>
<td>sec</td>
<td>sec</td>
</tr>
<tr>
<td>6</td>
<td>681</td>
<td>92.9</td>
<td>46.4</td>
<td>31</td>
<td>23.2</td>
</tr>
<tr>
<td>8</td>
<td>507</td>
<td>69.1</td>
<td>34.6</td>
<td>23</td>
<td>17.3</td>
</tr>
<tr>
<td>10</td>
<td>408</td>
<td>55.6</td>
<td>27.8</td>
<td>18.5</td>
<td>13.9</td>
</tr>
<tr>
<td>12</td>
<td>340</td>
<td>46.4</td>
<td>23.2</td>
<td>15.5</td>
<td>11.6</td>
</tr>
<tr>
<td>14</td>
<td>292</td>
<td>39.8</td>
<td>19.9</td>
<td>13.3</td>
<td>10</td>
</tr>
<tr>
<td>16</td>
<td>255</td>
<td>34.8</td>
<td>17.4</td>
<td>11.6</td>
<td>8.7</td>
</tr>
<tr>
<td>18</td>
<td>226</td>
<td>30.8</td>
<td>15.4</td>
<td>10.3</td>
<td>7.7</td>
</tr>
<tr>
<td>24</td>
<td>170</td>
<td>23.2</td>
<td>11.6</td>
<td>7.7</td>
<td>5.8</td>
</tr>
</tbody>
</table>

**Example 41.1** A sprayer has a nozzle width of 14 inches and the sprayer is traveling at 15 mph. How long should spray be collected from one nozzle?

13.3 seconds

You collect 21 ounces in 13.3 seconds, how many gallons per acre is the sprayer calibrated for?

21 gal/acre
precise pattern over time. Stainless-steel and ceramic nozzles are less affected by formulation type. Plastic nozzles are affected by the solvents in an herbicide formulation and may swell shut, lowering the nozzle output. If the output pattern of a nozzle is nonuniform, check to make sure that the screen for the nozzle (or screens at other places in the sprayer) is not plugged. If individual nozzle output is 10% higher or lower than the average, then the nozzle should be replaced.

**Spot Check Rates**
As you are spraying the field, conduct routine checks to make sure the correct amount of solution is being applied. For example, if you know that each trip around the field is 20 acres and the application rate is 5 gal/acre, then each trip should use 100 gal. If < 100 gallons are used, you are underapplying and if > 100 gallons are used, you are overapplying. Recalibrate the sprayer as needed to match the desired and true output. If the amount is slightly less, the pressure gauges may not be correct or main screen or nozzles may be plugged. If the amount is more, check the pressure output and the system for leaks.

**References and Additional Information**


Acknowledgements
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Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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Herbicides can cause predictable symptoms to plants. Injury symptoms may be due to improper application, unintentional crop exposure (e.g., drift or carryover from past applications), or may develop if adverse environmental conditions (e.g., cold, dry, hot) occur after application. The purpose of this section is to show injury symptoms and discuss the mode of action of commonly used herbicides that occur in South Dakota corn production. Photographs and information are provided to assist in identification of herbicide injury symptoms, although symptoms may be due to other causes such as disease, or abiotic stress such as drought, cold, or hail damage.

**Introduction**

Herbicide injury to corn can occur for many reasons including:

- Carryover from previous year’s application.
- Carryover from early spring burn-down applications.
- Drift from nearby applications.
- Improper application of labeled chemicals (improper dose or growth stage).
- Applying the chemical when corn is under environmental stress.
- Tank or boom contamination with chemicals left over from previous applications.
- Double or incorrect overlap application.

Herbicide injury is often difficult to diagnose. At times, chemical carryover problems may not be seen until an application of a similar mode-of-action chemical is applied in the current season. In addition, the symptoms expressed in corn may not be due to herbicide injury. Environmental factors such as drought, high temperature, wind scouring, frost, or waterlogged conditions may be responsible. Root pruning from insects, purpling, yellowing, or dead tissue may occur due to nutrient deficiencies or toxicity levels, or mechanical damage could also result in injury that, at first, appears to be due to herbicides.

When diagnosing problems in the field, there are several things to observe. Look for patterns in the field associated with soil type, low or high spots, overspray in border rows, or overlap patterns from application equipment. Operator error (uncalibrated equipment, wrong chemical, or overlaps) may be the cause. But interactions with temperature, crop vigor, and soil type may combine to cause injury even if the chemical has been properly applied. If injury is not severe, most times corn will recover when growing conditions become favorable for growth.
Herbicides control plants in different ways. Herbicides that target the same specific biochemical or biophysical process in a plant to disrupt plant development are grouped into families. The Weed Science Society of America has designated a code for the primary site of action (WSSA Group #) that herbicide manufacturers often list on an herbicide label. This designation: 1) helps the user understand the way that the herbicide works and 2) should be consulted to help rotate sites of action in order to minimize the outbreak of herbicide-resistant weeds.

The herbicides in each of the families listed below are just examples of herbicide chemistries. Many herbicides have the same chemical but are listed by various trade names because of marketing. Premix herbicides may contain two or more of the families listed. Premix combinations or the addition of spray adjuvants or additives may result in heightened plant injury if applied during periods of stress, or at incorrect timings or rates. As with any herbicide application, always read and follow label instructions. Unfortunately, problems can occur, and the information provided may be used as a first reference. If crop injury is more than cosmetic, more detailed information will be needed to confirm the true cause of the problem.

**Acetyl-CoA Carboxylase (ACCase) Inhibitors (WSSA Group 1)**

WSSA Group 1 herbicides block the ACCase enzyme that is the first step in fatty acid synthesis. There are two major herbicide chemistries in this group, aryloxphenoypropionate and cyclohexanediones type. These herbicides are not labeled on corn and are often used to control volunteer corn in broadleaf crops such as soybean.

**Examples:** quizalofop (Assure; Targa); sethoxydim (Poast; Rezult G; Segment)

**Site and Mechanism of Action:** Stops Acetyl-CoA carboxylase (ACCase) enzyme in the plant and inhibits the formation of lipids used for the formation of cell and intercellular membranes.

**Appearance of Symptoms:** Corn is sensitive to these grass herbicides (Figures 42.1 and 42.2). Symptoms may first appear 2 to 4 days after treatment with wilting plants. If applied to corn before emergence, corn may not emerge. Severe symptoms take 1 to 3 weeks to develop after treatment. Leaf chlorosis (yellowing) begins followed by death of young leaves, with older leaves looking untouched. To determine whether this injury has occurred, pull the whorl from the corn plant and the base will be brown and mushy.

<table>
<thead>
<tr>
<th>Injury Symptoms</th>
<th>Typical Causes of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellowing or reddening of new leaves</td>
<td>Misapplication</td>
</tr>
<tr>
<td>Stunting of plant</td>
<td>Tank contamination</td>
</tr>
<tr>
<td>Death of tissue and browning</td>
<td>Drift from adjacent fields</td>
</tr>
<tr>
<td>Growing point dies, becomes brown and mushy</td>
<td></td>
</tr>
</tbody>
</table>

Figure 42.1 ACCase inhibitor symptoms, yellowing and bleaching (right), necrotic leaves (left). (Pictures courtesy of University of Wisconsin Extension and Sarah Berger, Univ. Florida, IFAS Extension)

Figure 42.2 Puma (fenoxaprop) applied at 10% tank contamination. (Mike Cowbrough Ontario Ministry of Agriculture, Food and Rural Affairs)
Acetolactate Synthase (ALS) Inhibitor (WSSA Group 2)
There are five chemical subgroups of ALS inhibitor chemistries: sulfonylureas (SU); imidazolinone (IMI); pyrimidinylthiobenzoates; triazolopyrimidines; and sulfonyaminocarbonyl-triazolinones. These compounds are found alone or in many premix combinations and, depending on the chemical, will control grasses, broadleaf weeds, or both. There are many of these herbicides registered for use in corn. However, the application of the wrong chemical can result in injury.

Sulfonylureas: There are many herbicides in this family and many premix herbicide combinations that contain this herbicide family. Examples of a few of the herbicides registered for corn include: thifensulfuron (Harmony 50SG; Thief; Treaty; Volta); halosulfuron (Permit, Sandea, Herbivore); indosulfuron methyl-sodium (Autumn); nicosulfuron (Accent, Adapt, Primero, NIC-IT 2L); and rimsulfuron (Resolve Pruvin, Rule, Solida).

Imidazolinone: Herbicides of this subgroup include imazaquin (Scepter); imazethapyr (Pursuit); and imazamox (Beyond, Clearmax). These herbicides are typically used in broadleaf crops, however, imazethapyr is labeled for use on CLEARFIELD corn varieties.

Pyrimidinylthiobenzoates: An example of an herbicide in this subgroup is pyrithiobac-sodium (Pyrimax; Staple), which is used for broadleaf weeds and some grasses in cotton.

Triazolopyrimidines: An example of an herbicide in this subgroup is flumetsulam (Python), which is labeled for soil and postemergent application in corn and soybean to control a wide array of broadleaf weeds.

Figure 42.3 Corn in the foreground shorter than plants in the background indicating stunted plants and stunted internode elongation, early signs of injury caused by ALS herbicides. (Pictures courtesy of University of Wisconsin Extension)

Figure 42.4 Bottle-brush roots due to ALS herbicides. (Pictures courtesy of University of Wisconsin Extension)

Figure 42.5 Shortened internodes due to post-ALS herbicide application. (Pictures courtesy of University of Wisconsin Extension)

Figure 42.6 ALS herbicide applied at V8. Note the pinched cobs on each corn ear. (Pictures courtesy of University of Wisconsin Extension)
**Sulfonyaminocarbonyl-triazolinones:*** Examples of herbicides in this subgroup include flucarbonzone (Everest, PrePare, Sierra) and propoxycarbozone (Olympus). Both of these chemistries are used to control grass weeds in wheat.

**Site and Mechanism of Action:** These herbicides block the acetolactate synthase enzyme and stop the formation of branched chain amino acids.

**Appearance of Symptoms:** Two to 4 days after treatment the growing point becomes yellow and plant death is seen within 7 to 10 days after treatment (Figures 42.3, 42.4, and 42.5). Plants may have red or purple leaf veins. Shortened internodes may be observed. Yellow “flash” with chlorosis and yellowing in the whorl and crinkled leaf edge may be observed. Corn ears may have pinched appearance (Figure 42.6).

<table>
<thead>
<tr>
<th>Injury Symptoms</th>
<th>Typical Causes of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Stunted plants, stunted internodes (Figs. 42.3, 42.5)</td>
<td>• Hybrid sensitivity</td>
</tr>
<tr>
<td>• Yellow translucent leaves</td>
<td>• Applied too late</td>
</tr>
<tr>
<td>• Death of growing point</td>
<td>• Carryover from previous application</td>
</tr>
<tr>
<td>• Bottle-brush roots (Fig. 42.4)</td>
<td></td>
</tr>
<tr>
<td>• Corn ears may have pinched appearance (Fig. 42.6)</td>
<td></td>
</tr>
</tbody>
</table>

**Inhibitors of Microtubule Assembly (WSSA Group 3)**

These herbicides bind to tubulin and inhibit polymerization of microtubules in the cell, which leads to loss of structure and function. This stops the spindle apparatus during cell division and chromosomes cannot separate and form new cells. Swelling of root tips is often observed as well as shoot malformation. There are four main chemistry groups in the grouping, benzamides, dinitroanilines, phosphoamidates, and pyridines.

**Examples:** Pendimethalin (Prowl, Pendant); trifluralin (Treflan Products)

**Site and Mechanism of Action:** These herbicides bind to tubulin and inhibit polymerization of microtubules in the cell, which leads to loss of structure and function of the microtubule. This stops the spindle apparatus from forming during cell division and chromosomes cannot separate and form new cells.

**Appearance of Symptoms:** Short, thickened roots (Figure 42.7). Swelling of root tips is often observed as well as shoot malformation. Shoot may leaf out below ground or if above ground, shoot may show purpling.

<table>
<thead>
<tr>
<th>Injury Symptoms</th>
<th>Typical Causes of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Roots stunted</td>
<td>• Applied at the wrong time</td>
</tr>
<tr>
<td>• Root clubbing (Fig. 42.7)</td>
<td>• Shallow planting of crop with exposure to</td>
</tr>
<tr>
<td>• Shoots may be purple</td>
<td>herbicide during germination</td>
</tr>
</tbody>
</table>

*Figure 42.7. Prowl injury to corn root clubbing (left) compared with uninjured corn (right) (Photo courtesy of Sarah Berger, Univ. Florida IFAS Extension).*
Auxin Mimic Herbicides (WSSA Group 4)
There are many subfamilies of chemistries that act as synthetic auxin. The families include benzoic acid, phenoxycarboxylic acids, pyridine carboxylic acids, and quinolone carboxylic acids. There are many herbicides in this group and many premix herbicide combinations that contain these herbicide families.

Examples: Auxin mimic herbicides include: 2,4-D; dicamba (Banvel, Clarity, Distinct, Status, Diablo, Rifle); clopyralid (Stinger, Solix, Clean Slate), fluoroxypr (Starane Ultra, Comet). Premix combinations such as clopyralid + fluoroxypr (Widematch, Colt AD, Truslate) may contain one or more of these herbicide types.

Site and Mechanism of Action: The specific site of binding for these herbicides has not been identified. These herbicides all act similar to auxin, a growth regulator naturally produced inside the plant. The addition of synthetic auxin disrupts nucleic acid metabolism and protein synthesis, which ultimately leads to plant death. These herbicides often accelerate shoot growth and inhibit root growth.

Phenoxycarboxylic Acid Subgroup
Example: 2,4-D

Appearance of Symptoms: Symptoms appear within hours of application on sensitive species. Corn symptoms may first be observed as wilt. Later, leaves may be tightly rolled in the whorl (onion-leaf) (Figure 42.8), stalk may be brittle, and brace roots may proliferate (Figure 42.10). Some corn hybrids are more sensitive than others. The amine formulation of 2,4-D is less volatile and less likely to drift compared with ester formulations, especially at warmer temperatures (> 70°F). If corn is growing quickly, symptoms may be more severe. High winds may cause treated plants to undergo green snap of corn stems or lodging due to root injury. If the herbicide is applied too late in the season, grain fill may be poor (Figure 42.9).
Injury Symptoms

- Rolled leaves
- Fused brace roots
- Stalk bending and brittleness
- Missing kernels on ear
  (Fig. 42.9)

Typical Causes of Injury

- Applied to rapidly growing corn
- Applied too late

Benzoic Acid Subgroup

Examples: dicamba (Banvel, Clarity, Distinct, Status, Diablo, Rifle)

Appearance of Symptoms: First appearance of symptoms can be within hours after application on sensitive species. Injury may occur if used as a pre-emergence application and corn is planted shallow, planted in an open seed furrow, or if the soil is coarse and sandy. If applied early post-emergence, onion leafing or brace root abnormalities may be noted if heavy rains occur soon after application. Corn plants may lodge or have green snap in windstorms. Grain fill may be compromised, if applied too late in the season.

Inhibitors of Photosynthesis (WSSA Groups 5, 6, and 7)

These groups contain many diverse herbicide families, and the classification by group is done by how each family interacts specifically with the Photosystem II binding sites. If the herbicide binds at Photosystem II site A, then the herbicide is placed in Group 5; if binding occurs at Photosystem II site B, then the herbicide is considered in Group 6; and if at Photosystem II site A but has a different binding mechanism than herbicides in Group 5, then the herbicides are placed in Group 7. While the site of action differs for these different groups, the herbicide symptoms are similar.

WSSA Group 5: Atrazine (Aatrex) and metribuzin (Glory, Dimetric) (can be applied pre-emergence or postemergence to corn).

WSSA Group 6: Bromoxynil (Bronate, Buctril) and bentazon (Basagran) (applied postemergence to corn)

WSSA Group 7: Amides and Ureas

Site and Mechanism of Action: All inhibit photosynthesis but bind or interact at different sites in Photosystem II. When photosynthesis stops, electron flow, CO₂ fixation, ATP and NADPH₂ formation are all inhibited. In addition, the electrons are now free to form free radicals with other compounds and result in cell membrane disruption.

Figure 42.11 Atrazine injury to corn from pre-emergence application when corn was growing under cooler than normal conditions. (Photo courtesy of Purdue Extension)

Figure 42.12 Buctril (bromoxynil) injury to corn. Note that the leaves that were present are most injured, newest leaves coming out of the whorl have little or no injury. (Photo courtesy of University of Wisconsin Extension)

Figure 42.13 Basagran (bentazon) injury to corn. Basagran is not translocated in the plant so injury is seen where droplets hit the leaf. The premix herbicide Laddok (bentazon plus atrazine) may also result in this type of injury. (Picture courtesy of Erick Larson at the Mississippi State University Extension Service; MSUCares, Mississippi State University)
Appearance of Symptoms: Typically first symptoms are seen a few days after application (Figures 42.11, 42.12, 42.13). Water-soaked appearance of leaves, yellowing, and browning (necrosis) (of oldest leaves if applied to soil, spotting on leaves if postapplied).

Injury Symptoms
- Yellow leaves
- Necrotic spotting
- Older leaves most affected

Typical Causes of Injury
- Cool, wet conditions slowing corn growth
- Crop oil synergy if applied postemergence

Inhibitors of Lipid Synthesis (not ACCase inhibition) (WSSA Group 8)
The herbicides in this category inhibit plant processes that include fatty acid and lipid biosynthesis but have a different site of action than those of WSSA Group 1. There is poor epicuticular wax formation on leaves, which leads to greater abiotic (water stress) and/or biotic stresses (e.g., inability to withstand pathogens or insect attack) for the plant. Thiocarbamate and phosphorodithioates (not used in corn) are two herbicide chemistries in this grouping.

Examples of Thiocarbamate Herbicides: EPTC + safener (Eradicane); butylate + safener (Sutan +)

Site and Mechanism of Action: The specific site of action for these herbicides has not been identified. The mechanism of action is to inhibit the growth of roots or shoots of seedlings. These herbicides stop fatty acid biosynthesis and other lipids, reducing the epicuticular wax formation on leaves.

Appearance of Symptoms: Symptoms appear during or soon after plant emergence (Figure 42.14). Plant may leaf out underground or if the plant emerges, will be stunted and have malformed leaves, and reduced or stunted root growth.

Amino Acid Derivative Herbicide (WSSA Group 9)
The active ingredient glyphosate is the common name for all trade-name herbicides in this family. Glyphosate is also found in premix herbicide combinations. Only corn hybrids with the glyphosate-resistant trait should be treated by postemergence applications of glyphosate, although this herbicide can be applied in burn-down treatments before corn emergence.

Example: glyphosate (Roundup and many others with active ingredient of glyphosate)

Site and Mechanism of Action: This herbicide binds to the 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS) enzyme, which stops synthesis of aromatic amino acids (amino acids that contain a phenyl ring).
The depletion of these aromatic amino acids leads to problems in protein synthesis and other growth pathways.

**Appearance of Symptoms:** Symptoms are slow to develop. Wilted plants may be seen in as little as 3 to as long as 10 days after exposure (Figures 42.15, 42.16, 42.17). Symptoms become more severe with time after treatment. Extreme heat, cold, or drought will slow and reduce the effects of glyphosate.

**Typical Causes of Injury**
- Misapplied to nonglyphosate-resistant corn

**Phosphoric Acid Type Herbicide (WSSA Group 10)**
The active ingredient glufosinate is the common name for all trade-name herbicides in this family. Only corn hybrids with glufosinate-resistant trait (LibertyLink®) should be treated by postemergence applications of glufosinate, although this herbicide can be applied in burn-down treatments before corn emergence.

**Example:** glufosinate (Liberty 280, Rely, Ignite, Finale)

**Site and Mechanism of Action:** This herbicide stops the activity of glutamine synthase an enzyme needed to convert ammonia into other nitrogen compounds. Consequently, ammonia accumulates to toxic levels in leaves causing cell destruction and inhibiting photosynthesis. In addition, glutamine, a needed amino acid in plant growth, is depleted.

**Injury Symptoms**
- Yellow, then brown foliage
- Growing point dies
- Purpling of midveins may be present on older leaves

*Figure 42.17 Purple midrib due to glyphosate injury. (Picture courtesy of Erick Larson at the Mississippi State University Extension Service; MSUCares, Mississippi State University, diagnosing glyphosate injury at: http://msucares.com/crops/corn19.html). Note that purpling may also be caused by hybrid type OR phosphorus deficiency. If a nutrient deficiency was the problem, however, the entire plant would be compromised when small, not just a few leaves.*

*Figure 42.18 Glufosinate injury to non-LibertyLink® corn. (Photo courtesy of Missouri Extension)*

*Figure 42.19 Glufosinate (Liberty) damage to non-LibertyLink® corn. (Photo courtesy of University of Wisconsin Extension)*
Appearance of Symptoms: Only apply this herbicide to GMO corn hybrids that have the LibertyLink trait. Symptoms on LibertyLink® corn may appear if applied when corn is stressed (drought, too hot, or excessively wet conditions) or if applied too late in the season. Drift on non-LibertyLink® hybrids will result in symptoms 3 to 5 days after treatment (Figures 42.18 and 42.19).

### Injury Symptoms
- Pale, yellow, or purple leaves
- Water-soaked lesions

### Typical Causes of Injury
- Applied too late in the season
- Misapplied to non-LibertyLink® corn

### Pigment Inhibitors (WSSA Groups 13 and 27)
These two groups of herbicides block the formation of pigments, the compounds that provide color to the plant leaves, through two different mechanisms. Plants affected by herbicides in either of these groups have bleached white leaves because chlorophyll and other pigment compounds are not formed. Clomazone (Command) is a WSSA Group 13 herbicide that inhibits the 1-deoxy-D-xylose 5-phostage synthatase (DOXP synthase), which stops plastid isoprenoid synthesis. Herbicides in Group 27 inhibit the 4-hydroxyhenyl-pyruvatedioxygenasis (4-HPPD) enzyme, which stops plastoquinone biosynthesis, inhibiting caretonoid and chlorophyll synthesis.

#### DOXP Inhibitor Subgroup
**Example:** Group 13 herbicide clomazone (Command, Epic)

**Site and Mechanism of Action:** This herbicide inhibits the 1-deoxy-D-xylose 5-phostage synthatase (DOXP synthase) enzyme found in the carotenoid and chlorophyll pigment pathway in plants (Figure 42.20). The lack of compounds in the leaf that give the leaf color is the reason why the plant appears bleached white.

**Appearance of Symptoms:** Plant leaves are white.

#### HPPD Inhibitor Subgroup
**Example:** Group 27 herbicides include isoxaflutole (Balance); mesotrione (Callisto); tembotrione (Laudis); topramezone (Impact)

**Site and Mechanism of Action:** These herbicides bind at 4-hydroxyhenyl-pyruvate dioxygenase (4-HPPD), which stops caretonoid biosynthesis and results in bleached (white) plants

**Appearance of Symptoms:** Appearance of bleached (white) tissue on leaves within a few days after exposure.

**Note:** Some herbicides are now formulated with safeners to protect the crop plant from injury. For example, Balance Flexx 2SC* (Bayer) contains isoxaflutole plus a safener (cyprosulfamide). Safeners can protect the plant by increasing the herbicide metabolism (breakdown of herbicide) in the plant but not the weed.

*Figure 42.20 Injury of isoxaflutole + atrazine WITHOUT crop safener. This type of injury will be similar for both the DOXP and HPPD inhibitors. (Mike Cowbrough, Ontario Ministry of Agriculture, Food and Rural Affairs)*
**Protoporphyrinogen Oxidase Inhibitors (WSSA Group 14)**

The WSSA Group 14 herbicides inhibit protoporphyrinogen oxidase (Protox or PPO inhibitor). This stops chlorophyll and heme biosynthesis, which results in a series of events that lead to singlet oxygen and radical formation. The free radicals then begin a chain reaction of lipid peroxidation. WSSA Group 14 contains many different types of herbicide chemistries including diphenylethers, oxadiazoles, phenpyrazoles, and pyrimidindiones.

**Examples:** fomesafen (Flexstar, Reflex, Prefix); carfentrazone (Aim); flumioxazin (Valor, Outflank, Panther); saflufenacil (Sharpen, Kixor)

**Site and Mechanism of Action:** Herbicides in this group inhibit the protoporphyrinogen oxidase (PROTOX) enzyme resulting in cell membrane destruction.

**Appearance of Symptoms:** Appearance of necrotic (dead tissue) speckling on leaves within a few days after exposure (Figures 42.21-42.23).

<table>
<thead>
<tr>
<th>Injury Symptoms</th>
<th>Typical Causes of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Water-soaked appearance</td>
<td>• Applying under high temperature and humidity increases the potential for crop injury</td>
</tr>
<tr>
<td>• White veins</td>
<td></td>
</tr>
<tr>
<td>• Brown tissue in areas that were water-soaked</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 42.21* Symptoms of HPPD injury. Corn plants have chlorotic (yellow) to white veins (tiger stripping) and the lower leaves may droop. (Picture courtesy of University of Wisconsin Extension (left) and Illinois Extension (right).)

*Figure 42.22* Corn with fomesafen injury. (Mike Cowbrough, Ontario Ministry of Agriculture, Food and Rural Affairs)

*Figure 42.23* Saflufenacil injury to corn. The herbicide was applied postemergence to corn when it is labeled only for pre-emergence. Note that the symptoms look like symptoms shown for WSSA Group 15 (inhibitors of very long-chain fatty acid synthesis). (Mike Cowbrough, Ontario Ministry of Agriculture, Food and Rural Affairs)
Inhibitors of Synthesis of Very Long-Chain Fatty Acids (WSSA Group 15)
Acetamide, chloracetamide, and oxyacetamide herbicides inhibit very long-chain fatty acid synthesis. This inhibition, in turn, reduces the formation of cell membranes which then inhibits plant growth.

Examples: metolachlor (Dual products); pyroxasulfone (Zidua); alachlor (Micro-Tech); acetochlor (Harness, Surpass, Volley, Breakfree and others); dimethenamid-p (Outlook, Propel, Establish and others)

Site and Mechanism of Action: These herbicides inhibit the formation of very long-chain fatty acids. The exact site of attachment is unknown. Plants do not emerge or growth of seedling roots or shoots is poor.

Appearance of Symptoms: If plants emerge, shoots often have buggy-whipped appearance (leaf entrapment) (Figure 42.24). These symptoms will be observed during or soon after plant emergence.

Injury Symptoms
- Poor emergence
- Stunted plants
- Leaf out before emergence
- Buggy whipping (leaf entrapment)

Typical Causes of Injury
- Overapplication
- Delayed corn emergence due to cold or waterlogged soil
- Hybrid sensitivity
- Applied during corn emergence (spike) which is too late
- Application to sandy soils

Auxin Transport Inhibitor (WSSA Group 19)
Example: Diflufenzopyr is in this group and is found only in herbicides premixed with other herbicides. Premix combinations include + Dicamba, Group 4; Distinct has 50% dicamba + 20% diflufenzopyr; Status has 44% dicamba + 17% diflufenzopyr + safener; Celebrity Plus has nicosulfuron (Group 2) + dicamba + diflufenzopyr.

Site and Mechanism of Action: The exact site is unknown. This auxin transport inhibitor blocks natural auxin transport to roots and stems; there is a safener in Status that reduces the potential for corn injury.

Appearance of Symptoms: Symptoms on susceptible plants are often observed within hours.

Cell Membrane Disruptor, Photosystem I Electron Diverters (WSSA Group 22)
This herbicide group includes paraquat and diquat. These postemergence herbicides will injure all crops. The herbicide accepts electrons from Photosystem I and becomes a radical, which then reduces molecular oxygen to superoxide radicals and form hydrogen peroxide that continue to break down components of the cell.

Example: paraquat (Gramoxone Max; Gramoxone Inteon; Firestorm; Para-shot, Parazone 3L)

Site and Mechanism of Action: The site of action is in Photosystem I. These herbicides accept electrons from the photosystem, causing free radicals to be formed, followed by production of hydrogen peroxide that leads to destruction of cell membranes and other components of the cell.

Appearance of Symptoms: The free radicals destroy the integrity of cell membranes, which rapidly leads to leaf wilting and desiccation. Localized symptoms are often observed within hours of application (Figures 42.25 and 42.26). The first symptom is water-soaked lesions in spots on the plant. Because the herbicide is
contact type, the spots will form only where the herbicide was applied. Young leaves that had not emerged from the whorl will not show injury. Plants may outgrow the symptoms and may not suffer yield loss.

<table>
<thead>
<tr>
<th>Injury Symptoms</th>
<th>Typical Causes of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Water-soaked lesions</td>
<td>• Drift</td>
</tr>
<tr>
<td>• Yellow spotting</td>
<td>• Tank contamination</td>
</tr>
<tr>
<td>• Dead tissues but only as spots</td>
<td>• Sprayed after corn emergence</td>
</tr>
</tbody>
</table>

**Summary**

Avoid common causes of herbicide injury.

- Make sure that there is no residual herbicide left in the tank from another application, and clean the tank using label instructions to avoid contamination.
- Avoid overspray (areas of overlap of the sprayer) and drift. Overspray may cause residual herbicide carryover for future crops.
- Establish buffer zones with a safe distance to open water and wells.
- Be conscious of wind speed and direction to avoid drift to sensitive crops and noncrop areas.
- Before application, make sure the sprayer is calibrated. This should also involve checking all nozzles to make sure that the amount discharged and spray pattern is correct (See Chapter 41).
- Read all label instructions prior to herbicide mixing and make sure the crop is at the correct stage of growth for treatment.
- Recheck your calculations about how much herbicide and other adjuvants need to be added to the tank. Add the herbicide and adjuvants in the same order listed on the label to avoid mixing problems. If unsure about the compatibility of products, do the quart jar test (see herbicide labels) prior to adding large amounts to the tank.

