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Methods of Tillage for Winter Wheat at Archer Field Station

By
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AGRICULTURAL EXPERIMENT STATION
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LARAMIE
SUMMARY

Storage of soil moisture and prevention of soil blowing are vital factors in successful production of winter wheat.

Field trash intermingled with a cloddy mulch furnishes the best condition for reception and retention of soil moisture. It also furnishes the best condition for preventing wind and water erosion.

As a general rule little moisture is added to the soil during the summer months; the main accomplishment of fallow is to conserve the moisture that has accumulated in the soil before late May or early June.

Medium-shallow tillage with the eccentric one-way disk has proved more productive than any other method of tillage.

Under the alternate fallow and cropping method of production the soil lost 33 percent of its nitrogen over a period of 35 years, and under continuous cropping and plowing it lost 26 percent. Under continuous cropping and listing it lost 16 percent. Results indicate that the less the soil is stirred, the less the loss of nitrogen. Rotation of crops and green manure have not materially reduced the loss of nitrogen. Application of barnyard manure is the only method which has greatly reduced nitrogen losses from the soil. The effect of application of nitrogen in the form of a commercial fertilizer on the soil is now being tested.

Fallow tillage should permit placing the seed in moist soil. The method of seeding should leave field trash and clods at the top of the drill ridges.

Growth resulting from the seeding of a spring cereal with the winter cereal may furnish the needed protection in cases where there is danger from soil blowing.
INTRODUCTION

Probably no other tilled crop produced on dryland reflects research results as much as does winter wheat. The increased acreage and acre yield of this crop are due largely to better methods of tillage and seeding, both of which are factors in checking soil erosion.

Before 1922 most of the winter wheat grown in Southeastern Wyoming was produced on stubble land, and generally the yields were unsatisfactory. Survival of winter wheat on fallow was very uncertain because of soil blowing. During the spring of 1922, after preliminary tests, methods-of-fallow and seeding experiments for winter wheat were established at the Archer Field Station. The practical effects of these experiments are shown in Table 1. These data were taken from the Wyoming Agricultural Statistics.

EXPERIMENTS WITH FALLOW

In 1922 a 6-inch Van Brunt grain drill was converted into a 12-inch tandem double-disked furrow drill at this station. During the same year a 6-foot field cultivator (duckfoot) was imported from Canada by the International Harvester Company for this station. Use of these implements, with variations, constituted the first marked change in the production of winter wheat in this region.

Tillage for the methods-of-fallow and seeding-winter-wheat experiments established in 1922 consisted of early plowing, late plowing, and late duckfooting. The seedings were made with a 7-inch common drill and a 12-inch furrow drill. Grain-yield data obtained from this experiment are shown in Table 2.

† The work at the Archer Field Station covered by this bulletin was conducted cooperatively by the Division of Dryland Agriculture—now the Division of Soil Management and Irrigation, Bureau of Plant Industry—and the Division of State Experiment Farms, College of Agriculture, University of Wyoming.

* Agronomist, Division of Soil Management and Irrigation, Bureau of Plant Industry, Soils, and Agricultural Engineering. Appreciation for helpful suggestions is expressed to Dr. C. E. Leighty, John S. Cole, and O. R. Mathews of the Division of Dryland Agriculture, and to W. L. Quayle, former director of the State Experiment Farms. Acknowledgment is made to Leroy D. Willey and W. E. Lyness of the Division of Dryland Agriculture, who conducted the work reported in this bulletin before July 18, 1918, at which time the author took sole charge.
The data show that all furrow-drill seedings produced larger yields than the common-drill seedings. Early-spring plowed fallow seeded with the common drill produced the smallest 4-year average yield—7.9 bushels per acre.

Early tillage was done at the same time as the tillage for the spring cereals, while late tillage was done during the latter part of May or the early part of June.

Farmers interested in the results desired additional information. Accordingly the experiment was enlarged in 1927 to include listing, subsoiling, and early-spring duckfooting.

The winter-wheat plots were harvested with a binder. In order to make some of the results comparable with those where a combine is used, the quantity of straw removed was returned to the fall-listed plot, to one of the spring-listed plots, and to one of the spring-duckfooted plots. Grain-yield data obtained from this experiment are reported in Table 3.

From Table 3 it will be noted that the 10-year average grain yield produced by the early shallow subsurface duckfoot tillage (depth 3 inches) is slightly larger than that produced by subsoiling (depth 14 inches). In both cases the field trash was left at the surface of the soil. Plots tilled with the moldboard plow (depth 7 inches) produced smaller...
yields than the shallow subsurface duckfoot tillage. Fall listing (depth 6 inches) produced slightly larger yields than spring listing (depth 6 inches). Larger yields were produced by early-spring duckfooting than by listing.

Early-spring-plowed fallow made a very good seedbed. However, the surface of the soil was mellow and therefore subject to blowing, especially when seeded with the common drill. Seedings made with the furrow drill were more resistant to blowing. A cloddy, ridged surface intermingled with field trash affords protection to fallowed ground against soil erosion.

As will be noted in Table 3, the grain-yield differences caused by the addition of straw are small—not sufficient to draw conclusions. However, on land more subject to blowing, field trash mixed with the soil at the top of the furrow-drill ridges is a vital factor in prevention of soil blowing during winter and early spring months. Some of this land is very productive, but the burning of straw on such land would soon render it unproductive in that the crop would be destroyed by soil blowing.

During 1937 the methods-of-fallow experiment was revamped for the purpose of determining the merits of new methods of fallow. The lister dammer and the Peacock dammer were being advocated because they reduced run-off caused by sudden downpours. Difficulties encountered in use of these machines were: (1) clogging with field trash, (2) only partial killing of weeds, and (3) fields left so rough that further tillage was difficult. To overcome these objectionable features of pit

<table>
<thead>
<tr>
<th>TABLE 2—Average Yields from Methods of Tillage and Seeding for Winter Wheat on Fallow, 1923 to 1926, inclusive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early-plowed fallow, common drill</td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td>1923</td>
</tr>
<tr>
<td>1924</td>
</tr>
<tr>
<td>1925</td>
</tr>
<tr>
<td>1926</td>
</tr>
<tr>
<td>4-yr. average</td>
</tr>
</tbody>
</table>

* Spring wheat—seeded with common drill.
tillage, an eccentric feature of the disks of an International Harvester disk harrow plow (Wheatland plow or one-way disk) was developed at this station in 1936.

The disk-harrow plow, when equipped with eccentric disks, pits the soil in a waffle-like pattern and at the same time tills all the surface of the soil. It handles a heavier layer of field trash—partially covering and mixing it with the surface soil. Only in sod is the pitting unduly rough.

The revamped methods-of-fallow experiment contained four new methods of tillage: (1) plowing without moldboard, (2) listing with dammers, (3) Peacock listing with dammers, and (4) eccentric one-way disking. The Peacock machine differs from the listing with dammers in that the furrows, made with bull-tongue shovels, are closer together.

TABLE 3—Average Yields from Methods of Tillage and Seeding for Winter Wheat on Fallow, 1927 to 1936, inclusive

