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Dry-Land Crop Production on the Clay Soils of Western South Dakota

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CIRCULAR 85 ♦ MARCH 1951

DRY-LAND CROP *Production*

**ON THE CLAY SOILS
OF WESTERN SOUTH DAKOTA**

BUREAU OF PLANT INDUSTRY, SOILS AND
AGRICULTURAL ENGINEERING ♦ SOUTH
DAKOTA STATE COLLEGE EXPERIMENT
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Cover: A good crop of wheat on fallowed land, Newell Irrigation and Dry-land Field Station, South Dakota

Dry-Land Crop Production on the Clay Soils of Western South Dakota¹

A. OSENBRUG and O. R. MATHEWS²

Dry-land production at the Belle Fourche Field Station (now called the Newell Irrigation and Dry-land Field Station) has been carried on for 40 years. This span of years has included periods of prosperity and of stress. While one cannot foresee the future, the best guide to what may occur is a record of what has happened in the past. The 40 years just concluded provide material that should be of interest to all concerned with farming in the dry-land portion of South Dakota.

The Belle Fourche Field Station was established in 1906 primarily to study the problems of irrigation. The station was also selected as a place to conduct investigations in crop production on non-irrigated land. At that time, information on dry farming in the dry-land portion of the Great Plains was almost completely lacking, and recommendations on how to grow crops on limited rainfall were based chiefly on theory.

The soil on the station and much of the adjacent area is classified as Pierre

clay, but is locally termed "gumbo." It is a residual soil developed from the Pierre shale that underlies the region, and it merges into partially decomposed shale at depths ranging from 3.5 to 7 feet. The soil is extremely sticky and plastic when wet, and must dry for a longer time than most soils before it can be worked satisfactorily. When too much moisture is present, tractors or other heavy equipment may compact it so much that crops which follow are affected adversely. If plowed while wet, it may turn up in lumps that bake into hard clods. When dry, it shrinks and cracks to depths up to 24 inches. These cracks provide channels, which in a badly cracked soil may absorb a heavy rain without material runoff. Water penetration below the cracked layer is very slow. Wet or dry, the soil requires more power for tillage than most soils, and a very dry soil may turn up in such large lumps that tillage is impracticable.

The experimental field was broken out from virgin sod in 1907, and the first crop was grown on uniformly prepared land in 1908. Crops were grown under planned sequences and methods, beginning in 1909. The re-

¹Prepared for publication by the South Dakota Agricultural Experiment Station as a cooperative enterprise.

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sults used in this publication are from 1909 to 1948, inclusive, and will present some of the general information obtained from these experiments.³

All of the research has been directed toward establishing a stable agriculture for the semi-arid and sub-humid lands. In order to realize this objective, it was necessary to obtain facts not only on the production that could be achieved under different methods, but also on the basic causes of such differences. Work on moisture conservation practices was supplemented by measurements of the different climatic factors, and by determinations of soil moisture at intervals during the growing season under different practices. Crop rotations were used to furnish a continuing record of production under different sequence and tillage practices.

Some lines of investigation have been explored and then dropped, but there has been a solid group of rotation and cultural methods continued throughout the years. Production achieved under the different cultural practices and sequences provides a means of measuring the possibilities and limitations of farming in the area.

The problems, as they were envisioned when the work was started and as they have since developed, may be roughly outlined as follows:

(1) **Moisture.** The quantity of water available for crop production and its efficient use was, and still is, the number one problem. It has been studied through widely different cultural practices and crop sequences, supplemented by actual measurements of soil moisture.

(2) **Crop adaptation.** Crops which seemed to be adapted to the area were grown in rotations and under tillage practices designed to show their relative productivity and dependability, and the extent to which annual yields might be influenced by tillage method or sequence. In any given year, all plots of a crop in the rotation field were planted to the same variety, and varieties were changed only when it had been clearly established that another variety was superior.⁴

(3) **Maintenance of soil productivity.** It was recognized when the work was started that the soil was low in organic matter and nitrogen, and that maintenance of levels high enough for sustained production might become highly important. Rotations involving the use of barnyard manure, green manure crops, and grass and legume hay crops were set up to measure their relative effectiveness. Emphasis was placed on green manure crops, because if it became necessary to return more organic matter to the soil, the quantity of barnyard manure available for use would meet only a fraction of the requirements.

(4) **Erosion.** This was not recognized as a major problem when the work was started, but it soon became evident that erosion, particularly wind erosion, must be considered. Within the limitations imposed by the different cultural practices, constant efforts have been made to maintain the soil in a condition resistant to erosion.

³Detailed results are being prepared for publication as a U. S. Technical Bulletin.

⁴Variety tests were conducted by other divisions of the Bureau in the early years, and by the Division of Soil Management and Irrigation under informal cooperation with subject-matter divisions, and with the State Experiment Station in recent years.

Climate As It Affects Dry-Land Farming

The climatic factors—precipitation, evaporation, temperature, humidity, and wind velocity have been paramount in determining crop production potentialities of the arable dry-land soils of western South Dakota. The first four are closely interrelated, and any of them serves as a better indication of crop production than might be expected. Together they form material for detailed studies of crop-climate relationships.

Precipitation: Rainfall is probably the most important single climatic factor in this area. Not only is total precipitation during the crop year important, but timely distribution is in many cases equally essential. The ideal situation rarely occurs, and crop yields are almost always limited by insufficient moisture at some period during the growing season. The nearest approach to ideal crop conditions was in 1915 when outstanding yields of all crops were produced.