If you suspect herbicide injury:

- Document crop injury symptoms (types), field patterns (the entire field, edges, only in specific areas), and timing of what symptoms were seen, when symptoms were seen, and the progression of symptoms.
- Check weather information to determine whether the injury may be due to frost, hail, sheer winds, or other weather-related problems.
- Contact the applicator or chemical representative.
- Photograph and document injury symptoms.
- Check growing points to determine whether plant can recover.
- Determine the extent of the injury.
- Map areas of the field that are damaged.
- Keep records of crop yields from undamaged and damaged areas.

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*Figure 42.25 Paraquat injury. (Photo courtesy of William M. Brown Jr., Bugwood.org)*

*Figure 42.26 Paraquat injury to older plants. Note absence of injury to young leaves in the whorl. (Photo courtesy of Purdue University Extension)*
References and Additional Information


Acknowledgements
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The preceding is presented for informational purposes only. SDSU does not endorse the services, methods or products described herein, and makes no representations or warranties of any kind regarding them.
This chapter discusses herbicide-resistant weeds, often found in corn, that have been confirmed in South Dakota and the surrounding states of North Dakota, Minnesota, Iowa, and Nebraska (Table 43.1). According to the International Survey of Herbicide Resistant Weeds (www.weedscience.org), which allows self-reporting of confirmed cases, 9 herbicide-resistant weed biotypes have been reported and confirmed in South Dakota, as of 2015. In the surrounding region, Minnesota reported 19 herbicide-resistant biotypes, Iowa 17, North Dakota 14, and Nebraska 13. These are mentioned because weeds do not recognize state boundaries and growers must be diligent to prevent or confine these problematic species.

Since the 1960s, when the first triazine-resistant weed was reported, there has been a steady increase of herbicide-resistant biotypes, with over 250 incidents of herbicide resistance reported in the U.S. in 2015. The frequent use of single site-of-action herbicides across multiple crops and years has been reported to accelerate herbicide-resistance selection in weed populations. Using application rates below the label recommended rates may also reduce herbicide effectiveness and promote herbicide resistance. Often the problem is first observed as a few scattered plants that survive herbicide applications. However, due to the ability of these weeds to produce thousands (and, in some cases, millions) of seeds per plant, the survival of even a few plants allows the biotype to quickly become a widespread infestation. Herbicide resistance is an inheritable trait, passed from one generation to the next. This means that once the trait is in the population, other methods of control are needed to control the remaining plants. In addition, some herbicide-resistant biotypes show resistance to different herbicides that have different sites of action.

To reduce selection for herbicide-resistant biotypes, it is necessary to diversify weed-management programs, crop rotations, and the types of herbicide chemistries and sites of action that are used. The best time to take action against pesticide resistance is BEFORE the resistance is in your field or area. Unfortunately, most action is taken as a REACTION to the problem when it occurs, rather than before it is seen. Programs for herbicide-resistance management should include cultural, mechanical, sanitation, herbicide mode-of-action rotations, and crop rotations.

**Herbicide-resistant Biotypes in South Dakota**
Kochia biotypes resistant to ALS herbicides (WSSA Group 2) (Table 43.2) were first reported in South Dakota in 1998. The problem was noted in northeastern SD after only three consecutive seasons of ALS herbicide use. In 2007, a common ragweed biotype was the first glyphosate-resistant (WSSA Group 9)
<table>
<thead>
<tr>
<th>Weed Species</th>
<th>State</th>
<th>Resistance Sites of Action and WSSA Group Number</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kochia</strong> (<em>Kochia scoparia</em>)</td>
<td>SD, MN, ND</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td></td>
<td>IA, ND, NE</td>
<td>Photosystem II inhibitors (WSSA Group 5)</td>
</tr>
<tr>
<td></td>
<td>ND, NE</td>
<td>Synthetic auxins (WSSA Group 4)</td>
</tr>
<tr>
<td></td>
<td>SD, NE, ND</td>
<td>EPSPS inhibitors (WSSA Group 9)</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>Multiple resistance (2 sites of action): Photosynthesis inhibitors (WSSA Groups 5 and 6)</td>
</tr>
<tr>
<td><strong>Common sunflower</strong> (<em>Helianthus annuus</em>)</td>
<td>SD, IA</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td><strong>Common ragweed</strong> (<em>Ambrosia artemisiifolia</em>)</td>
<td>SD, ND, MN, NE</td>
<td>EPSPS inhibitors (WSSA Group 9)</td>
</tr>
<tr>
<td></td>
<td>MN</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td></td>
<td>MN</td>
<td>Multiple resistance (2 sites of action): ALS (WSSA Group 2); EPSPS inhibitors (WSSA Group 9)</td>
</tr>
<tr>
<td><strong>Giant ragweed</strong> (<em>Ambrosia trifida</em>)</td>
<td>NE, MN, IA</td>
<td>EPSP inhibitors (WSSA Group 9)</td>
</tr>
<tr>
<td></td>
<td>IA</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td></td>
<td>MN</td>
<td>Multiple resistance (2 sites of action): ALS inhibitor (WSSA Group 2); EPSPS inhibitors (WSSA Group 9)</td>
</tr>
<tr>
<td><strong>Wild oat</strong> (<em>Avena fatua</em>)</td>
<td>SD, MN, ND</td>
<td>ACCase inhibitors (WSSA Group 1)</td>
</tr>
<tr>
<td></td>
<td>SD, ND</td>
<td>ALS inhibitor (WSSA Group 2)</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>Multiple Resistance (2 sites of action): ACCase inhibitors (WSSA Group 1); ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td><strong>Tall (common) Waterhemp</strong> (<em>Amaranthus tuberculatus (=A. rudis</em>)</td>
<td>SD, NE, MN, IA, ND</td>
<td>EPSPS inhibitors (WSSA Group 9)</td>
</tr>
<tr>
<td></td>
<td>IA, MN</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td></td>
<td>IA</td>
<td>Photosystem II inhibitor (WSSA Group 5)</td>
</tr>
<tr>
<td></td>
<td>NE</td>
<td>PPO inhibitor (WSSA Group 14)</td>
</tr>
<tr>
<td></td>
<td>NE</td>
<td>Synthetic auxins (WSSA Group 4)</td>
</tr>
<tr>
<td></td>
<td>NE</td>
<td>HPPD (WSSA Group 13)</td>
</tr>
<tr>
<td></td>
<td>MN</td>
<td>Multiple Resistance (2 sites of action): ALS inhibitors (WSSA Group 2); EPSPS inhibitors (WSSA Group 9)</td>
</tr>
<tr>
<td></td>
<td>IA</td>
<td>Multiple Resistance (3 sites of action): ALS inhibitors (2); HPPD (13); Photosystem II inhibitor (5)</td>
</tr>
<tr>
<td></td>
<td>IA</td>
<td>Multiple Resistance (4 sites of action): ALS inhibitors (WSSA Group 2); HPPD (WSSA Group 13); Photosystem II inhibitor (WSSA Group 5); EPSP synthase inhibitor (WSSA Group 9)</td>
</tr>
<tr>
<td><strong>Redroot pigweed</strong> (<em>Amaranthus retroflexus</em>)</td>
<td>MN</td>
<td>Photosystem II inhibitor (WSSA Group 5)</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>ALS inhibitor (WSSA Group 2)</td>
</tr>
<tr>
<td><strong>Palmer amaranth</strong> (<em>Amaranthus palmeri</em>)</td>
<td>NE</td>
<td>Photosystem II inhibitor (WSSA Group 5)</td>
</tr>
<tr>
<td></td>
<td>NE</td>
<td>HPPD (WSSA Group 13)</td>
</tr>
<tr>
<td><strong>Horseweed</strong> (<em>Conyza canadensis</em>)</td>
<td>SD, NE, IA</td>
<td>EPSPS inhibitors (WSSA Group 9)</td>
</tr>
<tr>
<td><strong>Common lambquarters</strong> (<em>Chenopodium album</em>)</td>
<td>MN, IA</td>
<td>Photosystem II inhibitor (WSSA Group 5)</td>
</tr>
<tr>
<td><strong>Velvetleaf</strong> (<em>Abutilon theophrasti</em>)</td>
<td>MN</td>
<td>Photosystem II inhibitor (WSSA Group 5)</td>
</tr>
<tr>
<td><strong>Common cocklebur</strong> (<em>Xanthium strumarium</em>)</td>
<td>IA, MN</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
</tbody>
</table>
Table 43.1 Weed species, reporting state, and resistance sites of action and designated WSSA group number (see Chapter 42 for more details). Herbicide examples by WSSA group number are reported in Table 43.2. (Modified from International Survey of Herbicide Resistant Weeds; www.weedscience.org)

<table>
<thead>
<tr>
<th>Weed Species</th>
<th>State</th>
<th>Resistance Sites of Action and WSSA Group Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marshelder (Iva xanthifolia)</td>
<td>ND</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td>Shattercane (Sorghum bicolor)</td>
<td>NE, IA</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td>Wild mustard (Sinapis arvensis)</td>
<td>ND</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td>Eastern black nightshade (Solanum ptycanthum)</td>
<td>ND</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td>Pennsylvania smartweed (Polygonum pensylvanicum)</td>
<td>IA</td>
<td>Photosystem II inhibitor (WSSA Group 5)</td>
</tr>
<tr>
<td>Giant foxtail (Setaria faberi)</td>
<td>IA</td>
<td>Photosystem II inhibitor (WSSA Group 5)</td>
</tr>
<tr>
<td></td>
<td>IA</td>
<td>ACCase inhibitors (WSSA Group 1)</td>
</tr>
<tr>
<td></td>
<td>MN</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td>Yellow foxtail (Setaria pumila)</td>
<td>MN</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td>Giant green foxtail (Setaria viridis var. major)</td>
<td>MN</td>
<td>ALS inhibitors (WSSA Group 2)</td>
</tr>
<tr>
<td></td>
<td>MN</td>
<td>ACCase inhibitor (WSSA Group 1)</td>
</tr>
</tbody>
</table>

Table 43.2 WSSA group number, herbicide site of action (Modified from http://www.wssa.net/Weeds/Resistance/WSSA-Mechanism-of-Action.pdf) and herbicide example(s). Herbicide labels often highlight the WSSA group number(s) for the herbicide(s) site(s) of action found in the formulation.

<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 (synthetic auxin)</td>
<td>2,4-D, clopyralid, dicamba</td>
</tr>
<tr>
<td>5</td>
<td>Photosynthesis inhibitor (PSII inhibitor) (triazine)</td>
<td>Atrazine, Metribuzin</td>
</tr>
<tr>
<td>6</td>
<td>Photosynthesis inhibitor (contact)</td>
<td>Bentazon</td>
</tr>
<tr>
<td>9</td>
<td>EPSPS 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 (Very Long-Chain Fatty Acid inhibitor) (VLCFA)</td>
<td>Acetochlor, metolachlor</td>
</tr>
<tr>
<td>22</td>
<td>Cell membrane disrupter (Photosystem (PS)1 inhibitor)</td>
<td>Paraquat</td>
</tr>
</tbody>
</table>
weed identified in South Dakota. Since then, glyphosate-resistant biotypes of waterhemp, kochia, and horseweed have been confirmed and grass weeds, particularly wild oat, have been reported to be resistant to ALS (WSSA Group 2) and ACCase (WSSA Group 1) herbicides. Among all the resistant biotypes reported, kochia and waterhemp appear to be the most widespread and problematic. Figure 43.1 shows where glyphosate-resistant biotypes of several weed species have been confirmed, but unconfirmed populations maybe much more extensive.

**How and Why do Herbicide-resistant Weeds Develop?**

Weeds become resistant to a herbicide when offspring from a once-controlled 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 (e.g., thicker cuticle) that reduces herbicide uptake or reduces movement of an herbicide within a plant (e.g., isolates the herbicide in vacuoles, sheds herbicide-treated leaves). Glyphosate-resistant biotypes have been reported to have seven different and distinct mechanisms of resistance, including hypersensitivity (leaf drop) that does not allow the herbicide to translocate; changed site of action caused by one or two amino acid changes in the sensitive region of the enzyme; and multiple (40-fold or greater) copies of the gene targeted by the herbicide. These mechanisms of resistance can cause the biotype to have 3 to 100 times less sensitivity to glyphosate than the wild, sensitive types. Repeated use of herbicides with the same mode-of-action allows any offspring that possesses these new characteristics to survive, produce seed, and develop increased densities after a few years.

**Management to Prevent Resistance**

Preventing herbicide resistance requires a diversified and integrated weed-control program. Fields scale changes in weed species composition occur slowly. Utilize a diverse management system that conscientiously and proactively selects methods to minimize the chances of resistant weeds becoming a problem. This management tactic is more practical than responding after resistance has occurred. By the time the problem has been noticed, populations often have become widespread across one or multiple fields and weed seed banks have increased. It should be noted that using ANY single method of management continuously can produce problems. For example, tillage at the same time every year reduces the weeds that emerge at that time but may favor early emerging species that are now too large to control, or encourage late-emerging species that are missed by the tillage implement.

Diversified weed-management programs should include biological, mechanical, cultural, sanitation, and herbicide options. Such management programs should:

- Practice using a mix of pre-emergence herbicides, and herbicide tank mix partners that contain herbicides that have several sites of action. The HERBICIDE RESISTANCE ACTION COMMITTEE (HRAC) within the Weed Science Society of America (WSSA, www.wssa.net) has developed a numbering system to help producers select chemicals with different sites of action (Table 43.2). For example, one formulation may contain several different active ingredients, but all may act as Group 2 (ALS inhibitor) herbicides, whereas a different formulation may have two active ingredients and be listed as a Group 2 + Group 4 (an ALS inhibitor + an auxin growth regulator).
- Rotate crops that do not require the use of the same herbicides year after year.
- Use mechanical weed-control options when appropriate.
- Practice good sanitation for equipment (planters, combines), seeds, manure spreading, and areas around fields.

**Crop Rotation:** Crop rotations may include different crop species, such as wheat, soybean, or crops that
require different herbicide programs, such as conventional or LibertyLink® varieties. 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), also can disrupt weed life cycles and enable different control options. Note that to minimize problems of not matching herbicides with crop characteristics or rotating to crops where carryover may be a problem, excellent field records are required. In addition, always follow labeled instructions including rate, herbicide compatibility, surfactant addition, application timing, use frequency, and maximum allowable rate in a season.

**Scout Fields:** Always scout the field to understand what weeds are present prior to an herbicide application and choose the chemical solutions with the best efficacy for the weed spectrum present. Scouting after application and recording weed escapes is vital information for future planning. Poor herbicide efficacy could be caused by a number of issues, including faulty equipment, skips, incorrect mixing, and climate issues (e.g., rain soon after application, cold conditions, etc.). These problems must be ruled out before claiming that herbicide resistance was the cause.

**Use Pre-emergence Herbicides:** Pre-emergence herbicide application is recommended to ensure consistent weed control. Pre-emergence and postemergence herbicides should be chosen 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.

**If Herbicide-resistant Biotypes are Present**
When controlling herbicide-resistant biotypes always include herbicides that have a different site of action than the confirmed (or suspected) resistance. In no-till fields, added challenges associated with managing herbicide-resistant biotypes have caused some people to abandon no-till practices. However, tilling fields may prolong the persistence of herbicide-resistant weed seed banks. South Dakota State University research has demonstrated that common ragweed seed left on the soil surface in a no-tillage field may cause greater weed densities the following year, but if emerged plants are controlled, the seed bank becomes depleted in just a few years, compared with densities in tilled fields where seeds may be dormant and persist for a longer period of time (Moechnig et al., 2012).

As herbicide-resistant biotypes become more common, it will become increasingly important to minimize weed seed movement among fields. It is always important to clean equipment before entering different fields to prevent the spread of weed species. It is commonly believed that new infestations of glyphosate-resistant weeds are most often caused by independent selection within that field rather than movement of seeds between fields. However, 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 (Figs. 43.2, 43.3).

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 looks similar to waterhemp, but may have a slightly faster growth rate and may adapt to herbicides more quickly (see...
Chapter 38). In the Southern U.S., Palmer amaranth has proven to be a very challenging weed to control in fields. Some biotypes have developed resistant to formulations that contain single, as well as multiple modes-of-action, including glyphosate (Group 9), ALS (Group 2) and PPO (Group 14) herbicides (Table 43.2). There is concern that Palmer amaranth has moved to South Dakota and other Northern states as a contaminant of cotton seed used as livestock feed, with livestock manure, or through unclean harvesting equipment. This has already occurred in Michigan and Nebraska. As of 2015, there are confirmed patches of Palmer amaranth in Sully, Douglas, and Bennett counties of SD. In one case, manure from animals fed in the Southern states was spread, along with Palmer amaranth.

**Avoiding Selection for Additional Herbicide-resistant Weed Biotypes**

Diversifying weed-management programs to control a particular resistant-biotype in a field does not mean that another species will not be selected in the future. Most herbicides are effective only on 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. 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 herbicide-resistant species. For example, adding fomesafen with glyphosate may effectively control glyphosate-resistant biotypes of waterhemp but would provide only limited control of common lambsquarters or velvetleaf. Therefore, it will be important to monitor populations of these other difficult species, make management adjustments when necessary, and be sure to use effective management programs for these species in rotational crops.

**South Dakota Glyphosate-resistant Weeds**

Due to the changing herbicide formulations, rates, and restrictions, specific herbicides for control are not reported here but can be found at the annually updated iGrow.org website in the Corn Pest Management Guidelines.

**Kochia (Kochia scoparia)**

Herbicide-resistant kochia (*Kochia scoparia*) is a challenging weed in corn (Figs. 43.2 – 43.4). ALS-resistant kochia was first seen in the mid-1990s in wheat and soybean fields of northeastern SD (Wolf, 1998) after just 3 years of ALS inhibitor herbicide applications. In some fields, over 1000 seedlings per ft$^2$ were present early in the season. Glyphosate-resistant kochia was confirmed near Gettysburg, SD in 2009. Since then, scouting reports suggest that infestations have 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 common lambsquarters and five times as much as giant foxtail (Moechnig et al., 2003). Seed spreads very rapidly to form new infestations because of the plant’s tumbleweed tendencies when it becomes mature, which scatters plants across fields and in mats along fence lines.

Pre-emergence herbicides such as atrazine may be very effective in controlling kochia infestations, but care must be taken as triazine-resistant kochia has been reported in neighboring states. There are several broadleaf herbicides available for kochia control in corn. However, consecutive use of the same site of action and even mixtures with herbicides having multiple sites of action may contribute to resistance.

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 corn planting may eliminate much of the kochia infestation. However, effective burn-down herbicide options are not well-known as glyphosate has previously been the standard herbicide. 2,4-D is a common burn-down herbicide but will not likely be effective on many kochia populations. Indeed, some auxin-resistant biotypes have been reported in North Dakota, so care must be taken to rotate out of this herbicide family as well. Potentially effective options could be paraquat (Gramoxone®), glufosinate (Liberty®), or lactofen (Cobra®). Since kochia emerges very early in spring, a late-fall application of a soil residual herbicide may provide suppression or control in early spring.

LibertyLink® corn may be an alternative option. Since Liberty® acts like a contact herbicide with limited mobility in plants, the first application must be applied to small weeds (less than 4 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 postemergence 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 by aggressively managing it in corn or wheat. However, the prolific seed production potential of kochia will require nearly complete control 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.

**Waterhemp (Amaranthus tuberculatus)**

A glyphosate-resistant biotype of the annual weed waterhemp (*Amaranthus tuberculatus*) was confirmed in 2010 in South Dakota (Fig. 43.5). Since then, field surveys suggest that glyphosate-resistant waterhemp is common. Table 43.1 indicates that in surrounding states, waterhemp biotypes have been found that are resistant to five other site-of-action chemistries, with some biotypes having multiple resistances. In most cases, effective management requires both pre-emergence and postemergence 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 SD is also resistant to WSSA Group 2 herbicides (ALS inhibitors), so those herbicides will not control the ALS-resistant waterhemp. It has not been shown that waterhemp resistant to both chemicals is present in South Dakota fields.

However, no matter which herbicide program is followed, best control of waterhemp results when the application is applied to small (less than 4 inches tall) plants and uses enough water per acre to ensure thorough herbicide coverage of the weeds. Auxin herbicides (WSSA Group 4; e.g., Banvel, Clarity) in corn may give excellent control, but care must to taken to apply at these herbicides at the correct corn growth stage to avoid green snap or brace root problems.

Waterhemp can produce upwards of 100,000 seeds per plant, if the plant emerges early (Uscanga-Mortera et al., 2007). Later emerging waterhemp may produce only 100 seeds. This emphasizes the importance of
early season control. Waterhemp seed may survive in the soil for 4 to 5 years (Buhler and Hartzler 2001; Steckel et al., 2007), so seed bank depletion may require aggressive control for several years. Aggressive control would require pre-emergence and postemergence herbicides, at labeled use rates, in corn and rotational crops, such as soybean. 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.

**Horseweed (marestail) (Conyza canadensis)**
Glyphosate-resistant horseweed (*Conyza canadensis*) has become relatively common in eastern South Dakota no-till fields (Figs. 43.6, 43.7). 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, or saflufenacil (Sharpen®). Soil residual herbicides include saflufenacil, atrazine, or flumetsulam (Python®).

Postemergence herbicide options are limited and should be applied while horseweed is small (less than 4 – 6 inches). However, the goal should always be to control horseweed prior to corn emergence.

**Common Ragweed (Ambrosia artemisiifolia)**
Glyphosate-resistant common ragweed (*Ambrosia artemisiifolia*) was first confirmed in 2007 and was the first confirmed glyphosate-resistant weed in South Dakota (Fig. 43.8). However, occurrences of resistance seem to be expanding much more slowly than kochia and waterhemp. There are a number of pre-emergence and postemergence herbicides that can provide good to excellent control of common ragweed in corn. If fields contain herbicide-resistant biotypes, they 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 4 years after production, but less than 1% may emerge thereafter. However, 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 herbicide resistant (Fig. 43.9). Volunteer corn in hybrid corn and volunteer soybean in corn can be
problematic. Low densities (1 plant/ft²) of volunteer corn can reduce hybrid corn yield by about 3% with higher densities reducing yield up to 30%. Grain from volunteer corn can be harvested, but it may be of lower quality, be at an incorrect moisture content, or be a bridge to insect and disease problems. Even partial control of volunteer corn can increase corn yields. Hybrid selection is crucial to successfully control corn from past corn crops. For example, if the recent past hybrid corn was glyphosate-resistant, conventional hybrids, of ALS-resistant or glufosinate-resistant hybrid corn may be selected.

In most instances, volunteer soybean has not been thought of as a weedy species. However, Alms et al. (2016) reported that volunteer glyphosate-resistant soybean at low densities (1-5 plants/ft²) can reduce corn yield 10%. This corn yield reduction is similar to reductions that can be observed with similar densities of velvetleaf or redroot pigweed. At high densities, volunteer soybean can reduce corn yield by 50% or more. Volunteer soybean, at present, can be managed using common corn herbicides, however, as new herbicide-tolerant varieties are introduced, control may become more difficult.

References and Additional Information

Websites


International survey of herbicide resistant weeds at: www.weedscience.org (accessed 5 November 2015)

Papers


Acknowledgements
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    Office of the Assistant Secretary for Civil Rights
    1400 Independence Avenue, SW
    Washington, D.C. 20250-9410;

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Introduction
In numerous surveys of organic growers, weed management and control issues rise to the top of their list of major problems in grain and vegetable cropping systems. Undesirable plants interfere with production, may reduce yields, may cause problems with harvest, and reduce product quality. Early emerging weeds and high weed densities usually cause the greatest yield reductions, whereas late-emerging weeds may interfere with harvest operations and taint harvested products.

Typically, a successful organic weed-management system relies on rotational cropping as a base with further control provided through integrated methods. Most chemical control for weeds is not allowed in organic production. Therefore, the “many little hammers” approach for weed control and management is often discussed, as a single operation will not provide acceptable control. Weeds should be disrupted at key points during their life cycle to prevent growth and seed production.

Weed management should be a planned system over several years and include mechanical or physical methods, cultural control, and biological control techniques, where possible. Starting with a clean seedbed helps the crop establish without weed interference. Then, good management practices should be used that encourage faster corn growth to overtop and outcompete shorter weeds and to provide thicker and

**Role of Competitive Crops and Crop Rotations**

Conventional systems that have used synthetic fertilizers and pesticides cannot become certified as “organic systems” in a single year. Several years are needed to transition away from these chemicals. During the transition period, competitive crops should be grown and managed to reduce the weed seed bank in the soil. Once organic certification is achieved, these crops can be used in rotation to aid in weed management.

Successful organic systems generally rely on multiyear, soil fertility and pest (insect, disease, and weed) management plans. Crop rotations that minimize bridging of diseases and insects from one year to the next also help the main crop remain healthy and better able to withstand other abiotic and biotic stresses. The management plan may include cover crops (Fig. 44.1) and the use of crop seed free of disease and weed seed. Critical criteria for getting a “good” start include seedbed preparation, optimal planting dates and seeding rates, and the use of approved materials.

**Alfalfa** can be grown for 2 to 3 years to help minimize weeds. When planting alfalfa, choose a variety that regrows quickly and use a companion crop such as oats to help control weeds during alfalfa establishment. In trials at South Dakota State University, it has been found that no herbicides are needed during establishment, and even though the field may be quite weedy, alfalfa can establish well. Cut alfalfa at optimum times and heights, leaving enough plant to provide vigorous regrowth, and do not cut too late in the fall (after September 1), so that root carbohydrates have sufficient time to replenish for overwintering conditions. In the first year, if planted with oats, cut oats at heading (late June), and then allow the alfalfa to grow until mid- to late-bloom (about mid- August). This typically is the only cut during the first year. In the second and third years, alfalfa should be cut two or three times at recommended timings. A benefit to alfalfa in the rotation is that weeds are also cut and not allowed to go to seed. Typically, this will help deplete the weed seed bank and the fast regrowth of alfalfa will not allow new weeds to establish. Do not allow the stand to stay in so long that it becomes weak and noncompetitive. Another concern if the stand stays in too long is that alfalfa will dry the soil. These concerns must be balanced against the value of a good alfalfa crop and the weed control that it brings to the system. When coming out of alfalfa, tillage should be done in the fall or spring, preceding corn planting. The mechanical disruption of the terminated alfalfa will slow its regrowth, and volunteer alfalfa plants, even if present, typically do not result in reduction of corn yields.

![Figure 44.1 Buckwheat can be used as a smother or cover crop in organic systems to aid in weed management (courtesy John Ruter, University of Georgia, Bugwood.org and Carl Dennis, Auburn University, bugwood.org)](1581712_UGA1203099)
**Smother crops** can provide an environment where weeds do not thrive and weed seed banks can be depleted. Buckwheat, cereal rye, sorghum, corn for silage, and other crops may be used for this purpose (Fig. 44.1). Typically, seeding rates are high and rows are narrow to get early canopy cover. If planted in narrow rows, cultivation is not used for in-season control, whereas wide-row plantings may require between-row weed control (flaming or cultivation) to minimize weed populations. Short-season spring crops may be followed with overwintering crops. Residues may be left on the field to further hamper weed establishment.

**Cover crops** planted after a short-season spring crop or interseeded into crops after the critical weed-free period can also provide some weed suppression. Vigorous cover crops not killed by overwinter conditions must be controlled through physical means prior to seeding cash crops because these vigorous plants will act as weeds. Flail mowing before seed set in cereal rye has provided successful control in the spring, as has roller-crimping immediately after rye flowering. The mowed or crimped rye can form mulch and, if thick enough (~4 inches), prevents emergence of weed seedlings. Additionally, some cover-crop species, including rye and radish (and other brassicas), have allelochemicals in the residue that are leached into the soil, further hampering weed-seed germination and reducing weed pressure.

**Physical Weed Control for Weed Management**

Physical weed control is the most widely used method for immediate weed control in organic systems. Plastic barriers and hand-hoeing may be used throughout the field to minimize weeds in high-value crops, such as sweet corn, and transplanted crops, such as tomatoes and peppers. In grain and commodity crops, these operations may be too expensive, except in small areas where extra weed management may be needed, such as isolated patches of perennial weeds. Other physical means of weed control include cultivation (secondary tillage, rotary hoe), flaming, hoeing, and abrasive-grit applications.

**Cultivation**

Many types of cultivation implements are available and may be used once or many times during the season. Cultivation provides a clean seedbed and can be used to provide immediate control of weeds between the rows. In the Midwest, two or three cultivations are typical for organic corn grain systems. Timing for all cultivation operations is critical, and it may take several years to establish optimal timing for weed control in your fields. However, complacency and performing the same operation at the same time every year will result in a spread of species other than those that were originally problematic. Rotary hoeing and harrowing can be used if the corn and weeds are not too large (that is, weeds at the white-thread stage). Rotary hoeing on a diagonal, rather than up and down the rows, at 10 to 12 mph is purported to provide the greatest weed control.

There are challenges with cultivation that should be considered prior to adoption. In rolling landscapes, erosion possibilities may outweigh the benefits of tillage and should be assessed because permanent damage can occur to soils with one untimely operation. Soil health may also be reduced by untimely operations causing crusting, reduced water infiltration, and reduced organic matter and residues in surface soils.

**Mulching**

Mulching with residues, plastic, or approved organic plant meals (such as corn gluten, soybean, or mustard meals) hampers weed germination, establishment, and development. Meal application rates are often very high, at hundreds of pounds per acre. Placement should be between rows so that crop growth and development are unimpeded. However, within-row weed management should not be forgotten, as weeds
closest to the crop tend to cause the greatest yield loss. If within-row weeds become a problem, abrasive grits sprayed toward the base of the crop plants, hand-hoeing, or shielded cultivators to get as close to the crop as possible may need to be used.

**Hand-hoeing**

Hand-hoeing is a time-tested approach to control weeds. However, the practice is often overlooked in organic production fields because of cost and labor requirements. Notwithstanding, new infestations of a weed, control of within-row weeds, or control of scattered plants may warrant individual attention. Weed seeds can last in the seed bank for 3 to 50 years, and one weed can produce several hundred to several hundred thousand seeds. “An ounce of prevention, can be worth pounds of cure” – through careful management, weeds can be controlled (Fig. 44.3).