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Early-spring plowed fallow, common drill</th>
<th>Late-spring plowed fallow, common drill</th>
<th>Early-spring plowed fallow, furrow drill</th>
<th>Late-spring plowed fallow, furrow drill</th>
<th>Late-spring duckfoot fallow, common drill</th>
<th>Late-spring duckfoot fallow, furrow drill</th>
<th>Straw returned, hail-listed, furrow drill</th>
<th>Late-spring listed, furrow drill</th>
<th>Late-spring returned, early-spring duckfoot, furrow drill</th>
<th>Early-spring duckfoot, furrow drill</th>
<th>Late-spring subsaulted, furrow drill</th>
</tr>
</thead>
<tbody>
<tr>
<td>1927</td>
<td>8.5</td>
<td>11.8</td>
<td>9.5</td>
<td>9.0</td>
<td>6.2</td>
<td>6.0</td>
<td>8.7</td>
<td>6.8</td>
<td>7.5</td>
<td>6.0</td>
<td>8.7</td>
</tr>
<tr>
<td>1928</td>
<td>15.2</td>
<td>17.8</td>
<td>19.2</td>
<td>19.2</td>
<td>24.8</td>
<td>25.3</td>
<td>28.2</td>
<td>27.8</td>
<td>28.8</td>
<td>29.7</td>
<td>32.2</td>
</tr>
<tr>
<td>1929</td>
<td>12.5</td>
<td>15.3</td>
<td>7.0</td>
<td>10.7</td>
<td>10.3</td>
<td>10.8</td>
<td>15.2</td>
<td>14.8</td>
<td>16.3</td>
<td>15.0</td>
<td>15.3</td>
</tr>
<tr>
<td>1930</td>
<td>9.8</td>
<td>11.7</td>
<td>12.5</td>
<td>14.8</td>
<td>9.5</td>
<td>13.3</td>
<td>16.3</td>
<td>16.5</td>
<td>17.8</td>
<td>17.3</td>
<td>17.8</td>
</tr>
<tr>
<td>1931</td>
<td>16.7</td>
<td>17.3</td>
<td>17.3</td>
<td>17.3</td>
<td>17.2</td>
<td>16.3</td>
<td>17.3</td>
<td>18.2</td>
<td>16.7</td>
<td>17.5</td>
<td>18.5</td>
</tr>
<tr>
<td>1932</td>
<td>9.7</td>
<td>8.2</td>
<td>11.2</td>
<td>10.3</td>
<td>6.7</td>
<td>11.0</td>
<td>15.2</td>
<td>11.0</td>
<td>12.0</td>
<td>15.3</td>
<td>16.2</td>
</tr>
<tr>
<td>**</td>
<td>8.8</td>
<td>9.0</td>
<td>8.5</td>
<td>8.5</td>
<td>9.3</td>
<td>9.7</td>
<td>8.8</td>
<td>7.8</td>
<td>8.3</td>
<td>8.5</td>
<td>7.8</td>
</tr>
<tr>
<td>1934</td>
<td>2.5</td>
<td>3.3</td>
<td>2.5</td>
<td>2.8</td>
<td>2.0</td>
<td>2.3</td>
<td>4.2</td>
<td>3.5</td>
<td>3.3</td>
<td>6.2</td>
<td>5.5</td>
</tr>
<tr>
<td>**</td>
<td>12.7</td>
<td>11.0</td>
<td>13.2</td>
<td>14.5</td>
<td>12.5</td>
<td>14.0</td>
<td>16.3</td>
<td>14.5</td>
<td>14.0</td>
<td>12.2</td>
<td>12.7</td>
</tr>
<tr>
<td>**</td>
<td>1.8</td>
<td>3.0</td>
<td>1.0</td>
<td>1.7</td>
<td>1.3</td>
<td>1.0</td>
<td>3.5</td>
<td>2.8</td>
<td>2.7</td>
<td>3.0</td>
<td>2.3</td>
</tr>
<tr>
<td>**</td>
<td>10-yr. average</td>
<td>9.8</td>
<td>10.8</td>
<td>10.2</td>
<td>10.9</td>
<td>11.0</td>
<td>13.4</td>
<td>12.4</td>
<td>12.7</td>
<td>13.1</td>
<td>13.7</td>
</tr>
</tbody>
</table>

* All plots reseeded to spring wheat with the common drill.
** Low yields were due to drought.
It will be noted that early-spring plowing is not included in this methods-of-fallow experiment. It was discontinued because, as shown in Table 3, it was not quite as productive as late-spring plowing. However, late tillage, with the exception of late-spring plowing, produced lower yields than early-spring tillage. The early-eccentric-pitted plots, as shown in Table 4, produced the highest average yield.

During years when heavy fall precipitation occurred, the advantage of early-spring-tilled fallow was sometimes wiped out. It appears that heavy fall precipitation gives deep tillage an advantage; however, such fall precipitation is an exception. As shown in Table 4, the largest average yields of winter wheat were produced on rather shallow early-spring-tilled land.

With exception of the late deep pitting (depth 14 inches), the pitted plots as a group produced larger yields than the level-tilled plots. Other tillage, with exception of duckfooting (depth about 3 inches), was between 5 and 6 inches deep. The deeper the tillage the greater the aeration and evaporation of soil moisture—a condition which sometimes causes an excessive amount of dry mulch, which in turn may result in poor germination of seed.

Tillage that controls weed growth and mixes the field trash with the surface soil, thereby protecting it from erosion and aiding in its
reception of water, is to be preferred. The eccentric one-way disk accomplishes this type of tillage and establishes a pattern of pits which retain water that would in some instances result in run-off. These factors, in addition to thorough killing of plant growth, are favorable for crop production.

The lister type of implement does not make for such thorough killing. This is an important factor, especially since the advent of downy chess or cheat grass (*Bromus tectorum*). Present subsurface tillage methods are not sufficiently effective in control of this grass. For this reason some farmers are returning to use of the plow for major primary tillage. However, experimental results indicate that larger yields are produced with greater economy and soil protection when the land is tilled with the eccentric one-way disk.

**GREEN-MANURE ROTATIONS**

Winter wheat is produced on the green-manured land in rotations 115 and 117. Yields from fallowed land in rotation 118 are presented for comparison. All three of these are 4-year rotations where corn follows winter wheat and oats follows corn. The oats stubble in rotation 115 is seeded to winter rye the year before it is seeded to winter wheat. The winter rye is plowed under for green manure—generally when in the bloom stage, which is about the middle of June. The field peas in rotation 117 are plowed under for green manure about the middle of July. In rotation 118 the plot to be seeded to winter wheat is fallowed. The 34-year average yields of winter wheat, 1914-1947, inclusive, produced in these rotations are as follows:

- Rotation 115—Rye, green manure ............... 12.9 bus. per acre
- Rotation 117—Peas, green manure ............. 12.7 bus. per acre
- Rotation 118—Fallow .................. 13.7 bus. per acre

During years of abundant moisture the green-manured plots produced larger yields than the fallowed plot, while the reverse is true during years of insufficient moisture. It is probable that the green-manure crops reduce the soil moisture sufficiently to affect winter-wheat yields adversely, especially during dry years. If soil moisture were always abundant, it is probable that the green-manured plots would produce larger yields than the fallowed plot.

**Winter Wheat in Corn Rows**

Good grain yields are possible by seeding winter wheat in corn rows when late August or early September precipitation is sufficient to produce vigorous plants in the fall. Table 5 contains the average yields of
winter wheat seeded in corn rows, also reseedings to spring wheat, in rotations 114, 116, and 119, for the 34-year period 1914-1947, inclusive.

The winter wheat in these rotations is seeded about September 1. All of the corn crop is removed at maturity. Three total crop failures occurred during the 34-year period—one from drought and two from hail. Data in Table 5 show that winter wheat when seeded in corn rows produced a fairly good crop about two out of three years. However, in rotation 19, which contains the same crops as rotations 114, 116, and 119 (except that spring wheat replaces winter wheat), the 34-year average yield of spring wheat on disked or duckfooted corn ground is 10.2 bushels per acre. In rotation 425 winter wheat is seeded in corn rows, the same as in rotations 114, 116, and 119, but in this case the ear corn is harvested and the stover is left standing on the plot. The 24-year average yield, 1924-1947, inclusive, produced in this rotation is 10.7 bushels per acre. The decision whether to seed winter or spring wheat on corn ground can be based on the amount of fall precipitation and the distribution of labor.

**METHODS OF CULTIVATION**

In 1913 a series of plots was laid out for a method-of-cultivation experiment with winter wheat and other crops. Tillage methods consisted of fall plowing, spring plowing, fallow, fall plowing subsoiled in alternate years, and fall listing. In the case of winter wheat, the spring plowing was changed to late-fall plowing and fall plowing to early-fall plowing. However, because of the shortness of the season little time

---
elapses between the early and late fall plowing. Average yields of winter wheat produced by the various methods of tillage during the 32-year period, 1914-1945, inclusive, are as follows:

<table>
<thead>
<tr>
<th>Method</th>
<th>Yield (bus. per acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early-fall plowing*</td>
<td>7.8</td>
</tr>
<tr>
<td>Late-fall plowing</td>
<td>6.9</td>
</tr>
<tr>
<td>Fall plowing subsoiled</td>
<td>7.5</td>
</tr>
<tr>
<td>Listing</td>
<td>7.5</td>
</tr>
<tr>
<td>Fallow</td>
<td>13.3</td>
</tr>
</tbody>
</table>

*The plowing was 6 to 7 inches deep while the subsoiling was 10 to 12 inches deeper than the plowing.