The average rainfall of 16.06 inches during the 40-year period was found adequate for moderate crop production. Frequently, crop yields are reduced below average by factors other than total rainfall, such as high temperatures and unfavorable distribution of rainfall throughout the growing season. However, precipitation falling late in the growing season increases the supply of soil moisture which is available to crops the following year. As a result of this carry-over of soil moisture from the previous year, above-average crop yields may be produced in years of below-normal rainfall. In general, however, precipi-

tation is a fairly good indicator of crop production. Rainfall much in excess of 20 inches has not increased yields proportionally, and the years of highest rainfall have been less productive than some years with lesser quantities.

June rainfall is the highest of any month, and the precipitation for this month probably is more critical for the development of grain crops than that of any other month. Bumper yields have been obtained principally in years when above-average late June or July rains have enabled such crops to realize their full potentialities. The three months of May, June and July provide about half of the annual rainfall.

Evaporation: In a dry climate, loss of water from the surface of the soil by evaporation is a major item in determining the portion of the rainfall that is available for crop use. For the growing season (April through September), the average evaporation from a water surface maintained at approximately ground level has been 35.2 inches. The seasonal amounts have ranged from 27.5 inches in 1915, the most productive crop year, to 46.7 inches in 1911, the least productive year.

Evaporation serves as a measure of water used by crops. The quantity that plants must actually transpire through their tissues to maintain normal growth varies with the evaporation from a free water surface. Evaporation is usually low when rainfall is high and vice versa.

Temperature: Extreme summer temperatures are damaging to crops

that are short of water and occur most frequently when rainfall is deficient. Temperatures in excess of 100° usually occur four or five times during the summer. The number of 100° temperatures has ranged from 21 in 1936, to none in several years. In 1915 the maximum temperature did not exceed 87° until the last day of August. Extremely high temperatures do not often occur more than two or three days in succession.

Frost-free period: The average frost-free period extends from May 11 to September 27, a period of 139 days. Frosts have occurred as late as May 31 and as early as September 7. Late spring frosts occasionally injure dry-land crops. Fall frosts have frequently injured corn, sorghum and potatoes,

but have not greatly reduced their yields. The danger of frost damage, however, has made it necessary to grow very early varieties of both corn and sorghum.

Wind: Wind movement was measured by an anemometer with the cups placed 2 feet above the surface of the ground. April and May, with average velocities of 7.3 and 6.5 miles per hour, respectively, are the windiest months of the growing season. Damage from wind erosion is most likely to occur in the spring when the soil is most susceptible to blowing, but there is danger of soil movement from November through May. High velocities for short periods rather than high average velocities are responsible for the soil blowing.

Tillage and Crop Sequence

The field used for these studies is gently sloping. The work consists of annual cropping, where different crops are grown on the same land year after year by using different tillage methods; two-year rotations where small grains are alternated with fallow or corn; three-year rota-

tions with two years of small grains and one of row crop or fallow; four-year rotations consisting of a grain crop, a cultivated crop, another grain crop, and a fallow or a green manure crop; and five-and-six-year rotations involving the use of grass crops or legumes.

Effects of Tillage Methods

Tillage Methods for Continuous Cropping, and Alternate Fallow and Cropping

Five crops—winter wheat, spring wheat, oats, barley and corn—were grown continuously using four methods of tillage, and by alternate fallowing and cropping.

The four methods of tillage used under continuous cropping were sup-

posed to cover the extremes in moisture conservation that could be attained where crops were grown each year. They were: (1) Fall plowing; (2) Fall plowing and subsoiling; (3) Listing; (4) Shallow plowing.

(1) **Fall plowing.** The land was plowed as soon as possible after harvest to a depth of about 8 inches. This

was designed to represent as favorable a condition for water conservation as could be attained by ordinary methods on land cropped each year.

(2) **Fall plowing and subsoiling**
The land was plowed at the same time as ordinary fall plowing, but a subsoiler was run in every other furrow to an additional depth of 8 inches, or a total of 16 inches. This operation was to break up the subsoil, making it more accessible to roots and providing a reservoir for moisture storage. The total labor involved was nearly double that on fall plowing, but the objective was to attain the utmost in water conservation and efficient use, regardless of expense. The land was subsoiled for two successive years, and then subsoiling was omitted for two successive years.

(3) **Listing.** This operation under favorable soil conditions is cheaper than plowing, but listing a dry soil after harvest was nearly impossible. The furrows on listed land were presumed to catch drifting snow and thus partially make up for any loss of moisture through fall weed growth. The land was listed when the fall plowing was done, except for corn, but was not worked down until

spring. Listing and planting for corn were performed in one operation.

(4) **Shallow plowing.** Shallow spring plowing for spring grains, or late shallow plowing for fall-sown grains was supposed to represent slipshod farming without any attempt at water conservation. The land, after plowing, was given the least amount of cultivation necessary to prepare a fair seedbed.

Alternate fallow and crop meant the loss of one crop to store moisture for the next one. The yields under the four continuous methods and on fallowed land are given in Table 1.

The average yields of spring wheat, oats and barley, grown on spring-plowed land were much lower than on fall-plowed land. This was not due to difference in water conservation, as spring measurements showed little difference between the two in soil moisture content. The chief cause of the difference between the two was in emergence. Spring-plowed land was usually wet when plowed, and on drying, baked into hard clods extending below the depth at which small grains are seeded. These clods could not be worked down sufficiently to make a good seedbed either when wet or dur-

Table 1. Acre yields of small grains and corn grown by using four methods of continuous cropping and by alternate fallowing and cropping. Belle Fourche Field Station,* 1909—1948†

Crop	Shallow spring or fall plowed	Fall plowed	Fall plowed and subsoiled	Listed	Alternately fallowed and cropped‡
Winter wheat, bu.	13.2	13.7	13.0	12.4	22.0
Wheat, bu.	11.3	14.1	14.2	14.8	22.0
Oats, bu.	25.5	30.1	30.7	32.0	44.8
Barley, bu.	19.7	23.6	22.6	21.0	35.4
Corn, bu.	14.7	15.1	15.3	16.2	21.6
Corn stover, lbs.	1439	1676	1638	1404	1632

*Now called the Newell Irrigation and Dry-land Field Station.

