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SEEDING SMALL GRAIN IN FURROWS

TABLE OF CONTENTS

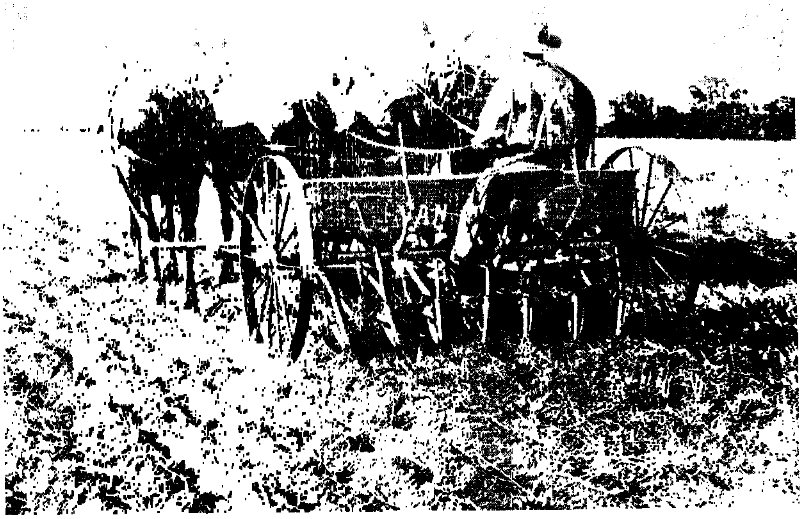

Fig. 1.—Seeding in disked unplowed stubble with a disk furrow drill.

Fig. 2.—Snow covering wheat sown in furrows. (Manhattan, December, 1916.)

SEEDING SMALL GRAIN IN FURROWS[1]

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INTRODUCTION

Experiments recently conducted and now in progress seem to show beyond reasonable doubt certain advantages in a method of seeding that has been used but little for wheat and not extensively for other grains. This is the method of seeding in furrows or listing[2] as it is sometimes called because of the similarity to listed corn.

Briefly, the method consists of seeding the grain in furrows somewhat deeper and farther apart than those made with drills commonly used. (Figs. 1, 2, 3.) In the experiments reported in this paper the furrows have varied from 10 to 14 inches apart and from about 3 to 6 inches deep except as otherwise indicated. In recent experiments and in general practice 12 inches apart has been adopted as the most desirable spacing for average conditions.

Acknowledgements. — The experiments reported in this bulletin at the Fort Hays Experiment Station, Hays, Kan., were in charge of F. A. Kiene, Jr., from 1914 to 1917, and in charge of A. F. Swanson, beginning with 1919; those at Colby were in charge of John J. Bayles in 1918 and 1919, and in charge of B. F. Barnes in 1921; those at Tribune have been in charge of G. E. Lowrey. The experiments at the Fort Hays Experiment Station have been in cooperation with the Office of Cereal Investigations, Unted States Department of Agriculture.

1. Contribution No. 153 from the Department of Agronomy.

2. The term "listing" is considered objectionable because it is easily confused with listing the ground in preparation for seeding.

Fig 3—Wheat sown with a furrow drill at Manhattan, September, 1917.

The advantages so far suggested or observed for this method of seeding are (1) better and more certain germination when the surface soil is dry; (2) better protection of the grain from low temperature during the winter; (3) retention of snow which otherwise is blown from the field; (4) less injury from heaving of the soil as a result of alternate thawing and freezing in the spring; (5) less injury from soil blowing; (6) less injury from drought; and (7) less seed is required.

Possible disadvantages are (1) the extra power usually required with the furrow drill due to its heavier draft; (2) water logging on poorly drained soils; and (3) greater weed growth because of wider spacing of the rows.

The purpose of this bulletin is to present and interpret the experimental results relating to this method of seeding. It is recognized that much of the data are inconclusive and some defective.

The lack of suitable drills for seeding in furrows and the shortage of labor in certain cases during the war have been a serious handicap in conducting the work. While it is believed that the former objection has been largely overcome, its effect is reflected in the experimental results, as for example when unequal stands were secured because of failure to place the seed properly in the bottoms of the furrows. The results in such cases are presented for what they are worth as a guide to further research rather than as proof of the value or lack of value of the new method.

EARLY HISTORY

The earliest experiments on seeding wheat in furrows appear to be those of the Kansas Agricultural Experiment Station begun by Prof. E. M. Shelton (1889) in the fall of 1888. These were discontinued in 1899 and resumed in the fall of 1913. Redding (1899) of the Georgia Agricultural Experiment Station recommended this method of seeding for winter oats and wheat as early as 1899 and states that the idea "was conceived several years ago and annually since we have sown the larger portion of the fall-sown area in drills 18 to 24 inches apart."

The method has been used in various other southern states for seeding winter oats especially in Alabama where in some sections 75 per cent of the fall-sown crop is said to be planted by this method. It has been used to a limited extent only for wheat. In western Kansas and Nebraska there may occasionally be found what are known as lister drills which seed the grain in furrows about 11 inches apart. A considerable number of these drills have been used at various times but very little in recent years, partly at least because of heavy draft and their failure to work satisfactorily in trashy or poorly prepared ground. This point will be discussed later.

Fig. 4.—Winter wheat sown with a furrow drill. Note the rough ground which catches snow and reduces the danger of soil blowing.

Fig. 5.—A field of wheat sown with a furrow drill at Manhattan. The wheat has tillered sufficiently to occupy the space between the rows as shown by looking over the field. The ridges between furrows have disappeared.