From these data, as well as from those in Tables 3 and 4, it would appear there is no advantage in deep tillage for winter wheat. The only substantial difference in yield was produced on fallowed land, in which case more moisture was stored in the soil and probably more plant food was available for the crop.

Yields of winter wheat from some additional tillage studies are shown in Table 6. It will be noted that the continuously disked plot produced the smallest average yield. No doubt the heavy infestation of downy chess or cheat grass was a factor contributing to the low yield. Plowing tends to decrease the infestation of this grass, but yields immediately after plowing were slightly smaller than from crops seeded in stubble one or two years after a plowing.

**TABLE 6—Effect of Fallow, Plowing, and Disking on Winter-wheat Yields at Archer Field Station, 1924 to 1947, inclusive**

<table>
<thead>
<tr>
<th>ROTATION</th>
<th>(BUSHELS PER ACRE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fallow</td>
</tr>
<tr>
<td>568 Fallow and disked winter-wheat stubble</td>
<td>12.0</td>
</tr>
<tr>
<td>571 Continuously disked winter-wheat stubble</td>
<td>6.6</td>
</tr>
<tr>
<td>572 Plowing and one year disking winter-wheat stubble</td>
<td>7.0</td>
</tr>
<tr>
<td>573 Plowing and two years disking winter-wheat stubble</td>
<td>7.1</td>
</tr>
<tr>
<td>561 Disked oat stubble</td>
<td>8.3</td>
</tr>
<tr>
<td>562 Disked oat stubble</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>12.0</td>
</tr>
</tbody>
</table>
The above results would indicate that the type of tillage is of little importance in affecting winter-wheat yields when a crop is grown each year. It appears that the only tillage that materially affects the yield of winter wheat is that which aids in conservation of moisture, prevents run-off, and makes the surface soil resistant to soil blowing.

SOIL MOISTURE

The soil at the Archer Field Station has been classified as Altvan loam (Joplin series). It is about 2 feet deep and contains a sufficient amount of clay to make firm clods. Below the 2-foot level the soil becomes gravelly with rather large stones and pockets of coarse sand intermingled with deposits of lime. The leaching of the lime from the surface soil has caused some of the soil in the top six inches to become slightly acid. Figures 1 and 2 show a profile of the soil in a basement pit at the station.

Conditions such as shown in Figure 1 do not permit the taking of moisture samples to a depth much below the 3-foot level. Conditions shown in Figure 2 are rather limited but permit the taking of deeper samples. Both figures show that a high experimental error, due to the lack of soil uniformity, may be expected at depths greater than 2 feet. At this station plant roots become scarce in the third foot of soil; hence the storage of soil moisture in the root zone of most plants is rather limited. However, the soil-moisture data contain some information concerning storage of soil moisture. The 5-year average percentages of soil moisture in the top 3 feet of soil during late spring, after harvest, and in late fall, for the different methods of fallow and during the years the plots were cropped, are shown in Table 7.

![FIG. 1—Northeast corner of station bunkerhouse basement pit. The soil is about 2 ft. deep. The white streaks and patches are deposits of lime in coarse gravel and cobblestones which are cemented together with a dough-like clay. This formation did not shatter when blasted.](image-url)
Table 7 shows a loss of soil moisture on all methods of fallow between the late-spring and mid-August sampling period. However, soil moisture increased on all methods of fallow during the fall. The data show an additional increase between the late-fall and late-spring sampling period in the years the plots were cropped. But, because of the demand of the growing crop, the soil moisture decreased between late spring and the after-harvest period to about one-half that of the late-spring samples. The purpose of fallow is to supply needed moisture during this critical period.

The fallow plots tilled with the eccentric one-way disk produced the highest average yield—22.2 bushels per acre. However, practically the same percentages of moisture were tared in the oil by other methods of tillage, but these methods did not make a thorough killing of weeds, especially downy chess, except on the plowed plots. The average yield produced on the plowed plots is 19.3 bushels per acre.

Deep Peacock tillage causes greater drying of the soil than shallow tillage and makes only a partial killing of downy chess; yet, it produced a larger grain yield with less moisture than the continuously cropped plot (rotation 571). This plot is tilled by disking the stubble—an operation which resulted in maximum stand of downy chess.

Soil-moisture samples were taken from rotations 306 and 307 with a view of determining the effect on soil-moisture content when a crop is harvested before it is mature. These rotations consist of fallow, winter rye on fallow, and millet on winter rye ground. All primary tillage is done with the eccentric one-way disk. The winter rye is cut for hay between the heading and blooming stage of growth or about the middle of June. The plots are tilled with the eccentric one-way disk as soon
as the winter rye hay is removed. The 3-year average percentages of soil moisture in the top 3 feet of soil in these plots are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Late Spring</th>
<th>After Harvest</th>
<th>Late Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fallow</td>
<td>17.8</td>
<td>14.3</td>
<td>14.6</td>
</tr>
<tr>
<td>Winter Rye</td>
<td>18.1</td>
<td>11.2</td>
<td>12.5</td>
</tr>
<tr>
<td>Millet</td>
<td>18.2</td>
<td>9.1</td>
<td>10.7</td>
</tr>
</tbody>
</table>

**TABLE 7—Five-year Average Percentages of Soil Moisture in Top 3 Feet of Soil in Method-of-fallow Experiment with Winter Wheat at Archer Field Station, 1939-1943, inclusive**

<table>
<thead>
<tr>
<th>Tillage Methods</th>
<th>YEAR FALLOWED</th>
<th>YEAR CROPPED</th>
<th>Five-Year Average* Grain Yield 1938-42, Inc.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Late Spring</td>
<td>After Harvest</td>
<td>Late Fall</td>
</tr>
<tr>
<td>Late-spring plowed</td>
<td>14.5</td>
<td>13.2</td>
<td>14.3</td>
</tr>
<tr>
<td>Early-spring plowed without moldboard</td>
<td>14.6</td>
<td>12.5</td>
<td>13.0</td>
</tr>
<tr>
<td>Late-spring plowed without moldboard</td>
<td>14.8</td>
<td>11.4</td>
<td>12.4</td>
</tr>
<tr>
<td>Late-spring listed</td>
<td>15.2</td>
<td>10.6</td>
<td>11.8</td>
</tr>
<tr>
<td>Early-spring listed</td>
<td>15.2</td>
<td>13.6</td>
<td>14.0</td>
</tr>
<tr>
<td>Early-spring listed with dammers</td>
<td>14.7</td>
<td>12.7</td>
<td>13.6</td>
</tr>
<tr>
<td>Early-spring listed with Peacock dammers</td>
<td>15.7</td>
<td>12.7</td>
<td>14.1</td>
</tr>
<tr>
<td>Late-spring listed with Peacock dammers</td>
<td>14.8</td>
<td>13.0</td>
<td>13.8</td>
</tr>
<tr>
<td>Early-spring eccentric one-way</td>
<td>14.9</td>
<td>14.1</td>
<td>14.5</td>
</tr>
<tr>
<td>Late-spring eccentric one-way</td>
<td>15.2</td>
<td>13.4</td>
<td>14.3</td>
</tr>
<tr>
<td>Early-spring duckfoot</td>
<td>14.8</td>
<td>13.7</td>
<td>14.1</td>
</tr>
<tr>
<td>Late-spring Peacock (deep)</td>
<td>15.5</td>
<td>11.9</td>
<td>12.9</td>
</tr>
<tr>
<td>Continuous winter-wheat disked</td>
<td>15.3</td>
<td>8.9</td>
<td>9.9</td>
</tr>
</tbody>
</table>

Late spring, last week of May to first week of June.
After harvest (spring grain) to mid-August.
Late fall, late October to early November.

*The winter-wheat crop was destroyed by hail in 1943; hence the grain yields were advanced one year ahead of the soil-moisture data.