†Subsoiling and listing were not carried on for the whole period for crops other than spring wheat and corn, but yields are adjusted to make all methods comparable.

‡Annual yields are one-half of the acre yields.

ing the drying process, and the seedbed remained poor until mellowed by rains. If rains fell before or soon after seeding, there was little difference between the two methods. If germination and emergence on spring-plowed land were greatly delayed, materially reduced yields might result. In 1947 there was an extreme case of this when emergence on spring-plowed land was delayed until mid-June, and

the yields were only about one-fifth as high as on fall plowing. (Fig. 1.)

The difference between late, shallow plowing and early plowing for winter wheat was small. The land was usually dry when plowed, and turned up in clods. Rains during the comparatively short interval between harvest and seeding were seldom sufficient to permit working the early plowed land into a good seedbed.



Fig. 1. (Lower) Barley on spring-plowed and (upper) fall-plowed land, showing an extreme case of delayed emergence on spring-plowed land

Late, shallow plowing did little more than scrape the surface, and, as a consequence, frequently formed a better seedbed than deeper tillage.

There was only a small difference between spring and fall plowing for corn. Spring plowing for corn is done later in the season but further in advance of planting than for small grains. There is a greater possibility of the soil being mellowed by rains between plowing and planting, and a greater likelihood of substantial rains falling shortly after planting. The years when germination was delayed were much fewer than for small grains.

Subsoiling was not materially different from fall plowing for any crop and did not reduce the number of failures. Experimentation for this type of tillage was discontinued in 1937 for all crops except spring wheat.

Yields of small grains on listed land are variable, but, as a whole, are about equal to those on land plowed at the same time. The lower cost of listing was offset by the greater amount of work necessary to level it down and prepare a seedbed in the spring.

Listing and plowing for corn present a contrast. Average yields of ear corn were higher on the listed land and stover yields were much lower. Listed corn made a much poorer growth than corn on plowed land, with smaller stalks and fewer suckers. As a consequence it did not suffer from drought quite so early, and was able to produce ears in some years when plowed land could not. In favorable years the yields on plowed land were the highest. The average yield of ear corn was a little higher on

plowed land, until yields began to decline seriously about 10 years ago on land continuously cropped to corn. The decline on the listed land did not begin until about five years ago.

Small grains on fallowed land produced acre yields much in excess of those on land continuously cropped by the best methods. In no case was the yield on fallowed land double that on continuously cropped land, so more grain would have been grown on the continuously cropped land. The number of failures is not shown in the table, but yields low enough to constitute practical failures occurred in nearly 30 percent of the years on cropped land and in only 15 percent of the years on fallowed land. Neither acre yields nor annual yields tell the whole story about the place of fallow in a cropping system. This is discussed more fully under crop sequence.

Yields of corn grain were increased considerably by fallowing, but stover yields were not increased at all. Fallowing for corn is not recommended.

The different small grains respond to fallow about equally. For a cash crop, wheat should be the crop grown on fallowed land. If the crop is to be grown for feed, choice can be based on preference, or on the needs of the livestock to which the grain is to be fed.

Moisture determinations have shown that water seldom penetrates deeper than three feet on this soil, and that roots of annual crops use moisture to a depth of three feet or less. The quantity of rainfall available to crops, in soils wet to a depth of three feet or more, is less than six inches. This probably is the reason why till-

age practices such as summer fallow are less effective on a clay soil than on lighter soil where water and roots can penetrate more readily.

The results are generally applicable to most of the clay soils of the west-river area. Soils that permit water and roots to penetrate to depths of more than three feet are likely to show more response to fallow.

Tillage Methods for Small Grains and Corn in Rotations

Both wheat and oats produced higher yields on disked or duckfooted corn land than on corn land plowed either in the spring or in the fall. Yields on fall-plowed corn land were higher than those on spring-plowed corn land by about the same margin as in the continuous cropping experiment.

Both wheat and oats produced higher yields on fall-plowed than on spring-plowed small grain land. Corn also produced higher yields on fall plowing, but the difference was much smaller than with grains.

It seems evident that the main difference between methods lies in the seedbed, and in whether or not moisture is lost while preparing the seedbed.

Listing vs. Plowing in Preparing Small Grain Stubble for Corn

Comparisons of corn on spring-plowed, fall-plowed, and listed small grain land have been made since 1923, and average yields are presented in Fig. 2. The grain yield on listed land has been fully equal to that on spring plowing, but considerably lower than on fall plowing. Listing and seeding in one operation is by far the cheapest method of planting corn on small

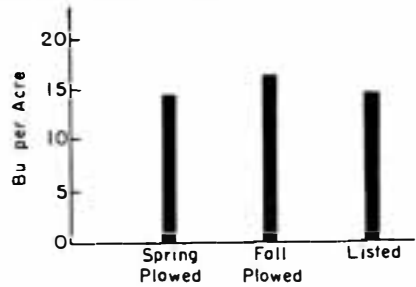


Fig. 2. Average acre yields of corn on small grain stubble land prepared by three methods of cultivation, 1923-48

grain land. Listing has a decided place in economical corn production on soils that do not crust so badly in the lister furrow that emergence may be prevented. More weeds usually appear on listed small grain land than on plowed land, and timely cultivation is essential. When such work is timely, weed control is relatively easy. Listing delays maturity by about a week and planting must be done relatively early.