GERMINATION IN DRY SOIL

One of the advantages of the furrow method of seeding is the possibility it offers of placing the seed in contact with moist soil, thus insuring prompt and uniform germination (figs. 4, 5, and 6). In semiarid sections one of the serious difficulties in growing winter wheat and to a certain extent in seeding spring-sown cereals is the dry surface soil which makes it difficult to secure a good stand. For example, Cardon (1915) states with reference to seeding in the Great Basin of Utah: "It is impractical to sow seed in the dry soil because it will not germinate until rain falls and then if the storms brought insufficient moisture for continued growth the plant very likely would die after sprouting. It is almost impossible to place the seed below the dry soil and if it were possible it is not practical because small seeds placed so deep often have difficulty in getting their first leaves to the surface. . . . The chief problem seems to be a mechanical one involving some improvement of the machinery now used in seeding the grain. The improvement believed to be necessary comprises a means for opening a furrow through the dry surface soil sowing the seed in moist earth at the bottom of the furrow and leaving the furrow partly open so that the plants will not have to force their way through several inches of dry soil. It is believed that seed could be sown with good results in dry weather by this method as the seed would germinate rapidly and a good stand of grain would be established before winter, thus greatly increasing the possibilities of a good crop." In the semiarid Great Plains, wheat may be sown apparently with sufficient moisture for germination but if seeding is followed with a few days of drying winds the soil loosened by the drill may dry out before the seed germinates.

It will be seen that the furrow method of seeding is an attempt to overcome the situation described by Cardon so far as placing the seed deeper in the soil and covering it is concerned, and the protection afforded by the ridges may be expected to prevent to some extent the drying out of the soil which sometimes interferes with germination in the Great Plains. That beneficial results are sometimes secured by this method is indicated by the experimental results so far secured.

At the Tribune Branch Experiment Station, Greeley county, Kan., a field of rye was sown in the fall of 1917 on ground previously in beans, half being sown with a common double-disk drill and the remainder with a furrow drill spacing the rows 14 inches apart. The portion sown with the common drill failed to germinate while that sown with the furrow drill produced a good stand and a fair yield of hay the following spring. In the dry fall of 1917 at Manhattan, a marked difference in germination and early growth was observed with wheat and barley in favor of the furrow method. (Fig. 6.) In seeding cowpeas at Manhattan in disked wheat stubble soon after harvest it has

Fig. 6.—Winter wheat sown in furrows (right) and in ordinary manner (left) at Manhattan. Note the heavier more vigorous growth in the furrows due to the better germination and growth.

been found possible in at least two instances to secure good germination with the furrow drill where the common drill failed entirely or produced very thin uneven stands.

Kiene (1914, p. 89) found that winter oats, emmer, and spelt sown at the Fort Hays Branch Experiment Station in the fall of 1913 with a nursery drill in furrows made by a nursery plow germinated sooner than when sown by hand in a manner comparable to the usual method of seeding. Again in the fall of 1914 better stands were secured by seeding with a furrow drill than by seeding with an ordinary disk drill. Estimated stands were as follows: wheat 85 percent for the ordinary method and 100 percent for the furrow method; black winter emmer 80 percent for the ordinary method and 92.5 percent for the furrow method; winter barley 80 per cent for the ordinary method and 95 percent for the furrow method (Kiene, 1915, p. 49). Again, in the fall of 1915 wheat and barley in furrows "germinated and came up a little quicker and showed a little more vigor until the grain began to head out." (Kiene, 1916, p. 41.)

In the fall of 1916 wheat in furrows emerged two days before that sown in the usual way (Kiene, 1917, p. 51). In 1920 Swanson (1920, p. 45) observed a difference of two days in emergence of spring-sown oats in favor of the furrow method.

Shelton (1889) states that wheat sown in furrows in the fall of 1889 "sent its shoots above ground a day or more in advance of seed sown near by upon the surface.[3] It made a ranker and more luxuriant growth, the plants having a much better color than those which grew upon the surface."

In the dry fall of 1892, planting wheat by several methods Georgeson et al (1893) observed that "The ground was rather dry when seeded and for a long time the seed did not germinate. The lister and hoe drill put the seed down in the moist ground whereas the other methods employed did not put it below the dry layer of surface earth." Due to this fact and to a difference in winter surival the grain in furrows produced much the better yields the following summer. (Table VI.)

On the other hand, it is only fair to say that in certain tests (Tables XIII and XIV) to be discussed later, better stands have been secured with the ordinary disk drill. Also in seeding commercial fields comprising several hundred acres, at the Fort Hays station, often when moisture for germination was none too plentiful no differences in germination have been observed. Whether the failure of the furrow method to produce better stands in these instances was due to a uniformly dry soil to the depth of seeding for the furrow drill, to faulty construction of the drill, or to the method itself cannot be stated fully at this time. In some cases it is certain that the construction of the

3. The description of the experiment indicates that the wheat was sown with a drill spacing the rows 6 inches apart.

drill was at fault. This point is further discussed in connection with yields and drills for seeding.

From the few observations that have been made it seems reasonably certain that there are some conditions where seeding in furrows will be a distinct advantage from the standpoint of securing better and more uniform germination and early vigorous growth of the plants. There are no doubt other conditions, as when no moisture is present at any depth likely to be reached by the drill, in which no such advantage will be secured.

PROTECTION FROM WINTERKILLING

Perhaps the most striking and the most important advantage of seeding in furrows is the protection of the grain from winter injury. That this method of seeding would result in better protection of the plants during the winter was recognized from the first as one of the main arguments in its favor. As early as July 1889 Shelton (1889) states that seeding in furrows will "almost certainly enable wheat so planted to pass even the severest winters uninjured by winterkilling. Who has not noticed in fields of wheat, more or less completely destroyed by winter freezing, that every plant fortunate enough to have root in some dead furrow or other depression in the field has almost certainly passed the rigors of winter unharmed? If the entire crop be put beneath the surface, may it not altogether escape winterkilling seems at least a reasonable question."