When the winter rye is harvested between the heading and blooming stages of growth and no plant growth is allowed to develop, a sufficient amount of soil moisture is left in the soil to produce in the following spring a moisture condition equivalent to that of fallow. Probably somewhat comparable results would be obtained if winter wheat replaced the winter rye. This would use the crop for hay and reduce the winter-wheat acreage that would otherwise be harvested for

* The 6-year average percentages for late spring and late fall bear out the same conclusions.
grain. The protein content of such cereal hays compares favorably with that of alfalfa.

Rotations 7-26, 18-26, and 19-26 were cropped to spring wheat, corn, potatoes, and beans. The plots in rotation 7-26 were duckfooled (sub-surface tilled) for all the crops except corn, in which case the plot was plowed. The plots in rotation 18-26 were manured and duckfooled, while the plots in rotation 19-26 were manured and plowed. Table 8 contains the 5-year average percentages of soil moisture in the top 3 feet of soil in these rotations.

TABLE 8—Five-year Average Percentages of Soil Moisture in Top 3 Feet of Soil in Rotations 7-26, 18-26, and 19-26 at Archer Field Station, 1939-1943, inclusive

<table>
<thead>
<tr>
<th>Rotation</th>
<th>SPRING WHEAT</th>
<th>CORN</th>
<th>POTATOES</th>
<th>BEANS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Late Spring</td>
<td>After Harvest</td>
<td>Late Fall</td>
<td>Late Spring</td>
</tr>
<tr>
<td>7-26</td>
<td>17.0%</td>
<td>9.1%</td>
<td>15.2%</td>
<td>12.0%</td>
</tr>
<tr>
<td>18-26</td>
<td>15.9%</td>
<td>9.3%</td>
<td>10.6%</td>
<td>16.5%</td>
</tr>
<tr>
<td>19-26</td>
<td>15.5%</td>
<td>8.9%</td>
<td>9.7%</td>
<td>16.0%</td>
</tr>
<tr>
<td>Average</td>
<td>16.1%</td>
<td>8.8%</td>
<td>10.1%</td>
<td>15.9%</td>
</tr>
<tr>
<td>CC Beans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Late-spring soil samples were not taken in 1939.

Data in Table 8 show that in most cases slightly more moisture was stored in the soil after duckfooling than after plowing. It appears that a manure mulch had no appreciable effect on the soil-moisture content. The data also show that more moisture was left in the soil after row crops than after the spring-wheat crop. Corn left nearly 2 percent, potatoes 3.7 percent, and beans 4 percent more moisture in the soil than did the spring wheat. The percentage of soil moisture left after the bean crop compares favorably with that of fallow. Land cropped continuously to beans had a higher percentage of soil moisture than the best methods of fallow.

SOIL NITROGEN

Nitrogen is essential to all life. Since land life is dependent upon the soil for this element it is important to know the trend as to nitrogen content of tilled soils. For this reason soil samples were taken during the falls of 1947 and 1948 from a number of plots on which the various cropping, tillage, and rotation work had been conducted. Table 9
<table>
<thead>
<tr>
<th>Rotation and Plot</th>
<th>Cropping Treatment</th>
<th>Year Started</th>
<th>(0''-6'') % N in Soil, % N Lost or Gained</th>
<th>(6''-12'') % N in Soil, % N Lost or Gained</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.C. Corn—Dup.—A,B(^1)</td>
<td>Continuous</td>
<td>1923</td>
<td>.075 39</td>
<td>.082 8</td>
</tr>
<tr>
<td>M.C. Corn—Dup.—C,D(^1)</td>
<td>Alternate crop and fallow</td>
<td>1923</td>
<td>.075 39</td>
<td>.080 10</td>
</tr>
<tr>
<td>M.C. Corn—A,B,E,F</td>
<td>Continuous</td>
<td>1913</td>
<td>.070 43</td>
<td>.076 15</td>
</tr>
<tr>
<td>M.C. Corn—C,D</td>
<td>Alternate crop and fallow</td>
<td>1913</td>
<td>.070 43</td>
<td>.078 12</td>
</tr>
<tr>
<td>M.C. W. wheat—A,B,E,F</td>
<td>Continuous</td>
<td>1913</td>
<td>.083 24</td>
<td>.084 6</td>
</tr>
<tr>
<td>M.C. W. wheat—C,D</td>
<td>Alternate crop and fallow</td>
<td>1913</td>
<td>.082 33</td>
<td>.088 1</td>
</tr>
<tr>
<td>M.C. Spring wheat, barley, oats,—A,B</td>
<td>Continuous</td>
<td>1913</td>
<td>.080 27</td>
<td>.092 3</td>
</tr>
<tr>
<td>M.C. Spring wheat, barley, oats,—C,D</td>
<td>Alternate crop and fallow</td>
<td>1913</td>
<td>.081 34</td>
<td>.088 1</td>
</tr>
<tr>
<td>Rot. 2, 3, 7, and 9—A,B,Ç</td>
<td>Small grains, small grains, corn</td>
<td>1913</td>
<td>.080 34</td>
<td>.084 6</td>
</tr>
<tr>
<td>Rot. 8—A,B,C</td>
<td>Oats, spring wheat, fallow</td>
<td>1913</td>
<td>.083 32</td>
<td>.085 4</td>
</tr>
<tr>
<td>Rot. 68—A,B,C</td>
<td>Oats, corn—manured, spring wheat</td>
<td>1913</td>
<td>.099 19</td>
<td>.091 2</td>
</tr>
<tr>
<td>Rot. 14—A,B,C,D</td>
<td>Spring wheat, rye (GM), oats, corn</td>
<td>1913</td>
<td>.085 30</td>
<td>.085 4</td>
</tr>
<tr>
<td>Rot. 16—A,B,C,D</td>
<td>Spring wheat, peas (GM), oats, corn</td>
<td>1913</td>
<td>.082 33</td>
<td>.084 6</td>
</tr>
<tr>
<td>Rot. 71—A,B,C,D</td>
<td>Oats, corn, spring wheat, fallow—manured</td>
<td>1913</td>
<td>.089 27</td>
<td>.088 1</td>
</tr>
<tr>
<td>Rot. 72—A,B,C,D</td>
<td>Spring wheat, corn, oats, fallow—manured</td>
<td>1913</td>
<td>.092 25</td>
<td>.088 1</td>
</tr>
<tr>
<td>Rot. 7—A,B,C,D</td>
<td>Potatoes, beans, spring wheat, corn</td>
<td>1926</td>
<td>.072 41</td>
<td>.079 11</td>
</tr>
<tr>
<td>Rot. 7—A,B,C,D</td>
<td>Potatoes, beans, spring wheat, corn</td>
<td>1931</td>
<td>.072 41</td>
<td>.086 3</td>
</tr>
<tr>
<td>Rot. 18—26, 19—26,—A,B,C,D</td>
<td>Potatoes, beans, spring wheat, corn (all manured)</td>
<td>1926</td>
<td>.102 16</td>
<td>.084 6</td>
</tr>
<tr>
<td>Rot. 18—31—A</td>
<td>Potatoes, beans, spring wheat, corn (all manured)</td>
<td>1931</td>
<td>.102 16</td>
<td>.090 1</td>
</tr>
<tr>
<td>Rot. 41—A,B,C,D,E,F(^2)</td>
<td>Spring wheat, oats, corn, crested wheat (3 plots)</td>
<td>1913</td>
<td>.085 30</td>
<td>.086 3</td>
</tr>
<tr>
<td>Rot. 42—A,B,C,D,E,F(^2)</td>
<td>Spring wheat, oats, corn, alfalfa (3 plots)</td>
<td>1913</td>
<td>.079 35</td>
<td>.081 9</td>
</tr>
</tbody>
</table>

\(^1\) From 1913 to 1922, the area occupied by the M.C. Corn—Dup. plots was in M.C. Flax.
\(^2\) Rotations 41 and 42 were changed to deferred-type rotations in 1937. The grass in rotation 41 was also changed from brome to crested wheat in 1937.

**NOTE:** The nitrogen content of the virgin sod was used as a basis for determining the percentage loss or gain of nitrogen.

Data furnished by Dr. Lyle T. Alexander, Principal Soil Scientist, U. S. Department of Agriculture.
presents a summary of the soil-nitrogen-analysis data for the 1947 samples as contained in Table 10. Losses were determined by subtracting the 1947 content from the content of a comparable soil that was still in native grass.