**Flaming, Steaming, and Microwave Systems**

Flaming, steaming, and microwave systems have been used to kill weeds through desiccation and high-temperature exposure (Fig. 44.4). Young weeds (and germinating seeds, in some cases) can be killed quite readily with these practices. Larger weeds need to be treated for a longer period of time and the growing point must be affected. The problem with these methods is that the contact time needs to be optimized, often leading to slow operating speeds for equipment, low labor efficiency, and high fuel bills. Caution must be taken because crops can be sensitive to the heat as well. Typically, corn can withstand the heat if the growing point is below the soil surface, but care must be taken not to directly heat the crop, once the growing point is above ground.

**Abrasive grit**

Abrasive-grit systems are being tested by SDSU, the University of Illinois, and USDA-ARS for their ability to control weeds (Fig. 44.5). The machine uses organically certified grits (walnut shells, corncobs, soybean meal, pelletized poultry manure) applied at 100 psi to in-row weeds with nozzles pointed toward the base of the plant. The grit blasts the weeds causing enough damage to kill young broadleaf weeds and injure the growing points of older weeds. We found that two operations, one at V1 or V2 and another at V3 or V4, controlled broadleaf weeds and maintained cash-crop yield. If the operation occurred at V5, weeds were well-developed and, while abrasion caused some damage to the weeds because of earlier interference, corn yield was reduced (author’s unpublished data). Timing on grass weeds needs more research because of the ability of a defoliated plant to regrow if the growing point is below ground at the time of treatment. Optimization of grit types, rates, timing, and spectrum of weeds controlled are still in the early stage of research.

Figure 44.3 Carefully tended cropping areas in Vietnam display minimal weed problems. (Courtesy of the author)

Figure 44.4 An image of a propane flamer. (Courtesy of Michigan State University)

Figure 44.5 Four-row grit applicator for weed control in row crops designed by SDSU Ag & Biosystems Engineering Dept. (Dan Humburg and Corey Lanoue) Ground corncob grit was used as the spray. (Courtesy of F. Forcella, USDA-ARS)
Robotic Hoeing and Flaming
Recent developments in nonchemical weed control include the “Robovator,” a robotic implement that hoes weeds within crop rows (Fig. 44.6). In this case, the crops have to be precision-planted and the Robovator uses a knife to remove any and all plants between the spaced crop plants. An equally innovative implement is a robotic flame weeder that senses the presence of a crop plant and withholds a flame jet, but singes all other plants (Fig. 44.7).

Organic Approved Sprays
There are some chemical herbicides approved for use in organic production, however, the efficacy of these applications are inconsistent in South Dakota. In 2015, sprays approved for application for weed control in organic systems with or without approved organic surfactants included: clove, cinnamon, and garlic oils; citric acid; and ammonium nonanoate. Reports from credible research trials should be consulted prior to purchase, as rates, surfactant types, and timing of applications have had mixed results. As with any pesticide application, always read and follow label directions.

Summary
Premium prices for organically grown crops can be financially beneficial. However, based on numerous surveys of organic producers, weed management is one of the most challenging aspects of growing organic crops. As in conventional systems, there is no one “silver bullet” technique for weed control. Understanding the biology of the weedy species infesting the area will help in planning timely operations to disrupt weed establishment and growth. The use of many diverse techniques (e.g., smother crops, flaming, cultivation) and crop rotations are key aspects to minimize weed problems in organic farming.
References and Additional Information


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.


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(1) mail: U.S. Department of Agriculture
Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov;

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The purpose of scouting and having field records is to provide information, from which economically and environmentally sound recommendations are developed. The economic-based pest threshold is the severity level at which the yield loss equals the cost of controlling the plant disease. Field scouting is conducted to: 1) diagnose disease problems; 2) determine disease severity; 3) determine the need for applying fungicides; and 4) assess the effectiveness of previously applied control strategies. The purpose of this chapter is to discuss the basics of field scouting (Table 45.1).

### Preparing to Scout a Field

**Step 1.**
Understand the pathogen biology and control approaches. Have an idea when certain diseases occur in the season.

**Step 2.**
A grower, crop consultant, and/or commercial agronomist can perform the scouting. Scouting starts by assembling the needed tools (Table 45.2). Obtain information on the weather for the past four days and the forecast for the next four days. Be aware of disease alerts in the area (from iGrow.org, crop newsletters, etc.). Check the disease ratings for the cultivar planted. Also be aware of the field disease history, cropping history, and what seed treatments were used. In addition, a recent remote-sensed image of the field, if available, may be used to direct scouting activities.

**Step 3.**
Start with the big picture – the entire field – look for stunted, yellowing plants, or areas that raise suspicion. If you see a problem, ask: Are the infected plants in any pattern (e.g., random, clustered, patchy)? Scouting...
for diseases should be done periodically, starting with assessing plant-stand establishment (seed and seedling diseases), then assessing for early season diseases (foliar diseases), midseason diseases (foliar diseases), and finally, late-season diseases (stalk rots and ear rots).

If a remote-sensed image is available, scout areas that are anomalous (look different) first. If no imagery is available, then start scouting the field by first walking into the field at least 30 ft (about 10 steps) from the edge of the field and assessing 10 plants. This assessment should include the percentage of the entire plant that is covered by the disease. Do this for at least 10 stops in a zigzag pattern to cover the large portion of the field while avoiding the edges of the field (Fig. 45.1). If the field has rolling topography, make sure to include scouting points at each landscape position (footslope, shoulder, summit), as stress conditions and disease incidence may differ. The average of all the points assessed will indicate the severity of the disease.

**Step 4.**
Collecting an accurate and reliable estimate of disease intensity (severity/incidence) is important in making disease-management decisions. Inspect the infected plants to assess what parts of the plant are infected: the entire plant (systemic/wilting), lower leaves, midcanopy, top. For example, bacterial stalk rot usually infects the top part of the plant. Specific activities include:

1. Splitting the stalk and looking for any discoloration of the stalk or pith disintegration.
2. Distinguishing between fungal, bacterial, viral, and nematode diseases.
   a. Fungal leaf spots and blight diseases usually are smaller in size. The spots could be irregular in shape, as in northern corn leaf blight, or could have a regular shape, such as gray leaf spot. Bacterial blights could have larger lesions, such as Goss's and Stewart's wilts, or small lesions, such as Holcus spot.
   b. Yellowing and stunted growth are usually symptoms of virus and nematode infection.

Take samples of diseased plants and send to the South Dakota State University Plant Diagnostic Clinic to obtain or confirm diagnosis. Every county 4-H office has self-addressed envelopes for mailing samples to the clinic.

Finding only two or three plants with disease does not justify applying fungicides. Disease intensity can be measured as incidence or severity. Incidence is the percentage of units assessed with disease. For example, three diseased plants out of 10 sampled plants would have a 30% disease incidence. Severity, on the other hand, is the amount of unit area that is covered by disease lesions. This can be on the leaf basis or on the plant basis. For example 30% severity on whole plant basis would mean that 30% of the plant’s total area is

<table>
<thead>
<tr>
<th>Table 45.2 Useful tools to use when scouting production fields:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clipboard or notebook</strong></td>
</tr>
<tr>
<td><strong>Scouting sheet</strong></td>
</tr>
<tr>
<td><strong>Plastic bucket</strong></td>
</tr>
<tr>
<td><strong>Hand lens (at least 10x magnification)</strong></td>
</tr>
<tr>
<td><strong>Shovel</strong></td>
</tr>
<tr>
<td><strong>Sharp pocket knife or single-edge razor</strong></td>
</tr>
<tr>
<td><strong>GPS</strong></td>
</tr>
<tr>
<td><strong>Marker/sharpie</strong></td>
</tr>
</tbody>
</table>

**Figure 45.1 Sampling plan. Walk in the field at least 10 steps from the field edge and examine 10 plants at every black dot.**
covered by lesions. Usually severity is more informative.

**Step 5.**
Create and implement a management plan. The in-season rescue treatment for foliar fungal diseases is fungicide application. However, little research has been done on corn foliar disease threshold for individual foliar diseases partly because of the difficulty in keeping other stresses from interfering with yield response to disease. Additionally, diseases differ in the minimum amount of severity/incidence that can occur before significant yield loss is observed. For instance, for northern corn leaf blight, a 10% severity may cause similar yield loss as 30% eye spot severity. In sweet corn, common rust incidence threshold was found to be 80%.

The general consensus for fungal disease threshold to justify fungicide application is fungal diseases (excluding common rust) occurring on 3rd leaf below ear leaf and higher on 50% of plants. The best timing for fungicide application is between VT (tasseling) and R2 (bliyster). However, depending on the disease pressure, a fungicide can be applied until R5 (dent). Earlier fungicide application has not been associated with consistent yield gain, except for corn-on-corn rotations and in no-till situations. Scout for diseases at V6 to determine the need for early fungicide application (especially for corn-on-corn and no-till fields). If fungal diseases are developing on lower leaves on 50% of the plants, an early fungicide application may be beneficial. Scout again at tasseling and note the different diseases beginning to develop and which leaf positions are affected. If no disease is observed on the 3rd leaf below ear leaf and higher leaves at this stage, scout again at R2 growth stage. If the current weather is wet and warm, scout every four days.

The most critical period for yield protection is between R2 and R5 (dent). Diseases occurring past R5 will cause minimal yield loss. Protection of ear leaf and leaves above the ear from fungal infection protects against yield loss. Scout early and continue scouting for foliar fungal diseases every 4-5 days until R3 to decide the need for fungicide application.

A proactive management plan might include cultural methods (planting date, residue management, drainage, avoiding compaction, rotations); preventative treatments (seed treatments, selecting a suitable plant population, applying adequate fertilizers, selecting appropriate corn hybrids); and possible fungicide treatments.

**References and Additional Information**

**Websites**

**Papers and Manual**

Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, South Dakota Corn Utilization Council, and the USDA-AFRI-IPM. Special thanks to Daniel Clay for reviewing this chapter.


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Mycotoxins are secondary metabolites produced by some fungi that are highly toxic to humans and animals. Consequently, the presence of mycotoxins can raise serious concerns if allowed to enter the food chain. Some fungal pathogens infect corn ears and cause ear rots/molds and in addition to reducing corn yield, produce the mycotoxins. Mycotoxin consumption in livestock can lead to reduced intake or feed refusal, altered endocrine system, suppressed immune function, and other effects. Corn showing symptoms of fungal infections that produce mycotoxins should be sampled and sent for laboratory analysis. Production of mycotoxins starts in the field, and may continue during the storage period, depending on storage conditions. Mycotoxin levels never decrease during storage, but concentrations may increase if grain is not stored correctly.

To minimize mycotoxins in the food supply, the Food and Drug Administration has established action and advisory levels for these compounds. Mycotoxins and their level of toxicity vary by fungal pathogens producing them. Therefore, each mycotoxin has a different acceptable maximum level, depending on the end-use product or the animal consuming the product. The purpose of this chapter is to discuss mycotoxins in corn production.

**Introduction**

There are several mycotoxins that can contaminate corn. These include: aflatoxins produced by *Aspergillus spp* (Fig. 46.1); fumonisins, deoxynivalenol (also known as vomitoxin) and zearalenone produced by *Fusarium spp*.; and ochratoxins produced by *Penicillium verrucosum*. The level of mycotoxin(s) contaminating grain is dependent on many factors, including: the incidence and severity of ear rot in the field; the amount of damage on corn kernels during combining; the prevailing weather conditions (Robertson et al, 2011); and the adoption of cultural practices that minimize yield-limiting factors.

**Aflatoxins**

The fungus *Aspergillus flavus* produces aflatoxins in corn. This fungus is abundant in nature, but
infection in corn is favored by dry and hot weather during grain fill, and at or after physiological maturity. Aflatoxins are highly toxic and carcinogenic. Consumption of aflatoxins by livestock can cause feed refusal, reduced growth rate, and rough hair coat among other symptoms. The FDA-established action level for aflatoxin in grain is 20 ppb in lactating dairy cows. The level of aflatoxin for beef cattle, swine, or poultry is 100 ppb (Table 46.1). In combination with drought, other stress factors such as insect injury, nematode infestation, and fertility stress can increase chances for this mold to develop.

**Fumonisins**
Fumonisins are a family of mycotoxins produced by many species of Fusarium including the corn pathogens *Fusarium verticillioides* and *F. proliferatum*. Corn ears with Fusarium ear rot typically have scattered infected kernels on ears. Kernels with moisture levels > 18% have increased chances for Fusarium infection. Fumonisin consumption in animals affects the liver of cattle and immune system in pigs and poultry. Allowable amount of fumonisins varies by animal type and the age of the animal (Table 46.2).

### Table 46.1 FDA action levels for aflatoxins in human food, animal feed, and animal feed ingredients.

<table>
<thead>
<tr>
<th>Intended Use</th>
<th>Grain, Grain Byproduct, Feed or Other Products</th>
<th>Aflatoxin Level (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human consumption</td>
<td>Milk</td>
<td>0.5 ppb</td>
</tr>
<tr>
<td>Human consumption</td>
<td>Foods, peanuts and peanut products, brazil and pistachio nuts</td>
<td>20 ppb</td>
</tr>
<tr>
<td>Immature animals</td>
<td>Corn, peanut products, and other animal feeds and ingredients, excluding cottonseed meal</td>
<td>20 ppb</td>
</tr>
<tr>
<td>Dairy animals, animals not listed above, or unknown use</td>
<td>Corn, peanut products, cottonseed, and other animal feeds and ingredients</td>
<td>20 ppb</td>
</tr>
<tr>
<td>Breeding cattle, breeding swine and mature poultry</td>
<td>Corn and peanut products</td>
<td>100 ppb</td>
</tr>
<tr>
<td>Finishing swine 100 pounds or greater in weight</td>
<td>Corn and peanut products</td>
<td>200 ppb</td>
</tr>
<tr>
<td>Finishing (i.e., feedlot) beef cattle</td>
<td>Corn and peanut products</td>
<td>300 ppb</td>
</tr>
</tbody>
</table>

(Source: National Grain and Feed Association)

### Table 46.2 FDA guidance levels for fumonisins in animal feed.

<table>
<thead>
<tr>
<th>Class of Animal</th>
<th>Grain or Grain Byproducts</th>
<th>Total Fumonisins (FB1, FB2 and FB3) Levels in Grain or Grain Byproducts and (Complete Diet) [parts per million (ppm)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horses and Rabbits</td>
<td>Corn and corn byproducts not to exceed 20% of diet**</td>
<td>5 ppm (1ppm)</td>
</tr>
<tr>
<td>Swine and Catfish</td>
<td>Corn and corn byproducts not to exceed 50% of diet</td>
<td>20 ppm (10 ppm)</td>
</tr>
<tr>
<td>Breeding Ruminants, Breeding Poultry and Breeding Mink*</td>
<td>Corn and corn byproducts not to exceed 50% of diet</td>
<td>30 ppm (15 ppm)</td>
</tr>
<tr>
<td>Ruminant &gt; 3 months old being raised for slaughter and mink being raise for pelt production</td>
<td>Corn and corn byproducts not to exceed 50% of diet**</td>
<td>60 ppm (30 ppm)</td>
</tr>
<tr>
<td>Poultry being raised for slaughter</td>
<td>Corn and corn byproducts not to exceed 50% of diet**</td>
<td>100 ppm (50 ppm)</td>
</tr>
<tr>
<td>All Other Species or Classes of livestock and pet animals</td>
<td>50% of diet**</td>
<td>10 ppm (5 ppm)</td>
</tr>
<tr>
<td>Livestock and Pet Animals</td>
<td></td>
<td>10 ppm (5 ppm)</td>
</tr>
</tbody>
</table>

*Includes lactating dairy cattle and hens laying eggs for human consumption
**Dry weight basis
(Source: National Grain and Feed Association)
Deoxynivalenol (DON) or Vomitoxin
Deoxynivalenol is produced by *Gibberella zeae* (also known as *Fusarium graminearum*). This compound is sometimes called vomitoxin because it can cause vomiting in swine, especially young pigs. The main negative effect of this mycotoxin is feed refusal and reduced feed intake. Gibberella-infected ears when peeled back have pinkish-red kernels covered with the fungal mycelium. Levels of DON acceptable in animal feeds vary by animal type, but generally beef cattle and poultry can tolerate higher levels than swine (Table 46.3). Infection by this fungus is favored by temperatures between 70-80°F after silking. This disease is more prevalent in fields of continuous corn. Grain moisture content of greater than 20% is also conducive for this ear rot and mycotoxin problem to develop.

Zearalenone
Zearalenone is a second mycotoxin produced by *Gibberella zeae* (*Fusarium graminearum*). Zearalenone interferes with reproduction hormones in animals. Often found with DON. The FDA does not have recommended action or advisory levels for zearalenone, but levels over 560 ppb is of concern.

Ochratoxins
Ochratoxins are produced by *Penicillium verrucosum*. This fungus usually colonizes corn in storage if grain has > 18% moisture. However, Penicillium ear rots also can develop in the field, especially on ears with mechanical or insect damage. Unlike other ear rot pathogens, Penicillium attacks only mature kernels (after black layer). The fungus may invade and discolor the embryo resulting in “blue eye.” Ochratoxin A is the most common ochratoxin, and swine are the most sensitive. No FDA guidelines for this toxin are available at this time.

Sampling for Ear Rots and Mycotoxins
Scouting fields before harvest is important to determine the amount of ear rot in a field and consequently if there is a risk of mycotoxin contamination of grain. Scout fields by peeling back the husks and inspecting at least 10 ears and at least 5 random stops throughout the field. If > 10% of ears in a field have > 10-20% moldy kernels, the field should be scheduled for harvest as early as possible. Care should be taken not to damage kernels during harvest. The grain should be cooled and dried to < 15% moisture content immediately after harvest. Grain from fields where ear rot was a problem should be stored in a separate bin to grain from fields where the ears were healthy.

### Table 46.3 FDA advisory levels for vomitoxin.

<table>
<thead>
<tr>
<th>Intended Use</th>
<th>Grain or Byproducts</th>
<th>Vomitoxin levels in grains or grain byproducts and complete diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Consumption</td>
<td>Finished products</td>
<td>1 ppm</td>
</tr>
<tr>
<td>Swine</td>
<td>Grain and grain byproducts not to exceed 20% of diet</td>
<td>5 ppm (1 ppm)**</td>
</tr>
<tr>
<td>Chickens</td>
<td>Grain and grain byproducts not to exceed 50% of diet</td>
<td>10 ppm (5 ppm)**</td>
</tr>
<tr>
<td>Ruminating beef and feedlot cattle older than 4 months</td>
<td>Grain and grain byproducts *</td>
<td>10 ppm (10 ppm)**</td>
</tr>
<tr>
<td>Ruminating dairy cattle older than 4 months</td>
<td>Grain and grain byproducts *</td>
<td>10 ppm (5 ppm)**</td>
</tr>
<tr>
<td>Distillers grains, brewers grains, gluten feeds, and gluten meals *</td>
<td>Ruminating beef and feedlot cattle older than 4 months, and ruminating dairy cattle older than 4 months</td>
<td>30 ppm</td>
</tr>
<tr>
<td>(10ppm beef/feedlot)**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5ppm dairy)**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All other animals</td>
<td>Grain and grain byproducts not to exceed 40% of diet</td>
<td>5 ppm (2 ppm)**</td>
</tr>
</tbody>
</table>

* 88 percent dry matter basis ** Complete diet figures shown within parentheses
(Source: National Grain and Feed Association)
To sample grain for mycotoxin testing from a moving grain stream, take a composite sample of 10 lbs using a diverter-type mechanical sampler. If a mechanical sampler is not available, take a fistful of seeds carefully from the grain stream (avoid personal injury) and collect 10 lbs. For stationary corn, use a grain probe, and sample the load at several locations until a composite sample of 10 lbs is collected. With any sampling method, care should be taken to obtain a representative sample of the entire load. Representative samples can be sent to diagnostic labs for mycotoxin analysis. The South Dakota State University Plant Disease Clinic performs these tests and seed can be mailed to:

SDSU Plant Disease Clinic
SPSB 153 Jackrabbit Drive, Box 2108
Brookings, SD 57007.

Reducing Mycotoxin Development in Grain

All ear rot pathogens are abundant in the environment and therefore development of ear rots is driven by favorable conditions (dry and hot for Aspergillus ear rot; hot for Fusarium ear rot; and cool and wet for Gibberella ear rot). Many ear rot pathogens also survive on infested residue. The following practices can reduce chances of mycotoxin development on corn.

• Use crop rotation to reduce ear rot fungal pathogens inocula.
• Minimize yield-limiting factors by selecting an appropriate hybrid for the field, timely seeding, planting at suitable population, using adequate fertility, and controlling pests and diseases.
• Manage insect pests to minimize insect injury to ears and kernels.
• Scout fields before harvesting to determine the level and type of ear rots.
• Minimize kernel damage during harvest by adjusting combine settings to prevent damage.
• Harvest early to avoid continued development of ear rots, and consequently mycotoxin production, when risk of disease and contamination are high.
• If mycotoxin problems are suspected, screen the kernels to remove cracked kernels.
• Dry grain to < 15% moisture immediately after harvest (within 24h) and before storage.
• Clean combines, carts, augers, and bins with pressurized air to avoid cross-contamination.
• Regularly check bins during storage to ensure molds are not developing during storage.
References and Additional Information


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The outbreak and severity of corn diseases are dependent on environmental conditions (weather, temperature, wind, rain, etc.), choice of cultural practices (no-till/minimum till, corn on corn, etc.), and the hybrid grown. Thankfully, due to corn genetic resistance and low disease pressure, South Dakota producers generally have minimal yield loss due to diseases. However, problems can exist when there are sources for the pathogen, and the climatic conditions favor rapid disease development (warm [> 75°F] and high relative humidity). In many fields, the source of the pathogen is from surface residue of susceptible plants or the soil. In some years and under specific practices such as no-till combined with corn-on-corn rotation, diseases can cause significant yield losses. To select corn hybrids that will optimize yield and minimize disease problems, it is important to understand the pathogen biology and the field history. The purpose of this chapter is to discuss how to identify corn diseases and to provide management strategies. We will discuss fungal, bacterial, nematode, and viral pathogens, which cause seed and seedling diseases, leaf diseases, stalk rots, ear rots, mycotoxins, and reduce plant vigor. Chemical control options for fungal diseases are available online at iGrow.org. The pest-management guides are updated annually. Fungicides are not effective against bacteria and viruses.

**Fungal Foliar Diseases**

There are several fungal pathogens that can infect corn and may cause significant yield losses in South Dakota if the right conditions occur. Yield reductions are related to hybrid susceptibility, cultural practices, inoculum presence, weather conditions, and timing of infection. Because most fungal pathogens are residue-borne – unlike rusts that must be blown up on southerly winds – fungal disease management includes residue management through crop rotation and tillage (where applicable), hybrid selection, and fungicide application.

**Anthracnose Leaf Blight**

Anthracnose infection tends to be high in continuous cornfields and plants that are potassium deficient. This disease is most prevalent on young corn plants when leaves are closer to the soil surface. Anthracnose of corn is caused by the fungus *Colletotrichum graminicola* and overwinters on infected corn residues (leaves and stalks). Splashing rain and wind carry the conidia spores to young corn plants where primary infection takes place. Disease development is favored by warm, moist weather (70-85°F) and high humidity.
The symptoms are oval-shaped lesions that are approximately ~1/2-inch long with a dark brown border, which is surrounded by a yellow halo (Fig. 47.1a). Under magnification (20X hand lens), small, black spines (setae, which resemble porcupine-like structures) may be observed on the dead tissue/lesion (Fig. 47.1b).
1. Select resistant varieties. Scout and keep records of diseases occurring in your field and select hybrids with good tolerance or resistance to the diseases in your area.
2. Consider residue management. If high levels of infection were present in the current year, consider doing a tillage operation to bury residue. Burying residues will help reduce the amount of inoculum in the field. The anthracnose pathogen survives on infested cornstalk residue.
3. Practice crop rotation. Rotating away from corn allows the residue to break down and therefore helps to reduce the inoculum level in the field. For fields with a history of severe corn diseases, longer rotations (> 2 years) out of corn can reduce the risk of disease development.

Common Rust
Common rust of corn is caused by the fungus *Puccinia sorghi*. Urediospores of the fungi are blown north from Mexico and the Gulf states on the wind currents where they are deposited into South Dakota cornfields. Common rust prefers cool temperatures (60-76°F) and approximately six hours of moisture (dew, humidity) for optimal infection. Common rust occurs very frequently in South Dakota. The symptoms of common rust are small raised spots (pustules) that are a dark, reddish-brown color and are oval to elongate in shape. These pustules are scattered over both the upper and lower surface of the corn leaves (Fig. 47.2).

Because this pathogen does not overwinter in South Dakota, rotations and tillage are not effective control methods. The management for common rust includes:
1. The use of resistant hybrids. Resistance ratings may not be available for all hybrids as common rust is rarely economically damaging (Fig. 47.2).
2. Scout for early detection. Fungicides can be used to control common rust if the disease is rapidly increasing. Fungicides can be economical especially on seed corn production fields.
Southern Rust
Usually southern rust reaches South Dakota when corn is around dent growth stage and rarely does it develop to reach yield-reducing levels. Southern rust is caused by the fungus *Puccinia polysora*. Urediniospores of the fungus are blown north from Mexico and the Gulf states on the wind currents where they are deposited into South Dakota cornfields. Southern rust prefers warmer temperatures (77-82°F) and approximately six hours of moisture (dew, humidity, free fall moisture, irrigation) for optimal infection.

The symptoms include small raised spots that appear primarily on the upper leaf surface, orange to light brown in color, and are usually densely packed on a leaf surface (Fig. 47.3a). Southern rust can be differentiated from common rust by color (light brown vs. dark red), distribution on the leaf surface (packed vs. random), halo around pustules (present vs. absent) (Fig. 47.3b), and the rapturing of the leaf surface by pustules (limited vs. extensive).

Common Smut
Corn smut is commonly observed in corn (dent, sweet, and popcorn) in South Dakota. However, corn smut is not usually an economically damaging disease. Corn plants generally are infected early in the growing season. Yield losses have been reported to be as high as 20% some years. Common smut of corn is caused by the fungus *Ustilago maydis*. Immature corn smut galls (called huitlacoche) are treated as a delicacy in Mexico. Spores from the common smut galls overwinter in the soil. These overwintering spores are called teliospores. Teliospores can be blown long distances with soil particles or carried into a new area on unshelled seed corn, and in manure from animals that are fed infected cornstalks. Spores germinate with moisture and air temperatures between 50-95°F. Common smut is most severe when young, actively growing plant tissues are wounded (Fig. 47.4).
The symptoms for common smut include the development of a smut gall. A smut gall is composed of a mass of black, greasy, or powdery spores enclosed by a smooth, greenish-white to silvery-white membrane (Fig. 47.4a). As the spores mature, the outer covering of the gall becomes dry and papery and disintegrates, releasing the spores. Any portion of the corn plant located above ground can become infected, including, tassels, ears, leaves (Fig. 47.4b), and areas near the stem nodes and aerial roots.

Management of common smut includes:
1. Maintain appropriate soil fertility levels.
2. Avoid injury to roots, stalks, and leaves during cultivation.
3. Use smut-resistant hybrids. Dent corn tends to be more resistant to corn smut than popcorn or sweet corn.
4. Seed treatment for grain harvested from cornfields with moderate incidence of common smut.
5. Use rotations and tillage to reduce spore populations.

Crazy Top
Young corn plants subjected to saturated soil conditions are prone to crazy top infection. This is a rare disease on corn in South Dakota but is observed occasionally on a few scattered corn plants along a field edge. Crazy top is caused by the soil-borne fungus *Sclerophthora macrospora*. This fungus attacks all types of corn and a number of wild grasses. Infected grasses at the edge of the field also serve as an additional inoculum source. Crazy top develops when soils have been flooded shortly after planting or before plants are in the four- to five-leaf stage. The crazy top pathogen survives in the soil as oospores. These germinate into sporangiospores. It is the sporangiospores that produce zoospores that swim in a film of water and infect young developing corn plants.

The most common characteristic of this disease is proliferation of the tassel, where instead of a normal tassel a mass of leafy structures develops (Fig. 47.5a). Sometimes infected plants may have excessive tillering and multiple small ears. Leaves of severely infected plants may show chlorotic striping (Fig. 47.5b).

The management for crazy top includes:
1. Providing adequate soil drainage. This will reduce the risk of flooding and subsequent infection.
2. Do not plant corn in low, wet spots – especially if the disease has occurred in the area before.
3. Control grassy weeds (witchgrass, foxtails, crabgrass and barnyardgrass can be infected). This fungus attacks corn and grassy weeds; controlling the weeds will reduce the inoculum buildup.
4. Seed treatment will not control crazy top of corn.

Eye Spot
Eye spot is a residue-borne disease and can be a problem in continuous cornfields and in reduced-tillage systems. Eye spot is caused by the fungus *Aureobasidium zeae* (previously known as *Kabatiella zeae*). The spores produced by this fungus are widely distributed by wind. Infection takes place during cool, wet weather. The fungus overwinters on corn residue. In the spring, the fungus produces spores that are carried to the new corn crop. The fungus may also be seed-borne, but this source of fungal inoculum
Eye spot symptoms include small circular spots (lesions) about 1/8-inch in diameter (Fig 47.6). The central area of the spot dies, leaving a tan to cream-colored center surrounded by a distinct brown to purple border. The border is frequently encircled by a yellow halo that is easily seen when the leaf is held to the light.

Eye spot can be most severe in reduced-tillage systems where the crop residues are left on the soil surface. Management for eye spot includes:
1. Plant corn hybrids that have resistance to eye spot. Resistant hybrids are the main line of defense against this disease.
2. Practice crop rotation. Rotating away from corn helps to reduce the inoculum level in the field.
3. Consider residue management. Burying residues will help reduce the amount of inoculum in the field.
4. Fungicide can be used to control eye spot. Fungicides can be economical especially on seed corn production fields.