Carleton (1900) also called attention as early as 1900 to the probable advantages of seeding in furrows. He says "We probably do not have exactly the ideal drill for winter wheat sowing in districts of extreme drouth. The proper kind of machine when made will possess a combination of the features found in both the press drill and what is known as the lister drill. When so planted, the wheat is put so far down that the growing roots are surrounded with the abundant moisture of the packed portion of the soil and the firm surface dirt falls in and around the plant from above filling up the row to such an extent that it will require a severe winter indeed to kill out the plant to the root."

While these early prophecies have not been completely fulfilled, the experimental evidence is sufficient to show some very marked advantages so far as winterkilling is concerned.

Protection from winterkilling is the principal argument advanced in favor of this method for seeding winter oats in the south. Thus Redding (1899) in speaking of the furrow method of seeding says, "But a more important discovery is the fact that when seeds are sown in open furrows and barely covered leaving the furrows open or unfilled the oat plants are very much less liable to be killed by a severe freeze. . . . . The winter rains, light freezes, and thaws gradually but only partly fill in the open furrows and the more vital and senitive parts of the plants are left at the original depth below the reach of very heavy freezes. The long anticipated freeze at last came and our theory was put to a crucial test. On February 8, 1899, the thermometer sank to 15 degrees, followed on successive mornings by 19 and 17 degrees. On the 12th it was down to 11 degrees and on the morning of the 13th it stood 7 degrees below zero—the coldest day since February 8, 1833. The result was that fall-sown oats and January-sown oats were pretty generally destroyed everywhere. But *our open furrow drilled oats excepting two acres stood the test remarkably well and though seriously injured made 40 bushels to the acre.*[4] Of the two acres so planted that were badly killed, the rows were laid east and west; of all the other sections, the rows were laid north and south, thus developing another significant point, that the ideal direction would be northeast and southwest in order to protect the plants, by means of the wall of earth, against the northwest wind.

"In order to make more sure of the correctness of the preconceived theory that the open furrows would secure the oats from fatal freezing, on two one-acre sections that were sown in open furrows running east and west, the furrows on every alternate tenth acre were filled up flush by running over them with a clod-crusher and smoother. The result was that the oats on these alternate tenths were almost entirely destroyed, not one plant in ten surviving the severe freeze, and the plots were resown with spring oats. But the other tenths, of which the furrows were left open, although severely injured, produced 40 bushels of grain per acre, or more than half of the expected full crop."

McClelland (1915) is responsible for the statement made after a number of years' experimental work that "drilling in open furrows has been found usually to give better results during severe winters."

Georgeson et al (1893) found that wheat in furrows survived the dry fall and rather severe winter of 1892-93 better than wheat sown by other methods. Thus, it is stated that on "April 15 it was noted that the listed plots were by far the best. They showed no signs of winterkilling and were making a good spring growth . . . . . . All the others gave but poor promise of a crop." The wheat in furrows produced 19.6 bushels per acre as compared with 11.6 bushels for seeding in the usual way. (Table IV.)

More recent experiments in Kansas, principally at Manhattan and at Hays, have shown similar advantages for winter oats, winter barley, winter emmer, and winter spelt. Thus at Manhattan in 1913-14, 86.5 percent of oats survived when sown in furrows and only 7.5 percent when sown in the usual way. (Figs. 7 and 8.) In the following season comparable figures for oats were 44.9 for seeding in furrows and 33.3 for the ordinary

4. The italics appear in the original paper.

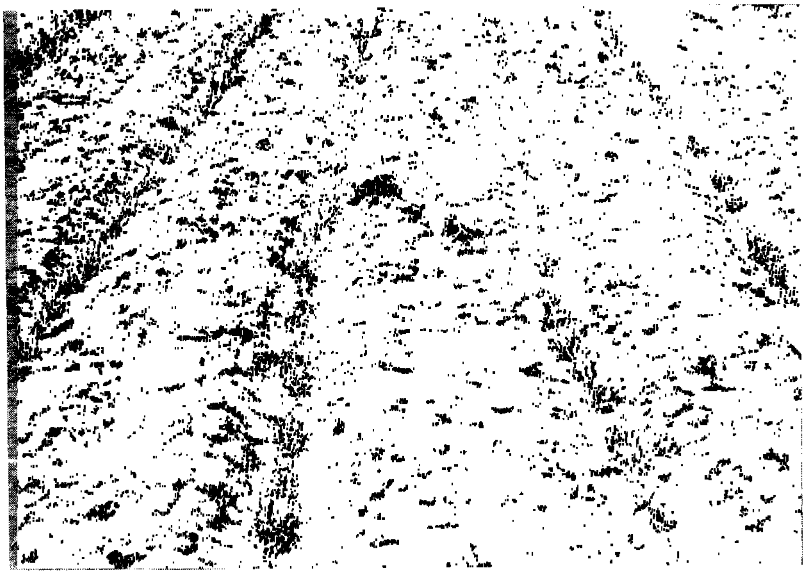


Fig. 7.—Winter oats sown in furrows 20 inches apart. The survival of plants was 86.5 percent. On the same field the survival of plants on areas sown in the usual way was only 7.5 percent. (See fig. 8.)

Fig. 8.—Winter oats sown in the usual way at the same time and rate as those shown in figure 7. Note the dead plants in the drlil rows with an occasional tuft of living plants.

method. Of winter barley in 1915, 57.6 percent survived when sown in furrows and 30 percent when sown in the usual way. In 1916 only 3 percent of winter barley survived when sown in the usual way as compared with 87 per cent when sown in furrows.