Fall plowing, in spite of its higher yield, has limitations. If the land is dry in the fall, plowing may be a difficult and expensive operation. (See Fig. 3.) If moisture conditions are favorable for fall plowing, there is danger that the soil may mellow down so much during the winter that wind erosion may occur.

Duckfooting vs. Plowing for Fallow and Corn

The expense and difficulty of plowing this heavy soil led to the introduction of experiments to determine whether the plowing operation could be omitted without material loss in yield. There was also the hope that tillage which did not cover the crop residue might aid in controlling wind erosion on fallowed land.

Table 2. Acre yields of wheat on plowed and on duckfooted fallowed land; and yields of corn on spring-plowed, fall-plowed, and duckfooted small grain stubble land, 1932-48*

Crop	Cultural Method	Number of plots	Average yield (bushels)
Wheat.....	Plowed fallow	2	20.1
	Duckfooted fallow	2	20.5
Corn	Spring-plowed grain stubble	18	10.1
	Fall-plowed grain stubble	8	10.8
	Spring duckfooted stubble	1	9.8

*Yields of corn in 1940 and 1945 are not included owing to uneven damage by hail and grasshoppers.

A comparison of duckfooting and plowing small grain stubble land for fallow and for corn is shown in Table 2.

As shown in the table, differences in yields following duckfooting and following plowing have been inconsequential, and duckfooting may be used without reduction in yield. There is no evidence of decreasing yields on land that has not been plowed for 20 years. The grain crop pre-

ceding fallow in these experiments had been binder harvested, and the quantity of stubble left after a summer of duckfoot tillage was not sufficient to be an effective protection against wind erosion. When grain is harvested with a combine, the quantity of stubble left should be greater and wind erosion control more effective, but there will be more difficulty with the tillage operations.



Fig. 3. Fall plowing under very dry conditions

Effects of Crop Sequence

The order in which crops are grown may affect the yield, the cost of production, and the distribution of labor. Some crops that are not so valuable in themselves are valuable for their effect on crops following. Thus the effect of sequence may be an important factor in determining the cropping order or practice to use.

Comparison of Fallow, Corn, and Small Grain Preceding Small Grain

Yields under the three systems are of concern to all of those engaged in

farming in dry-land areas. The yields on corn ground are those obtained on disked, or duckfoot-cultivated corn ground. Yields under this method were higher than from other methods of preparing corn ground. The yields of grain after grain are those obtained on fall-plowed land.

As will be noted in Fig. 4, yields were highest on fallowed land, intermediate on corn ground, and lowest on small grain land. The response of the different spring-sown small grains

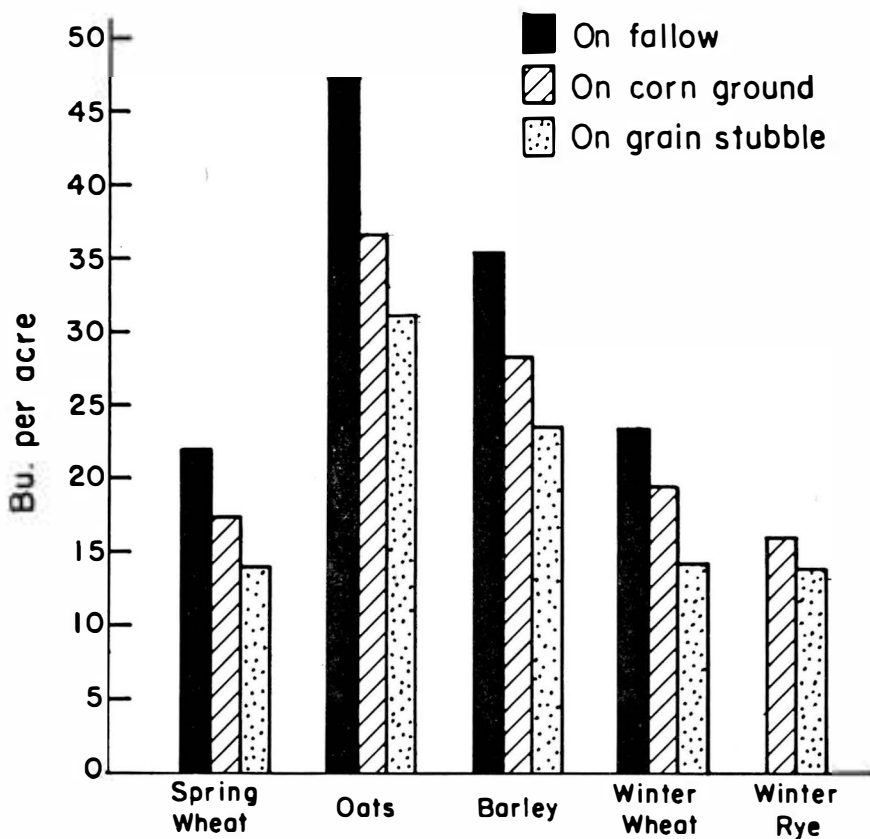


Fig. 4. Yields of small grains following summer fallow, corn, and small grains

to the different sequences was much the same. Winter wheat was relatively more productive on corn ground and fallow than were the spring-sown crops. In that part of the area where winter wheat can be grown, it should be the favored crop in the better sequences, provided that soil blowing can be prevented.

As far as could be observed, the differences in yield in the different sequences were due almost entirely to the moisture present. Summer fallow stored the most moisture, as would be expected when one year's crop was sacrificed to store moisture for the next crop. The fact that crops feed to a depth of only three feet on Pierre clay soil definitely reduces the quantity of water available to crops that can be stored in fallow and greatly reduces the effectiveness of the practice. Results from Ardmore, South Dakota,⁵ where crops feed to a depth of four feet, were more favorable to fallow. Corn usually leaves some moisture available to wheat in the first and second foot-sections of the soil, and almost all that may be present in the third foot-section. Grains profit greatly from this distributed available

moisture. Small grain land is bankrupt in moisture at harvest time, and usually does not have time to build up an adequate reserve between harvest and the time that the next crop begins to grow rapidly.