**Gray Leaf Spot**
Hybrid susceptibility and weather strongly influence gray leaf spot development. Gray leaf spot can develop to reach economically damaging levels especially in no-till corn-after-corn fields. Gray leaf spot is caused by the fungus *Cercospora zeae-maydis*. The fungus overwinters on infected corn residue at the soil surface. Infection takes place during prolonged warm (75-90°F) and humid conditions (> 90% relative humidity) with leaves remaining wet (from dew, irrigation, or rainfall) for twelve hours or more.

Gray leaf spot early infection symptoms are small, pinpoint lesions. Early symptoms can be easily confused with those of other diseases such as eye spot, anthracnose, and mature common rust lesions with no pustules. As lesions mature, they elongate and turn brown to gray in color. These lesions are often bound by the veins on the leaf (Fig. 47.7). Under favorable conditions, lesions can coalesce to form large, irregular areas of dead tissue on the leaves.

Gray leaf spot can reduce corn yields. Hot, dry weather will slow disease spread. Management of gray leaf spot includes:
1. Planting resistant cultivars.
2. Practice residue management. Burying the residues will help reduce the amount of inoculum from building up in the field.
3. Use crop rotations.
4. Scout the field from VT to R1 and use fungicides if the infestation is greater than the economic threshold (lesions on third leaf below the ear leaf or higher on 50%) and if a susceptible hybrid was seeded. Under moderate disease pressure, timely fungicide applications can greatly minimize the impact on yield.

**Northern Corn Leaf Blight**
New northern corn leaf blight lesions can produce spores in as little as 1 week, allowing northern corn
leaf blight to spread much faster than many other corn leaf diseases. Spores of the fungus are spread by wind and rain splash. Northern corn leaf blight is caused by the fungus *Exserohilum turcicum*, previously called *Helmithosporium turcicum*. The fungus overwinters as mycelia and conidia on corn residues left on the soil surface. During warm, moist weather in early summer, new conidia are produced on the old corn residue, and the conidia are carried by the wind or rain to lower leaves of young corn plants. Infection by germinating conidia occurs when free water is present on the leaf surface for 6- to 18-hours and the temperature is between 65°F and 80°F. Lesions develop within 7-12 days. Secondary spread within fields occurs by conidia produced on the leaf tissues. Conidia can be carried by wind over long distances where infection can occur in other fields. In this case, lesions may develop in the mid- to upper canopy.

The symptoms associated with northern corn leaf blight are often referred to as cigar-shaped lesions (Fig. 47.8). They are typically 1- to 6-inches long, gray-green to tan-colored, and often observed on the lower leaves. As the disease develops, the lesions spread to all leafy structures, including the husks. The lesions may become so numerous that the leaves are eventually destroyed causing major reductions in yield due to lack of carbohydrates available to fill the grain. The leaves then become grayish-green and brittle, resembling leaves killed by frost. Yield losses can reach as high as 30-50% if the disease establishes itself before tasseling.

Management systems that leave corn residues on the soil surface can have a high risk of this disease. The fungus prefers wet areas in production fields. Hot, dry weather slows disease growth. Management for northern corn leaf blight includes:
1. Planting resistant hybrids to northern corn leaf blight. This is the most effective form of northern corn leaf blight control.
2. Utilizing fungicide application when warranted. Numerous fungicide trials across the Midwest have found that products that contain a triazole are usually more effective than those that do not contain this chemistry.
3. Practicing crop rotation. Rotating away from corn helps to reduce the inoculum level in the field. The longer the rotation, the more benefits from rotation.

**Physoderma Brown Spot**

Physoderma brown spot is of minor importance on corn in South Dakota but occasionally can develop in corn when rainfall is abundant in spring and the mean temperature is high (73-86°F). Physoderma brown spot is caused by the fungus *Physoderma maydis*. The fungus overwinters as thick-walled sporangia in infected tissue or soil that germinate under moisture and light to produce zoospores. Zoospores swim in water and when in contact with leaf surface of young corn leaves, infection is initiated. Corn plants are most susceptible 50- to 60-days after germination and they become resistant with age. Standing water in the leaf whorls for at least 24 hours and high temperatures are required for infection to take place.

Corn plants infected with Physoderma maydis develop very small oblong to round, yellowish spots on lead blade, leaf sheath, stalk, and sometimes on the outer ear husk and tassels. Infected tissues turn chocolate brown to reddish brown and coalesce to form large irregular blotches. Stalks infected at the nodes beneath the sheaths often break and result in heavy lodging (Fig. 47.9)

This disease can survive for 3 years on corn residue and in soil. Management should include the use of crop rotations to reduce inoculum, and the use of tillage to bury crop residues.
Fungal Stalk Rots

Stalk rots are among the most common and damaging of the corn diseases. Yield losses (5-20%) result from premature plant death and lodged plants. Stalk rot diseases are primarily caused by fungi that commonly occur in the field. Typical stalk rot symptoms include wilting plants with leaves that turn color (gray or brown), pith discoloration (lower internodes of the plant darken to tan or brown), and roots that may decay.

**Anthracnose Stalk Rot**

Anthracnose stalk rot of corn is caused by the fungus *Colletotrichum graminicola*, which overwinters on infested corn residues (leaves and stalks). This is the same fungus that can cause anthracnose leaf blight (see description above). However, presence of the leaf blight phase does not necessarily lead to stalk rot phase. The fungus produces reproductive structures, called acervuli, which contain setae (porcupinelike structures). Conidia, fungal reproductive spores, are produced in large quantities in the acervuli and infect new plants. Splashing rain and wind carry the conidia spores to young corn plants where primary infection takes place. Disease development is favored by warm, moist weather (70-85°F) and high humidity. Anthracnose stalk rot is one of the most important stalk rot diseases in the United States.

The symptoms for anthracnose stalk rot are stalks that often have shiny, black lesions on the stalk’s outer rind (Fig. 47.10).

Anthracnose stalk rot management should include:

1. The use of resistant hybrids. If available, resistant hybrids are effective at managing anthracnose stalk rot.
2. The use of a balanced soil fertility program. Ensure optimal levels of nitrogen (N) and potassium (K) are maintained in the soil.
3. Consider lowering the plant populations. High plant populations tend to have an increased severity of stalk rots.
4. Tillage to reduce surface residues. Burying crop residues can reduce the fungus survivability in the soil.

5. Control foliar diseases. High foliar disease severity may weaken the stalk making it more prone to stalk rot development.

**Charcoal Rot**
This pathogen also causes stalk and stem rot of alfalfa, sorghum, and soybean. Although this disease has been found on corn in South Dakota, its incidence and severity remain very low.

Charcoal rot is caused by the fungus *Macrophomina phaseolina*, and it is often called the dry weather wilt. Charcoal rot typically affects prematurely senescing plants that are under drought stress. Disease development is ideal when soil is dry and soil temperatures are 90°F or higher. The signs of charcoal rot include sclerotia, which are tiny, black, round, survival structures produced by this fungus (Fig. 47.11). When sclerotia are produced inside the stalk it gives the appearance of charcoal dust (hence how this disease got its name). Rotating the field into soybeans may not help with disease control because soybeans generally support a higher microsclerotia population than corn. Seed treatments may not be effective against this disease.

Management should include the use of resistant hybrids, if they are available, and adjusting planting date to coincide with greater moisture availability.

**Diplodia Stalk Rot**
Diplodia used to be one of the most common and damaging stalk rots found in corn, but now anthracnose and Fusarium stalk rots have increased in incidence and exceed Diplodia in the Midwest. Corn is the only host of this pathogen. Infection is favored by wet, warm conditions shortly after pollination.

The fungus, *Diplodia maydis* (also known as *Stenocarpella maydis*), causes both Diplodia stalk and ear rot of corn. The fungus overwinters on crop residue. Conidia (produced in the pycnidia) can be splashed onto other areas of the plant. Infection at the nodes below the ear results in stalk rot, whereas infection of the silks and husks will cause ear and kernel rot. Injury by birds and insects also favor infection.

The symptoms for Diplodia stalk rot are wilted plants with shredded pith tissues. On the outside of the stalk, minute, dark brown/black pycnidia (reproductive structures) are embedded in the rinds (Fig. 47.12). The pycnidia feel rough and cannot be easily dislodged from the surface (unlike the perithecia in Gibberella stalk rot). Infected plants may have stalks that are easily broken. Diplodia stalk rot can result in low test weights, high harvest losses, and reduced harvest speeds.

Management should include: 1) the planting of corn hybrids with corn borer resistance and high scores for stalk strength as planting these hybrids minimizes wounds caused by insects; 2) crop rotation and tillage to reduce corn residue on the soil surface, and a 3) balanced fertility program.

**Gibberella Stalk Rot**
Gibberella stalk rot is one of the most common stalk rots in the corn belt. Gibberella stalk rot is caused
by the fungus *Gibberella zeae*, which is called *Fusarium graminearum* in its asexual stage. This fungus is also a common seedling pathogen of corn and soybeans, and the causal pathogen of Fusarium head blight (scab) of wheat, barley, oat, and rye. The symptoms are a pinkish-red discoloration of the inside the cornstalk (Fig. 47.13). Perithecia (reproductive structures) may be observed on the surface of the stalk rind as small, round, black specks often near a node and are easily scratched off. Perithecia overwinter on the crop residue and act as the primary inoculum for the next growing season. This pathogen causes both ear rot and stalk rot of corn. Disease development is favored by warm, wet conditions. Stalk breakage and lodging often occur due to this disease. To manage Gibberella stalk rot, plant hybrids with good stalk strength and corn borer resistance, rotate crops, control the surface residues, use management practices that minimize yield limiting factors, and schedule harvest based on stalk strength.

### Fusarium Stalk Rot

Fusarium stalk rot is one of the most difficult diseases to diagnose. This pathogen is usually suspected after the diagnostic characteristics of the other stalk rot pathogens have been ruled out. This fungus infects sorghum, sugarcane, wheat, cotton, pineapple, and tomato. It overwinters on the infected surface residues. Corn borer adults can spread the disease in the cornfield.

Fusarium stalk rot is caused by many different Fusarium species, including *F. verticillioides*, *F. proliferatum*, and *F. subglutinans*. Fusarium stalk rot is favored by dry weather prior to silking and warm, wet weather after silking. The symptoms are white fungal growth on the outside of the stalk (Fig. 47.14). Infected plants may have poor kernel quality and test weights.

The management for Fusarium stalk rot includes using a hybrid with good stalk strength and disease resistance, crop rotation, tillage to facilitate the breakdown of crop residues, planting at an appropriate seeding rate, soil tests, and application of appropriate amounts of K and N, insect control, and scouting to assess stalk conditions. If conditions are favorable for stalk rot development, field scouting is critical for determining which fields should be harvested first to avoid or minimize plant lodging and ear drop.

### Scouting for stalk rots

The most common method used while scouting for stalk rots is the Push or Pinch Test. For this test, walk through a cornfield and randomly select a minimum of 100 plants representing a large portion of the field (10 plants at 10 random stops in the field). To test for stalk rot:

1. Push the plant tops approximately 30 degrees from vertical. If plants fail to snap back to vertical, the stalk has been compromised by stalk rot.
2. Pinch or squeeze the plants at one of the lowest internodes above the brace roots (pinching the same internode on each plant). If the stalks crush easily by hand, their integrity has been reduced by stalk rot.

If > 10% of plants exhibit stalk rot symptoms, harvest that field first to reduce the potential for plant lodging and yield loss.
Corn Ear Rots
Fungi cause several ear and kernel rots in corn that may result in yield loss, both in quantity and grain quality. In terms of quality, many ear rot pathogens also produce mycotoxins (see Chapter 46 on mycotoxins) that can affect feed value and marketability of the grain. Development of ear and kernel rots is enhanced by stalk lodging, and insect and bird injury. Weather also plays a major role in what type ear rot is likely to develop.

Gibberella Ear Rot
Gibberella ear rot, also called red rot, is quite common in corn especially under prolonged rainy weather late in the growing season. Its symptoms are characterized by a reddish mold that appears at the tip and grows down the ear (Fig. 47.15). If infected early, the entire ear may rot and be covered with a pinkish mycelium that causes the husk to tightly adhere to the ear. Gibberella ear rot is caused by Gibberella zeae. This pathogen overwinters on corn debris and has a wide host range including small grains. In wheat, this pathogen results in Fusarium head blight. The fungus infects the ear through silks and progresses down the ear. The disease is favored by cool, wet weather just after silking. Corn following corn is more prone to Gibberella ear rot development. This fungus produces mycotoxins (deoxynivalenol (DON) and zearalenone) in infected grain.

This disease reduces yield, test weight, and storage life. If grain is contaminated with mycotoxins, it may be unsuitable for many uses. Management of this pest includes:
1. Select resistant hybrid, husk tightness and hybrids that dry-down rapidly.
2. Scout fields prior to harvest to identify high-risk areas.
3. Adjust the combine to minimize kernel damage.
4. Dry infected corn to 15% moisture or less.
5. Use residue management through tillage and rotation to reduce inoculum load.

Fusarium Ear Rot
Fusarium ear rot develops under hot dry weather and occurs at and after flowering. Infection can occur through the silks but damage by birds, insects, or hail increase chances of infection (Fig. 47.16). Several Fusarium species cause ear rot, but the most common species are F. verticillioides and F. proliferatum. These Fusarium species overwinter in corn residue from corn and other plants. The fungus infects corn ear through silk and wounds, and it can enter the ear through hail damage or wounds from feeding insects. Occasionally, Fusarium stalk rot can develop systemically and cause ear rot. These Fusarium species also produce mycotoxins (Chapter 46).

The symptoms vary greatly depending on the genotype, environment, and disease severity. Individual infected kernels can be scattered in the ear, and under severe conditions, the fungus may consume the entire ear. Infected kernels have whitish pink to lavender fungal growth.

This disease reduces yield and grain quality. The kernel can be completely consumed by fungus and be contaminated with mycotoxins (fumonisins), which can be fatal to
livestock (horses and pigs). Management for this disease includes:
1. Selection of resistant hybrids. The relative rating should be based on previous history. If this has been a problem in past years, select hybrids with high scores for ear rot resistance.
2. The use of tillage and rotation to reduce pest populations and overwintering.
3. The control of insects that can cause wounds.
4. Store infected grain separately to avoid infecting the entire bin.
5. Dry grain to < 15% moisture if grain is to be stored through the next summer.

**Diplodia Ear Rot**
Diplodia ear rot develops in cornfields with history of this disease and when weather is wet and warm around the silking time. Diplodia ear rot is caused by *Diplodia maydis* (also known as *Stenocarpella maydis*). Infected corn residue is the main source of inoculum. Ears are most prone to infection about three weeks after flowering when the silk dies off. Conidia are spread through splashing rain during wet weather. Corn is the only known host of this disease. The infected ears have husks that appear bleached to straw-colored and can be seen from a distance with dead ear leaf. Unlike Gibberella ear rot, Diplodia ear rot starts at the base of the cob (47.17). Infected kernels are dull gray to brown. If infection occurs several days after flowering, the ears do not show external symptoms, but white fungal mycelium may be seen between the kernels.

This disease reduces yields, kernel size, and test weight. The management of Diplodia ear rot includes the selection of resistant hybrids. In fields with previous history of this disease, select hybrids with greater resistance.
1. The use of crop rotation and tillage to reduce inoculum.
2. Grain from infected fields should be dried to a moisture content < 15% as quickly as possible.
3. Grain from infected fields should be cleaned to remove damaged kernels.

**Aspergillus Ear Rot**
Aspergillus ear rot is most important ear disease because of the production of aflatoxins that are dangerous to humans and animals (Chapter 46). Two common species *Aspergillus flavus* and *A. parasticus* infect corn. Of these, *A. flavus* is the most predominant species. The fungus overwinters in the soil and debris and infection is favored by hot, dry weather. The fungus is spread to silk by wind or insects. This disease can be important under drought conditions. Insect damage predisposes the kernels to infection and consequent Aspergillus ear rot development. In most cases only a few kernels on an ear are infected. Infected kernels have masses of olive to yellow-green spores on and between them (Fig.47.18). Usually the tip of the ear is where infected kernels tend to concentrate but any other part of the ear can be infected. Sporulation of the fungus is most evident on kernels that were injured. However the fungus can also be present on kernels without showing symptoms.

If Aspergillus ear rot is present in a field, the grain needs to be tested for aflatoxins. If concentrations are > 20 ppb the grain cannot be sold or transported across state lines. The blending of corn to reduce concentrations is prohibited for interstate trade. If the grain is used for ethanol production, the distillers...
grain will have elevated aflatoxin levels. The risk of this disease can be reduced by:
1. Selecting appropriate hybrids. Most seed corn companies do not rate hybrids for Aspergillus ear rot resistance. Hybrids with good drought resistance should provide some protection.
2. Use management techniques that increase water use efficiency, such as a balanced soil fertility program, and seeding at appropriate rates and dates.
3. Control insects to prevent injury to ears.
4. Practice tillage to reduce the inoculum.
5. If the grain is harvested from infected fields, use techniques that minimize kernel damage, harvest the grain separately, screen the grain to remove broken kernels, control insects, and maintain low temperatures and moisture during storage.

Bacterial Diseases
Bacterial diseases can be destructive if infections are severe and widespread. The selection of resistant hybrids and the use of other integrated pest management strategies are the cornerstones for controlling bacterial diseases. There are four bacterial diseases that occur on corn in South Dakota: Goss's wilt, Holcus leaf spot, bacterial stalk rot, and Stewart's wilt.

Goss's Bacterial Wilt and Leaf Blight
Goss's wilt has increased in occurrence in South Dakota. Continuous corn production especially under irrigation increases the spread of this disease. Additional hosts for this pathogen include green foxtail, shattercane, barnyardgrass, and other common grass species.

Goss's bacterial wilt and leaf blight of corn (Goss's Wilt) is caused by the bacterium *Clavibacter michiganensis* subsp. *nebraskensis*. The bacteria overwinter on infested crop residue on the soil surface from which they are splashed onto growing corn plants. The bacteria enter the plants either through their natural plant openings or wounds created by hail, heavy rainfall, sand blasting, high winds, and insect feeding. Disease development is favored by high humidity (moisture) and temperatures of 80°F.

The symptoms for Goss's bacterial wilt and leaf blight are foliar (leaf) blight (Fig. 47.19a) and a systemic wilt (Fig. 47.19b). Leaf blight is more common than systemic wilt. Lesions may be gray to tan in color with wavy, irregular margins that follow the leaf veins. The most obvious characteristics are the dark green to black water-soaked lesions often called “freckles” that appear on the infected area. Another characteristic of Goss's wilt is the bacterial ooze that may be found on the leaf surface. On the leaf surface, dry bacterial
Ooze may appear to shine and glisten in the sunlight. An easy technique to use when looking for the freckles is to use a lighted flashlight on the underside of the lesion or hold the leaf up to the sunlight so it is backlit. The dark freckles will appear translucent.

The risk of this disease is greater in corn-on-corn fields with high residues on the soil surface. The management of this bacterial disease includes:

1. The use hybrids tolerant of Goss's wilt. Check with your seed dealer for Goss's wilt ratings.
2. The use of rotations and tillage to reduce inoculum. Any type of tillage that buries infested residues and encourages residue decomposition will help reduce the inoculum level in the field. Rotating to a nonhost crop such as soybean, small grains, alfalfa, or dry bean will help reduce primary inoculum in the corn residues, but rotation will not completely eliminate the bacteria.
3. Control grassy weeds. Grassy weeds serve as additional hosts for Goss's wilt so weed control is important for disease control.
4. Fungicide applications are not effective against this bacterial disease. There are no in-season control measures available for the prevention or spread of Goss's wilt.

**Holcus Leaf Spot**

Holcus spot symptoms can resemble chemical injury to leaves, similar to paraquat drift. Holcus spot is occasionally observed in South Dakota and typically does not reduce yield or reduce grain quality. The pathogen is caused by a bacterium called *Pseudomonas syringae pv. syringae*, which overwinters in crop debris. Wounds caused by hail, blowing soil or wind can increase chances of infection. Warm (75-85°F), wet, windy conditions early in the season favor infection and the development of Holcus leaf spot. The pathogen has a wide host range including many grasses and dicots. It can have ice nucleating activity that may enhance frost injury to corn leaves. Holcus spot symptoms first appear as water-soaked, dark green lesions near the tips of lower leaves. They then develop into round or elliptical, tan to white spots that are 1/8 to ½” in diameter (Fig. 47.20). Red to brown margins develop around the spots, which may be surrounded by yellow halos. The management for this bacteria should include the use of crop rotations and tillage to bury the crop residue. The use of fungicides will not be effective against this bacteria.

**Stewart's Disease or Stewart's Wilt**

This disease is somewhat unique because its spread depends almost completely on an insect vector, the corn flea beetle. Stewart's wilt is occasionally observed in South Dakota. The use of seed treatment insecticides has reduced the occurrence of the disease. Infection occurs in plant tissues that are wounded during feeding by the corn flea beetle (*Chaetocnema pulicaria*). The corn flea beetle is the overwintering host and vector of the bacterium *Pantoea stewartii*, formerly called *Erwinia stewartii*, the bacterium that causes Stewart's wilt.

There are two phases of Stewart's wilt that occur on corn: the seedling wilt phase (occurs when young plants are infected systemically) and the leaf blight phase (occurs when the plants are infected after the seedling stage). In either case, symptoms appear as leaf lesions originating from flea beetle feeding scars. The bacteria overwinter in the insect gut. Leaf tissue surrounding feeding wounds initially become water-soaked. Pale-green to yellow linear streaks with irregular or wavy margins develop parallel to leaf veins. These lesions become necrotic with age and may extend to the entire length of the leaf on susceptible cultivars. When plants are infected systemically, symptoms appear on new leaves emerging from the plant whorl, and cavities may form in the stalks near the soil line. Bacteria spread throughout the vascular system of infected plants and occasionally infect kernels.

![Figure 47.20 Holcus spot in corn. (Courtesy of Emmanuel Byamukama)](image)
Foliar symptoms of the leaf blight phase are similar to those of the seedling wilt phase. Chlorotic or necrotic tissues may extend the entire length of leaves, or symptoms may be limited to a few inches depending on the susceptibility of the cultivar. Premature leaf death due to Stewart’s wilt may predispose the weakened plant to stalk rot resulting in reduced yields.

The bacteria will reduce yields for several reasons. First, early season infection reduces the plant population. Second, the disease reduces leaf area and sugar production, and consequently, the risk of stalk rot is increased. Management for this disease includes:

1. The use of resistant varieties. Stewart’s wilt is controlled effectively by planting resistant corn hybrids.
2. The control of corn flea beetles. This should include scouting and the application of appropriate insecticides, if needed.
3. Use of pathogen-free seed. The bacterium can be excluded from areas where it does not already occur by ensuring that the seed is pathogen-free.
4. Fungicides are not effective against this bacterial disease.

**Bacterial Stalk Rot**

Bacterial stalk rot typically develops midseason rather than at the onset of senescence. It is more common in irrigated corn when an open well is the source of irrigation water. Bacterial stalk rot is caused by the bacterium *Erwinia chrysanthemi pv. zaeae*. Infection is associated with warm temperatures (90-100°F) and high humidity. This pathogen overwinters only in stalk tissues above the soil surface. Infection can initially take place at the top or bottom of the plant. Early symptoms consist of plant lodging and dark brown, water-soaked lesions that progress to soft or slimy stalk tissues, which appear at stalk internodes located above the ground (Fig. 47.21). A foul odor often accompanies infected plant tissues. The management for bacterial stalk rot should include the use of tillage to bury surface residues and soil drainage to reduce disease incidence. Fungicides are not effective against this disease.

**Corn Nematodes**

Corn nematodes are microscopic, unsegmented roundworms that either feed inside the corn roots (endoparasites) or feed outside the corn roots (ectoparasites). Nematodes feed on root cells by puncturing the cell walls with their hollow stylets, which resemble minute hypodermic needles.

Nematodes cause yield losses in corn in two ways: directly, by injuring cells and using up cell metabolites; and indirectly, by creating wounds that become entry points for bacterial, fungal, and viral pathogens. Over a dozen nematodes have been found to infect corn in South Dakota and the extent of yield loss will depend on the type of nematode, the population density in the soil, soil type (sandy soils tend to support high population densities of certain nematodes), and other stresses such as fertility and moisture stress. The most common groups of plant parasitic nematodes found on corn are lesion (Pratelenchus), dagger (Xiphinema), lance (Hoplolaimus), needle (Longidorus), stubby root (Trichodorus and Paratrichodorus), and stunt (Tylenchorhynchus) nematodes.

Although several nematodes can be found infecting corn, few are of major concern in South Dakota. However, producers are encouraged to sample and test soil from low-yielding spots for corn nematodes.
Diagnosis of nematodes should not be based solely on plant symptoms because these can be caused by other problems such as low fertility, poor drainage, drought, herbicide injury, or other pathogens, including fungi and viruses. Under high nematode population density, the following symptoms may be displayed:

- Stunted plants and uneven plant height along the rows (Fig. 47.22).
- Yellowing of plants.
- Poor ear fill.
- Root necrosis and stubby roots (Fig. 47.23).

Management for corn nematodes includes:
1. Test soil for corn nematodes, especially if corn plants are stunted, yellowing (Fig. 47.22.), and have necrotic roots. Carefully dig up affected corn plants and send them to the South Dakota State University Plant Diagnostic Clinic for nematode extraction before corn reaches the V6 stage of development.
2. Practice crop rotation to check or reduce nematode population density.
3. Use nematicide seed treatment in areas where nematode population density is high. Though several reports show no consistent yield benefit with a nematicide seed treatment in corn, these may reduce high nematode population densities.

Viral Diseases
There are three viruses that are occasionally found infecting corn in South Dakota: wheat streak mosaic virus (WSMV), maize dwarf mosaic virus (MDMV), and brome mosaic virus (BrMV). Viruses are obligate pathogens that cannot be grown in artificial culture, cannot be seen with the naked eye, and must always pass from living host to living host in what is referred to as a “living or green” bridge.Managing corn viruses requires that the living bridge of hosts be broken. Fungicides and bactericides cannot be used to manage viral problems in corn.

Wheat Streak Mosaic Virus
Wheat streak mosaic virus (WSMV) was first observed in Nebraska in 1922. WSMV has been observed in varying degrees in South Dakota. WSMV is the most important endemic (always here, but varies in amount) viral disease in wheat but it rarely is observed or causes measurable yield loss in corn. The pathogen causing this disease is Wheat streak mosaic virus (WSMV). WSMV is transmitted by the wind-blown wheat curl mite (Aceria tosichella Keifer). Both the mites and virus survive South Dakota winters on seeded and volunteer winter wheat and perennial grasses. Corn serves as a host for the mites after wheat harvest until a new crop of wheat emerges. The symptoms for wheat streak mosaic virus include a red streak in the kernel (Fig. 47.24). This streak is a response to a toxin that is found in the mites’ saliva. The management of wheat streak mosaic virus includes:

1. The control of grassy weeds and volunteer wheat. Break the living bridge by controlling the grassy weeds and volunteer winter wheat. This prevents the mites from spreading the virus as the mites and virus cannot survive more than a day without a living host.
2. The use of resistant varieties/cultivars. If planting wheat, use the most tolerant/resistance cultivars/ hybrids available in your area.
Maize Dwarf Mosaic Virus
Maize dwarf mosaic virus (MDMV) is rarely observed in South Dakota. MDMV is vectored by many species of aphids, most commonly the corn leaf aphid, the greenbug, and the green peach aphid. MDMV can also infect Johnson grass and sorghum. The symptoms include small, chlorotic spots that are observed on green, young leaves that later develop into a mottle or a mosaic pattern along the veins of leaves, leaf sheaths, and husks. As infected plants continue to grow and the temperature rises, the mosaic symptoms may disappear while the young leaves become more yellow. Plants may be stunted, excessive tillering may occur, and poor seed set may take place. Management should include the use of tolerant hybrids, the control of the insect vector, and the control of Johnson grass.

Brome Mosaic Virus
Brome mosaic virus (BrMV) is transmitted by nematodes in the Longidoridae family. BrMV infects several grass species, and tillage along the field edges may move nematodes to the field. This virus is not common, but sometimes corn plants near field edges can be infected. Infected plants are stunted and leaves have mosaic, chlorotic streaks on the entire leaf (Fig. 47.25). Infection is systemic (throughout the entire plant) and infected plants do not produce an ear (Fig. 47.26). Sometimes infected plants die or are outcompeted by healthy plants. BrMV can be managed by using tolerant hybrids, avoiding movement of soil from the field edges, and controlling grassy weeds especially at the field edges.
References and Additional Information

Websites
- https://cropwatch.unl.edu/archive/-/asset_publisher/VHeSpfv0Agju/content/corn-disease-update-%E2%80%94-leaf-and-bacterial-diseases-developing

Paper and Manuals


Acknowledgements
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Foliar diseases can lead to premature leaf senescence, and predispose stalks to rotting, poor grain quality, and reduced yields. Common fungal diseases found on corn include common rust, northern corn leaf blight, gray leaf spot, eye spot, anthracnose leaf blight, and Physoderma brown spot. Management of foliar diseases involves managing the surface residue (through rotation or tillage), selecting resistant hybrids, and performing in-season fungicide application. Corn residue on the surface of the soil can increase certain foliar disease problems, such as gray leaf spot and northern corn leaf blight. Although the severity of these diseases varies from year to year, application of foliar fungicides may provide effective control in years of high disease pressure. The purpose of this chapter is to provide guidance on the use of fungicides.

Introduction

Fungicides are an effective in-season management tool for fungal leaf diseases, and sometimes can reduce chances of stalk rot development. A number of fungicide products that are effective against fungal pathogens on corn are available for use. However, some are more effective on certain pathogens than others. Most of the fungicides available are preventive in nature and stop the fungus from infecting or advancing within the plant. Therefore, timing of a fungicide treatment is critical. If fungicides are applied when the severity is already high, the benefit will be limited.