Similar differences were secured at Hays in 1914, 1915, and 1916. Thus in 1914 winter oats survived to the extent of 50 percent when sown in furrows but only 5 percent survived when sown in the usual way. Comparable figures for barley in the same season were 90 percent and 50 percent, respectively; for winter emmer, 90 percent and 57 percent, respectively; and for winter spelt, 95 percent and 85 percent, respectively. The survival for the winter of 1914-15 was: for Black Winter emmer 95 percent and 50 percent, and for winter barley 15 percent and 3 percent, respectively, the first named figure in each case being for the grain sown in furrows and the latter for the grain sown in the usual manner. Most of these figures both for Manhattan and Hays are given in connection with the data on yield, etc., in Tables V, VI, VIII, IX, and X. In none of the recent tests at Manhattan and Hays have the winters been sufficiently severe to show a marked effect on wheat.

In the fall of 1917 the United States Department of Agriculture cooperated with the South Dakota Agricultural Experiment Station in seeding wheat in furrows at the Highmore Branch Station at Highmore. Prof. Manley Champlin, who had charge of the experiments, wrote as follows in May and July, 1918, regarding them; "The winter wheat sown with a furrow drill came through in good shape, 100 percent surival sown on land which had grown an intertilled crop, Winter wheat sown under similar conditions with the ordinary drill killed out on all plots."[5]

Extensive experiments conducted cooperatively by the United States Department of Agriculture and the Montana Agricultural Experiment Station at the Judith Basin Substation and at the North Montana Substation have shown very decisive differences. Thus Osenbrug (1922) reports that the results of these investigations for the two years, 1920 and 1921, "indicate that the use of the furrow drill will solve the problem [of winterkilling] to a large extent. Winter wheat seeded with a furrow drill outyielded winter wheat seeded with an ordinary drill by an average of 6 bushels per acre in 1920 and 8 bushels per acre in 1921." Upon plots which were not protected by a straw mulch "the yield of winter wheat seeded with the furrow drill was practically 21 bushels per acre in 1921 or twice as much as that obtained on the ordinary drill seeding." Morgan (1921) states that "all winter wheat at the North Montana Substation regardless of variety, rate, date, or method of seeding killed during the winter with the exception of that seeded with the furrow drill and as this was thin it was plowed later in the season because of weed growth."

5. The author is under obligations to Professor Champlin who kindly supplied these data.

Taken altogether, these experiments appear to show rather conclusively that seeding in furrows offers considerable protection from winterkilling and that where losses from winterkilling occur this method may be expected to give better yields.

The results also emphasize the desirability of leaving the ground as rough as practical after the grain is sown in those areas where it will not be desirable to use the furrow method of seeding. Thus it may be pointed out that harrowing the ground after seeding or using drills which space the rows unnecessarily close together will likely increase the damage from winterkilling in areas where such injury occurs.

WHY SEEDING IN FURROWS AFFORDS PROTECTION

There are probably several reasons why seeding in furrows protects the wheat during the winter. The more important appear to be: (1) The protection afforded by snow covering the plants. Under ordinary methods of seeding most of the snow is likely to be blown off the fields. (2) Less damage from heaving. (3) Less exposure to low temperature. (4) Protection from cold drying winds.

Snow Covering.

It is common knowledge among farmers where snowfall is relatively light that a light covering of snow over grain fields greatly protects the plants from winterkilling although a heavy covering may be detrimental either by smothering the plants or by leaving an excess of water in the soil in the spring. That

Fig. 9.—Snow in furrows after a light snow with no wind. Compare with figure 2 which is the same field two days later.

seeding in furrows aids materially in keeping a light covering of snow over the wheat is well shown in figures 2 and 9. Not only do the ridges prevent the snow from being blown from the field but they seem to delay melting as for example in warm spells during the winter. This is illustrated in figure 10, showing a field of wheat after a winter thaw. The wheat in furrows was protected by a light snow covering which remained on the wheat for the remainder of the winter while adjoining fields were left practically bare.

Fig. 10.—View of a field of wheat after a January thaw at the Colby Branch Experiment Station. A furrow drill was used in seeding. Notice the snow in the furrows.

The relation of this method of seeding to retaining snow and protecting the plants was recognized in early experiments at the Kansas Station (Georgeson et al; 1892) it having been observed "that the furrows made by the lister drill aided in holding the snow and thus protected the wheat from the cold."

Exposure to Wind

The opinion prevails quite generally among farmers and others that cold drying winds during the winter are responsible for much damage aside from their relation to low temperature and soil blowing. Duggar and Cauthen (1913) mention the protection of "the plants from cold winds" as one advantage of the furrow method in Alabama, and Redding (1899) of the Georgia station emphasizes the importance of the direction of seeding "in order to protect the plants by means of a wall of earth against the northwest wind." No experimental data regarding the effect which may be expected from protecting the wheat from winter winds, aside from their effect on temperature and soil blowing which will be discussed later, have been secured at the Kansas station.

Heaving

Protection of the grain from heaving due to alternate thawing and freezing is emphasized by those who have investigated the furrow method of seeding winter oats. Thus Duggar and Cauthen (1913, p.124) state that "the plants being down in a trench are not lifted or heaved so much by alternate freezes and thaws as are oats sown broadcast," and McClelland (1916) states that when grain is sown in furrows "the subsequent heaving of the soil by freezing covers the plants instead of throwing them out and in this way they are saved."

No opportunity has been afforded to study this phenomenon in the experiments at Manhattan as no injury from heaving has occurred in any plots since the inauguration of these experiments. The point is of little importance as far as the semiarid regions of the United States are concerned as heaving there is seldom a factor of importance. It suggests the possibility, however, of using the furrow method of seeding in those subhumid portions of the winter wheat belt where injury from heaving is of common occurrence. The furrow method apparently has not been tried for wheat in those areas.

Temperatures

No doubt the most important reason for less damage to grain in furrows during the winter is the less rapid changes in temperature which occur in the soil surrounding the plants.