In considering the data in Tables 9 and 10 it may be well to bear in mind that the most rapid loss of nitrogen occurs during the years immediately following the breaking of the sod. The discussion of soil nitrogen as contained in USDA Yearbook 1938 (pages 367-69) fits, to a large extent, the conditions met in the study of the above tables. A quotation from page 369 follows:

"The loss is most rapid in the first 20 years, when it amounts to approximately 25 percent of the original quantity under natural conditions; a 10-percent further loss occurs during the second 20 years, and a 7-percent loss during the third 20 years, indicating that the nitrogen level does not decline indefinitely and that the end result will be a new equilibrium at a decidedly lower level than the original natural nitrogen content. That these losses can be controlled and soil fertility maintained at a higher level by appropriate rotations, manuring, and fertilizing is shown in other articles in the Yearbook.

"As a result of growing wheat on the same land for 12 years Snyder (372) in Minnesota showed that the nitrogen had been reduced 2,039 pounds, or about 26 percent of that originally found in the soil at the beginning of the test. The crops grown, however, accounted for less than 450 pounds of this nitrogen, showing that nearly 1,600 pounds had been lost, mainly through decay of the soil organic matter under this type of continuous farming."

Since the breaking of native sod and the tillage for the production of crops causes loss of nitrogen considerably in excess of that consumed by the crops, the checking of this loss is a problem to be considered. As a general rule, the greatest loss of soil nitrogen occurs in the plow level. Therefore, in consideration of the data in Tables 9 and 10 only the loss from the top 6 inches of soil will be considered.