Acre yields do not tell the whole story of the value of different sequences. A comparison of all production under a three-year rotation of a year of fallow and two of wheat; a three-year rotation of corn and two of wheat; and a system of growing wheat continuously for three years, is presented in Table 3. Wheat is used as the only grain crop for convenience in comparison. In actual practice, oats or barley might be the third crop in the rotation. It will be noted that the yield of wheat following wheat in three-year rotations is somewhat higher than that of wheat grown continuously. As discussed later, all crops of grain following grain in rotations with a row crop or fallow are slightly more productive than when grown each year on the same land.

The highest total yield of crops was obtained from the rotation of corn and two years of wheat, and the next highest yield was obtained from wheat alone (Table 3). If total production were the only thing to be con-

⁵Summer fallow at Ardmore, South Dakota, U.S.D.A. Circular 213.

Table 3. Total three-year production under three cropping systems, based on 1909—1948 average yields

Cropping sequence	Acre yield bushels			3-year total	
	1st year	2nd year	3rd year	Corn	Wheat
Wheat, continuous*	13.6	13.6	13.6	0	40.8
Corn, wheat, wheat	15.2†	17.1‡	14.6§	15.2	31.7
Fallow, wheat, wheat	0	21.2¶	14.6§	0	35.8

*Average of all continuous methods.

†Corn, average of spring-plowed plots in three-year rotation.

‡After duckfooted corn in three-year rotations.

§Average of all plots of wheat after small grain as second crop after corn or fallow.

¶After fallow in three-year rotation.

sidered, there would be no question as to the system to use, but there are many factors in addition that must be considered.

Corn is of use only to the extent that it can be efficiently used on the farm. Average yields on this heavy soil are too low to consider growing it as a cash crop. Corn is of great value only in farming systems where sale of livestock or livestock products is the chief source of income.

A three-year rotation of one year of fallow and two of wheat gives a total production of wheat only 88 percent as high as when wheat is grown continuously. But there are other factors that compensate for, and may overbalance, production alone. In a fallow system there are fewer failures, and more of the total production is obtained in years of partial failure. Crops are produced at a lower acre cost in a fallow system because it costs less to keep land fallowed for a year than to prepare for, seed, and harvest a wheat crop. Finally, fallowing provides for a certain degree of weed control. In a straight grain-farming system, weeds may reduce yields or make continued production by that method impossible.

Fallow is not without disadvantages, the chief of which is danger of wind and water erosion. This can be greatly reduced but not entirely prevented on most soils. Where erosion cannot be controlled, fallow has no place in the farming system. Fallow is of most importance in farming systems where the main income is from the sale of small grains. Fallow and corn are competitive systems, and

neither is likely to be used to the exclusion of the other. In actual practice the relative importance of corn or other row crops and fallow in the farming system is likely to depend upon the needs of the livestock grown.

Yields of Grain-after-Grain in 3-year Rotations Compared with Continuous Cropping

The question frequently arises as to whether the effect of a row crop or fallow in a rotation extends beyond its effect on the crop immediately following. There appears to be such an effect.

Every grain crop produced slightly higher yields when grown as the second grain crop after fallow or corn than when grown continuously on the same land. This residual effect increases the value of fallow or a row crop beyond that of its influence on the crop immediately following.

Comparative Yields of Small Grains after Corn, Sorgo, and Potatoes

Yields following potatoes were somewhat higher than after corn or sorghum, which conforms to results obtained elsewhere in the Great Plains. Yields of all small grains following corn were about equal to those of the same grains following sorgo. This is in distinct contrast to yields from farther south in the Great Plains, where sorgo continues to grow until late fall and exhausts soil moisture, resulting in lower yields of small grain the following year.

The average yields of winter wheat where corn stalks were left standing

and from land where the stover was harvested, for the period 1923-48, were 20.8 and 19.5 bushels per acre, respectively. The corn stalks caught snow which provided the crop with some extra moisture, and also provided protection from wind erosion and from severe winter temperatures.

Effect of Different Small Grains on Following Crops

There has been no measurable difference in yield of either small grains or row crops following the different small grains. This means that these grains can be grown for their value as crops, without giving consideration to relative effects on succeeding crops.

Practices to Maintain Soil Productivity

In any system of stable agriculture, the soil should be maintained at a productivity level that will permit crops to take full advantage of favorable climatic conditions. It was recognized in the beginning that moisture would most frequently limit crop yields on virgin land, but it was thought that under continued crop production, reduced organic matter levels might eventually limit yields in many years. For this reason, rotations with barnyard manure, with leguminous and non-leguminous green manure crops, and with sod crops were compared with rotations without such amendments.

Manure on Fallow Benefited Crop Yields Only in Favorable Seasons

This effect was measured in pairs of four-year rotations, one rotation of each pair with manured fallow and one with ordinary fallow. The sequence of crops in one group of rotations was fallow, wheat, corn, and oats. The other group was fallow, oats, corn, and wheat. Manure was applied to land being fallowed because response to added fertility should show to best advantage where moisture is most favorable. Manure was applied at the rate of approxi-

mately 10 tons to the acre. Each plot received an application at that rate once every four years.

The 40-year average yields of both wheat and oats on manured fallow were slightly, but not significantly, lower than on unmanured fallow. Yields were much the higher on manured fallow in a few years of exceptionally heavy May and June rainfall. In most years, however, yields on manured fallow were about the same or lower than those on unmanured fallow.