A higher average minimum temperature and probably less alternate thawing and freezing accompany the more uniform temperatures thus provided. This seems to be the result not only when the plants are covered with snow as illustrated in figure 9 but also to a less degree when there is no snow cover.

Experiments to determine the relative temperatures of the soil surrounding grain sown in furrows of different depths were begun at the Kansas Agricultural Experiment Station in the fall of 1914 and continued until the spring of 1919. During the first two seasons the temperature of east and west furrows only were compared but in later seasons north and south furrows were included. As there has appeared to be no marked difference the two sets are averaged and the data given in Table I. The furrows each season were approximately 2, 4, and 6 inches deep, the first set being about 8, the second 12, and the third 16 inches apart. Thermometers were also placed on the level surface for comparison, the bulbs being covered to the same depth. Two thermometers were placed in the bottom of each furrow with the bulbs covered from ¾ to 1 inch deep corresponding to the depth of the crowns of the plants. As earth from the ridges frequently found its way to the bottoms of the furrows, thus covering the bulbs deeper than was intended, it was found necessary to examine them from time to time and remove any excess in order to keep the thermometers on a comparable basis. Alcohol thermometers were used the first season. Thereafter electric thermometers manufactured by Leeds, Northrup & Co. were used. (Fig. 11.)

Fig. 11.—Installation of electric thermometers used to compare the temperature of the soil at the bottoms of furrows of different depths.

TABLE I.—RELATIVE TEMPERATURES NEAR THE SURFACE AND IN TWO-, FOUR-, AND SIX-INCH FURROWS

Year	Temperature			
	Surface	Two-Inch Furrows	Four-Inch Furrows	Six-Inch Furrows
1914-15				
Mean minimum temperature........................				
Dec. 3 to Mar. 24	— 0.06	0.0	0.31	0.59
For days only with a soil temp. of 0°C. or lower	— 1.92	— 1.59	— 1.22	— .84
Average daily range..............................	2.43	2.45	2.52	1.87
Lowest recorded temp..........................	— 6.8	— 4.9	— 4.9	— 3.7
1915-16				
Mean minimum temperature........................				
Dec. 6 to Feb. 9	— 2.85	— 1.86	— 1.31	— .93
For days only with a soil temp. of 0°C. or lower	— 3.57	— 2.56	— 1.95	— 1.57
Average daily range..............................	....	......	......	....
Lowest recorded temp..........................	—16.06	— 9.44	— 3.89	— 1.83
1916-17				
Mean minimum temperature........................				
Dec. 0 to Mar. 17	— 3.33	— 3.17	— 2.77	— 2.61
For days only with a soil temp. of 0°C. or lower	— 4.06	— 3.89	— 3.44	— 3.22
Average daily range..............................	4.83	4.50	4.50	4.00
Lowest recorded temp..........................	—17.28	—17.17	—15.61	—15.11
1917-18				
Mean minimum temperature........................				
Dec. 5 to Mar. 9..................................	— 3.83	— 3.89	— 2.67	— 1.64
For days only with a soil temp. of 0°C. or lower	— 6.04	— 6.14	— 4.07	— 3.02
Average daily range..............................	7.83	7.77	4.89	3.83
Lowest recorded temp..........................	—15.0	—14.7	—11.1	— 9.2
1918-19				
Mean minimum temperature				
Dec. 3 to Feb. 7.	— .11	— .28	— .11	— .28
For days only with a soil temp. of 0°C. or lower	0.0	— .47	— .06	— .23
Average daily range..............................	....	......	......	....
Lowest recorded temp..........................	— 2.77	— 1.94	— 1.11	0.0

As it was desired to obtain especially the minimum temperatures the time of reading the thermometers was chosen accordingly. Three readings daily were made the first year, four the second, and three thereafter except in 1918-19 when one only was recorded. The mean minimum temperature for the entire period each year, the mean minimum for days with a soil temperature of 0° C. or below, and the lowest recorded temperature in each season are indicated in Table I.

Perhaps the most significant measure of temperature so far as its relation to winterkilling is concerned is the lowest temperature recorded during the winter. In every season it will be observed that the lowest temperatures were recorded for those thermometers beneath the level surface and the temperatures were successively higher as the depth of the furrows increased. The difference was especially marked in 1915-16 when the lowest temperature recorded for the surface thermometers was -16.06° C. and for the 6-inch furrows,-1.83°C., or a difference of 14.23° C. The average minmimum temperatures for those days having a soil temperature of 0°C. or below also show in practically all cases considerable differences in favor of the furrows, the differences as before, increasing with the depth of the furrows.

The 4-inch furrows probably correspond most closely to what would be practical under field conditions, and the 2-inch furrows would to some extent correspond to furrows made by an ordinary drill, being if anything larger with more prominent ridges. Comparing these two it will be seen that in every case there is considerable difference in favor of the 4-inch furrows.

The average daily range in temperature is, as would be expected, usually greatest for the surface and least for the deepest furrows. There are some discrepancies, as for example in 1914 15, which cannot be explained.

The mean minimum temperature for the entire period appears to be related to winter survival, only as it coincides with the lowest temperatures recorded. When the temperature remains above freezing as occurred in a number of cases, the lowest minimum temperatures are likely to be recorded for the deepest furrows and the highest for the surface. This occurs because of the higher maximums reached by the surface and shallow furrows and the fact that although radiation of heat at night is more rapid from these locations, it is frequently not enough to overcome the greater absorption during the day. The net result is that the relative average minimum temperatures for the different locations are likely to depend on the proportion of the entire period in which the soil temperature is above freezing as compared with the number of days it is below freezing.