When deciding whether to apply a foliar fungicide, consider the following:

- The level of disease. Is there a significant amount of disease showing up on the leaves below the ear leaf?
- The current weather. For example, has it been warm and humid? Does the forecast predict continued hot conditions? If yes, disease severity may worsen, so application is advised. If no, disease outbreaks may not reach a critical stage and scouting should continue until corn has passed dent growth stage.
- The corn growth stage. How far along is the corn? If corn is at R5 (dent), diseases most likely will not
influence yield or will be minimal.

- Susceptibility of hybrid(s). For example, most the hybrids have moderate resistance to common rust and therefore, no treatment may be needed.

- Potential yield. If yield is predicted to be low (due to moisture stress, or poor fertility), chances of an economic gain due to fungicide treatment will be low.

- Grain price. When prices are high, it takes only a few bushels to pay for the cost of applying a fungicide (Table 48.1).

Once a fungicide treatment is deemed to be necessary, growers should ensure the sprayer is calibrated to deliver the recommended rate (as per the fungicide label), and that weather conditions are not too windy (> 10 mph) or too hot.

**Proactive Fungicide Treatments**

**Economic Benefit**

Several research studies have shown that when a fungicide is applied in the absence of disease or very low disease severity, the probability of increasing yield to pay for the treatment decreases significantly (Byamukama et al, 2013; Wise and Mueller, 2011; Pierce et al, 2011). For example, Mueller and Wise (2011) analyzed data from 613 treatment comparisons of strobilurin-treated and nontreated plots over a 10-year period in the Corn Belt region. The fungicides were applied between V14 and R5 (dent) with a majority of treatments being applied between tasseling (VT) and R2 (blister). They reported that when disease severity was less than 5% on the ear leaf at the end grain fill period, the fungicide treatment increased yields 1.5 bu/acre, and when the disease severity was > 5% the yield gain averaged 9.6 bu/acre. These results suggest that there may be some benefit from proactive fungicide applications. The yield enhancement has been linked to improved crop health (stays green longer) and reduced fungal populations. However, these benefits must be balanced against the long-term risk of the fungal pathogens developing resistance. Therefore, to avoid problems associated with unnecessary application of fungicides (such as resistance development, added expenses), growers should always scout to determine the need for a fungicide application.

**Fungicide Efficacy for Control of Corn Diseases - 2016**

The South Dakota State University Plant Pathology Extension is a member of the Corn Disease Working Group (CDWG) and has participated in the fungicide efficacy trials. The group has developed the following information on fungicide efficacy for management of major corn diseases in the United States. Efficacy ratings for each fungicide listed in the table were determined by committee members field-testing the materials over multiple years and at multiple locations. Efficacy ratings are based upon level of disease control achieved by product and are not necessarily reflective of yield increases obtained from product application. Efficacy depends upon proper application timing, rate, and application method to achieve optimum effectiveness of the fungicide as determined by labeled instructions and overall level of disease in the field at the time of application. Differences in efficacy among fungicide products were determined by direct comparisons among products in field tests and are based on a single application of the labeled rate as listed in Table 48.2.
Table 48.2 Systemic fungicides available that have been tested over multiple years and at multiple locations. The table is not intended to be a list of all labeled products. Efficacy categories: NR=Not Recommended; P=Poor; F=Fair; G=Good; VG=Very Good; E=Excellent; NL=Not Labeled for use against this disease; U=Unknown efficacy or insufficient data to rank product. This table is a joint publication by the Corn Diseases Working Group, coordinated by Dr. Kiersten Wise at Purdue University. A list of other fungicides approved fungicide on corn can be found in the crop protection guide for corn, http://igrow.org/up/resources/03-2016-2015.pdf.

<table>
<thead>
<tr>
<th>Fungicide (s) Class</th>
<th>Active ingredient (%)</th>
<th>Product/Trade name</th>
<th>Rate (fl oz)</th>
<th>Anthracnose leaf blight</th>
<th>Common rust</th>
<th>Eye spot</th>
<th>Gray leaf spot</th>
<th>Northern leaf blight</th>
<th>Southern rust</th>
<th>Harvest Restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td>QoI Strobilurins Group 11</td>
<td>Azoxystrobin 22.9%</td>
<td>Quadris 2.08 SC Multiple Generics</td>
<td>6.0–15.5</td>
<td>VG</td>
<td>E</td>
<td>VG</td>
<td>E</td>
<td>G</td>
<td>G</td>
<td>7 days</td>
</tr>
<tr>
<td></td>
<td>Pyraclostrobin 23.6%</td>
<td>Headline 2.09 EC/SC</td>
<td>6.0–12.0</td>
<td>VG</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>VG</td>
<td>VG</td>
<td>7 days</td>
</tr>
<tr>
<td></td>
<td>Picoxystrobin</td>
<td>Aproach 2.08 SC</td>
<td>3.0–12.0</td>
<td>VG</td>
<td>VG-E</td>
<td>VG</td>
<td>F-VG</td>
<td>VG</td>
<td>G</td>
<td>7 days</td>
</tr>
<tr>
<td>DMITriazoles Group 3</td>
<td>Propiconazole 41.8%</td>
<td>Tilt 3.6 EC Multiple Generics</td>
<td>2.0–4.0</td>
<td>NL</td>
<td>VG</td>
<td>E</td>
<td>G</td>
<td>G</td>
<td>F-G</td>
<td>30 days</td>
</tr>
<tr>
<td></td>
<td>Prothioconazole 41.0%</td>
<td>Proline 480 SC</td>
<td>5.7</td>
<td>U</td>
<td>VG</td>
<td>E</td>
<td>U</td>
<td>VG</td>
<td>G</td>
<td>14 days</td>
</tr>
<tr>
<td></td>
<td>Tebuconazole 38.7%</td>
<td>Follicur 3.6 F Multiple Generics</td>
<td>4.0–6.0</td>
<td>NL</td>
<td>U</td>
<td>NL</td>
<td>U</td>
<td>VG</td>
<td>F-G</td>
<td>36 days</td>
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<tr>
<td></td>
<td>Tetraconazole 20.5%</td>
<td>Domark 230 ME</td>
<td>4.0–6.0</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>E</td>
<td>U</td>
<td>G</td>
<td>R3 (milk)</td>
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<tr>
<td>Mixed modes of action</td>
<td>Azoxystrobin 13.5%</td>
<td>Quilt Xcel 2.2 SE</td>
<td>10.5–14.0</td>
<td>VG</td>
<td>VG-E</td>
<td>VG-E</td>
<td>E</td>
<td>VG</td>
<td>VG</td>
<td>30 days</td>
</tr>
<tr>
<td></td>
<td>Propiconazole 11.7%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Bensovinflupyr 10.27%</td>
<td>Trivapro A 0.83 + Trivapro B 2.2 SE</td>
<td>A = 4.0</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>E</td>
<td>VG</td>
<td>E</td>
<td>7 days (A) 30 days (B)</td>
</tr>
<tr>
<td></td>
<td>Azoxystrobin 13.5%</td>
<td></td>
<td>B = 10.5</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>E</td>
<td>VG</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Propiconazole 11.7%</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Cyproconazole 7.17%</td>
<td>Aproach Prima 2.34 SC</td>
<td>3.4–6.8</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>E</td>
<td>VG</td>
<td>G-VG</td>
<td>30 days</td>
</tr>
<tr>
<td></td>
<td>Picoxystrobin 17.94%</td>
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<td></td>
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<tr>
<td></td>
<td>Flutriafol 19.3%</td>
<td>Fortix 3.22 SC Preemptor 3.22 SC</td>
<td>4.0–6.0</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>E</td>
<td>VG-E</td>
<td>VG</td>
<td>R4 (dough)</td>
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<tr>
<td></td>
<td>Fluoxastrobin 14.84%</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pyraclostrobin 28.58%</td>
<td>Priaxor 4.17 SC</td>
<td>4.0–8.0</td>
<td>U</td>
<td>VG</td>
<td>U</td>
<td>VG</td>
<td>U</td>
<td>G</td>
<td>21 days</td>
</tr>
</tbody>
</table>
Table 48.2 Systemic fungicides available that have been tested over multiple years and at multiple locations. The table is not intended to be a list of all labeled products. Efficacy categories: NR=Not Recommended; P=Poor; F=Fair; G=Good; VG=Very Good; E=Excellent; NL=Not Labeled for use against this disease; U=Unknown efficacy or insufficient data to rank product. This table is a joint publication by the Corn Diseases Working Group, coordinated by Dr. Kiersten Wise at Purdue University. A list of other fungicides approved fungicide on corn can be found in the crop protection guide for corn, http://igrow.org/up/resources/03-2016-2015.pdf.

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<th>Northern leaf blight</th>
<th>Southern rust</th>
<th>Harvest Restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed modes of action</td>
<td>Pyraclostrobin 13.6% Metconazole 5.1%</td>
<td>Headline AMP 1.68 SC</td>
<td>10.0–14.4</td>
<td>U</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>VG</td>
<td>G-VG</td>
<td>20 days</td>
</tr>
<tr>
<td></td>
<td>Trifloxystrobin 32.3% Prothioconazole 10.8%</td>
<td>Stratego YLD 4.18 SC</td>
<td>4.0–5.0</td>
<td>VG</td>
<td>E</td>
<td>VG</td>
<td>E</td>
<td>VG</td>
<td>G-VG</td>
<td>14 days</td>
</tr>
<tr>
<td></td>
<td>Tetraconazole 7.48% Azoxystrobin 9.35%</td>
<td>Affiance 1.5 SC</td>
<td>10.0–14.0</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>G</td>
<td>7 days</td>
</tr>
</tbody>
</table>

1 Additional fungicides are labeled for disease on corn, including contact fungicides such as chlorothalonil. Certain fungicides may be available for diseases not listed in the table, including Gibberella and Fusarium ear rot. Applications of Proline 480 SC for use on ear rots requires a FIFRA Section 2(ee) and is only approved for use in Illinois, Indiana, Iowa, Louisiana, Maryland, Michigan, Mississippi, North Dakota, Ohio, Pennsylvania, and Virginia.

2 Harvest restrictions are listed for field corn harvested for grain. Restrictions may vary for other types of corn (sweet, seed or popcorn, etc.), and corn for other uses such as forage or fodder.

Many products have specific use restrictions about the amount of active ingredient that can be applied within a period of time or the amount of sequential applications that can occur. Please read and follow all specific use restrictions prior to fungicide use. This information is provided only as a guide. It is the responsibility of the pesticide applicator by law to read and follow all current label directions. Reference to products in this publication is not intended to be an endorsement to the exclusion of others that may be similar. Persons using such products assume responsibility for their use in accordance with current directions of the manufacturer. Members or participants in the CDWG assume no liability resulting from the use of these products.
**Fungicide Resistance**

Fungicide resistance is when a fungicide that used to control a given fungal pathogen, no longer offers any protection against the same fungus. Several factors are responsible for fungicide resistance including:

- The fungicide provides a selection process for pathogens that are resistant or tolerant to the treatment. Practices that increase the risk of fungicide resistance include:
  - Multiple applications of fungicides with same mode of action.
  - Reducing the application rate or using off-label products.
  - Multiple applications of the same mode of action fungicides within a single year.
- High genetic variability within the pathogens.
  - High variability suggests that some pathogens will have inherent tolerance to fungicide.
- High reproduction capacity of the pathogen.
  - Pathogens, which reproduce quickly (e.g., rusts), are likely to have increased diversity and therefore likely to be selected for when fungicides of similar modes of action are applied to the same area in a season.

To avoid fungicide resistance, growers should monitor the performance of the fungicides they use. One way to do this is to leave a strip of a nontreated area (one pass), where the yield and disease severity from the treated and nontreated zones can be compared. If the two areas have comparable disease severity, this would mean that the fungicide had minimal impact on the disease that year and this could probably be due to resistance development. In this case, samples of diseased leaves in the treated area and untreated area should be collected and sent to the SDSU Plant Diagnostic Clinic for fungicide sensitivity testing. Proper disease identification and appropriate fungicide selection is crucial for effective use of fungicides.

The risk of developing fungicide resistance can be reduced by:

- Rotating between different classes of fungicide within a season and also between seasons.
- Scouting to determine the need for a fungicide and avoid applying fungicide when it is not necessary or when it is too late (severe symptom on ear leaf and higher).
- Using a mixture of fungicide classes. Luckily, several fungicide products are “broad spectrum.”
- Practicing integrated disease management to reduce disease pressure.
- Following the label directions to determine the rates, growth stage of the crop, compatibility with other pesticides, and safety information.

**Fungicide Classes**

Fungicides are classified into groups depending on their mode of action. For instance, some fungicides interfere with fungal protein synthesis, while others interfere with respiration, etc. The Fungicide Resistance Action Committee (FRAC) is an international committee that is responsible for fungicide-resistance monitoring. The panel has developed FRAC codes that classify fungicides into classes with the same mode of action (Fig. 48.2). Fungicide labels contain the FRAC code and fungicides with the same FRAC code belong to the same class. When rotating fungicides, growers should ensure that rotation is made between different FRAC codes. Fungicide resistance has not been reported for corn pathogens in South Dakota.

**Host Resistance in Management of Plant Diseases**

Cultivar selection is a critical step in integrated pest management (IPM). Prior to the use of synthetic chemicals, farmers chose and saved seed from the best yielding and healthiest plants (e.g., bigger corn ears) for the next growing season. Today, planting a carefully selected corn hybrid may be the most important management decision to get maximum yield. Corn hybrids are developed to suit different needs: maturity, resistance to pests and diseases, plant characteristics (plant height, seed color, stalk strength, etc.).

Host resistance/tolerance, when available, is the first line of defense in plant disease management. Disease resistance genes have been bred into hybrids through conventional breeding or genetic engineering. Evolutionarily, plants and pathogens have co-existed together. When plants are attacked by a pathogen, the
Plants have evolved and developed a resistance gene against this pathogen. Over time, this pathogen also evolves to overcome the resistance gene.

Growers should keep good records on the performance of the hybrids grown to aid in their decision-making process. Monitoring performance of hybrids planted may also help indicate development or change in a pathogen race allowing the pathogen to overcome the resistance gene in the hybrid.

Unlike other traits, like glyphosate resistance, Bt, and other GMO traits, disease-resistance traits, to date, do not add to the cost of seed. Yet host resistance is an effective, sustainable, and affordable plant disease management practice. Several seed companies provide disease ratings for their hybrids making it easier to choose optimum characteristics for the growing conditions. When selecting a hybrid, growers should consider the history of diseases in their fields and cropping practices (such as corn on corn or no-till). For instance, corn on corn under irrigation is likely to have Goss’s wilt develop; therefore, a grower in this case would want to plant a Goss’s wilt resistant/tolerant corn hybrid.

Figure 48.2 Example of fungicide labels displaying the FRAC code (circled in blue). Prosaro has FRAC code 3 while Aproach has code 11. These two fungicides belong to two different groups and therefore can be rotated to prevent/manage resistance.
References and Additional Information

Websites

Paper and Manuals


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, South Dakota Corn Utilization Council, and the USDA-AFRI-IPM.


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Corn seed treatments vary in type, packaging, and purpose (Fig. 49.1). Because some fungicide seed treatments are highly poisonous, producers or applicators should follow label instructions. Most of the corn seed comes pretreated by seed companies with fungicides and/or insecticides. For a list of updated fungicides used for seed treatments that are registered for South Dakota, consult the current updated South Dakota Corn protection guide available online at the South Dakota iGrow.org website. The purpose of this chapter is to provide guidance on corn seed treatments. Tips for effective seed treatments are provided in Table 49.1.

### Table 49.1 Tips for using seed treatments:

1. Match your seed treatment to your problem.
2. Use high-quality seed.
3. Use proper handling techniques and labeled rates.
4. If treating the seed yourself, calibrate your equipment and use dedicated seed treatment equipment when available.
   a. Grain auger mounted treatment equipment may provide adequate coverage.
5. Treated seed should not be allowed to contaminate equipment used to transport or store, food or feed grains.
   a. Do Not Use Treated Seed for Food or Feed!!
6. Use caution when considering planter-applied (planter-box) seed treatments.

### History of Seed Treatments

Seed treatments were the first form of crop protection in modern agriculture. Egyptians and Romans treated seeds with sap from onions. In Europe before the 1800s, manure, chorine salts, copper, and hot water were used as seed treatments. Today, fungicides, insecticides, nematicides, and fertilizer are used as seed treatments for various agricultural crops and are useful tools in promoting stand establishment and seedling vigor (Munkvold et al., 2014). Seed treatments may also help preserve yield potential and prevent quality losses in grain by preventing development of seed- and soil-borne diseases (Rodriguez-Brljevich et al., 2009). The development of effective seed treatments can be noted as one of the most significant
advancements in plant disease management. In general, fungicidal seed treatments are used for three primary reasons:

- To manage soil-borne pathogens that can cause seed rots, seedling blights in many crops, root rots, smuts, or downy mildew.
- To manage diseases caused by seed-borne pathogens residing on the seed surface.
- To manage diseases caused by seed-borne fungi surviving inside the seed.

**Developing Your Seed Treatment Strategy**

Disease management in agricultural crops requires a multifaceted approach as part of an integrated pest management (IPM) program. Weather conditions cannot be precisely predicted at the time of planting, therefore seed treatments can be cheap insurance when conditions are conducive for seed and seedling diseases. When making a decision about seed treatments, consider:

1. Do you expect an economic return?
   a. Estimate the yield response relative to cost.
2. What is the history of seedling diseases in your field? For example, if a field is known to have high incidence of damping-off, then fungicide seed treatment is warranted. Likewise, if a field has a history of corn nematodes, a nematicide seed treatment then would be warranted.
3. What are the prevailing or expected climatic conditions at the time of planting?
   a. Wet and cool soils are favorable conditions for most seedling pathogens, including Pythium spp.
   b. Cool soil conditions also reduce seedling growth rate, providing a longer interaction time between the pathogen and the seed.
4. Is the crop for seed production?
   a. Grain for seed attracts higher prices, therefore, it may be beneficial to consider seed treatment in addition to other factors below.
   b. Fungicide seed treatments also can increase the likelihood of the seed being produced and offered for sale as disease-free.
5. Is corn following corn?
   a. Survival of seedling pathogens is typically higher in nonrotated fields.
6. Is corn being planted in a till or no-till/minimum-till field?
   a. No-till fields may have an increased risk of seedling diseases.
7. When will you plant?
   a. Planting early in the spring when the soil temperatures are low may increase the risk of seed/seedling infection.
8. What is the disease rating for the cultivar to be planted?
   a. Seed companies provide disease ratings for cultivars.
   b. For hybrids susceptible to seedling diseases, a seed treatment may be beneficial.
9. What is the germination rate for the seed lot?
   a. For seed with a low germination percentage, seed treatment may protect young seedlings with marginal vigor and improve plant stands compared with nontreated seed.
10. What is the desired plant population per acre?
    a. With increasing costs of seed, growers may opt for lower plant populations per acre, therefore to avoid further loss of plants; a fungicide seed treatment may be justified.
11. What is the expected price per bushel?
    a. Higher prices per bushel would indicate that fewer additional bushels are needed to offset seed treatment costs.
12. Is the seed for replanting?
    a. If replanting because of stand establishment problems (especially in wet spots) is considered, using fungicide treated seeds may increase chances of survival of replanted seed.
13. Fungicide seed treatments are not effective against bacterial pathogens or in managing viral diseases.
    a. Most seed treatment products do not control all types of fungal pathogens.
15. High quality, disease-free seed to prevent the spread of seed-borne diseases and promote healthy stand establishment.

16. Proper hybrid selection for host resistance and adaptation to the growing region.

17. Proper plant health management (fertility program, planting population, etc.).
   a. Healthy plants have a higher tolerance to the development of plant diseases.

18. Judicious use of plant protectant products such as herbicides, insecticides, and fungicides to reduce losses, promote healthy plants, prevent quality losses in seed, and for resistance management.

**Determining the Appropriate Chemical Treatment**

Field history is a key component in the decision-making process when selecting appropriate seed treatments. The cropping sequence and the history of major disease or insect pests within the field can be important factors in seed treatment decisions. Proper identification of disease agents is also important. Agronomy or Plant Pathology Extension Field Specialists at the Regional Extension Centers or the Plant Disease Diagnostic Clinic at SDSU can assist producers in identifying plant health problems throughout the growing season. Other web resources that can help with corn disease identification are outlined in the reference section of this chapter.

Effectiveness of control will vary with seed treatment product, rate, environmental conditions, and pests present. Seed treatments may provide some level of control for early season diseases as well as control of seedling blights and seed- or soil-borne diseases. They should not be viewed as season-long protection.

Newly opened land, such as CRP being returned to crop production, may present a special consideration (due to heavy pathogen inoculum) and most certainly will be a situation where seed treatments should be considered. Diseases such as root rots and seedling blights can often be more severe when crops are planted into these high-residue situations. Also, insect pressure on newly cultivated lands may differ from a typical cropping situation.

**In-furrow Seed Treatment vs. On-seed Treatments vs. Biotechnology Traits**

In-furrow fungicide application treats the soil, whereas on-seed treatment targets pathogens on the seed and those in the soil that will come in contact with the seed/root early in the season. In-furrow treatments usually require high active-ingredient rates compared to on-seed treatments. Both methods are effective in managing seed and soil-borne diseases. However, in-furrow fungicide treatments may require high application rates and also nontarget effects may be high with in-furrow treatments. As of 2015, biotechnology traits for disease management have not been incorporated in commercial corn hybrids. Disease-resistance genes in corn have been bred using the traditional/conventional approach. Therefore, plant disease management relies heavily on host resistance, cultural practices, and fungicides.

**Classification of Fungicidal Seed Treatments**

Fungicidal seed treatments can be classified based on movement of the seed treatment product in relation to the seed. Fungicides used as protectants (contacts) are effective only on the seed surface, providing protection against seed surface-borne pathogens and providing some level of control of soil-borne pathogens. These products generally have a relatively short residual. Protectant fungicides such as captan, maneb, thiram, or fludioxonil help control most types of soil-borne pathogens, with the exception of root-rotting organisms. Systemic seed treatment fungicides are absorbed into the emerging seedling and inhibit or kill the fungus inside host plant tissues. Systemic fungicides used for seed treatment include the following: azoxystrobin, carboxin, mefenoxam, metalaxyl, thiabendazole, trifloxystrobin, and various triazole fungicides, including difenoconazole, ipconazole, tebuconazole, and triticonazole.

Mefenoxam and metalaxyl are primarily used to target the water mold fungi Pythium. Biological agents as seed treatments are also available and may provide some level of protectant activity. Not all fungicides have activity against the same range of organisms. Refer to the specific crop-pest combinations listed in the text for product-use recommendations on the label. Always read and follow label directions. Consult the South Dakota Corn protection guide at the South Dakota igrow.org website for information for specific products.
4. Manage Plant Residues

Managing residue is critical for optimizing seed germination. Over the past 30 years, residue management problems have increased because corn yield, and consequently, corn residue have doubled. When returned to the soil, corn residue has helped South Dakota farmers increase soil organic matter (Soil OM) content of most fields. Soil OM in corn fields of eastern SD has increased an average of 24% from 1985 to 2010 (Clay et al., 2012). However, the higher amounts of crop residues have complicated seedbed preparation, slowed soil warming, and contributed to a corn “yield drag” (i.e. lower corn yields than expected) (Gentry et al., 2013). Techniques to reduce residue problems include:

a. Chopping the corn residue with a stalk chopper or chopping combine header. Combine corn headers often are integrated with stalk choppers that have enhanced capacity to chop residue. Chopping residue helps improve stand uniformity and yields (Gentry, 2013), and

b. Adopting tillage techniques that minimize contact between the seed and the surface residue, (for example strip tillage in the planting zone);

c. Harvesting and baling residue after grain harvest. This technique has been widely adopted in the recent past. However, problems with soil erosion, soil organic matter reduction, and nutrient deficiencies should be considered when deciding if, and how much, residue is harvested. Bailing residue may also the positive benefit of helping the soil warm up.

Proper Applications and Precautions

Fungicides and 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. Caution should be used when handling or working with seed treatment products. Fungicide seed treatments can be highly poisonous and many are irritants, therefore proper handling precautions must be taken when handling seed treatment chemicals, and producers or applicators must strictly adhere to all label directions regarding safe handling, mixing, storage, and disposal. Using personal protection, including an approved chemical respirator, goggles, and pesticide-resistant gloves, is recommended even if not specifically required by the fungicide label. Follow label rates, as overapplication may result in unintentional injury to the seed, and underapplication may reduce the effectiveness of products.

Properly calibrate all application equipment to assure uniform coverage. Uniform coverage of the seed is critical to optimize effectiveness of the seed treatment. Several seed treatment methods are available, though not all are appropriate for every situation. Commercial application or application through dedicated seed treatment equipment will likely provide the most uniform coverage. Grain auger mounted treatment equipment is available, and may provide adequate coverage in an on-farm situation; however, an auger that has been used to treat seed may be unusable for moving grain intended for food or feed. Likewise, treated seed should not be allowed to contaminate equipment used to transport or store food or feed grains. Use caution when considering planter-applied (planter-box) seed treatments. Good disease control depends on uniform fungicide coverage of the seed, and this is more difficult to accomplish in planter-applied situations. Always read and follow label directions. Understand the product-specific guidelines for proper application: how and when to apply, feeding or grazing restrictions, as well as important safety precautions. Always dispose of pesticide containers properly.

For more details on handling seed treatments, refer to the American Seed Trade Association guide on seed treatment stewardship www.seed-treatment-guide.com.
References and Additional Information

Websites

Paper and Manuals


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, South Dakota Corn Utilization Council, and the USDA-AFRI-IPM.


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To create a yield map, the location, ground speed, swath width, and rate that the grain is collected must be known. This paper discusses strategies to improve yield monitor data. Yield monitor data are used for many purposes, some of these are provided in Table 50.1.

**Yield Monitor Basics**
Most current yield monitors use an impact plate to estimate the flow rate of grain at the point where the clean grain elevator discharges grain (Fig. 50.1). The grain mass is thrown from the top of the clean grain elevator toward the base of the fountain auger. The impact plate is mounted in this space and intercepts the grain. A strain gage bridge, which measures weight much like an electric bathroom scale, measures the force of the grain on this plate. More grain mass means more force on the sensor plate. While the concept is simple, the actual device is not so simple. Anything that changes the impact force will be detected as a change in grain flow rate. While combining uphill, gravity can force the grain harder against the sensor plate to indicate more flow. While combining downhill, gravity can reduce the indicated flow because the grain is being thrown upward. Vibrations will also affect the sensor’s signal level, and a combine has lots of vibrations. The heightened sensitivity of this type of system is one reason it requires careful and regular calibration. The mass flow rate of the grain in pounds/second is determined using the sensor’s calibration equation. To convert the force on the plate into bushel/acre, precise ground speed, swath width, location, temperature, speed of clean grain elevator, and crop moisture content are needed.

**Table 50.1 The importance of yield monitors:**
1. Comparing corn hybrids.
2. Developing tile-drainage maps.
3. Negotiating rents.
4. Developing production plans.
5. Conducting on-farm research.
6. Developing management zones.
7. Developing profitability maps.
8. Documenting the impacts of adverse climatic conditions on yield.

![Figure 50.1 An impact-style flow-rate sensor using a curved plate and strain gage load cell to measure impact force of grain. The sensor is installed at the base of the fountain auger where grain leaving the clean grain elevator impacts. (Courtesy of authors)](image)
A moisture sensor located on the clean grain elevator or fountain auger is used to measure grain moisture (Fig. 50.2), whereas the differentially corrected global positioning systems (GPS) can be used to determine the location of the GPS receiver. The location is determined by calculating the distance between the satellites and the GPS receiver. The intersection of these distances is the location of the GPS receiver. These satellites can be located almost anywhere, and the accuracy of the GPS location is dependent on their distribution. The highest accuracy occurs when they are distributed across the sky. Ground speed and swath width multiply together to determine the area being harvested.

Preparing a Yield Monitor
While the flow rate sensor is the most important component of the yield monitoring system, it is actually the last part of the system that should be calibrated. Other sensors that should be routinely checked include the vibration, temperature, ground speed, and crop moisture sensors. To calibrate these sensors follow the manufacturer recommendation.

Vibration Calibration
Some yield monitor systems perform vibration calibration without user intervention, whereas others require this calibration. This calibration provides a baseline signal for the moisture and mass flow sensor. The calibration is conducted with an empty grain hopper prior to harvesting grain. Calibration is conducted by: 1) throttling up the combine; 2) engaging the thresher; and 3) lowering the header. Repairs or upgrades, such as replacing a drive chain, removing a drive chain link, or replacing an auger and flighting, may change the vibration in the system.

Temperature Calibration
Temperature information is needed to accurately calculate grain mass flow and moisture content. Temperature calibration should be done prior to starting the combine. The calibration might require the operator to enter the known outdoor temperature. The temperature output should be checked periodically during the season. Some systems do this automatically.

Ground Speed Sensor Calibration
Ground speed can be determined using the GPS or the combine speedometer. Systems using DGPS as the speed sensor typically don’t require calibration, whereas wheel-rotation based sensors (speedometers) may require calibration. Speedometers may not be accurate for many different factors, including if there is a change in the wheel configuration. Ground speed can be checked when the sensor is operating by determining the amount of time that is required to drive a known distance. Calibration is conducted by entering the actual distance traveled into the yield monitor display. The known distance should be measured with a tape measure from the beginning location of a nondriven wheel to its final position.

Crop Moisture Sensor Calibration
Crop moisture sensors provide information needed to measure the yield at 15.5% moisture, or determine whether additional drying is required. To calibrate the moisture sensor, 4 to 6 samples of grain are collected from the hopper. This can be done when calibrating the flow sensor, as described below. The moisture content samples can be added together into a container such a five-quart pail, or large coffee can. The moisture content of these samples should be determined using a calibrated sensor, such as the
moisture sensor at a grain terminal or elevator. Enter the average of this moisture content value into the yield monitor display prior to entering the load weight for the calibration load, below.