Corn, the second crop after fallow in all rotations, was not materially affected by manure either in individual years or for the whole 40-year period.

A residual effect of manure on the third crop in the rotations was evidenced in a number of years. In the rotations where wheat was the third crop there was no difference in yield for any period except the one for 1944-48, when the manured rotation was 4.5 bushels higher. In the rotations with oats as the third crop the residual effect was evident in other periods and particularly in the 1944-48 period. Whether the difference from 1944 to 1948 was due to climatic conditions generally favorable to the use of ma-

nure during that period, or whether the unmanured rotations are now unable to realize the potential set by the precipitation is still uncertain.

Manure on Row Crops Questionable

It was mentioned earlier that corn yields on land continuously cropped had declined seriously in recent years. Beginning in 1937, manure at the rate of 8 to 10 tons to the acre was applied annually as a top-dressing to the plot previously subsoiled. The manure improved the appearance and early growth of this plot, but it suffered more severely during periods of drought. The annual increase in yield was only about 1 bushel of grain and 270 pounds of stover. Evidently the application of manure alone was not adequate to improve productivity under continuous cropping to corn.

Manure Applied to Sorgo in Rotation with Wheat

Barnyard manure was applied every year after 1936 to sorgo grown in a two-year rotation with wheat. The land had been continuously cropped to barley from 1909 to 1936. The manure was applied as top-dressing and favorable responses were shown by sorgo in some years, but the average effect was negligible. Average yields from the manured and unmanured rotations were 4,056 and 4,024 pounds of fodder per acre, respectively. The average yield of wheat following manured sorgo was 20.2 bushels to the acre, as compared with a yield of 19.1 bushels on unmanured corn ground. The total benefit from manure during the 11-year period was not adequate to cover the cost of applying it.

Green Manure Crops Have Not Paid

As mentioned earlier, green manuring experiments were conducted extensively because it was believed that organic soil amendments might be needed, and that barnyard manure could satisfy only a small fraction of this need. Green manuring is an even more expensive operation than fallowing. It involves not only the loss of the land for a year, but also the cost of seed, planting, and plowing under green manure crops. A material increase in yield, or concrete evidence that it has maintained soil productivity at a higher level is needed to justify the practice.

Green manuring can be compared best with fallowing because the acre yields of the crops immediately following it are the total production for two years. Green manure crops are compared with unmanured fallow in order to measure any progressive changes in yield resulting from their use. Winter rye, field peas and sweet clover were used as green manure crops. After they were plowed under, the land was kept free from weeds the balance of the season. They were used in four-year rotations with the sequence of crops following being wheat, corn, and oats; or oats, corn, and wheat.

The 40-year average yields of both wheat and oats were higher on unmanured fallow than immediately following any of the green manure crops. This is shown in Table 4.

Yields on unmanured fallow were highest, followed by those on winter rye, field peas, and sweet clover as green manure, in that order. Yields on the green manured land were gen-

Table 4. Average acre yield of wheat and oats on unmanured fallow, and following three different green manure crops, 1909-48

Treatment	Acre yield—bushels	
	Wheat	Oats
Unmanured fallow	23.1	47.8
Winter rye, green manure	20.8	42.1
Peas, green manure	19.4	41.6
Sweet clover, green manure ..	18.0	40.9

erally higher than on fallow in good seasons, but the moisture used in growing the green manure crop depleted soil moisture so much that the succeeding crop was more subject to drought damage in unfavorable years.

The advantage for fallow was greater in the first 20 years than in the following 20 years. This may be due chiefly to the adoption of a policy in the later period of plowing the green manure crops under at an earlier stage. After the policy was adopted, yields on green manured land and on fallowed land were much the same.

Green manure rotations yielded higher in years with ample rainfall, particularly during the period 1944 to 1948. This was due chiefly to exceptionally favorable climatic conditions during three years.

Oats and wheat as the third crop in the rotation have shown a response to green manure crops in good years, and average yields in the green manured rotations are as high as, or higher than, the yield in the fallowed rotations.

For the rotations as a whole, green manure crops have fallen far short of paying for their use. The best that can be said is that losses from their use during the second 20-year period were

lower than during the first 20-year period.

Sod Crops Not Adapted to Short Rotations

Sod crops in the rotation have a desirable and beneficial physical effect on the soil for a temporary period. Land in sod rotations is more friable and works into a seedbed more readily. This physical effect disappears almost completely after about four years. Land that has been in sweet clover recently seems to be especially susceptible to wind erosion. Sod crops leave the land exceedingly dry and often decrease the yields of succeeding crops. When used in deferred rotations with the land cultivated for longer periods between sod crops, yields of other crops are not reduced and may be increased in years of favorable precipitation, particularly in rotations with alfalfa. However, benefits of sod crops in rotations depend upon their value as crops rather than upon their effect on other crops.

Summary of Soil Productivity Observations

Practices designed to maintain productivity have not paid for their use. The soil has not reached a stage where such practices are profitable in poor or average years, but indications are that more benefit is derived in favorable years than was realized in earlier years. Studies with inorganic soil amendments are now under way to determine how often and to what extent crops respond to applications of nitrogen and phosphorus.

Erosion Hazards

While erosion control has not been a main purpose of these experiments, it soon became evident that erosion was a factor that should be considered. From the time that work on the plots was started, some surface soil movement took place, but it was not until the thirties that a condition generally conducive to greater soil movement by wind arose.

Smooth bare soils, or soils not fully protected by crops or crop residues are almost always in a condition to move in the early spring and usually during open winters. Movement may take place while the ground underlying the surface inch or two of soil is frozen or too wet to permit cultivation. If the soil is moist below the surface, there is little tendency for it to move after the first spring tillage operation has been performed.