RELATION OF SNOW TO TEMPERATURE

Without doubt most of the differences in temperature recorded in the preceding pages were due to differences in the depth of snow covering the thermometers. This influence is especially marked when the snowfall is light and accompanied by heavy winds in which case the snow is blown entirely from the level soil and deposited in the furrows (figs. 2 and 9) the depth of snow increasing with the depth of the furrows. This occurred a number of times in the course of the experiments and is undoubtedly the responsible factor in those cases where wide differences in temperature were recorded.

There is some evidence, however, to show that when there is no snow the temperature of the soil at the bottom of the furrows fluctuates less and therefore fails to reach so low a minimum in cold weather as when the surface is level. The experiments already described afforded a number of instances in 1914-15 and 1915-16 for observing this effect. Snow covered the ground so much of the time in 1916-17, 1917-18, and 1918-19 when the soil temperature was below freezing that there was no opportunity to make a similar study in those seasons.

The average daily minimum temperatures for those days with a soil temperature of 0°C. or below, during which there was no Snow on the ground are shown in Table II.

TABLE II.—AVERAGE DAILY MINIMUM TEMPERATURES FOR DAYS WITH A SOIL TEMPERATURE OF 0°C. OR BELOW AND WITH NO SNOW

Location of thermometers	Temperature, degrees C.	
	1914-15	1915-16
Surface	-0.8	-0.96
Two-inch furrows	-0.4	- .49
Four-inch furrows	-0.52	- .31
Six-inch furrows	-0.06	- .19

It will be seen that the differences, though slight, coincide in general with those previously noted in showing lower minimum temperatures for the surface thermometers and higher minimum temperature as the depth of furrow increased.

PROTECTION PROM SOIL BLOWING

It is well known that cultivating the ground in such a manner as to leave it as rough as possible reduces the tendency to blow. Thus Jardine (1913) says "It has been shown that the first principle in dealing with soils which are inclined to blow is to keep the surface rough and corrugated. A rough surface checks the movement of soil particles; the smaller ones lodge in the crevices leaving the heavier clodded portions elevated and protective." Seeding with a hoe drill has been recommended frequently for soils which blow because of the condition in which such a drill leaves the soil. Thus Murray (1921) in discussing the soil blowing problem of western Canada says: "For seeding summer fallow we have been using hoe drills and find that they leave the ground rougher and less liable to blow than when other types of drills are used."

In view of these facts, it seemed reasonable to expect that seeding in furrows would reduce the danger of blowing, as compared with ordinary methods of seeding, considering the much rougher condition in which the ground is left. This expectation has been realized to a considerable degree, although it has been difficult to verify it by experimental data. One reason for this is that blowing is a phenomenon best studied in fields of considerable area. The momentum gained by the soil particles is apparently a factor of considerable importance which obviously cannot find full expression on a small plot, and any treatment which causes one plot to blow is likely to cause injury to adjoining plots which do not blow. On the other hand, the experimental difficulties encountered in comparing large fields in regard to differences in topography, time of preparation, time of seeding, etc., are obvious. In spite of these difficulties a few observations apparently of some significance have been made.

Among some other seedings at the Colby Branch Experiment Station in the fall of 1918 were some plots sown east and west on November 20 (about two months later than the optimum date) with the furrow drill and others for comparison with a single-disk drill. There were four plots in each set Sown at four different rates; viz., 1, 2, 3, and 4 pecks per acre. The average yields were 20.8 bushels per acre for the plots sown in the usual way and 30.2 bushels for those sown with the furrow drill. (Table XXIX.) This difference in yield was attributed to soil blowing by Mr. John J. Bayles, formerly Superintendent of the Colby station and in charge of the experiments at that time.

In the fall of 1916 a 20-acre field of wheat at the Fort Hays station was divided into equal parts, one-half being sown with the common disk drill and one-half with the furrow drill. The north half of the field which was sown with the common drill was practically destroyed by soil blowing, while the remainder had a fair stand. The season, however, was very dry and the soil in poor condition, being part of another experiment in which this field had been cropped to wheat continuously for a number of years. As a result, the yields were very low, being but 3.3 bushels per acre for the portion sown with the furrow drill and 1.8 bushels for that sown with the common drill.

In the season of 1918 it was thought that less blowing occured on those portions of several commercial fields which had been sown in furrows as compared with those portions sown in the ordinary manner. There was no serious injury from blowing in that season. In the season of 1919, however, when there was serious damage from blowing, and in 1920 when about 200 acres were abandoned because of damage from soil blowing, and again in 1921, when considerable damage occurred, no marked difference could be seen depending on the method of seeding. In each season a considerable portion of several of the badly injured fields had been sown with the furrow drill.

In discussing experiments with the furrow method of seeding at the Fort Hays station in 1920 Swanson (1920) states that "In the general fields the furrow drill did not show any outstanding advantage over the common drill in the prevention of soil blowing after the small furrows were once leveled down, but it is believed that a field that has been furrow drilled will not blow so quickly."

A number of winter wheat varieties were sown with a double-disk Monitor drill and also with the furrow drill in tenth-acre plots extending north and south at the Tribune station in the fall of 1919. A good stand was secured. Early in March the plants were badly damaged by a heavy wind which drifted the soil and exposed the plant roots, followed by a period of cold weather when the temperature dropped to -18° F. The percent of survival as determined on March 20 by counting the number of living and the number of dead plants in several parts of each plot is shown in Table III.

TABLE III.—PERCENT OF SURVIVAL OF WHEAT VARIETIES SOWN WITH A FURROW DRILL AND WITH A COMMON DISK DRILL AT THE TRIBUNE STATION, 1920

Variety	Sown with furrow drill	Sown with common drill	Difference in Favor of furrow drill
Kanred	71.4	37.1	34.3
Improved Turkey	61.6	20.6	31.0
Turkey	81.1	9.7	71.4
Kharkof	68.2	10.5	57.7
Blackhull	66.2	2.3	63.9

The survival, it will be seen, is decidely in favor of the furrow method for all varieties. The unfavorable March weather combined with a later drouth entirely killed the surviving plants so that no yields were recorded.