**Mass Flow Sensor Calibration**

Mass flow sensor calibration is the last step in the overall yield monitor system calibration and is the most critical. To avoid harvesting delays, mass flow sensor calibration should be conducted during harvest preparation. Different crops require different mass flow calibrations and the predicted yields are only as good as the calibration. For this process select a relatively uniform and level area of the field. Calibration loads should be collected sequentially in the most uniform portion of a field. Each load should be loaded into a weigh-wagon or instrumented grain cart, with the true weight of the load entered into the yield monitor mass flow calibration screen.

The rule of thumb for a good calibration is to control what you can control while maintaining as much uniformity in the noncontrollable variables as is possible. The ground speed, header width utilization, and load size are the three variables that are easiest for the operator to control, while the instantaneous yield and field slope are out of the operator's control. To maintain the desired uniformity, it is best to collect calibration loads in flat areas with relative uniform high yield. Each load should contain at least 3,000 pounds of grain. In 150 bu/acre corn, this requires about 800 feet of travel with an 8-row head, or 520 feet with a 12-row head. There are a variety of methods that could be used to collect calibration loads that span the full range, including loads collected from high-yield areas and low-yield areas. This method is less desirable than varying speeds in constant-yield areas and should be avoided.

The recommended number of calibration loads varies by manufacturer, but more calibration loads are generally better if they span the range of yields. The loads should be collected during the same day and with weather conditions as uniform as possible. Avoid splitting calibration load collections between two separate days, as the crop conditions might change. In corn, varieties with higher or lower test weight require new calibration curves.

**Method 1**

Collect samples where the combine is traveling at 110%, 100%, 75%, and 50% of the expected harvest speed. For example, if the typical harvest speed in a high-yield area is 4 mph, speeds of 2, 3, 4, and 4.5 mph could be used to span the range of expected grain flow rates. For each of the harvest speeds, the amount of grain harvested should be weighed. If one load were collected at each of these four speeds with full header utilization, the resulting calibration would have four points. While this is fewer than would be optimal, it will produce a calibration that spans expected flows.

**Method 2**

To generate further calibration points, it is possible to collect calibration loads at the same 3 to 4 ground speeds while utilizing only a fraction of the header (75%, for example). If 4 speeds were used with two possible header utilization settings, the resulting calibration would have eight points. The harvested grain for measurement should be weighed.

**Importance of Multiple Point Mass Flow Calibration**

Imagine that a series of 12 different loads of grain were harvested in a perfectly uniform field. Each load was collected by selecting a swath width and combine speed that were held constant for that whole load. Each of those loads would have been acquired with a different, but constant flow rate of grain impacting the flow sensor. Each flow rate and an associated sensor signal are depicted in Figure 50.3. Note that they do not form a straight line. Most combine grain flow sensors are nonlinear. With lots of calibration points, it is easy to calculate an accurate mathematical model. If only three points were collected, the model could overestimate or underestimate the yields in high-yield areas of the field.
Potential Sources of Yield Monitor Error

Poor or Old Calibration Loads
Using old calibration data or poor calibration load collection procedures can create systematic error. Over time, the operating conditions of the yield sensor components or the combine itself can change due to machine wear or sensor output drift, while poor calibration technique should be evident due to differences in the indicated yield and the amount of grain delivered to the elevator. In either case, the best solution is to perform a new calibration of the entire system.

Calibration Loads Do not Span the Flow Rates
A yield monitor system is most accurate in yield regions that are similar to a calibration point. The group of calibration loads should represent the span of yields that will be observed in the field. If errors are in the field extremes, adding a few new calibration loads improves results. For example, if the calibration was conducted in a field averaging 170 bu/a and the current field is averaging 240 bu/a, adding calibration points at 100% and 110% of the harvest speed would likely resolve the issue.

Poor Calibration of the Moisture, Temperature, and Speed Sensors
If the moisture, temperature, or speed sensors are not properly calibrated, repeating the calibration procedures usually will improve measurements. Poor calibration of the moisture sensor results in incorrect predictions of dry-grain or marketable-grain totals from a field. Recalibration of this sensor can be done at any time and can also be used to correct previously collected yield data. The need for recalibration of this sensor system can be determined by comparing the moisture content indicated by the monitor for one or more loads with moisture content determined at the elevator.

The mass flow sensor and grain moisture sensor rely on a properly calibrated temperature sensor to provide correct results due to their reliance on temperature for output calculation. The temperature sensor can also be recalibrated at any time, but yield data results produced while the system was out of calibration are not easily correctable.

A poorly calibrated ground speed sensor results in area measurements that are erroneous. This will cause the yield calculation to also produce an error since yield is flow rate divided by the rate that area is being covered. The error can also show up as a mismatch of a known area of a field compared to the area displayed on the yield monitor. Data collected with a poorly calibrated speed sensor can be easily corrected by multiplying yield data by \( \frac{D_{\text{New}}}{D_{\text{Old}}} \), where \( D_{\text{New}} \) is the indicated distance traveled by a newly calibrated sensor and \( D_{\text{Old}} \) is the indicated distance traveled by the old calibration.

Inaccurate Setting on the Number of Rows (Swath Width Error)
When collecting yield data on a combine, it is the operator’s responsibility to ensure that the yield monitor is aware of the harvesting operation at every point in the field. This includes adjusting the swath width.
in the monitor for cleanup passes and other areas where the full header is not being utilized. This type of error is usually easy to spot in post-processing. This will appear as a combine pass that has very low yields and it is too close to an adjacent full swath harvest area.

**Sudden Speed Changes**
Changes in combine speed can result in erroneous yield measurement because yield is the amount of grain in a given area and the combine measures average yield as opposed to instantaneous yield. For example, the combine measures 10 bu in 1/20th of an acre. The yield per acre for this measurement would be 200 bu/a (=10 bu/0.05 acres). As the combines slows from 4 mph to 3 mph, the area decreases from 0.05 to 0.0375 acres, which in turn results in a yield estimate of 267 bu/a (=10 bu/0.0375 acre). Increases in the combine speed have the opposite effect.

**Wear of the Flighting in the Clean Grain Elevator**
As a combine operates, there is expected wear on many of the moving parts. The clean grain elevator flighting is the combine part that has the most potential to impact yield monitor operation because of wear. As the flighting wears the ejection speed of the grain leaving the elevator begin to decline. This slippage of grain past the flights results in a gradual decrease in the force measured by the mass flow sensor impact plate. This wear and the resulting change in operating parameters require periodic recalibration of the mass flow sensor.

**Changing to New Chain and Flighting**
When the auger flighting wear becomes critical, it is often replaced. This creates an immediate, noticeable change in the amount of grain ejected per revolution and the ejection speed of the grain, and a subsequent jump in the output of the mass flow sensor. The mass flow sensor should be recalibrated when the chain or flighting of the clean grain auger are replaced.

**Changing Speed Setting or Increment on the Clean Grain Elevator**
Some combines have more than one sprocket driving the clean grain elevator to allow for speed changes with high- or low-volume crops. If changes are made to the speed or level sensor in the clean grain elevator, it is possible that the yield monitor output would show a sudden change as well. Recalibration of the mass flow sensor should be completed as soon as a new operating regime setting is implemented.

**Buildup of Plant Residue or Debris on the Sensor Plate**
After many hours of operation, there is a tendency for grain residue to build up on the impact plate of the yield monitor mass flow sensor, particularly when harvesting softer varieties or wet grain. This results in changes to the coefficient of friction on the surface of the impact plate, typically causing the sensor to indicate higher yield as the amount of residue builds. This effect is more common in soybeans than in corn, but it is still another reason that periodic calibration loads should be collected during the entire harvest season. If a combine is used to harvest multiple crops, the yield monitor should be calibrated, or at least checked, each time the type of crop is changed.

**Summary**
A well-calibrated yield monitor system is a “good” tool for understanding sources of spatial yield variation. Constant honing of production practices for the variability of individual fields is a result. A systematic calibration of the yield monitor system is essential if high-quality data are to be obtained. Producers are understandably reluctant to slow harvest by making the controlled passes required to collect calibration loads. Learning how your monitor system works can help to identify when recalibration is needed. For more information about yield monitor calibration contact your local dealer.
References and Additional Information

Websites
1. http://fabe.osu.edu/precisionag

Papers

Acknowledgements
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(3) email: program.intake@usda.gov;

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Historically, the major corn insect pests in South Dakota have been northern and western corn rootworm, European corn borer and black cutworm. Bt-corn hybrids are effective against most of these pests. However, there are also minor or sporadic pests of corn in South Dakota including the bird cherry oat aphid, corn leaf aphid, fall armyworm, true armyworm and common stalk borer. Although these pests are considered minor, each is capable of reducing corn yields under the appropriate conditions.

Issues faced: This chapter discusses the biology and management of important corn insect pests commonly observed in South Dakota.

Corn Rootworm
Northern corn rootworm (*Diabrotica barberi*, Smith & Lawrence) and Western corn rootworm (*Diabrotica virgifera virgifera*, LeConte) (Fig. 51.1).

Pest Highlights
- Northern corn rootworm and western corn rootworm can cause economic damage to corn in South Dakota.
- Bt-corn hybrids that target corn rootworm are effective against corn rootworm larvae.
- Crop rotation is an effective tactic in managing corn rootworms.
- Corn rootworm larvae are currently the most damaging insect pests of continuous corn in South Dakota.

Rootworm Description
Adult northern corn rootworm beetles are approximately 1/4-inch long and vary in color from yellow to green (Fig. 51.1 top). Western corn rootworm beetles are slightly larger with a black head and yellow thorax and abdomen. The western corn rootworm adults have three black longitudinal stripes on their hardened forewings. The stripes can vary in size and may appear as three distinct stripes or one broad stripe that covers the majority of the forewings (Fig. 51.1 bottom). The wormlike larvae of both species
(Fig. 51.2) are white with a brown head and grow to approximately 5/8-inch in length. Both the larvae and adults have chewing mouthparts.

**Rootworm Biology**

Adult corn rootworm beetles feed on corn pollen, silks and leaves. Feeding on the pollen and silks has the potential to reduce pollination and ear fill; however, significant injury from adult feeding occurs infrequently. Adults may also feed on soybean, sunflowers and garden flowers but have not been reported as pests of these crops in South Dakota. Adult female corn rootworms deposit eggs into the soil from late summer into the fall or until the females are killed by the first hard frost (Fig. 51.2). In South Dakota, rootworm eggs are primarily laid in cornfields where they overwinter in the soil. Fields that are planted to corn following corn have an increased chance of being infested with corn rootworm eggs from the previous season. Egg hatch occurs once the corn roots begin to grow. Corn rootworm larvae feed on corn roots in June and July during active root growth. Larvae transform into pupae in mid-July, and adult rootworm beetles emerge from the soil from late July through August (timing will vary due to soil moisture and temperature) and mate rapidly after emerging.

The principal cause of yield losses associated with corn rootworm is larval feeding on corn roots during active root growth. The damage to corn roots reduces water and nutrient uptake, and yield is reduced on average by 15% to 17% for each node of corn root pruned by rootworm larvae. Furthermore, roots weakened by larval feeding can result in goose-necked plants (Fig. 51.3) and lodged corn (Fig. 51.4). Lodged corn is difficult to harvest and decreases harvest efficiency and overall yields (see Chapter 37 for tips on harvesting lodged corn). Typically, larval infestations are clustered within fields, and areas within the field that experienced higher infestation levels in a previous year tend to have higher infestations in the same areas when corn is planted the following year (Ellsbury et al., 1998).

Corn rootworm larvae are generally unsuccessful when feeding on the roots of other crops including soybean, wheat, sunflower and alfalfa. This specialization makes crop rotation an excellent management option. Although multiple species of foxtail (Setarai spp.) grasses including green, yellow and giant can serve as alternative hosts for corn rootworm larvae, the roots of these grasses are a poor nutritional substitute and produce smaller corn rootworm individuals (Ellsbury et al., 2005). Other management options include the use of Bt-corn hybrids that have rootworm-active toxins or in-furrow granular and liquid insecticides.
Management: Bt-corn Hybrids
Many genetically engineered Bt-corn hybrids are resistant to corn rootworm larvae (Table 51.1). These Bt-corn hybrids produce toxins derived from the soil-dwelling bacterium Bacillus thuringiensis that are toxic to rootworm larvae. Although Bt corn reduces rootworm larval feeding injury, adult corn rootworm are not affected by Bt toxins. Bt corn targeting corn rootworm became commercially available in 2003, and these hybrids produced only one Bt toxin that targeted rootworm. More recently, Bt-corn hybrids have become commercially available that produce a pyramid of toxins (two or more toxins) that target corn rootworm. To delay the development of Bt-resistant rootworm, the EPA mandated that Bt-corn hybrids must be planted with non-Bt corn refuges, which depending on the Bt toxin(s) produced, range in size from a 20% block of non-Bt corn to 5% refuge-in-the-bag (RIB). However, reports of Bt-resistant corn rootworm already have been documented in Iowa, Nebraska and Illinois to Cry3Bb1 and mCry3A Bt toxins.

### Table 51.1 Bt-corn genes that provide resistance to northern and western corn rootworm larvae.

<table>
<thead>
<tr>
<th>Bt toxin(s)</th>
<th>Trade name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cry3Bb1</td>
<td>YieldGard VT Triple</td>
</tr>
<tr>
<td></td>
<td>Genuity VT Triple Pro</td>
</tr>
<tr>
<td></td>
<td>Genuity VT Triple PRO RIB Complete</td>
</tr>
<tr>
<td>mCry3A</td>
<td>Agrisure RW</td>
</tr>
<tr>
<td></td>
<td>Agrisure GT/RW</td>
</tr>
<tr>
<td></td>
<td>Agrisure CB/LL/RW</td>
</tr>
<tr>
<td></td>
<td>Agrisure 3000GT</td>
</tr>
<tr>
<td></td>
<td>Agrisure Artesian 3011A</td>
</tr>
<tr>
<td></td>
<td>Agrisure Viptera 3111</td>
</tr>
<tr>
<td></td>
<td>Agrisure 3122 E-Z Refuge</td>
</tr>
<tr>
<td></td>
<td>Optimum AcreMax XTreme</td>
</tr>
<tr>
<td></td>
<td>Optimum TRIsect</td>
</tr>
<tr>
<td>Cry34/35Ab1</td>
<td>Herculex RW</td>
</tr>
<tr>
<td></td>
<td>Herculex XTRA</td>
</tr>
<tr>
<td></td>
<td>Optimum AcreMax 1</td>
</tr>
<tr>
<td></td>
<td>Optimum AcreMax RW</td>
</tr>
<tr>
<td></td>
<td>Optimum AcreMax Xtra</td>
</tr>
<tr>
<td>Cry3Bb1 + Cry34/35Ab1</td>
<td>Genuity SmartStax</td>
</tr>
<tr>
<td></td>
<td>Genuity SmartStax RIB Complete</td>
</tr>
<tr>
<td></td>
<td>Refuge Advanced Powered by SmartStax</td>
</tr>
<tr>
<td>mCry3A + eCry3.1Ab</td>
<td>Agrisure Duracadie 5222 E-Z Refuge</td>
</tr>
<tr>
<td>mCry3A + Cry34/35Ab1</td>
<td>Optimum Intrasect XTreme</td>
</tr>
<tr>
<td>Cry34/35Ab1 + eCry3.1Ab</td>
<td>Agrisure Duracadie 5122 E-Z Refuge</td>
</tr>
</tbody>
</table>

Management: Rootworm T-band/in-furrow Insecticides and Seed Treatments
Many different insecticides are labeled for rootworm larval management (Table 51.2). Granular or liquid insecticides are applied in-furrow or very close to the seed furrow during planting. Alternatively, systemic insecticidal seed treatments are also available to corn growers for the management of corn rootworm larvae (Table 51.2). It is not advised to use a Bt-corn hybrid that has more than one toxin targeting corn rootworm in combination with any conventional soil insecticide application. The purpose of this recommendation is to reduce economic inputs and to reduce selection pressure on corn rootworm to adapt to two distinct management tactics.

For a list of T-band/in-furrow insecticides and also insecticide seed treatments that are currently labeled for the management of corn rootworm larvae, please refer to the current edition of the South Dakota Pest Management Guide: Corn.

### Table 51.2 Node-Injury Scale scores.

<table>
<thead>
<tr>
<th>Node-Injury score</th>
<th>Root Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>No feeding injury observed</td>
</tr>
<tr>
<td>1.00</td>
<td>One full root node pruned</td>
</tr>
<tr>
<td>2.00</td>
<td>Two full root nodes pruned</td>
</tr>
<tr>
<td>3.00</td>
<td>Three full root nodes pruned; scale maximum</td>
</tr>
</tbody>
</table>

Management: Crop Rotation
Crop rotation has been an effective management tool against corn rootworm for over a century. Adult rootworm lay eggs in cornfields during August, and larvae that hatch the following spring in fields rotated away from corn starve to death. However, populations of both northern and western corn rootworm have adapted to crop rotation in parts of the corn belt.

Rotation-resistant northern corn rootworm are present in South Dakota. These northern corn rootworm
populations have adapted to crop rotation by having an extended diapause, and are sometimes referred to as “extended-diapause” rootworm. Female rotation-resistant northern corn rootworm still lay eggs in cornfields; however, only a proportion of those eggs hatch the following year while another proportion will hatch two, three or even four years later. Extended crop rotations that do not vary over time (e.g., a three year corn-soybean-wheat rotation repeated again and again) can select for a greater percentage of eggs to hatch during years corn is planted, although this process would take many rotations cycles to build significant northern corn rootworm populations.

Rotation-resistant western corn rootworm are not presently found in South Dakota, these populations are typically found east of the Mississippi River. Rotation-resistant western corn rootworm are commonly called the “soybean variant” rootworm, but this name can be misleading. Western corn rootworm adapted to crop rotation by laying eggs not only in cornfields, but any other crop. The name “soybean variant” emerged because rotation-resistant western corn rootworm first appeared in areas dominated by corn-soybean rotation.

Assessing Management Success through Rating Corn Roots
Rating corn roots for rootworm feeding injury can assess whether rootworm populations have reached economically damaging levels within a field. Rating roots for rootworm feeding injury is additionally advantageous because it measures the effectiveness of any rootworm management strategy that is presently being practiced within a field. However, roots are rated within the planting season and there are no remediation treatments presently available to reduce yield loss if significant feeding has occurred.

To rate corn roots for injury, 10 roots should be dug from random areas within the field during July or August. Use a spade and dig in a circular pattern approximately 4 - 5 inches away from the cornstalk. Remove excess dirt without damaging the corn roots. Soak the sampled roots in water for 24 - 48 hours, and remove any remaining soil using a high-pressure hose. Allow the roots to dry prior to rating.

Corn roots are rated on the 0 - 3 Node-Injury Scale (Olson et al., 2005). Only root nodes 4, 5 and 6 are rated for rootworm feeding injury. The brace roots that emerge from the stalk above the soil line represent node 7, while node 6 roots emerge at the soil line. To begin rating a corn root, count the total number of roots within a node for nodes 4, 5 and 6. For example:

Root sample #1:  
Node #4 has 10 roots  
Node #5 has 12 roots  
Node #6 has 10 roots

Re-inspect each of the nodes and determine the number of roots that display rootworm larval feeding injury, typically referred to as “pruned” roots. A root is considered pruned if the root has been eaten back to approximately 1.5 inches from the stalk. In this example:

Root sample #1:  
Node #4 has 5 / 10 roots pruned  
Node #5 has 4 / 12 roots pruned  
Node #6 has 2 / 10 roots pruned

Calculate the proportion of pruned roots for each node by dividing the number of pruned roots by the total number of roots. In this example, node #4 has 5 pruned roots out of 10 total roots, so the proportion of pruned roots for node #4 is 0.50. Sum the proportion of pruned roots for nodes 4, 5 and 6 to get the Node-Injury score. In this example, root sample #1 would score:

\[0.50 \text{ (Node #4)} + 0.33 \text{ (Node #5)} + 0.20 \text{ (Node #6)} = 1.03\]

Rate all 10 sampled corn roots and then average the Node-Injury score to estimate the amount of root injury within a field. Table 51.2 describes how root injury is scored on the Node-Injury Scale. Depending on the cost of rootworm management and price of corn, economic loss from rootworm larval feeding may
begin to occur above average Node-Injury scores of 0.25. For Bt corn that targets corn rootworm, greater than expected injury is said to occur if average Node-Injury scores exceed 1.00 for Bt corn with only a single Bt toxin and 0.50 for Bt corn with a pyramid of Bt toxins.

**Scouting and Economic Thresholds**

Scouting for adult rootworm during August can help assess the risk of injury to corn planted within a field the following year. A simple method used to scout for adults are yellow sticky cards. These cards are can be
purchased through several retailers, and cost approximately $2 per card. The cards have alternating yellow and white sides, with the yellow side being covered in a gluelike substance. If yellow stick cards are being used to scout for corn rootworm populations, 10 cards should be placed randomly throughout the field in August. The cards are then replaced on a weekly basis (they should not remain in fields longer than 10 days) throughout August. For each card, count the total number of corn rootworm adults on the card and divide this total by the number of days the card was left in the field to calculate the number of rootworm adults captured per day. If averages exceed two or more adults captured per day, the economic threshold has been reached (Dunbar and Gassmann, 2013).

**European Corn Borer (Ostrinia nubilalis, Hübner)**

**Pest Highlights**
- South Dakota has univoltine (one generation) and bivoltine (two generations) ecotypes.
- Bt-corn hybrids with toxins specific to the European corn borer provide effective management.
- Univoltine corn borers can be more damaging and harder to manage than bivoltine corn borers.
- Per-plant yield loss can range from 2% to 6% per larva in the absence of management.

**European Corn Borer Description**
European corn borer larvae are light tan to pink in color with dark brown spots on each segment of their body. Larvae have a dark brown head capsule, three pairs of true legs and four pairs of abdominal prolegs (Fig. 51.6). Mature larvae range in size from ¾- to 1-inch in length. The female European corn borer moth is approximately ½-inch in length with triangular wings that have yellow to brown wavy markings. The male moths are smaller and tend to be darker in color (Fig. 51.7).

**European Corn Borer Biology**
Within a single generation, European corn borer undergoes four developmental stages/forms: egg, larva, pupa, and adult. During larval development, there are five instars or larval stages. Each subsequent instar undergoes a period of growth followed by a molt (casting off skin). When the larvae reach the fifth and final instar, they pupate and transition from a caterpillar to a moth. Like all insects, the European corn borer life cycle is effected by the climate, resulting in a different number of generation per year occurring in different parts of the state. In northern South Dakota, European corn borer is univoltine (one generation per year). In central and southern South Dakota, European corn borer can be univoltine or bivoltine (two generations per year).

**Univoltine European Corn Borer (one generation per year)**
European corn borer populations with only one generation per year are most commonly found in the northern counties of South Dakota. Moths of these populations begin flying in mid-June, with peak populations occurring in mid-July. Seasonal temperatures affect adult emergence, but moths generally lay eggs on the underside of corn leaves from June to July. Eggs hatch within one week. Newly hatched larvae feed on the leaf collars and may migrate toward the tassels to feed on pollen. Young larvae often feed on the leaf surface and midribs, resulting in a “windowpane” type injury that is characterized by the removal of the surface layer of the leaf (Fig. 51.8). Second- and third-instar larvae will feed in the whorl, causing a
“shot hole” type of injury (Fig. 51.9). Fourth-instar larvae tunnel into the stalk, molt into fifth-instar larvae and continue feeding until the end of the growing season. Fifth-instar larvae overwinter in stalk residues left in the field, and transform into pupae and moths in the following spring.

**Bivoltine European Corn Borer (two generations per year)**

In southern portions of South Dakota, European corn borer can have up to two generations per year. Adult moths begin flying in mid-May and females lay eggs on the underside of the leaves when corn is between growth stages V6 to V9. Similarly to univoltine populations, newly hatched bivoltine larvae also feed on the leaf surface and midribs, and may cause windowpane damage (Fig. 51.8). Second- and third-instar larvae feed in the whorl, causing a shot hole injury (Fig. 51.9) that is visible when leaves unfurl. Fourth-instar larvae tunnel into the stalk and then molt into fifth-instar larvae approximately 10 days later. Larvae then transform into pupae after an additional 10 days.

The second generation of European corn borer moths emerge from the stalks about 8 days after pupating, and lay eggs on the underside of leaves, leaf collars and on the ear husks during tasseling (VT) and silking (R1). Approximately 1 week later, the second-generation eggs begin to hatch. European corn borer larvae burrow into the stalks and ear shanks and feed on developing kernels. Fifth-instar larvae overwinter in stalks and residue left on the field. The winter survival potential of larvae is directly related to the amount of residue remaining in the field, with greater survival occurring with increased levels of residue.

Both the single (univoltine) and two (bivoltine) generation European corn borer moths may visit fields that are located in the center of the state. This phenomenon has been observed as far south as Lake, Minnehaha and Moody counties.

**European Corn Borer Injury to Corn**

Tunneling injury attributed to European corn borer results in stalk breakage, reduction in water and nutrient transport, secondary infection with stalk rot fungi, and ultimately yield loss. Injury to ear shanks and kernels can result in ear drop, loss of grain quality and secondary infection of mycotoxin-producing fungi (see Chapter 46 for more information on mycotoxins). Leaf feeding by early instar larvae causes “shot hole” and “windowpane” type injuries that are usually not serious enough to reduce photosynthesis. However, leaf feeding injury can be used to indicate the presence of European corn borer larvae in the field. The timing of larval infestation affects final yield (Table 51.3), with northern parts of the state being

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>% Yield loss/larva/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>V10 (midwhorl)</td>
<td>5.9</td>
</tr>
<tr>
<td>V16 (green tassel)</td>
<td>5.0</td>
</tr>
<tr>
<td>R1 (pollen shed)</td>
<td>4.0</td>
</tr>
<tr>
<td>R2 (blister)</td>
<td>3.1</td>
</tr>
<tr>
<td>R4 (dough)</td>
<td>2.4</td>
</tr>
</tbody>
</table>

(After North Central Regional Extension publication No. 327)
more susceptible to economic losses because larval feeding occurs throughout the entire season. The first generation of the bivoltine European corn borer tends to cause more injury than the second-generation because they occur during a more sensitive growth stage of the corn.

**European Corn Borer Management: Bt-corn Hybrids, Scouting and Insecticides**

Bt-corn hybrids targeting European corn borer produce toxins in their leaves, stalks and ears that negatively effect larvae (Table 51.4). These Bt-corn hybrids have performed very well during outbreaks of the European corn borer. However, the severity of corn borer infestations fluctuates from year to year. The decision to deploy Bt-corn hybrids is made before planting and before the extent of this late-season problem is known. Therefore, techniques to reduce the economic risk associated with decisions to choose treatments and varieties are needed.

Bt corn may be most suitable for planting in areas with high previous history of univoltine European corn borer populations (Fig. 51.9). Univoltine populations are less predictable than bivoltine European corn borer. In bivoltine areas, corn borer outbreaks often decline to levels below economic thresholds in a year after an outbreak. When corn-on-corn rotations are used, the increased risk of European corn borer may be great enough to warrant regular planting of Bt corn. Refuges of non-Bt corn must be planted in or around fields with corn hybrids containing Bt toxins targeting European corn borer. Scouting is needed to maximize the effectiveness of insecticides (Table 51.5). Insecticide treatments can be effective against this pest.

![Table 51.4 Bt-corn toxins that provide resistance to European corn borer larvae.](image)

**Table 51.5 Estimated timing for European corn borer scouting:**

1. Look for egg masses, newly hatched larvae, and signs of injury on leaves in June and July.
2. V8-R1 (green tassel through pollen shed) for univoltine corn borer.
3. V8-V14 (mid- to late-whorl) for first-generation bivoltine corn borer.
4. R1-R2 (silking through blister) for second-generation bivoltine corn borer.

**Black Cutworm (Agrotis ipsilon, Hufnagel)**

**Pest Highlights**

- Black cutworm larvae feed on corn seedlings early in the season.
- Bt toxins Cry1F and Vip3A are effective against black cutworm.
- Significant stand loss can occur if the seedlings are cut below the growing point.
- Black cutworm does not overwinter in South Dakota. Moths migrate into the state in early spring and are attracted to wet and weedy fields.

**Black Cutworm Description**

Black cutworm larvae vary in color from dark brown to black and are approximately 1½-inches long.

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when mature (Fig. 51.10). Their skin has a rough, pebbly texture. Larvae have three pairs of true legs and four pairs of abdominal prolegs. Adult black cutworm are dark brown in color with a dark mottling across each forewing (Fig. 51.11).

**Black Cutworm Biology and Injury to Corn**
Moths start migrating into South Dakota from the southern U.S. in early April. Strong southerly winds influence the transport, distribution and severity of black cutworm infestations. Female moths deposit eggs onto weeds and crop residues prior to corn planting. Upon hatching, black cutworm larvae feed on weeds and move to corn seedlings when they emerge in May and early June. Black cutworm larval feeding results in cutting of corn seedlings, which may occur at or below the soil surface. Feeding that occurs below the growing point can result in extensive seedling stand loss.

**Black Cutworm Scouting and Management**
There are Bt-corn hybrids that produce toxins that are effective against black cutworm larval feeding. Bt toxins Cry1F and Vip3A are resistant to black cutworm. Many seed treatments are also labeled for management of black cutworm, including clothianidin and thiamethoxam.

Weed management can greatly influence black cutworm populations. First, adult female black cutworm lay eggs on low-lying weeds and plant debris. Fields with no-till or reduced-tillage management can attract egg-laying females. Second, having weeds within a field can reduce the risk of injury to corn because black cutworm larvae develop better on many weed species than they develop on corn. Black cutworm larvae should starve to death if weeds and plant residue are tilled into the soil more than 2 weeks before corn planting.