Data in Table 9 show that a 33-percent nitrogen loss occurred in the top 6 inches of soil of the winter-wheat plots C and D, which are alternately cropped and fallowed, during a 35-year period and that under the same cropping system the soil in the spring-wheat, oats, and barley plots lost 34 percent of its nitrogen in the top 6 inches of soil during the same period. The soil in the winter-wheat plots A, B, E, and F and the spring-cereal plots A and B lost 24 percent and 27 percent, respectively, in the top 6 inches during a 35-year period. From data in Table 10, which contains the individual plot percentages of soil nitrogen, it will be found that, if calculated, plot F in the winter-wheat group lost only 16 percent of the nitrogen in the top 6 inches during 35 years.
<table>
<thead>
<tr>
<th>Rotation</th>
<th>Plot Cropping Treatment</th>
<th>Year Started</th>
<th>0''-6'' Depth</th>
<th>% Nitrogen</th>
<th>% Carbon¹</th>
<th>C/N</th>
<th>6''-12'' Depth</th>
<th>% Nitrogen</th>
<th>% Carbon¹</th>
<th>C/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.C. corn—Dups.²</td>
<td>A Continuous—S.P.</td>
<td>1923</td>
<td>1st</td>
<td>.077</td>
<td>.076</td>
<td>.076</td>
<td>65</td>
<td>1st</td>
<td>.085</td>
<td>.085</td>
</tr>
<tr>
<td></td>
<td>B Continuous—F.P.</td>
<td>1923</td>
<td>2nd</td>
<td>.074</td>
<td>.073</td>
<td>.074</td>
<td>66</td>
<td>2nd</td>
<td>.081</td>
<td>.081</td>
</tr>
<tr>
<td></td>
<td>C Alt. crop and fallow</td>
<td>1923</td>
<td>Av.</td>
<td>.072</td>
<td>.071</td>
<td>.072</td>
<td>60</td>
<td>Av.</td>
<td>.075</td>
<td>.075</td>
</tr>
<tr>
<td></td>
<td>D Alt. crop and fallow</td>
<td>1923</td>
<td>% Carbon¹</td>
<td>.076</td>
<td>.071</td>
<td>.076</td>
<td>62</td>
<td>% Carbon¹</td>
<td>.085</td>
<td>.085</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C/N</td>
<td></td>
<td></td>
<td></td>
<td>7.9</td>
<td></td>
<td>.67</td>
<td>.67</td>
</tr>
<tr>
<td>M.C. corn</td>
<td>A Continuous—S.P.</td>
<td>1913</td>
<td>1st</td>
<td>.070</td>
<td>.070</td>
<td>.070</td>
<td>63</td>
<td>1st</td>
<td>.078</td>
<td>.078</td>
</tr>
<tr>
<td></td>
<td>B Continuous—F.P.</td>
<td>1913</td>
<td>2nd</td>
<td>.068</td>
<td>.062</td>
<td>.065</td>
<td>63</td>
<td>2nd</td>
<td>.070</td>
<td>.067</td>
</tr>
<tr>
<td></td>
<td>C Alt. crop and fallow</td>
<td>1913</td>
<td>Av.</td>
<td>.067</td>
<td>.067</td>
<td>.067</td>
<td>65</td>
<td>Av.</td>
<td>.079</td>
<td>.077</td>
</tr>
<tr>
<td></td>
<td>D Alt. crop and fallow</td>
<td>1913</td>
<td>% Carbon¹</td>
<td>.074</td>
<td>.072</td>
<td>.073</td>
<td>70</td>
<td>% Carbon¹</td>
<td>.079</td>
<td>.078</td>
</tr>
<tr>
<td></td>
<td>E Continuous—S.S.</td>
<td>1913</td>
<td>C/N</td>
<td>.069</td>
<td>.068</td>
<td>.068</td>
<td></td>
<td></td>
<td>.74</td>
<td>.74</td>
</tr>
<tr>
<td></td>
<td>F Continuous—S.L.</td>
<td>1913</td>
<td></td>
<td>.079</td>
<td>.078</td>
<td>.078</td>
<td></td>
<td></td>
<td>.085</td>
<td>.086</td>
</tr>
<tr>
<td>M.C. w. wheat</td>
<td>A Continuous—L.F.P.</td>
<td>1913</td>
<td>1st</td>
<td>.087</td>
<td>.091</td>
<td>.089</td>
<td>83</td>
<td>1st</td>
<td>.076</td>
<td>.073</td>
</tr>
<tr>
<td></td>
<td>B Continuous—E.F.P.</td>
<td>1913</td>
<td>2nd</td>
<td>.087</td>
<td>.090</td>
<td>.088</td>
<td>86</td>
<td>2nd</td>
<td>.085</td>
<td>.083</td>
</tr>
<tr>
<td></td>
<td>C Alt. crop and fallow</td>
<td>1913</td>
<td>Av.</td>
<td>.083</td>
<td>.083</td>
<td>.083</td>
<td>78</td>
<td>Av.</td>
<td>.086</td>
<td>.084</td>
</tr>
<tr>
<td></td>
<td>D Alt. crop and fallow</td>
<td>1913</td>
<td>% Carbon¹</td>
<td>.079</td>
<td>.081</td>
<td>.080</td>
<td>62</td>
<td>% Carbon¹</td>
<td>.091</td>
<td>.088</td>
</tr>
<tr>
<td></td>
<td>E Continuous—S.S.</td>
<td>1913</td>
<td>C/N</td>
<td>.091</td>
<td>.092</td>
<td>.092</td>
<td></td>
<td></td>
<td>.091</td>
<td>.089</td>
</tr>
<tr>
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<td>F Continuous—F.L.</td>
<td>1913</td>
<td></td>
<td>.103</td>
<td>.102</td>
<td>.102</td>
<td></td>
<td></td>
<td>.069</td>
<td>.088</td>
</tr>
<tr>
<td>M.C. sp. wheat</td>
<td>A Continuous—S.P.</td>
<td>1913</td>
<td>1st</td>
<td>.083</td>
<td>.083</td>
<td>.083</td>
<td>86</td>
<td>1st</td>
<td>.095</td>
<td>.091</td>
</tr>
<tr>
<td></td>
<td>B Continuous—F.P.</td>
<td>1913</td>
<td>2nd</td>
<td>.090</td>
<td>.088</td>
<td>.089</td>
<td>94</td>
<td>2nd</td>
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<td>.089</td>
</tr>
<tr>
<td></td>
<td>C Alt. crop and fallow</td>
<td>1913</td>
<td>Av.</td>
<td>.086</td>
<td>.084</td>
<td>.085</td>
<td>80</td>
<td>Av.</td>
<td>.096</td>
<td>.083</td>
</tr>
<tr>
<td></td>
<td>D Alt. crop and fallow</td>
<td>1913</td>
<td>% Carbon¹</td>
<td>.081</td>
<td>.077</td>
<td>.079</td>
<td>76</td>
<td>% Carbon¹</td>
<td>.090</td>
<td>.077</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>C/N</td>
<td></td>
<td></td>
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<td></td>
<td>.96</td>
<td>.92</td>
</tr>
<tr>
<td>M.C. oats</td>
<td>A Continuous—S.P.</td>
<td>1913</td>
<td>1st</td>
<td>.093</td>
<td>.089</td>
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<td>85</td>
<td>1st</td>
<td>.096</td>
<td>.094</td>
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<tr>
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<td>B Continuous—F.P.</td>
<td>1913</td>
<td>2nd</td>
<td>.099</td>
<td>.095</td>
<td>.097</td>
<td>88</td>
<td>2nd</td>
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<td>.094</td>
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<tr>
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<td>C Alt. crop and fallow</td>
<td>1913</td>
<td>Av.</td>
<td>.085</td>
<td>.086</td>
<td>.086</td>
<td>80</td>
<td>Av.</td>
<td>.088</td>
<td>.091</td>
</tr>
<tr>
<td></td>
<td>D Alt. crop and fallow</td>
<td>1913</td>
<td>% Carbon¹</td>
<td>.077</td>
<td>.080</td>
<td>.078</td>
<td>72</td>
<td>% Carbon¹</td>
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<td>.085</td>
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<td>C/N</td>
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<td>.94</td>
</tr>
<tr>
<td>M.C. barley</td>
<td>A Continuous—S.P.</td>
<td>1913</td>
<td>1st</td>
<td>.086</td>
<td>.083</td>
<td>.084</td>
<td>82</td>
<td>1st</td>
<td>.096</td>
<td>.087</td>
</tr>
<tr>
<td></td>
<td>B Continuous—F.P.</td>
<td>1913</td>
<td>2nd</td>
<td>.087</td>
<td>.091</td>
<td>.089</td>
<td>86</td>
<td>2nd</td>
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<td>.091</td>
</tr>
<tr>
<td></td>
<td>C Alt. crop and fallow</td>
<td>1913</td>
<td>Av.</td>
<td>.082</td>
<td>.081</td>
<td>.082</td>
<td>74</td>
<td>Av.</td>
<td>.079</td>
<td>.078</td>
</tr>
<tr>
<td></td>
<td>D Alt. crop and fallow</td>
<td>1913</td>
<td>% Carbon¹</td>
<td>.077</td>
<td>.074</td>
<td>.076</td>
<td>70</td>
<td>% Carbon¹</td>
<td>.034</td>
<td>.085</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C/N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.78</td>
<td>.78</td>
</tr>
<tr>
<td>Rot. 2</td>
<td>A Sp. wheat—S.P.</td>
<td>1913</td>
<td>1st</td>
<td>.077</td>
<td>.074</td>
<td>.076</td>
<td>76</td>
<td>1st</td>
<td>.081</td>
<td>.080</td>
</tr>
<tr>
<td></td>
<td>B Oats—S.P.</td>
<td>1913</td>
<td>2nd</td>
<td>.077</td>
<td>.076</td>
<td>.076</td>
<td>77</td>
<td>2nd</td>
<td>.080</td>
<td>.078</td>
</tr>
<tr>
<td></td>
<td>C Corn—S.P.</td>
<td>1913</td>
<td>Av.</td>
<td>.079</td>
<td>.076</td>
<td>.078</td>
<td>75</td>
<td>Av.</td>
<td>.091</td>
<td>.088</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>% Carbon¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.75</td>
<td>.74</td>
</tr>
<tr>
<td>Rot. 3</td>
<td>A Sp. wheat—F.P.</td>
<td>1913</td>
<td>1st</td>
<td>.086</td>
<td>.082</td>
<td>.084</td>
<td>80</td>
<td>1st</td>
<td>.092</td>
<td>.091</td>
</tr>
<tr>
<td></td>
<td>B Oats—F.P.</td>
<td>1913</td>
<td>2nd</td>
<td>.088</td>
<td>.087</td>
<td>.088</td>
<td>82</td>
<td>2nd</td>
<td>.089</td>
<td>.087</td>
</tr>
<tr>
<td></td>
<td>C Corn—F.P.</td>
<td>1913</td>
<td>Av.</td>
<td>.086</td>
<td>.086</td>
<td>.086</td>
<td>78</td>
<td>Av.</td>
<td>.089</td>
<td>.085</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>% Carbon¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.74</td>
<td>.74</td>
</tr>
</tbody>
</table>
### TABLE X—Percentage of Nitrogen and Carbon and Carbon/Nitrogen Ratio of Soils (oven-dry) from Various Cropping Treatments at Archer Field Station, 1947 (Continued)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Plot</th>
<th>Cropping Treatment</th>
<th>Year Started</th>
<th>0”-6” Depth</th>
<th>6”-12” Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>% Nitrogen</td>
<td>% Carbon C/N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1st</td>
<td>2nd</td>
</tr>
<tr>
<td>Rot. 7</td>
<td>A</td>
<td>Oats—S.P.</td>
<td>1913</td>
<td>.074</td>
<td>.073</td>
</tr>
<tr>
<td>do.</td>
<td>B</td>
<td>Barley—S.P.</td>
<td>1913</td>
<td>.070</td>
<td>.076</td>
</tr>
<tr>
<td>do.</td>
<td>C</td>
<td>Corn—S.P.</td>
<td>1913</td>
<td>.075</td>
<td>.076</td>
</tr>
<tr>
<td>Rot. 8</td>
<td>A</td>
<td>Oats—on fallow</td>
<td>1913</td>
<td>.088</td>
<td>.086</td>
</tr>
<tr>
<td>do.</td>
<td>B</td>
<td>Sp. wheat—F.P.</td>
<td>1913</td>
<td>.081</td>
<td>.084</td>
</tr>
<tr>
<td>do.</td>
<td>C</td>
<td>Fallow</td>
<td>1913</td>
<td>.079</td>
<td>.082</td>
</tr>
<tr>
<td>Rot. 9</td>
<td>A</td>
<td>Oats—S.P.</td>
<td>1913</td>
<td>.084</td>
<td>.084</td>
</tr>
<tr>
<td>do.</td>
<td>C</td>
<td>Corn—S.P.</td>
<td>1913</td>
<td>.083</td>
<td>.084</td>
</tr>
<tr>
<td>Rot. 14</td>
<td>A</td>
<td>Sp. wheat—D.F.</td>
<td>1913</td>
<td>.083</td>
<td>.085</td>
</tr>
<tr>
<td>do.</td>
<td>B</td>
<td>W. rye—stubbled in</td>
<td>1913</td>
<td>.086</td>
<td>.087</td>
</tr>
<tr>
<td>do.</td>
<td>C</td>
<td>Oats—on G.M.</td>
<td>1913</td>
<td>.083</td>
<td>.085</td>
</tr>
<tr>
<td>do.</td>
<td>D</td>
<td>Corn—S.P.</td>
<td>1913</td>
<td>.085</td>
<td>.085</td>
</tr>
<tr>
<td>Rot. 16</td>
<td>A</td>
<td>Sp. wheat—D.F.</td>
<td>1913</td>
<td>.081</td>
<td>.085</td>
</tr>
<tr>
<td>do.</td>
<td>B</td>
<td>Peas—F.P.</td>
<td>1913</td>
<td>.081</td>
<td>.085</td>
</tr>
<tr>
<td>do.</td>
<td>C</td>
<td>Oats—on G.M.</td>
<td>1913</td>
<td>.079</td>
<td>.078</td>
</tr>
<tr>
<td>do.</td>
<td>D</td>
<td>Corn—S.P.</td>
<td>1913</td>
<td>.085</td>
<td>.084</td>
</tr>
<tr>
<td>Rot. 41a</td>
<td>A</td>
<td>Sp. wheat—D.F.</td>
<td>1913</td>
<td>.089</td>
<td>.085</td>
</tr>
<tr>
<td>do.</td>
<td>B</td>
<td>Oats—F.P.</td>
<td>1913</td>
<td>.088</td>
<td>.084</td>
</tr>
<tr>
<td>do.</td>
<td>C</td>
<td>Corn—S.P.</td>
<td>1913</td>
<td>.085</td>
<td>.085</td>
</tr>
<tr>
<td>do.</td>
<td>D</td>
<td>Crested wheat</td>
<td>1913</td>
<td>.082</td>
<td>.080</td>
</tr>
<tr>
<td>do.</td>
<td>E</td>
<td>Crested wheat</td>
<td>1913</td>
<td>.096</td>
<td>.084</td>
</tr>
<tr>
<td>do.</td>
<td>F</td>
<td>Crested wheat</td>
<td>1913</td>
<td>.088</td>
<td>.086</td>
</tr>
<tr>
<td>Rot. 42a</td>
<td>A</td>
<td>Sp. wheat—D.F.</td>
<td>1913</td>
<td>.086</td>
<td>.086</td>
</tr>
<tr>
<td>do.</td>
<td>B</td>
<td>Oats—F.P.</td>
<td>1913</td>
<td>.077</td>
<td>.079</td>
</tr>
<tr>
<td>do.</td>
<td>C</td>
<td>Corn—S.P.</td>
<td>1913</td>
<td>.076</td>
<td>.076</td>
</tr>
<tr>
<td>do.</td>
<td>D</td>
<td>Alfalfa</td>
<td>1913</td>
<td>.071</td>
<td>.074</td>
</tr>
<tr>
<td>do.</td>
<td>E</td>
<td>Alfalfa</td>
<td>1913</td>
<td>.076</td>
<td>.080</td>
</tr>
<tr>
<td>do.</td>
<td>F</td>
<td>Alfalfa</td>
<td>1913</td>
<td>.080</td>
<td>.084</td>
</tr>
<tr>
<td>Rot. 68</td>
<td>A</td>
<td>Oats—F.P.</td>
<td>1913</td>
<td>.096</td>
<td>.098</td>
</tr>
<tr>
<td>do.</td>
<td>B</td>
<td>Corn—S.P.—man’d.</td>
<td>1913</td>
<td>.102</td>
<td>.106</td>
</tr>
<tr>
<td>Rotation</td>
<td>Plot Cropping Treatment</td>
<td>Year Started</td>
<td>0”-6” Depth</td>
<td>% Nitrogen</td>
<td>% Carbon</td>
</tr>
<tr>
<td>----------</td>
<td>------------------------</td>
<td>--------------</td>
<td>-------------</td>
<td>------------</td>
<td>----------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1st</td>
<td>2nd</td>
<td>Av.</td>
</tr>
<tr>
<td>Rot. 71</td>
<td>A Oats—on fallow</td>
<td>1913</td>
<td>.090</td>
<td>.094</td>
<td>.092</td>
</tr>
<tr>
<td>do.</td>
<td>B Corn—S.P.</td>
<td>1913</td>
<td>.101</td>
<td>.091</td>
<td>.091</td>
</tr>
<tr>
<td>do.</td>
<td>C Sp. wheat—D.F.</td>
<td>1913</td>
<td>.078</td>
<td>.079</td>
<td>.078</td>
</tr>
<tr>
<td>do.</td>
<td>D Fallow—manured</td>
<td>1913</td>
<td>.094</td>
<td>.095</td>
<td>.094</td>
</tr>
<tr>
<td>Rot. 72</td>
<td>A Sp. wheat—on fallow</td>
<td>1913</td>
<td>.090</td>
<td>.094</td>
<td>.092</td>
</tr>
<tr>
<td>do.</td>
<td>B Corn—S.P.</td>
<td>1913</td>
<td>.093</td>
<td>.092</td>
<td>.092</td>
</tr>
<tr>
<td>do.</td>
<td>C Oats—D.F.</td>
<td>1913</td>
<td>.089</td>
<td>.088</td>
<td>.088</td>
</tr>
<tr>
<td>do.</td>
<td>D Fallow—manured</td>
<td>1913</td>
<td>.088</td>
<td>.087</td>
<td>.088</td>
</tr>
<tr>
<td>Rot. 7-26</td>
<td>A Potatoes—D.F.</td>
<td>1926</td>
<td>.068</td>
<td>.070</td>
<td>.069</td>
</tr>
<tr>
<td>do.</td>
<td>B Beans—D.P.</td>
<td>1926</td>
<td>.074</td>
<td>.073</td>
<td>.074</td>
</tr>
<tr>
<td>do.</td>
<td>C Sp. wheat—D.F.</td>
<td>1926</td>
<td>.074</td>
<td>.072</td>
<td>.073</td>
</tr>
<tr>
<td>do.</td>
<td>D Corn—S.P.</td>
<td>1926</td>
<td>.073</td>
<td>.070</td>
<td>.072</td>
</tr>
<tr>
<td>Rot. 18-26</td>
<td>A Potatoes—D.F.—man’d.</td>
<td>1926</td>
<td>.089</td>
<td>.091</td>
<td>.090</td>
</tr>
<tr>
<td>do.</td>
<td>C Sp. wheat—D.F.—man’d.</td>
<td>1926</td>
<td>.111</td>
<td>.111</td>
<td>.111</td>
</tr>
<tr>
<td>Rot. 19-26</td>
<td>A Potatoes—S.P.—man’d.</td>
<td>1926</td>
<td>.117</td>
<td>.118</td>
<td>.118</td>
</tr>
<tr>
<td>do.</td>
<td>B Beans—S.P.—man’d.</td>
<td>1926</td>
<td>.094</td>
<td>.093</td>
<td>.094</td>
</tr>
<tr>
<td>do.</td>
<td>C Sp. wheat—S.P.—man’d.</td>
<td>1926</td>
<td>.099</td>
<td>.100</td>
<td>.100</td>
</tr>
<tr>
<td>Rot. 7-31</td>
<td>D Potatoes, beans, spring wheat, corn. All plots duckfooted</td>
<td>1931</td>
<td>.070</td>
<td>.073</td>
<td>.072</td>
</tr>
<tr>
<td>Rot. 18-31</td>
<td>A Potatoes, beans, spring wheat, corn. All plots man’d. and duckfooted</td>
<td>1931</td>
<td>.101</td>
<td>.102</td>
<td>.102</td>
</tr>
</tbody>
</table>