Winter wheat has been the only crop to be seriously damaged. It does not grow enough in the fall to make an adequate ground cover and is usually in a weakened condition in the spring. Even a very little soil movement may give it a setback from which it does not fully recover. Winter wheat on the plots has usually been protected from incoming soil by listing the surrounding roads and alleys, but occasionally the furrows were not fully effective in preventing soil from adjacent roads from blowing on to the rotation winter wheat plots. Minor damage has also resulted from soil movement originating on the plots themselves.

Fallowed land without protection from residues is subject to blowing, and a smooth bare fallow is in a con-

dition for serious movement to take place. Plots being fallowed should be left as rough as possible and cultivated only when necessary to control weeds. Enough clods to help materially in erosion control usually remain in the fall, but it is desirable that the land be ridged late in the fall, especially if the clods have been mellowed by abnormal rainfall. Leaving binder stubble on the surface while the land is being fallowed is helpful, but has not been fully effective in controlling soil movement. Where grain is harvested with a combine, the stubble and residue are more effective.

Corn and sorgo stubble are usually subject to some surface soil movement in the early spring and during open winters, but the movement is less than on fallow. Ridging or roughening the land by cultivation late in the fall, however, often is desirable.

Fall-plowed land is resistant to erosion when first plowed, but may mellow enough during the winter to make spring soil movement a hazard. It is usually still rough enough in the spring, however, to be somewhat more resistant to blowing than smooth surfaces.

Grain stubble land, and land where corn has been husked and the stalks left standing, are seldom subject to wind erosion.

The main purpose of wind erosion control measures has been to prevent loss of topsoil rather than to protect crops. It has been accomplished by leaving a protective cover on the soil where the cropping practice permitted, and by maintaining a roughened condition on soils without residues.

Water erosion has not been as serious as on some soils, because the torrential rains occur most frequently during the period of the year when the soil is dry and cracked and thus in condition to absorb water rapidly. When the soil is wet, it is practically

impossible to prevent runoff from even moderately heavy rains, and then water erosion does occur. It is wise to use practices that reduce the soil loss from runoff. Subsurface cultivation is replacing deeper cultivation in a number of comparisons.

Conclusions and Recommendations

Dependable Crops for Dry-Land Areas and Their Yields

Dry-farming, to be successful, depends upon the use of adapted crops and varieties grown in sequences and under cultural practices that make efficient use of labor and of the moisture supply.

The adaptation of crops is fixed not only-by their average yield, but also by their reliability. The annual yields of crops cannot be presented in this summary, but are presented in detail in a U. S. technical bulletin.⁶ Variety experiments are not presented, but the recommended varieties of the different crops are given.

Table 5 presents the average yields of all plots of the different crops grown in the rotations for the 40-year

period. These averages afford reasonably good, but not exact, comparisons between crops.

Average yields of small grains have been good, considering the price of the land. However, small grains are subject to successive years of low yields or failures, and farm enterprises must be based on the probable recurrence of such periods.

Spring wheat and winter wheat are the most important cash crops and should be given the preferred place in cropping systems where grain is grown for sale. Winter wheat responds very strongly to the extra moisture in fallowed land. In the small portion of western South Dakota where it survives the winter regularly, it can be grown to best advantage with that preparation.

⁶In the process of publication.

Table 5. Average yields of crops grown in rotation and tillage experiments, 1909-48

Grain, seed, or tuber crops		Forage yields	
Crop	Acre yield, bushels	Crop	Acre yield, pounds
Winter wheat	16.3	Sorgo, total	4156
Spring wheat	17.5	Corn stover	1673
Winter rye*	15.3	Grass hay†	1331
Oats	36.7	Alfalfa hay†	1824
Barley	25.1	Sweet clover hay*	1833
Flax	6.6		
Potatoes	66.3		
Corn	16.1		

*Not grown for full 40-year period.

†Yields are from established stands.

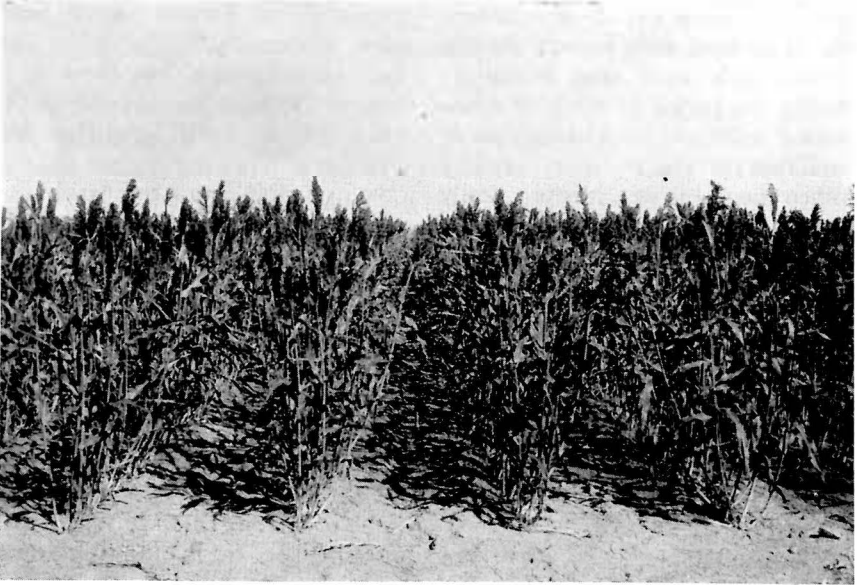


Fig. 5. A field of sorgho, or forage sorghum, a dependable feed crop

Winter rye is hardier than winter wheat but is less productive, and its value per bushel is lower. For the years in which both were grown, the average yield of winter rye was 2.4 bushels lower than that of winter wheat. It produces considerably fewer pounds of feed per acre than do barley and oats.