Experiments in Montana (Osenbrug, 1922) previously mentioned indicate that furrow drilling is a "promising means of retarding soil drifting and winterkilling."

In connection with blowing the testimony of a Montana farmer, Mr. A. L. George of Kolin, Mont., regarding the effect of seeding in furrows in a very trying season may be of some value. Mr. George secured a furrow drill in the fall of 1920 which he used for seeding part of his land. In a letter to the writer dated April 7, 1921, he says, "As to the success of this method, will say it has been almost perfect so far as blowing under the most trying test we have ever had. Some of the furrows are almost level but never a bit of dust was seen to rise from the ground when the fields adjoining looked like a vast storm approaching for hours at a time."

Murray (1921) has pointed out that an effective preventive of blowing on the blow soils of Canada is to plant winter rye early. A practical difficulty, however, is the dry falls which interfere with germination and growth and the danger of winterkilling in northern latitudes. It seems that seeding in furrows may assist in reducing the injury from blowing by making it possible to grow winter wheat and rye in areas where they are now not generally successful.

It would seem from the foregoing that there are some conditions when seeding in furrows may be expected to reduce the danger of soil blowing to a very considerable extent. It must be admitted on the other hand that there are conditions when this method alone will not prove effective. In some seasons and on some soils the surface layer may become so finely pulverized that in high winds extreme ridging as with a corn lister is effective only if repeated as rapidly as the furrows fill up. It appears that under such conditions and with continued high winds seeding in furrows alone cannot be expected to prevent injury.

RESISTANCE TO DROUTH

The supposed greater drouth resistance of wheat sown in furrows is frequently mentioned. as a point in its favor. Shelton (1889) called attention to this in his first paper on the subject. "If," said he, "corn planted at the bottom of a deep furrow germinates more surely and better withstands the effect of drouth, thus making sure a larger yield, why may not as much be expected of wheat when treated in a like manner?" Georgeson et al. (1893) also mentioned the superiority of the furrow method in surviving the dry spring of 1893, but the difference seems to have been due more to a better start in the fall than to actual ability to withstand drouth.

The results of one or two experiments appear to show that drouth resistance is a factor but there are others which make it appear that seeding in furrows will not always or even usually enable the grain to withstand drouth better than methods commonly employed.

The most favorable and clear cut effect of this method in relation to drouth was observed at the Colby station in 1919. The conditions for germination and fall growth of the wheat were unusually favorable, a 3-inch rain having fallen just before seeding. Winter came on late, permitting an unusually heavy growth in the fall and the winter was so mild that even volunteer spring wheat and oats survived in that section. The grain was covered with about a foot of snow from the middle of December until spring. Conditions continued unusually favorable until harvest except for a protracted drouth in May. This drouth greatly injured the plots of wheat sown with the common drill as shown by the stunted plants and short heads in all but the border rows of the plots, i. e., the rows adjoining the alleys. On the other hand, the wheat sown in the furrows appeared to be injured scarcely at all. Measurements at harvest time showed a difference in height of plants of from 8 to 10 inches in favor of those in the furrow plots. The average difference in yield for all plots was 7.6 bushels in favor of the furrow method. (Table XVII.) In the preceding year at Colby there was a gain for seeding in furrows of 3.2 bushels when sown on fallow and 4.4 bushels when the wheat was sown on corn ground. Moisture appeared to be the limiting factor in production and there were no indications that the grain had been injured by low temperatures or soil blowing and no marked differences in stand were observed. In the same year there was no significant difference in yield of wheat sown on kafir ground even though it appeared that the grain suffered from drouth to a greater degree than in the cases just mentioned.

In practically every season at Hays since reliable experiments have been conducted, drouth has been a factor in the yields of wheat, yet no large differences in yield have been secured except in those seasons and with those grains severely injured by winterkilling. Also in some of the driest seasons at Manhattan in which the effects of drouth have been very apparent no advantage for the furrow method has been observed either in appearance and growth of the plants or in yield.

The results of a simple experiment conducted in the cereal crop nursery at Manhattan in 1921 apparently throw some light on this question. This experiment consisted of growing wheat in furrows spaced different distances apart varying from 4 to 16 inches by 2-inch intervals. This was ,repeated a number of times with different rates of seeding and the entire series then repeated but with the surface leveled after seeding. The object of the experiment was to determine the optimum spacing of wheat in furrows, the effect of this spacing on rate of seeding and the effect of spacing on yield aside from the effect of seeding in furrows.

Good stands were secured in the fall of 1920 and the winter was one of the mildest on record. There was no evidence of any winterkilling whatever. In the very early spring there were no apparent differences in the appearance of the plants in the furrows and those sown with the surface level. Somewhat later there was a very marked difference as to tillering, color, and rapidity of growth of the plants. Examination showed that where the ground had been leveled after seeding the soil was badly cracked exposing the roots of many plants. (Fig. 12.) Some of these susequently died. On the other hand, where the ground was ridged with the grain in the furrows between, similar cracks had appeared on the ridges or spaces between the rows but practically not at all in such a way as to expose the plants. (Fig. 13.) The grain in furrows produced an average yield of 35 bushels per acre as compared with 23.2 busels for that sown with the surface leveled. Of 49 comparisons all but 4 were in favor of the grain in the furrows. The results in detail are presented later.

Fig. 12.—Wheat sown with the surface of the ground level showing exposure and injury to the plants as a result of the ground's cracking.

The cracked condition of the ground was due to dry weather and was similar to that frequently observed when a heavy snow melting in the spring saturates the ground and is then followed by dry windy weather.