Conventional insecticides can be used in conjunction with scouting to manage black cutworm. Black cutworm larvae are nocturnal and hide during the day. Therefore, scouting focuses on larval feeding injury. Scouting for black cutworm larval feeding injury should begin at the VE (germination and emergence) stage and continue through the V5 (fifth leaf) stage. Fifty plants should be examined throughout a field, with special attention given to areas of the field that have a history of increased moisture or weeds. Look for plants that show signs of cutting or leaf feeding. Measure the length of any black cutworm larvae found. An insecticide treatment is recommended if 5% (2.5 in 50) of the seedlings scouted show signs of cutting or leaf feeding and if black cutworm larvae are less than 1 inch. For a list of insecticides registered for black cutworm management on corn, please refer to the current edition of the South Dakota Pest Management Guide: Corn.

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**Figure 51.10** A black cutworm larva on a corn leaf. (Courtesy of Adam J. Varenhorst)

**Figure 51.11** A black cutworm moth. (Courtesy of Robert J. Bauernfeind, Kansas State University, Bugwood.org)
Western Bean Cutworm (Striacosta albicosta, Smith)

Pest Highlights
- Western bean cutworm larvae feed on developing kernels late in the season.
- Bt toxins Cry1F and Vip3A are effective against western bean cutworm.
- Western bean cutworm can reduce yields up to 40%.
- Injured ears may be susceptible to mycotoxin-producing fungi.

Western Bean Cutworm Description
Western bean cutworm larvae have a brown to gray body that is about 1¼-inch long at maturity. Larvae have an orange-brown head with a black dorsal shield located directly behind the head. The larvae have three pairs of true legs and four pairs of abdominal prolegs (Fig. 51.12). Western bean cutworm moths are approximately ¾-inch long, brown in color, with a distinct white band on the leading edge of their forewings (Fig. 51.13).

Western Bean Cutworm Biology and Injury to Corn
In South Dakota, western bean cutworm moths begin flying in early July and reach peak flight populations during the third or fourth week of July or when corn is between the VT (tasseling) and R1 (silking) stages. Female moths lay eggs on top of the leaves in the upper canopy. The eggs hatch within a week and the first-instar larvae begin migrating toward the developing ears. Larvae usually go through five instars. The third- through fifth-instar larvae feed on developing kernels for approximately one month before migrating to the soil, where they prepare to overwinter. Once in the soil, the larvae construct earthen cells that are 5 to 10 inches below the surface.

Several western bean cutworm larvae can feed simultaneously on a single ear of corn, which can result in yield reductions by as much as 40% per plant. Damaged ears may also be susceptible to infection from mycotoxin-producing fungi.

Western Bean Cutworm Scouting and Management
Bt-corn hybrids that express either the Cry1F or Vip3A toxins provide resistance to western bean cutworm larvae. Scouting for western bean cutworms should start at VT (green tassel) stage and continue through the R3 (milk) stage. Eggs and newly hatched larvae are usually found in the silks or leaves in the upper canopy. At least 100 plants (10 plants from 10 locations on the field) per 40-acre field should be inspected to accurately gauge the infestation level. Both the center and borders of the cornfield should be inspected. Western bean cutworms should be managed if 8% of the scouted plants have eggs or newly hatched larvae. For insecticides to be effective, they must be applied before the larvae enter the ears. For a list of insecticides that are currently registered for western bean cutworm management on corn, please refer to the current edition of the South Dakota Pest Management Guide: Corn.
Armyworm

Fall Armyworm (*Spodoptera frugiperda, J.E. Smith*), and True Armyworm (*Mythimna unipuncta, Haworth*)

**Pest Highlights**

- Armyworms do not overwinter in South Dakota and are considered minor pests of corn.
- Fall armyworms are attracted to late-planted corn and will feed on foliage and ears.
- Corn near the field margins or fields with grass established prior to planting are at greater risk for true armyworm infestations.
- Young corn (VE-V8) is more susceptible to true armyworms.

**Fall Armyworm Description**

Fall armyworm larvae vary greatly in color, ranging from tan to green or even black. The larvae have a characteristic white inverted “Y” on the front of their dark brown to black heads. They also have three narrow, yellow-white lines that run the length of their bodies. Each segment of their body has six black tubercles or spots. Fall armyworm larvae have three pairs of true legs and four pairs of abdominal prolegs (Fig. 51.14). Adult fall armyworm moths have forewings that are dark grey with light- and dark-grey markings. The tip of each forewing has a characteristic white spot. Their hindwings are light grey in color (Fig. 51.15).

**Fall Armyworm Biology and Injury**

Fall armyworm moths migrate from the Gulf states and have one generation per year in South Dakota. The female fall armyworm preferentially lays eggs in late-planted corn from July to August. Eggs generally hatch five to seven days after oviposition, and the larvae will begin feeding on corn. Initially, larvae feed in protected areas, including the whorl. As larvae mature they feed on the leaves with the exception of the tough midrib. Feeding injury from fall armyworm results in jagged edges of leaves where defoliation has occurred. During high levels of infestation, larvae may also feed on the ears where they consume developing kernels.

**Fall Armyworm Scouting and Management**

Late-planted cornfields and corn near the margins should be scouted for fall armyworms. Examine 20 plants in the field to determine whether fall armyworms are present. Evidence of fall armyworm feeding includes leaves that have a ragged appearance from defoliation, and the presence of frass that resembles sawdust near the whorl. The presence of fall armyworm feeding on corn ears is indicated by an entry hole in the husk and the presence of larvae. When 80% of plants are infested with fall armyworm larvae, treatment may be necessary. However, late-season infestations are difficult to manage with insecticides due to plant height and the location of the larvae within the whorl. Insecticide management of this pest is frequently not economical. For a list of insecticides registered for fall armyworm management on corn, please refer to the current edition of the South Dakota Pest Management Guide: Corn. Bt corn may also manage fall armyworm injury. Bt toxins that are efficacious against fall armyworm include Cry1F, Vip3A, and Cry1A.105 + Cry2Ab2.
**True Armyworm Description**

True armyworm larvae vary in color from tan to dark green to black. They have a dull orange stripe on each side of their body, and a network of black lines present on their orange head. True armyworm larvae have three pairs of true legs and four pairs of abdominal prolegs with dark bands (Fig. 51.16). True armyworm moths are tan to light brown in color with a small white spot in the center of each forewing (Fig. 51.17).

**True Armyworm Biology and Injury**

True armyworm is a migratory pest that overwinters in the southern U.S. It may have as many as three generations per year in South Dakota, but only the first generation pose a risk to corn. Female moths are attracted to and lay eggs in fields with living, grassy ground cover, including weeds or cover crops. When eggs hatch, the larvae begin to preferentially feed on grassy hosts. If initial hosts are consumed or destroyed, larvae will readily move to and feed on corn. Early vegetative corn (VE-V8) is at greater risk for defoliation by true armyworm larvae. Defoliation that occurs to corn after V8 is generally minimal, and does not require management. For young corn, the larvae will begin feeding on the lower leaves of the plant, and work towards the whorl (Fig. 51.18). True armyworm larvae consume all leaf tissues, excluding the midrib. There are instances during high infestations where entire corn seedlings will be removed by true armyworm larval feeding (Fig. 51.19). True armyworm larvae are nocturnal and will hide in the whorl of the plant during the day. However, true armyworm larvae do not tunnel into the stalk, and on larger plants larvae do not feed on the growing point. Feeding by true armyworm larvae results in jagged leaf edges, and in instances of severe defoliation only the leaf midrib will remain.

**True Armyworm Scouting and Management**

Scouting for true armyworm should occur near the field margins and be intensified for fields that had grassy weeds or cover crops present prior to planting. To reduce the potential for a true armyworm infestation, weeds and cover crops should be removed at least two weeks prior to planting. To scout for true armyworm, examine 20 random plants for signs of defoliation. Treatment is recommended for corn seedlings (VE-V2) if 10% or more of the plants are injured and the larvae that are less than ¾-inch in length are present. For corn that is in the 7-8 leaf stage (V7-V8) treatment is recommended if 25% or more of the leaf area is removed, there are more than eight larvae present per plant, and the larvae are less than ¾-inch in length. Larvae that are smaller than ¾-inch in length have the potential to feed for another
week and may cause subsequent defoliation. If treatment is necessary, please refer to the current edition of South Dakota Pest Management Guide: Corn for a list of insecticides that are currently registered for true armyworm management on corn. At present, there are no Bt toxins or seed treatments labeled for true armyworm management.

Common Stalk Borer (Papaipema nebris, Guenee)

**Pest Highlights**
- Common stalk borer is an occasional pest in South Dakota.
- Corn near field margins or fields with dense grassy weed history have the greatest risk of infestation.
- Infested corn will have irregular holes in the whorl, and may be bent or stunted due to abnormal growth.
- Young corn (V1-V7) is more susceptible to common stalk borer injury.

**Common Stalk Borer Description**
Common stalk borer larvae are approximately 1¼-inch long and have three pairs of true legs and four pairs of abdominal prolegs. Younger larvae have a characteristic purple saddle and cream-colored stripes on their abdomens (Fig. 51.20). The colors of the larvae fade as they mature. Larvae have an orange head with a black stripe on each side. Common stalk borer moths are red-brown in color (Fig. 51.21).

In South Dakota, common stalk borer has one generation per year. During the fall, female moths preferentially lay eggs on thin-stemmed, perennial grasses over annual, wide-leaved grasses or broadleaf plants. Eggs overwinter and hatch between mid-April and early June the following year. Maturing larvae initially feed in the stems of grasses and weeds until they outgrow their initial plant host. Larvae will search for larger hosts, including corn. Common stalk borer larvae primarily cause injury to corn by tunneling into the stalk but also feed on corn leaves. When larvae feed on the whorls, new leaves appear ragged when they unfurl. Larvae may also kill the plant by feeding on the growing point (Fig. 51.22), resulting in stand loss and ultimately yield loss.

**Common Stalk Borer Scouting and Management**
Infestations are more likely to occur near field margins where grasses or weeds are present. Large-stemmed weeds, such as giant ragweed, are preferred, although the host range is as large as 176 plant species. Minimum or no-till cornfields where grass or weeds are present prior to planting are also at an increased risk for infestation. Corn is most susceptible to common stalk borer when it is between the V1-V5 growth stages, and field margins are at greater risk of injury. Corn adjacent to grassy areas should be scouted by checking 30 plants from May to June. Common stalk borer infestations can be detected by observing ragged holes in the newly emerged leaves and the presence
of frass that resembles sawdust near the center of the plant (Fig. 51.22). Table 51.6 contains threshold information for common stalk borer. If an early infestation is detected, insecticides may be used to manage the common stalk borer. However, applying insecticides to infested corn is generally not effective because larvae are protected within the plant. Insecticide applications should target common stalk borer larvae as they migrate from weedy hosts to corn, which typically occurs from late May to approximately June 20 in South Dakota. A list of insecticides registered for management of common stalk borer on corn can be found in the current edition of the South Dakota Pest Management Guide: Corn. For fields with infestations occurring near field margins, the first 4-6 rows of corn should be treated with insecticide during larval movement. Removing weedy hosts from the field margins prior to corn planting may also reduce the populations of the common stalk borer. However, this may increase infestation levels if corn seedlings are present when weeds and grasses are destroyed. At present, only the Vip3A Bt toxin is labeled for management of common stalk borer.

### Table 51.6 Economic threshold for common stalk borer larvae in corn expressed as the percentage of corn whorls infested1.

<table>
<thead>
<tr>
<th>Plant Stage</th>
<th>$3/Bushel</th>
<th>$4/Bushel</th>
<th>$5/Bushel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>150</td>
<td>175</td>
<td>200</td>
</tr>
<tr>
<td>V1</td>
<td>5.8</td>
<td>4.9</td>
<td>4.3</td>
</tr>
<tr>
<td>V2</td>
<td>7.1</td>
<td>6.0</td>
<td>5.3</td>
</tr>
<tr>
<td>V3</td>
<td>9.3</td>
<td>8.0</td>
<td>7.0</td>
</tr>
<tr>
<td>V4</td>
<td>9.9</td>
<td>8.5</td>
<td>7.4</td>
</tr>
<tr>
<td>V5</td>
<td>11.3</td>
<td>9.7</td>
<td>8.5</td>
</tr>
<tr>
<td>V6</td>
<td>19.8</td>
<td>17.0</td>
<td>14.9</td>
</tr>
<tr>
<td>V7</td>
<td>54.7</td>
<td>46.9</td>
<td>41.1</td>
</tr>
</tbody>
</table>

1Assumes management cost of $10 per acre and 70% mortality of treated larvae.
2Economic threshold = Management cost / (corn price x [proportion of yield loss x expected yield] x .7)

Table adapted from Rice and Davis 2010 and Hodgson 2014.

**Corn Aphids**

**Bird Cherry Oat Aphid (Rhopalosiphum padi, Linnaeus) and Corn Leaf Aphid (Rhopalosiphum maidis, Fitch)**

**Pest Highlights**
- Bird cherry oat aphids infest the stalk near leaf collars and the ear.
- Corn leaf aphids mainly infest the whorl, tassel, and developing ears.
- Maize dwarf mosaic virus can be transmitted by corn leaf aphids.
- Heavy infestations may reduce photosynthesis, pollination, and ear development.
- Black sooty mold is an indicator of large aphid populations.

**Bird Cherry Oat Aphid Description and Biology**

The nymphs and adults of the bird cherry oat aphid are teardrop- or pear-shaped and dark green to olive in color. These aphids can be identified by a characteristic rusty red-orange patch present at the end of their abdomens near their cornicles (tailpipes) (Fig. 51.23). There are both winged and wingless forms of the bird cherry oat aphid. These aphids prefer small grains, but can also be found on corn.
**Corn Leaf Aphid Description and Biology**
The corn leaf aphids vary in color from green-olive to blue-green and have rectangular-shaped bodies (Fig. 51.24). There are both winged and wingless forms of the corn leaf aphid. These aphids prefer sorghum but will readily feed on corn as well.

**Bird Cherry Oat and Corn Leaf Aphid Scouting and Management**
The bird cherry oat aphids often feed on the stalk near leaf collars. When ears are present, the bird cherry oat aphids can be found near the shank and also under the first few layers of the husk. The corn leaf aphids often feed within the whorl but can also be found feeding on upper leaves. The corn leaf aphid will also readily feed on the tassels and ears when present.

When scouting for both species of aphids stop at five locations throughout the field and randomly choose 20 plants at each location to inspect. Examine the whorl and the underside of the leaves to determine whether either species of aphid is present. The presence of black sooty mold, which grows on the honeydew produced by the aphids can be used as an indicator of aphid infestations. The presence of ants foraging on the plant may also indicate the presence of aphids. Current management recommendations indicate that treatment may be necessary if 50% of the inspected plants have more than 500 aphids on them during periods of sufficient moisture. If the plants are drought-stressed, treatment may be necessary if 50% of the inspected plants have more than 100 aphids on them. For a list of insecticides currently labeled for management of bird cherry oat aphids or corn leaf aphids on corn, please refer to the current edition of the South Dakota Pest Management Guide: Corn.
References and Additional Information


Bohnenblust, E., and J. Tooker. 2012. Fall armyworm as a pest of field corn. Penn State Entomological Notes, The Pennsylvania State University, University Park, PA.


Hodgson, E. 2014. Stalk borers are migrating to corn. ICM News, Iowa State University, Ames, IA.

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(1) mail: U.S. Department of Agriculture
   Office of the Assistant Secretary for Civil Rights
   1400 Independence Avenue, SW
   Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

USDA is an equal opportunity provider, employer, and lender.
Several species of insects, as well as rodents and other animals, are economically important pests of stored grains. Unfortunately, this means that integrated pest management (IPM) for your corn crop is not finished until the grain has been delivered and accepted by the commercial buyer. The final stages of an IPM plan for your corn actually start before harvest and continue while the corn is being stored in bin facilities. During this storage period, the kernels are susceptible to direct damage from feeding unless necessary precautions are taken. The purpose of this chapter is to discuss storage sanitation considerations, stored grain insect pest management, bin aeration, and common stored grain insect pests of corn.

**Corn Storage Damage**

Direct insect feeding reduces germination, nutrition, weight, and ultimately market value. Insects and other animals also cause indirect damage, which results in the contamination and deterioration of the grain. This in turn, leads to reduced quality and lower market value, which can be attributed to the presence of heat damage, intact dead insects, insect parts, odors, or molds. The current Federal Grain Inspection Service (FGIS) regulation used to determine whether corn is infested, and also grading based on the maximum limits for broken corn and foreign material (e.g., dead insects or insect parts) are presented in Table 52.1.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Insects per 2.2 pounds of grain to receive FGIS “infested” designation</th>
<th>Maximum limits of broken corn and foreign material, (percent) by grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>2 live weevils 1 live weevil + 5 other live stored grain pests 10 other live stored grain pests</td>
<td>U.S. No. 1: 2.0 U.S. No. 2: 3.0 U.S. No. 3: 4.0 U.S. No. 4: 5.0 U.S. No. 5: 7.0 U.S. Sample Grade: &gt; 7.0</td>
</tr>
</tbody>
</table>

1Foreign material includes all matter that will pass through a 12/64 round-hole sieve.

It is important to remember that the insect pests attacking corn in the field are not the same species as the ones attacking the stored crop. Because damaged grain results in docked or reduced market prices, it is important to use an IPM plan with preventative tactics and routinely monitor grain bins for pest activity. These approaches rely heavily on preventative actions including sanitation, pre-binning insecticide
applications, and early detection of problems post-binning. This type of IPM plan should be employed until the grain leaves the farm.

**Storage Sanitation Considerations**

To ensure that the quality of stored grain is preserved, it is important to establish and follow an IPM plan (Table 52.2). A leading cause of decreased grain quality is improper storage conditions, especially poor sanitation. Proper sanitation accounts for approximately 80% of an effective IPM plan for stored grain. “Good” sanitation includes:

1. Determining whether the bin is weatherproof and does not have any leaks. Any holes or gaps should be caulked/sealed. After the bin is filled, the door should be caulked/sealed to remove potential entry points for insects and rodents.
2. Removing any established pests and their food sources prior to filling the grain bin. Bins should be swept and/or vacuumed, with special attention given to cracks and crevices of the floor.
3. Cleaning up any grain spills around the outside of the bin. All grain and dust should be disposed of away from the bin.
4. Establishing a 10-ft perimeter outside the bin that is devoid of vegetation and garbage.
5. Cleaning equipment used seasonally for handling or transporting grain.

Following these steps will reduce the chances of stored grain pests accidentally being introduced to the new crop during binning, and also reduce the overall chances of infestation.

**Stored Grain Insect Pest Management**

It is recommended that new grain should never be stored on top of old grain. However, if this situation arises, the old grain must be fumigated prior to the addition of new grain (Table 52.3). Fumigants are extremely hazardous, restricted-use insecticides and require a commercial applicators license with class 14 certification, or a private applicator certification in South Dakota. Because of the hazards associated with these insecticides, it is recommended to leave the application of fumigants to professionals. Additionally, fumigants have no residual period and are effective only against insects present in the grain at the time of application. Grain is susceptible to reinfestation within 72 hours post-application.

For an empty bin, a pre-binning application of a residual insecticide should be applied to all of the interior surfaces and also to the exterior walls and base once the debris has been removed (Table 52.4). Follow the label instructions regarding application rate, personal protective equipment, and re-entry times. Once the re-entry interval has expired, remove any insects that were killed by the insecticide.

For corn that will be removed from storage in May or June or used as a livestock feed within a year of harvest, protectant insecticides most likely will not be required (Table 52.4). A protectant insecticide should be applied to corn that is expected to be stored for greater than one year, and it should be applied only after high-temperature drying when the corn moisture is approximately 14% to 15%. These insecticides can be applied at the auger while the bin is being filled, or as a surface treatment that is referred to as either topdressing or capping-off.

Stored corn with a temperature above 55-60°F should be inspected each week, and every two weeks when the temperature is below 55°F. When inspecting stored grain, it is important to remember the associated hazards (Table 52.5). If an insect infestation is detected in stored grain, the grain can be: 1) moved to have a protectant insecticide applied; 2) fed to livestock as-is; 3) sold at a reduced market value; or 4) fumigated.

**Bin Aeration**

Stored grain insect pest development slows down when grain temperatures decrease to 60°F, and essentially stops when the temperature decreases below 55°F. Because of this, it is important to reduce grain temperatures to limit the risks of developing stored grain pest issues. Stored grain can be cooled once the outdoor temperatures begin to drop in the fall. For bins that are equipped with fans, run the fan during cooler temperatures. In addition to reducing potential insect issues, proper grain aeration will help
Table 52.2 The seven steps to a stored grain integrated pest management (IPM) plan:

**Step 1.** Structural maintenance: keep bins clean and repaired.

- **All season:**
  - Keep a 10-ft perimeter around the bin free of vegetation and trash.
  - Clean up grain spills outside of the bin.

- **Pre-binning:**
  - Confirm that bin facilities are weathertight and rodent-proof; seal any holes.
  - Screen ventilation openings to prevent entry of rodents and birds.
  - Do not mix new and old grain; remove all old grain from bin or fumigate old grain.
  - Use a broom, shop vacuum, or compressed air to clean the interior bin walls, ceiling, ledges, floors, and sills prior to filling with new grain.
  - Do not mix new and old grain; remove all old grain from bin or fumigate old grain.
  - Dispose of any debris removed from bins or machinery as insects may be present.
  - Examine the outer bin perimeter to determine whether rodent bait stations are necessary.

- **Post-binning:**
  - Caulk around any doors.
  - Do not seal roof aeration exhaust of inlet vents except during fumigation.

**Step 2.** Residual insecticide sprays (Table 52.4).

- **Pre-binning:**
  - Spray the interior wall surfaces, ledges, floors, and sills with a residual insecticide.
  - Spray exterior walls (10-15 ft vertically up from bin base depending on label) and exterior base.
  - For long-term storage (> 1 year) consider fumigating the area beneath the slotted floor (Table 52.3 for information regarding fumigants).

**Step 3.** Condition grain: store clean, dry grain.

- **Pre-binning:**
  - For long-term storage, corn moisture should be 15% or less.
  - Use a grain cleaner to remove cracked kernels and other debris.

**Step 4.** Use insecticide protectants (Table 52.4).

- **Post-binning:**
  - Treat grain at the auger as it is moved into storage or apply a topdressing.

**Step 5.** Proper aeration of grain.

- **Post-binning:**
  - Run bin fan and stirator to ensure uniform temperatures and prevent moisture buildup. This will reduce mold growth.
  - Cool bin to a temperature below 55°F to reduce insect activity and inhibit mold growth.

**Step 6.** Regularly inspect the grain.

- **Post-binning:** (if problems are detected, see Step 7)
  - Monitor the grain regularly for the presence of insects, or insect parts. For grain above 55-60°F inspect weekly. For grain below 55°F inspect every two weeks. Inspection should continue from binning until the grain is marketed.
  - Use a grain probe to take samples in a pattern from the surface and from the base of the grain mass.
  - Take samples from the center to the areas near the wall, with samples being no farther than 20 feet apart.
  - “Hot spots” felt on the grain surface or unusual odors are indicators of insect activity and should be examined.
  - During the winter, insects will move to the center of the bin, so sampling at that location is important.

**Step 7.** Treating detected infestations.

- **Post-binning:**
  - If an insect infestation is detected:
    1. Move the grain and re-treat as in Step 4. It is possible to kill some of the insects if the grain is moved during cold weather (below 32°F).
    2. Feed the grain to livestock.
    3. Sell at a reduced price.
    4. Fumigate (Table 52.3).

*These precautionary maintenance steps should be taken 2-3 weeks prior to binning.*
Table 52.3 Fumigant insecticides that can be used on stored corn grain.\(^1\)

<table>
<thead>
<tr>
<th>Active Ingredient</th>
<th>Insecticide*</th>
<th>Restricted Entry Interval (REI)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum phosphide</td>
<td>Detia</td>
<td>Corn must be aerated after fumigation. Do not enter bin if phosphine or hydrogen phosphide gas levels are above 0.3 ppm(^2) unless protected by approved respirator.</td>
<td>Do not fumigate if temperature is below 40°F. Follow the minimum exposure period guide on the label. Fumigated areas must be placarded according to each product’s label. Some products require grain to be aerated for 48 hours prior to offering to end consumer.</td>
</tr>
<tr>
<td></td>
<td>Fumex</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fumitoxin</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gastoxin</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phostoxin</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weevil-cide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon dioxide (CO(_2))</td>
<td>Carbon dioxide</td>
<td>When CO(_2) levels are below 5%.</td>
<td>Works best with grain bins designed for “closed-loop fumigation.” Requires specialized application equipment. Fumigation with CO(_2) takes 10 or more days. Self-contained breathing apparatus must be worn; respirators are not effective against CO(_2).</td>
</tr>
<tr>
<td>Magnesium phosphide</td>
<td>Magtoxin</td>
<td>Corn must be aerated after fumigation. Do not enter bin if phosphine gas level is above 0.3 ppm unless protected by approved respirator.</td>
<td>Do not fumigate if temperature is below 40°F. Follow the minimum exposure period guide on the label. Fumigated areas must be placarded according to each product’s label.</td>
</tr>
<tr>
<td>Methyl bromide</td>
<td>Meth-O-Gas 100</td>
<td>Corn must be aerated after fumigation. Do not enter the bin if methyl bromide levels are above 5 ppm unless protected by a full-face supplied-air respirator or self-contained breathing apparatus.</td>
<td>Do not fumigate if temperature is below 40°F. Fumigated areas must be placarded according to each product’s label.</td>
</tr>
</tbody>
</table>

\(^1\)All fumigant insecticides are restricted-use products and cannot be purchased or applied without proper certification and permit or licensing. Follow all label instructions.

\(^2\)Parts per million (ppm)

*This list is not meant to be comprehensive. Mention of a trade name neither constitutes endorsement of the products mentioned nor criticism of similar ones not used or mentioned.*
### Table 52.4 Pre-binning corn grain residual and protectant insecticides.

<table>
<thead>
<tr>
<th>Active Ingredient</th>
<th>Insecticide*</th>
<th>Restricted Entry Interval (REI)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bacillus thuringiensis kurstaki</em></td>
<td>DiPel® DF Biobit® HP</td>
<td>4 hours</td>
<td>Protectant insecticide to be applied as a topdressing to the top 4 inches of stored corn. Will not control weevils or other beetles. Effective against Indian meal moth larvae. Labeled for organic production.</td>
</tr>
<tr>
<td>Beta-cyfluthrin</td>
<td>Tempo® SC Ultra</td>
<td>When spray has dried.</td>
<td>Do not allow runoff to occur. Pre-binning residual spray only.</td>
</tr>
<tr>
<td>Deltamethrin</td>
<td>Suspend SC Centynal</td>
<td>When spray has dried.</td>
<td>Suspend: Do not allow runoff to occur. Pre-binning residual spray only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Centynal: Do not reapply within 21 days. May be applied as a protectant while grain is being loaded into the bin. Can be used as a pre-binning residual spray.</td>
</tr>
<tr>
<td>Dichlorvos resin strips (DDVP)</td>
<td>Nuvan Prostrips*</td>
<td>N/A</td>
<td>Treatment normally lasts 4 months. One 16 gram strip treats 100-200 cubic feet. Place strips in the headspace of the bin. Wear gloves when applying strips.</td>
</tr>
<tr>
<td>Pirimiphos-methyl</td>
<td>Actellic 5E</td>
<td>When spray has dried.</td>
<td>May be applied while grain is being loaded into bin or as a topdressing, cannot be used for both. Do not make more than one application per year.</td>
</tr>
<tr>
<td>Pyrethrin</td>
<td>Pyronyl</td>
<td>12 hours</td>
<td>Do not reapply within 30 days. May be applied as a protectant while grain is being loaded into the bin. Can be used as a pre-binning residual spray.</td>
</tr>
<tr>
<td>Malathion</td>
<td>6% Malathion Grain Dust Malathion 5EC</td>
<td>12 hours</td>
<td>Malathion dust: Apply to grain prior to loading bin. Do not apply to grain within 7 days of selling. Malathion 5EC: Pre-binning residual spray only, do not spray directly onto grain.</td>
</tr>
<tr>
<td>(S)-methoprene</td>
<td>Diacon IGR Diacon D IGR</td>
<td>30 minutes</td>
<td>Apply to grain as it is being loaded into bin, or apply as a topdressing, but do not flood area. May be used with aeration.</td>
</tr>
<tr>
<td>Silicon dioxide (diatomaceous earth)</td>
<td>Dryacide Insecto</td>
<td>Once dust settle</td>
<td>Can be applied to grain when being loaded into the bin. Can also be applied as a pre-binning residual insecticide. Labeled for organic production. Overapplication of products may reduce grade of grain.</td>
</tr>
</tbody>
</table>

1Follow the label instructions for all pesticides. Always wear proper personal protective equipment.
*This list is not meant to be comprehensive. Mention of a trade name neither constitutes endorsement of the products mentioned nor criticism of similar ones not used or mentioned.

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### Table 52.5 Bin-sampling safety protocol.

There are many potential hazards associated with sampling inside of a grain bin. For instance, suffocation can occur in grain bins due to bridged grain. Bridged grain occurs when grain mats together and forms a false floor. When the false floor is broken during sampling procedures, cave-ins can occur. Where possible:

1. Always have another person with a cellphone outside the bin in case there is a problem.
2. Wear a harness that is attached to a properly secured rope when entering a grain bin.
3. Use a pole to break up crusted grain from a distance.
4. If the grain begins to flow stay near the outer wall of the bin and continue walking and get to the bin ladder as quickly as possible.
maintain uniform temperatures throughout the bin. This will eliminate “hot pockets” that are favored by insects and mold. To ensure optimal airflow, level off the grain once the bin has been filled. When the grain is not level, areas with peaks can provide optimal conditions for stored grain insect outbreaks and mold growth.

**Common Stored Grain Insect Pests of Corn**

There are several species of insects that feed on stored grain in South Dakota. Both immature (larval) and adult stages of stored grain beetles are capable of causing damage to grain, while only the larval stage of the stored grain moths cause damage. These insect pests can be grouped based on whether they are internal feeders or external feeders. Internal feeders feed within the kernels, whereas external feeders consume grain dusts, cracked kernels, and other grain debris. Below are the common internal and external stored grain pests. In addition to these, other species including the foreign grain beetle and hairy fungus beetle may be observed in a bin feeding on molds or fungi growing on the grain.