Barley has produced more pounds of grain to the acre than has any other small grain. The difference between barley and oats, however, is not great, and choice between these feed grains can be based on the needs and preference of the grower.

Flax has a fairly good average yield, but has failed completely oftener than the other grain crops. It is a speculative crop to be grown only when economic and moisture conditions are favorable.

The average yield of **potatoes** has been so low that in spite of their favorable effect on crops that follow, they are of little importance except for home consumption.

Corn produced less grain to the acre than either oats or barley, and yields were less dependable. Yields of stover were fairly reliable, and the favorable effect of corn on crops that follow gives it a more important place in the cropping system than is warranted by its yield.

The early-maturing **grain sorghums** have not been grown long enough to make their yields comparable with those of other crops. Preliminary data, however, indicate that they may partially replace corn.

Sorgho, or forage sorghum (Fig. 5), has been the most dependable feed crop. It has been a total failure in only

two years, although there were several other years when yields were low. Its high yield and dependability give it an important place in a livestock farming system. The development of strains that are low in prussic acid removes most of the danger of livestock poisoning. The total yield of sorgo is about three-fourths of a ton higher than the total yield of corn.

Established stands of alfalfa have produced an average yield of more than 1800 pounds to the acre, but have produced less than 1000 pounds to the acre in more than a third of the years. The relatively high average yield is due chiefly to the production of more than one cutting in a few very favorable years. The average yield of grass was about a quarter of a ton to the acre lower than that of alfalfa, but grass yields have usually been slightly higher than alfalfa in the drier years. The yield of sweet clover was only a little higher than that of alfalfa in the years both were grown. In some years, however, sweet clover yields were sharply higher.

The average yields show that fairly good yields of all crops have been produced. Annual yields show that the use of different types of crops will reduce the number of failures, but will not eliminate them. The most protective and drought-resistant crops are those used for the feeding of livestock. There is a clear indication that farming is safer when carried on in conjunction with livestock production. The occasional year of failure, or near failure, for all crops points out the need for creation of reserves of feed and capital to carry on during drought periods.

Tested Varieties of Adapted Crops

Variety tests in recent years have been confined to only a few crops where primary developments appear to be taking place. The varieties recommended for this area by the South Dakota Experiment Station are as follows:

Winter wheat: Minter, Nebred

Spring wheat: Rushmore, Pilot, Rival, Mida

Winter Rye: Pierre, Dakold, South Dakota Common

Oats: Bruncker, Osage

Barley: Compana, White Smyrna, Plains, Feebar, Spartan

Grain sorghum: Norghum, Coes

Forage sorghum: Rancher, (39-30-S), Dakota Amber

Flax: Sheyenne

Corn: Wis. 255

Alfalfa: Ladak, Cossack, Ranger, Common

Grass: Crested wheatgrass, Ree, Brome

Sweet clover: Common, Madrid

Preferred Cropping Patterns for Dry-Land Farms in Western South Dakota

The relatively small number of crops that are well adapted to dry-land production makes the use of simple cropping systems or rotations possible. Crop rotations do not help maintain soil productivity unless they contain soil conserving crops or practices. They do, however, provide for the orderly production of crops in favorable sequences that permit efficient use of labor.

Simple three-year rotations with one year of row crop or fallow, and two years of small grains, will meet the needs of most farmers. Such a ro-

tation is highly flexible.

A sample rotation of this type would be sorgo, wheat, and barley. The sorgo would provide a relatively certain supply of rough feed. Wheat would provide a cash crop that could be planted on sorgo ground with little expense and a better than average chance of producing a crop. The crop of barley after wheat would be more speculative, but could be expected to furnish some feed in all years and a good yield in some.

Such a rotation permits variations to meet specific needs. Part or all of the sorgo acreage could be replaced by corn, grain sorghum or fallow. Part of the acreage allotted to wheat could be planted to a feed grain if desirable. The third year of barley might be replaced all, or in part, by oats or wheat. On a farm with little livestock where the chief income is from the sale of grain, the rotation could be fallow, wheat, wheat or corn, wheat, wheat.

In all rotations it is essential that the favorable place in the rotation be given the crop that will profit most by it. When wheat is grown, it should be placed on the row crop or fallowed land. If feed grains only are grown, barley should occupy this position.

Four-year rotations are also well adapted. Such rotations as fallow, wheat, sorgo, and barley; or corn, wheat, sorgo or grain sorghum, and barley are examples. In four-year rotations only half of the land is in small grain, but all of the small grain is grown in favorable sequences. These rotations are also flexible in that acreages of the different row crops and fallow are interchangeable. Land allotted to a small grain can also be

planted to any of the adapted grain crops.

Both the three- and four-year rotations provide for a cultivated crop or fallow often enough to help materially in weed control.

Alfalfa and grasses have a definite place on any farm producing livestock, but their place is not in short rotations. Present information suggests maintaining fields of these crops as units, and plowing them up when stands become thin or the fields unproductive. The land could then be planted to other crops for a number of years, and the sod crop grown in a different location. Grasses such as crested wheatgrass provide valuable early pasture, when not used for hay. Alfalfa fields can often be located along draws where they obtain excess water, with consequent benefit to production.

Any crop-livestock farming system presupposes the presence of pasture land sufficient to take care of the livestock during the summer grazing period and during open weather in the winter.

The cropping systems suggested do not provide for the regular use of soil-building crops or practices. Up to the present time these have not paid for themselves. Recent results indicate that fertility may become more of a factor in the future, and ways of maintaining soil productivity are being investigated. At the present time, fertility practices other than returning manure produced on the farm to the land, and the occasional replacement of alfalfa or grass acreages by annual crop, cannot be justified on the basis of expected returns.