1 The percentage carbon for all plots from M.C. Corn—Dup. to Rotation 9, inclusive, is an average of two determinations. Only one determination was made on the remainder.
2 From 1913 to 1922, the area occupied by the M.C. Corn—Dup. plots was in M.C. Flax.
3 Rotations 41 and 42 were changed to deferred-type rotations in 1937. The grass in rotation 41 was also changed from brome to crested wheat in 1937.

NOTE: Samples were analyzed at the Northern Great Plains Field Station, Mandan, North Dakota. Carbon determinations were made by the wet-combustion method.

Data furnished by Dr. Lyle T. Alexander, Principal Soil Scientist, U. S. Department of Agriculture
while a 26 percent loss occurred in plots A, B, and E during the same period. Plot F was listed and leveled with the disk or duckfoot; thus about one-third of this plot was affected by major tillage. Plots A, B, and E were fall-plowed and worked down with a disk or duckfoot. In addition plot E was subsoiled in alternate years.

The data show that three degrees of nitrogen losses occurred in a 35-year period even though the average yearly production of winter-wheat grain was practically the same. The data are not sufficient for definite conclusions, but they indicate that the type of tillage is a factor in consideration of the nitrogen problem.

The elevation profiles of the M. C. winter-wheat plots indicate that soil movement is not a fertility factor on these plots. This coincides with observations.

Most of the data in Tables 9 and 10 indicate that heavy losses of nitrogen have occurred where intensive cultivation has taken place. However, in rotations 18-26, 19-26, and 18-31, where each plot received yearly applications of 10 tons of manure per acre, the nitrogen losses were lower.

Row crops such as those in rotations 7-26 and 7-31, continuous cropping to corn, and fallow have greatly depleted the nitrogen content of the soil. Thus it appears that tillage methods should be given serious consideration if a low equilibrium of nitrogen is to be avoided.