**Internal Feeders**

Of the internal feeders, the weevils (Fig. 52.1A, B, and C) are generally given the most attention because they are among the most destructive pests of stored grain. The larvae of grain weevils develop within the kernels, and this pest can cause nearly complete destruction when infested grain is left undisturbed for long periods of time. Adult weevils are easily distinguished from other beetles by their elongated snouts.

The lesser grain borer (Fig. 52.1D) is a pest of a wide variety of grains including corn. The larvae and adult bore holes into whole undamaged kernels. Evidence of feeding may include a sweet musty odor and dust and thin brown shells on grain kernels.

The larvae of the angoumois grain moth (Fig. 52.1E, adult moth) are typically not a pest of shelled corn. However, the larvae are a pest of ear corn and can infest the corn before it is harvested. The larvae feed inside kernels, and cause an unpleasant smell. During a warm fall, several generations of the moth can complete their life cycle, resulting in significant damage.

**External Feeders**

External feeders consume grain dusts, cracked kernels, or other grain debris when present. The best management for these insects is prevention that includes proper aeration and corn grain cleaning.

The cadelle beetle (Fig. 52.2A), confused flour beetle (Fig. 52.2B), flat grain beetle (Fig. 52.2C), red flour beetle (Fig. 52.2D), and sawtoothed grain beetle (Fig. 52.2E) are present in the grain due to the availability of cracked kernels, dust, and other grain debris. In some instances, these beetles will feed on kernels that were damaged by internal feeders.

The larvae of the Indian meal moth (Fig. 52.2F, adult moth) cause direct damage to the grain by feeding on the seed germ. The larvae of this pest also reduce the quality of grain by producing waste and constructing silken webs in the grain.
Figure 52.1 Internal feeding stored corn grain pests. (A) Granary weevil (aka wheat weevil) adult. (Photo courtesy of Pest and Diseases Image Library, Bugwood.org); (B) Maize weevil adult. (Photo courtesy of Gary Alpert, Harvard University, Bugwood.org); (C) Rice weevil adult. (Photo courtesy of Pest and Diseases Image Library, Bugwood.org); (D) Lesser grain borer adult. (Photo courtesy of Pest and Diseases Image Library, Bugwood.org); (E) Angoumois grain moth adult. (Photo courtesy of Clemson University-USDA Cooperative Extension Slide Series, Bugwood.org)
Figure 52.2 External feeding stored grain pests. (A) Cadelle beetle adult. (Photo courtesy of Clemson University-USDA Cooperative Extension Slide Series, Bugwood.org); (B) Confused flour beetle adult. (Photo courtesy of Pest and Diseases Image Library, Bugwood.org); (C) Flat grain beetle. (Photo courtesy of Gary Alpert, Harvard University, Bugwood.org); (D) Red flour beetle adult. (Photo courtesy of Pest and Diseases Image Library, Bugwood.org); (E) Sawtoothed grain beetle. (Photo courtesy of Pest and Diseases Image Library, Bugwood.org); (F) Indian meal moth adult. (Photo courtesy of Pest and Disease Image Library, Bugwood.org)
References and Additional Information


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Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council. The authors would like to thank Dr. Kenneth Holscher for his help with editing and reviewing this chapter.


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(1) mail: U.S. Department of Agriculture
Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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In many years, corn drying is required to ensure that the crop will be of high quality and available to market in the future. Harvesting corn with moisture content > 22% requires special precautions, such as providing enough airflow to keep the corn cool and drying within days after harvest. Prior to storing corn, the bin should be cleaned and potential pest problems controlled (See Chapter 52). This chapter discusses corn drying and storage. Rules of thumb are provided in Table 53.1.

**Table 53.1 Corn drying rules of thumb:**

- Determine the desired moisture content of the grain, and the short and long-term storage requirements.
- Clean all equipment that will contact the grain (Ess et al., 2005).
- Minimize the number of broken kernels placed into the grain bin (Hanna, 2008).
- Grain with high moisture content (> 22%) needs to be dried prior to storage. The corn moisture content is a function of air temperature and relative humidity.
- If corn will be sold as #2 grain by the spring, it can be stored at 15.5% moisture. However, if it will be stored for 6-12 months, the moisture content should be reduced to 14%, and if storage is a year or longer, the moisture content should be 13%.
- Periodically, at least every two weeks, monitor the grain bin and electronic monitoring devices, if problems are detected, immediately resolve them, waiting will worsen the problem or make the problem uncontrollable.
- The most typical problems result from:
  - Improper grain cooling.
  - Poor initial quality.
  - Inadequate monitoring and failure to take immediate action.
  - Inadequate insect management.
  - Failure in the automatic temperature control system.

**Grain Drying**

High-moisture corn should be dried prior to storage. If the moisture content is > 22%, the grain should be dried within days after harvest. In South Dakota, due to low fall temperatures or inadequate airflow, natural air drying may not dry the corn fast enough to complete drying prior to winter. However, if drying can be delayed until spring, natural drying systems may be adequate.

High-temperature systems can be used to rapidly dry corn grain. These systems become more efficient as the drying air temperature increases. During drying it is not recommended to increase the kernel temperature to greater than 140°F. Details on different drier designs are available in Hellevang and Wilcke (2013).
The length of time that grain can be held before grade loss occurs is dependent on the grain moisture content and grain temperature (Table 53.2). At 60°F, corn at 18% moisture can be held for 63 days, whereas corn at 22% moisture can be held only for 16 days. Corn at 18% moisture can be held for 195 days if it is held at 50°F, whereas corn at 22% moisture can be held for 54 days. If the corn is at 28% moisture, it can be held for 20 days at 40°F but only 5 days at 60°F.

Storage
In South Dakota, grain is placed in grain bins or piles, when the temperature ranges from 20°F to 50°F. Each system has unique problems and advantages. In a grain bin, corn grain should not be stored if the moisture content is > 22%, and any grain peaks should be removed.

Grain bin storage: As temperatures decrease during fall and winter, the cooling process starts near the bin's edges and walls. Differential cooling can result in water migration from the center of the bin to the edges, and convection currents then occur that cause moisture movement to the top center of the bin. Even if you have an electronic monitoring system, it is recommend that the bin be checked weekly. Wet slimy grain, crusting, and condensation on vents, hatches, and the roof can be symptoms of serious problems. If the surface seals, severe spoilage can result. If crusting has occurred, stir the surface and in extreme cases remove the spoiled grain. Use aeration to cool the grain as outdoor temperatures decrease. Maintain the grain temperature within 15 to 20 degrees of the monthly average temperature during the fall (McKenzie and Van Fossen, 1995).

Bag storage: Storage of grain in plastic bags is becoming popular. However, these bags can be susceptible to mold and insect problems. If the moisture content is high (> 25%), ensiling can occur if the temperatures are above freezing. The temperatures in these bags generally mirror the average outdoor air temperatures. It is not recommend to store high-moisture grain (> 24%) in these bags until the air temperatures have decreased below 32°F. To prevent molding, high-moisture corn should be dried prior to spring warm-up. To prevent problems, the temperatures in the bags should be monitored periodically.

Grain pile storage: Under emergency situations, corn can be stored in piles (Hellevang, 1989). In these systems, water flow should be graded away from the pile, and a plastic sheet should be placed under the pile to prevent water migration from the soil to the pile. When designing a system, consider how much grain needs to be stored and if the grain will be stored as a conical, windrow, or constrained pile. Aeration should be provided to control grain temperature. It may also be possible to store grain in a machine shed.

<table>
<thead>
<tr>
<th>% Moisture content</th>
<th>Temperature (°F)</th>
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Table 53.2 Approximate storage time of grains as influenced by moisture content and temperature (°F). (modified from Behlen. 2012)
However, when placing grain in a nonreinforced building it is not recommended to pile the grain higher than a couple feet up the wall.

**Monitoring Temperature**
Grain temperatures can be monitored by placing temperature sensors at various locations in the grain bin, piles, and plastic bags. Sensors can be placed along the walls of the bin and suspended from the bin rafters. Problems can be avoided by monitoring temperatures. Temperatures can be managed by using aeration to change the grain temperature. Aeration can be used to cool the grain following harvest and equalize the grain temperature in the spring. Fans that push air into (positive pressure) or remove air from (negative pressure) the chamber can be used. Fans can be placed at the bottom of the bin. To avoid moisture migration, aerate the grain to keep the grain temperature within 10 to 15 degrees of the average outdoor temperature during the fall. (This is true only for negative pressure systems.) When tracking temperatures, smell the exhaust air for odors. The time required to change the temperature depends on fan size, the season and desired temperature change. The hours required for one aeration cycle can be estimated by dividing 15 by the airflow rate (cubic feet per minute per bushel).

In South Dakota, grain should be cooled to below 35°F in the fall. This process should be started when the average daily temperature is 10 to 15 degrees cooler than the grain temperature. Cool the grain to 20 to 30 degrees for winter storage. If hot spots are detected during inspections, aerate the system until differential heating is not observed.

In the summer, the grain should be kept cool. The goal should be to limit grain temperature to near 40°F. High temperatures increase the risk of mold and insects.

**Grain Moisture and Temperature Impact on Storage**
Grain moisture content and temperature have a direct impact on grain storage. Generally, increasing the temperature or moisture content decreases storage life (Table 53.2).

**Grain Bin Safety**
1. To minimize grain bin problems, ask the question would I let my child do this?
2. Do not enter a grain bin when unloading a grain bin.
3. Check to make sure automatic unloading equipment is turned off prior to entering a grain bin.
4. Use a safety harness when entering a bin if you are not standing on the floor.
5. Let someone know – preferably someone observing – that you are entering the bin.
6. Be careful when stepping on crusts as there may be a void underneath and you could become buried.
7. Wear a respirator that will remove mold spores and grain dust.

| Table 53.3 Troubleshooting guide. (Modified from McKenzie and Van Fossen, 1975) |
|---------------------------------|---------------------------------|---------------------------------|
| **Symptom**                     | **Probable cause**              | **Possible solution**           |
| Bad odor                        | Heating and moisture accumulation problem | Run the fan; check grain temperature and moisture content. |
| Crust                           | Spoiled grain                   | Check to see extent of crust and aerate. |
| Grain is warming up             | Moisture content is high        | Run the fan – may need to dry grain. |
| Grain is slimy or wet on top surface | Moisture migration             | Run the fan to dry grain and create uniform temperature. |
| Hard crust                      | Moisture migration              | Remove spoiled grain and aerate. |
| Water condensation (on roof?)   | Moisture migration – grain is warm | Aerate to cool the grain. |
| No air flow though grain when aerating | Air flow blocked by moldy grain | Determine location and scope of problem. Market or re-bin. |
| White dust on grain when stirred | Mold on grain                   | Assess extent of problem – remove molded grain. |
| Slow grain cooling              | Fines may be blocking aeration  | Run the fan longer – remove center core. |
References and Additional Information


Acknowledgements

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Understanding corn production costs is an important step in the optimization of the corn management system. The interactive tool “2015 Crop Budgets” is available online from South Dakota State University (sdstate.edu), https://www.sdstate.edu/econ/extension/index.cfm, and can be used for this purpose. This chapter is focused on the analysis of corn production costs in the northern Great Plains and heartland region.

**Corn Enterprise Vertical Analysis**

Is too much money spent on land rent, seed, fertilizers, and pest management? Vertical analysis may have the answers. Vertical financial analysis helps pinpoint where the money is spent and it provides a mechanism to compare production costs. Vertical analysis is done by converting the dollar amounts on a financial statement to percentages. It compares major expenses to gross revenue.

Knowing that direct expenses per acre are $456 is important, but knowing this represents 64% of gross revenue provides more information. You can track the percentage over time and compare it to industry benchmarks. Parameters can be set that will serve as an early warning sign of expenses moving out of proportion with revenues. Key expenses such as seed, fertilizer, rent, machinery costs, and labor/management can be watched, and modification plans can be made and implemented, if necessary. As gross sales per acre increased from 2006 to 2012, it was assumed that crop expenses would also go up. But what happens when expenses outpace revenue? Vertical analysis can help identify this change.

Vertical analysis is conducted by dividing a line item on an income statement by gross revenue. As an example, if gross revenue is $1,100/acre and seed is $110/acre and fertilizer costs are $170/acre, respectively, what percentage of your total revenue was spent on seed and how much was spent on fertilizer?

\[
\text{Seed} \quad \% \text{ revenue} = \frac{110}{1100} \times 100\% = 10.0\%
\]

\[
\text{Fertilizer} \quad \% \text{ revenue} = \frac{170}{1100} \times 100\% = 15.5\%
\]

---

1 Gross revenue in this analysis includes: hedging gains (losses), crop insurance, and other crop income that is tracked directly to the crop and is not included in bu/acre and $/bu (yield * price).
Guidelines to Using Vertical Analysis

Vertical analysis is essential to understand how the enterprise is doing financially, reveals inconsistencies, and aids in making astute business decisions. For example, from 2007 through 2012, the costs for seed, fertilizer, and land rent totaled 43.4% of gross revenue for all farms in the data set. Historical analysis suggests that it is difficult to be profitable if these key costs increase to > 50% of the gross revenues. Comparing different expense ratios allows individuals to help target expense reductions where they may have the most impact. If an expense makes up 16% of gross revenue and another expense makes up 4%, which solution is better: cutting the lower expense by 50% or cutting (without giving up yield) the higher expense by 20%? Focusing management efforts on the higher expense components may increase the return on investment.

Corn Production Costs

Source of Information

The cost, yields and selling price information provided in Table 54.1 is obtained from FINBIN Farm Financial Database, Center for Farm Financial Management, University of Minnesota. The Farm Financial Management Database is available at http://www.finbin.umn.edu/. Benchmarks can be obtained for individual states or products. The database summarizes actual farm data from thousands of agricultural producers who use FINPACK for farm business analysis. Data in FINBIN is contributed by farm management associations that use FINPACK as their farm business analysis and summary program. The analyses can be specified for specific groups. For example, in 2014 total direct expenses for South Dakota corn producers farming owned land producing 169 bu/acre was $316/acre with a net return of $73.48/acre. However, for rented land producing 170 bu/acre, the total direct expenses were $408/acre with a net return of $68.07/acre.

Data reported in this report were obtained for cash rented corn enterprise systems located in South Dakota, North Dakota, Minnesota, and Nebraska. Over 2,000 farms were included in the analysis. The analysis covers the years 2000 through 2014 and is split into 3 time frames, 2000 through 2006, 2007 through 2012, and 2013 through 2014. The focus is on key expenses in proportion to gross revenue from the corn enterprise. The information is presented for all farms in the data set and further broken down

<table>
<thead>
<tr>
<th>Table 54.1 The average cost of production, average grain yield, and selling prices for the top 40% of all producers compared with all producers.</th>
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into the group of farms in the top 40 percent of net profit (High). These numbers and percentages may be used to further compare to an individual’s corn enterprise cost.

**Cash Rent Corn Production Systems**

Direct expenses for the corn enterprise include seed, fertilizer, chemicals, crop insurance, repairs, drying, marketing, labor, miscellaneous, operating interest, and land rent. Land rent has been deducted from direct expenses in this analysis (Table 54.2). Direct expenses without rent ranged from $165 to $232 and averaged $193 during 2000 to 2006 for all farms. In high net profit farms, direct expenses, without rent, ranged from $138 to $226 from 2000 to 2006, with an average of $174 per acre. For the time period from 2007 to 2012 direct expenses without rent ranged from a low of $238 in 2010 to high of $444 in 2012, with an average of $364 for all farms. High net profit farms ranged from a low of $249 in 2007 to a high of $443 in 2012 with an average of $354. The average direct expenses without rent for 2013 and 2014 for all farms is $461 and for high-profit farms is $428. Direct expenses without rent as a percentage of gross revenue peaked in 2001 at 73% for all farms and reached a low of 40.5% for high-profit farms in 2010.

High-profit farms maintained the direct expense ratio at 40% to 45% of gross revenue for 11 of the 15 years from 2000 to 2014, with only 2009 being above 50%. High-profit corn producers have been able to remain profitable by keeping direct expenses in the range of 40% to 45% of gross revenues. From 2000 to 2006, land rents averaged $84/acre.

For all farms, rent doubled from 2007 to 2013. However, the high-profit farms maintained the land rent in a range of 16% to 20% of gross revenue. On the high-profit farms, land rent ranged from 16% to 30% of total revenues, whereas the expenses for seed, fertilizer, machinery costs (variable and fixed), labor, and management increased from $140 in 2000 to $478 in 2012. From 2012 through 2014, these costs decreased slightly to $460.

Historically, seed costs ranged from 10% to 11% of gross revenues. However, in 2013 and 2014, seed costs increased to 13% of gross revenues (Table 54.1). For the high-profit group, fertilizers generally range from 13% to 15% of gross revenue. However, in 2013 and 2014, the percentage of gross revenues increased slightly (16.5% to 17%). High-profit farms have maintained machinery costs in a range of 13% to 15% of gross revenue.

| Table 54.2 Direct expenses without rent and rent for the top 40% of all producers and all producers. |
|---------|-----------|-----------|-----------|
| Direct Expenses w/o Rent | $/a | % revenue | $/a | % revenue | $/a | % revenue |
| Rent | 84 | 20.5 | 137 | 17.1 | 195 | 22.5 |
| Direct Expenses w/o Rent | $/a | % revenue | $/a | % revenue | $/a | % revenue |
| range | $165-232 | 57.3 | $364 | 48.0 | $461 | 63.3 |
| Rent | 93 | 27.8 | 137 | 17.9 | 197 | 27.0 |
References and Additional Information

Center for Farm Financial Management, University of Minnesota http://www.finbin.umn.edu/ (accessed 5 November 2015)

Data Sources. South Dakota Center for Farm/Ranch Management

Nebraska Farm Business Association and Nebraskaland Farm & Ranch Management Education Program, All North Dakota Groups, MnSCU Farm Business Management, Southwest Minnesota Farm Business Management Association, Southeast Minnesota Farm Business Management Association


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(1) mail: U.S. Department of Agriculture
Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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Obtaining maximum profit from a corn crop depends on the timely planting of an appropriate hybrid, at the proper depth, with a planter that evenly spaces the seed. The success of a corn crop is dependent on equipment maintenance, seedbed preparation, the development of a sound fertility and pest management program, and planting the seed. Early planting is best, but temperatures should be warm enough to assure quick germination and emergence, and late enough to avoid hard frosts. Planting opportunity windows can be narrow due to spring rains or a late warm-up. Time spent in the off-season maintaining equipment and planning tentative season-long schedules can increase efficiency in the spring (when time is limited). This section discusses planter maintenance, planting date, replanting considerations, seeding rate, and planting depth.

**Planter Maintenance and Preparation**

A corn planter is a piece of precision equipment, with each component working together to place the seed in the ground at a uniform depth and with a uniform distance between seeds. Research has shown that the uniform spacing of seed can increase yields up to 20 bu/acre (Doerge and Hall 2000). Although they are conducted too late to correct an in-season problem, stand counts and population surveys can be useful for determining if a planter should be calibrated prior to the next use. Growing conditions should also be evaluated as poor seed quality, or problems such as soil crusting, areas that are too wet or too dry, or cold soil temperatures for extended periods, may be responsible for non-uniform stands. Potential yield losses due to uneven stands can be estimated (Carlson et al. 2000). If planter calibration is necessary, always follow the manufacturer’s instructions for calibrating seed metering equipment. Assistance is available from local Extension educators, crop consultants, or seed dealers.

During planting, it is important to place seed at the proper depth and ensure that the walls of the furrow are not smeared by the opener. Down pressure tension should be adjusted if seed is not placed at the desired depth (1½ to 2”) (see “Depth and Planting Options” section at the end of this chapter). Closers or packing wheels should apply enough pressure for good seed-to-soil contact; too much pressure...

---

**Table A.1. Planter Maintenance Checklist**

- Review owner’s manual.
- Replace worn parts.
- Calibrate seed meters.
- Calibrate planter fertilizer and pesticide applicators.
- Check down pressure springs.
- Maintain even and recommended tire pressure.
- Lubricate bearings and other moving parts.
will compact the seedbed. Adjust down pressure tension in consideration of soil moisture and residue conditions.

As no-till and reduced-till systems become increasingly popular, the planter takes on the additional task of manipulating soil and crop residue. Hence, there are more parts to wear out and maintain. Implements that manage residue on the planter are critical in no-till and other high-residue systems, as crop residue can interfere with openers and closures.

**Planting Dates**
The spring planting window generally ranges from late April to mid-June (table A.2). Historically, 10% of the corn acres in South Dakota are seeded by mid-May and continuing to mid-June. Seed germination depends on soil moisture and temperature. Care should be taken to avoid tillage and planting operations when soil is wet. Yields may or may not be reduced due to delayed planting. However, due to problems associated with compaction, “mudding” the seed in will reduce the yield both of the current years’ crop and of those crops grown in the future.

As a general rule, corn should not be planted until the soil temperature (measured at 2” between 7 and 8 a.m.) approaches 50°F. In cold soil conditions (below 50°F), seeds will readily absorb water but will not initiate root or shoot growth; this leads to seed rots and poor emergence. If circumstances force planting before soil temperatures reach 50°F, it is recommended to consult with a reputable seed dealer or agronomist to select

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**Table A.2. Suggested and historical dent corn planting dates in South Dakota by region**

<table>
<thead>
<tr>
<th>Approximate planting dates by reporting region</th>
<th>Historical acres planted, 1970 – 1994**</th>
<th>South Dakota Reporting Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suggested planting dates*</td>
<td>10%</td>
<td>50%</td>
</tr>
<tr>
<td>Earliest</td>
<td>Latest</td>
<td>Desired range</td>
</tr>
<tr>
<td>May 4</td>
<td>Jun 5</td>
<td>May 12 - 26</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>May 10 - 24</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>May 10 - 24</td>
</tr>
<tr>
<td>Apr 29</td>
<td>Jun 8</td>
<td>May 12 - 24</td>
</tr>
<tr>
<td>May 3</td>
<td>5</td>
<td>May 6 - 26</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>May 6 - 26</td>
</tr>
<tr>
<td>May 4</td>
<td>Jun 3</td>
<td>May 7 - 24</td>
</tr>
<tr>
<td>Apr 29</td>
<td>8</td>
<td>May 3 - 17</td>
</tr>
<tr>
<td>27</td>
<td>10</td>
<td>May 1 - 15</td>
</tr>
</tbody>
</table>

* Dates are best estimates obtained from historical and research data within a reporting region
** Adapted from National Agricultural Statistics Service (NASS) – South Dakota Field Office

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**Table A.3. Yield response of corn to planting date**

<table>
<thead>
<tr>
<th>Relative Maturity (MN Rating)</th>
<th>Average planting date</th>
<th>Daily yield loss from May 7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>April 17</td>
<td>April 27</td>
</tr>
<tr>
<td>101 – 103 d. (early)</td>
<td>130</td>
<td>132</td>
</tr>
<tr>
<td>112 – 118 d. (late)</td>
<td>143</td>
<td>145</td>
</tr>
<tr>
<td>Average</td>
<td>137</td>
<td>139</td>
</tr>
</tbody>
</table>

*No data for 1995 or 2000
Yield data collected from 1986 to 2001 (14 yrs*)
Southeast South Dakota Experiment Station, Beresford SD (Berg et al. 2001)

---

**Table A.4. Estimated accumulated GDUs required for corn**

<table>
<thead>
<tr>
<th>Growth Stage</th>
<th>RM* – 80 days (Early)</th>
<th>RM* – 95 days (Mid)</th>
<th>RM* – 110 days (Late)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergence</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>R1 (silking)</td>
<td>1100</td>
<td>1250</td>
<td>1400</td>
</tr>
<tr>
<td>R6 (maturity)</td>
<td>1900</td>
<td>2200</td>
<td>2500</td>
</tr>
</tbody>
</table>

* Relative Maturity (RM) of hybrid in days
an appropriate hybrid (one where the seed has been treated with a fungicide).

**Delayed Planting or Replanting Considerations**

Delayed planting reduces the number of growing degree units (GDU) accumulated during the season, hindering the crop from maturing before the first fall killing frost (see Appendix B). Corn killed by frost before maturity may not have completely filled kernels and has a slower dry-down rate, which can lead to excessive drying costs. If planting is delayed, late-maturing hybrids can lose up to 1.1 bu/Acre* per day compared to earlier-maturing hybrids that can be planted later in the season without realizing a loss (table A.3). Often, the trade-off is that earlier hybrids may inherently have a lower yield potential.

The number of GDUs that a hybrid needs to reach physiological maturity is related to maturity ratings (table A.4.). Since GDUs are based on temperature, the amount of GDUs accumulated in the spring and fall are less than during the peak summer months. Available GDUs decline with later planting dates. However, corn will usually emerge quicker if soil temperatures are warmer. If planting is delayed, an earlier maturing hybrid should be considered.

A rule of thumb is to plant 20% of fields with a full season hybrid, 60% with a mid-season hybrid, and the remaining 20% with a short-season hybrid (“20-60-20 rule”). If planting is delayed, growers are urged to consult their seed dealer to determine if an earlier-maturing hybrid is warranted.

**Seeding Rates**

The optimal population for an area is influenced by available water, nutrients, and overall soil productivity. Even within a field, optimal populations may vary by soil type or landscape position. Low populations can lead to increased weed pressure (from lack of competition), whereas higher plant populations increase seed investment with little return. Achieving an optimal population throughout the field gives corn a competitive edge over weeds and can optimize grain dry-down time in the fall.

Optimal corn populations vary from 24,000 to 32,000 plants per acre. Higher-productivity soils with sufficient drainage and available water can support higher populations. Data in table 3.5 provides a guide for selecting optimal population rates.

Some overall recommendations for seeding rate include:
- Increase populations by ≈10% for silage crops.
- Set seeding rates higher than target population to account for less than 100% germination and seedling mortality.
- Increase seeding rate by ≈ 2000 seeds/acre in no-till systems.
- Increase seeding rate by ≈ 2000 to 3000 seeds/acre in irrigated fields.

**Depth and Planting Operations**

Depending on field conditions at the time of planting, depth can vary from 1-½ to 3 inches. Under optimal conditions, seed is commonly placed 1-½ to 2 inches below the soil surface. In dry conditions, it may be advantageous to plant deeper (2 to 3”) to place the seed into a higher-moisture area. If soil is very dry and rain is not expected, seed may be placed up to 3 inches deep. Planting deeper than 3 inches is not recommended because placing the seed too deep (>3”) will not allow emergence (as the coleoptile cannot elongate enough to bring the leafy parts above ground). Although soil conditions may be dry, consider the probability of rain in the near future. Rain can seal the surface of the soil, making it difficult for the developing plant to emerge. Shallower depths (<2”) should be targeted if rain is likely.

Crop residue can affect seeding date (as soils warm more slowly in high residue systems). Seed can be left on the surface when seed openers “ride-up” over residue. When seeding into areas with heavy residue, plant at least 1-¼ inches but no more than 1-½ inches deep if moisture conditions are favorable. Check seed depth often in high-residue situations to make sure that seed is placed at the proper depth. These measurements should not include any surface residue. Seed left on the surface or in the residue layer will not grow or properly develop. If residue is problematic, consider residue management planter attachments.
Additional Information and References


Acknowledgements
Support for this document was provided by South Dakota State University, SDSU Extension, and the South Dakota Corn Utilization Council.


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Frost
Corn is usually safe from frost up to the two-leaf stage (V2) because the growing point is below the soil surface. Soil temperatures can be different than air temperatures. Soil water content and residue cover affect soil warming and cooling. Damage can occur if temperatures dip below freezing. If frost damage is suspected, an assessment can be conducted by slicing the plant in half vertically. If the innermost part of the plant (the area with the newest growth) appears mushy or discolored (brown and/or black), the plant will likely not recover. An assessment for frost damage should not be attempted until at least 3 days of warm temperatures following a frost event. Warm temperatures encourage the plant to resume growth, but cool temperatures will not. If an attempt at damage assessment is made before the plant has had time to recover, the assessment may not be accurate. Assessments conducted 3 to 10 days after frost are common. Frost damage can be spotty in a field, with the most severe damage in low-lying areas of fields and little to no damage in even slightly higher elevations.

Hail
Hail can defoliate the crop and cause breakage or bruising of the stalk, creating entry sites for insects and diseases. The severity of the damage caused by hail is related to the size and duration of the hail. In most hail cases, the crop will recover; yield loss depends on the growth stage at the hail event and the...
severity of the damage. A hail event occurring when the growing point is belowground may only strip the emerged leaves. As the crop develops, it becomes more vulnerable to leaf stripping. Damage to leaves and stalks can reduce yield if the movement of sugars from the leaves to the ears is restricted. Hail during ear development may result in a barren crop.

**Flooding and Drought**

Water is essential to crop growth and development, but it must be available within an optimal range. Too much water can kill plants from lack of soil O₂, or can result in disease problems. As with frost, flooding may be site-specific in the low-lying areas of a field. Drainage may be an option for frequently flooded areas. However, to determine the legality of drainage, local USDA-NRCS offices must be contacted prior to installing artificial drainage systems.

Drought also restricts corn yield. Dry conditions during silking will reduce kernel set and pollination. In a field that has both high and low landscape positions, drought will be noticed on hilltops and summits before the lower-lying areas are affected.

Weather conditions such as frost, hail, flood, or drought can severely reduce yields. Effects from these events are manageable to a certain extent, but loss can be expected when these events occur. The degree of loss depends on the severity of the event. Crop insurance has become a common component of corn production in the U.S.; the insurance provides the producer economic protection for uncontrollable events. Producers should consider crop insurance based on the consequences of crop loss.

More information on South Dakota climate and weather information is available from the South Dakota Office of Climatology (http://climate.sdstate.edu).
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Office of the Assistant Secretary for Civil Rights
1400 Independence Avenue, SW
Washington, D.C. 20250-9410;

(2) fax: (202) 690-7442; or

(3) email: program.intake@usda.gov.

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