**IMPLEMENTS FOR FALLOW TILLAGE**

The main purpose of fallow tillage is to conserve moisture and at the same time to leave the soil in condition to resist erosion, especially by wind. This is best accomplished by leaving the field trash at the surface or mixed with the surface soil, at the same time making a thorough killing of plant growth. To date the eccentric one-way disk has proved to be the best implement with which to accomplish such primary tillage. As shown in Tables 4 and 7, plots fallowed with this implement produced the largest yields of grain.

Figures 3 and 4 show the advantage of pitting in that the pits hold the water from sudden down-pouring storms, thereby preventing run-off.

Pitted plots, with the exception of the plot tilled deep with a Peacock dammer, produced larger average yields of winter wheat than the level-tilled plots. The lister-type pitting implement does not make a thorough killing of weeds; it leaves the soil so rough that it hinders further tillage. It is often difficult to operate this type of implement in heavy field trash. Deep tillage—14 inches—with the Peacock lister dammer will retain a large quantity of water; but tillage with that implement permits rapid loss by evaporation.
The duckfoot type of implement does not do a thorough job of killing downy chess and under some conditions is difficult to operate in fields with a heavy trash cover. This type of implement is best adapted for tillage after the land has been plowed or eccentric one-wayed. It may be necessary, in case of heavy crop residues, to till the land twice with the eccentric one-way before cultivating with the duckfoot.

Tillage with the rod weeder is very desirable, especially during the latter part of the fallow season, in that it packs the soil below the surface layer, leaves dry soil and field trash on the surface, and so produces a seedbed conducive to good germination.
The plow is the old standby, and since this region has become infested with downy chess, some farmers have returned to the practice of plowing for fallow. Tillage with the plow covers practically all field trash. However, it has been found advisable for protection from erosion to leave the field trash at the surface or mixed with the surface soil, as shown in Figures 5 and 6.

Data in Table 4 show that plowing without moldboard produced lower average yields than plowing with moldboard attached. Early-spring plowing without moldboard (depth 6 inches) and early-spring duckfooting (depth 3 inches) produced 15.6 and 15.7 bushels per acre, respectively. Neither plowing without moldboard nor duckfooting was efficient in killing downy chess.
Tillage after harvest of stubble land to be fallowed is not generally recommended in this region. Fall tillage should be undertaken only when the soil is moist and considerable plant growth is taking place. Cereals harvested for hay at this station often produce a second growth that would exhaust soil moisture if permitted to grow. This is especially true of winter rye as shown in Figure 5.

In order to prevent depletion of the reserve soil moisture left by harvesting an immature cereal crop for hay, the land is tilled with the eccentric one-way disk as soon as possible after the hay has been removed. A better job, such as shown in Figure 6, results if the tillage is accomplished almost immediately after a rain storm. Under these conditions the green cereal stubble turns up much the same as sod.

At times water from melting snow carries considerable topsoil from level-tilled fields. Loss of such water and soil is reduced by pitting with the eccentric one-way disk. This tillage mixes the field trash with the surface soil. (Figure 7.)

FIG. 7—Same field as shown in Figure 6. Note snow held by stubble and pits. They prevent run-off from melting snow as well as from sudden down-pouring storms.
At this station, land to be fallowed is generally tilled with the eccentric one-way disk during early spring and early June, once during midsummer with the duckfoot, and once about mid-August with the rod weeder. Fields tilled with the eccentric one-way disk may be seeded with the furrow drill without leveling.

**SEEDING RECOMMENDATIONS**

Experimental results obtained at this station indicate that September 1 is the optimum date for seeding winter cereals. Seedings on this date usually make sufficient growth before winter sets in for best results; under most conditions they escape, to considerable extent, infection from foot rot and mosaic. However, at this time of year the season is generally quite dry, and attention should be given to methods by which the seed is placed in moist soil. The seeding operation should be of such nature as to contribute toward making the field resistant to soil blowing during the winter and early spring months.

It is often difficult to place the seed in moist soil if the duckfoot or subsurface tillage implement has been used exclusively for fallow tillage. As a result of such tillage a rather deep, dry mulch is often formed over the moist soil. A layer of firm, moist soil, which the ordinary drill does not penetrate, is usually present at the dividing line.

In order that the moist soil be as near the surface as possible at seeding time, it is advisable to till fallow land during the latter half of the fallow season only deep enough to kill plant growth. The rod weeder has generally proved satisfactory for this type of tillage. This implement tends to lift undecayed trash to the surface. This establishes a condition in which the furrow drill mixes the field trash with the soil at the top of the grain-drill ridges. Such a condition is shown in Figure 8. Notwithstanding high winds with gusts reaching speeds of 82 miles per hour, and heavy grazing by deer, this field showed no damage from soil blowing.

Conditions sometimes develop whereby the soil at seeding time does not give promise of being sufficiently resistant to soil blowing to withstand the high winds of winter and early spring. Under such conditions it may be advisable to mix the winter wheat seed with a spring cereal such as an early-maturing barley. The barley makes rapid growth and, even though killed by cold weather, it furnishes the needed protection to the soil and the winter-wheat crop. Should soil blowing develop it may become necessary to make furrows and ridges at intervals at right angles to the wind. The lister is generally used for this operation.
HISTORY OF THE ECCENTRIC ONE-WAY DISK

In 1936 it was observed that the lister-dammer type of implement did not fully meet the requirements of fallow tillage. Tillage with this type of implement was very difficult in heavy field trash. Further, such implements did not do a thorough job of killing weeds. It was therefore decided to try pitting with a disk implement. The station's IHC disk-harrow plow (one-way disk) was used. After considerable experimental work with various patterns of notched disks it was found that they made an excellent pattern of pits—provided a smaller disk was placed between each notched disk.

FIG. 8—A winter-wheat field harvested with a combine, followed by tilling twice with the eccentric one-way disk, once with the duckfoot, and seeded with a tandem double-disk deep-furrow drill. Note field trash in ridges. Notwithstanding high winds with gusts reaching 82 miles per hour and heavy grazing by deer, this field showed no damage from soil blowing.

The notched disks made a good job of pitting in moist soil, but in dry soil the longer parts of these disks sprang to the pressure and soon broke off; so a decision was made to try eccentric disks. At this stage the IHC arranged a tillage demonstration at this station. The district manager, seeing the pitting accomplished by the notched disks, inquired how it was done. All information concerning this matter was given to the IHC engineers. The IHC's main contribution to the eccentric one-way disk was the system of placing the eccentric disks on the gang bolt.
DESCRIPTION OF THE ECCENTRIC ONE-WAY DISK

The eccentric one-way disk is an ordinary one-way disk or Wheatland plow with every other disk an eccentric disk. The eccentric disks are 2 inches larger in diameter than the other disks, with the gang-bolt hole 2 inches off center. The one-way at this station was equipped with 18-inch disks. (See Figure 9.)

FIG. 9—The eccentric one-way disk used for pitting at the Archer Field Station

To mount the eccentric disks properly on a one-way, it is suggested that one start from the rear of the gang bolt and proceed as follows:

1st disk—18 in.
2nd disk—20 in. eccentric with long side up
3rd disk—18 in.
4th disk—20 in. eccentric with long side to the rear
5th disk—18 in.
6th disk—20 in. eccentric with long side down
7th disk—18 in.
8th disk—20 in. eccentric with long side to the front

Continue in same fashion until all disks are mounted.

The gang-bolt hole in the 20-in. disks is 2 inches off center—this forms an eccentric disk.
The above principle can be applied to most disk implements with variations to meet the requirements of the operation.

This system of mounting the disks not only produces the desired pattern of pits but also gives an even distribution to the draft of the implement.

The above set-up is used for summer fallow. The same set-up can be used for pitting sod land, but the implement must be carefully regulated as to depth in order to prevent the smaller disks from cutting the sod. If considerable sod pitting is to be done it is advisable to remove the smaller disks and in their places put large washers to take up the space on the gang bolt. By removing the smaller disks it is possible to make the pits 1 inch deeper.
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AGRICULTURAL EXPERIMENT STATION
GEORGE DUKE HUMPHREY, Ph.D., President of the University

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