Assuming equal germination, both as to percent and time of emergence, and no disturbing factors in the winter or spring such as have been described, there seems to be no substantial reasons for expecting grain in furrows to survive drought better than when sown in the usual way. To do so, it would appear that the roots must go deeper or the plant must use water more economically. It is possible that there is a saving of

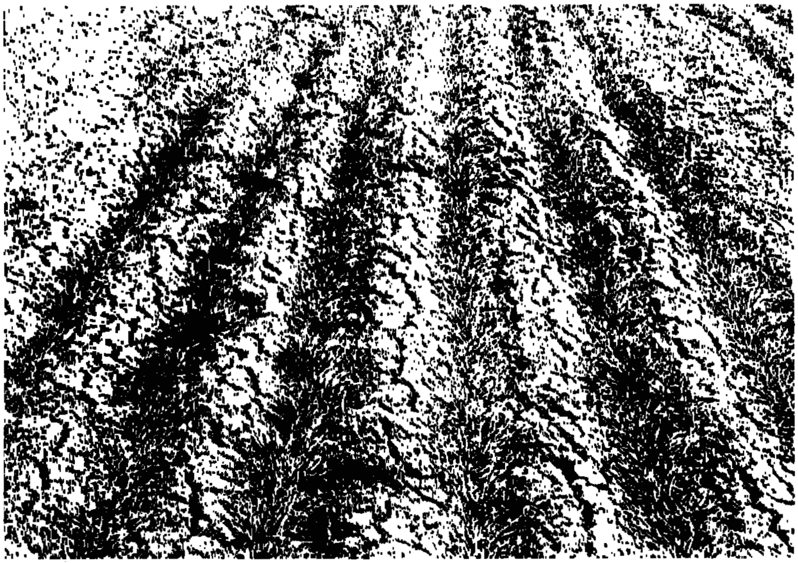


Fig. 13.—Wheat sown in furrows showing condition of the ground in the spring. Note the cracks in the soil between the rows and the absence of such cracks in the rows of wheat as compared with figure 12.

moisture in the early season to be used in later stages of growth as suggested by Cunningham (1914) for corn in wide-spaced rows and this perhaps is the explanation of the higher yields of the furrow plots at Colby in 1919.

RELATIVE YIELDS

The relative yield of grain sown in furrows as compared with the usual method is the final result of all the factors discussed in the preceding pages together with any other effects of the wider spacing of the rows or of placing the plants deeper in the ground. Yield records are available from experiments at Manhattan, Hays, Colby, and Tribune.

YIELDS AT MANHATTAN

In the first experiments in Kansas of which a record of yield is available the wheat in furrows was drilled with an improvised drill made by attaching three small shovels to the frame of a Buckeye one-horse drill. The rows were spaced 14 inches apart. This machine apparently was used until the fall of 1895 when a drill known as the Hollinger lister drill was secured. This resembled a hoe drill except the shovels were larger, made deeper furrows, and spaced the rows 11 inches apart.

In these early experiments the rate of seeding was 3 or 4 pecks per acre for the furrow method and 4 or 5 for the ordinary method except in 1896 when the rates were 5 and 6 pecks per acre, respectively.

Each method of seeding was repeated four times making five plots of each except in 1890 when there was but one of each. The average yields of grain and straw are given in Table IV.

TABLE IV.—YIELD OF WHEAT SOWN IN FURROWS
(Manhattan, 1890 to 1896)

Year	Yield of grain, bushels per acre		Yield of straw, tons per acre	
	Furrow method	Ordinary method	Furrow method	Ordinary method
1890	35.3	29.8	1.69	1.67
1891	29.4	31.9	1.54	2.03
1892	27.0	27.6	1.24	1.33
1893	19.6	11.6	.88	.77
1896	31.9	35.6	1.68	2.33

The low yields of the furrow plots in 1891 were attributed to too much water. The wheat in furrows was "actually water-logged at times for short periods," and "while the surface-planted wheat had no lack of moisture the listed wheat had too much." (Georgeson et al., 1891.) It may also be suggested in view of later experiments that the difference in the rate of seeding may have had something to do with the results, especially in view of the lower yields of straw from the wheat in furrows.

The season of 1892 was considered a favorable one for wheat. "On March 3 it was noted that the listed plots showed a full stand; the plants were green and vigorous and looked better than the wheat on any other plots." The yields, however, fail to show any advantage for the furrow method in this season. The fact that the lowest yields were secured on those plots which produced the least straw suggests again the possible effect of the difference in the rate of seeding.

The results secured in 1893 are particularly significant in view of the winterkilling that occurred and the effect on survival of the different methods of seeding. The furrow method not only produced the best average yields, but in every case the yields were materially higher than those secured from seeding with a shoe drill. It is only fair to say that another method included in this experiment, viz, seeding with a hoe drill gave somewhat better average yields (14.8 bushels) than were secured from the shoe drill (11.6 bushels). However, since the latter gave the best average yields for all years in which they were compared, the principal comparison here should be with the shoe drill. The differences in yield were attributed to better germination and stand and better winter survival.

The season of 1896 was considered a satisfactory one for wheat but heavy rains in the fall "washed several of the plots, the growth became irregular and the results are therefore not satisfactory." The yields are given however for what they may be worth.

No further experiments were conducted at Manhattan until the fall of 1913 when experiments were again inaugurated by W. M. Jardine, then director of the Agricultural Experiment Station. For these experiments a so-called lister drill which opened the furrows with miniature listers was secured. This drill proved unsatisfactory largely because the shovels were placed in two alignments and those in the rear partly or completely filled the furrows made by the forward shovels. This covered the grain so deeply that germination was poor and uneven and that which did germinate was often without the protection which seeding in furrows was supposed to provide.

The experiments were continued in 1915 with the same drill but thereafter with a disc furrow drill to be described later which made better furrows and spaced the rows 14 inches apart.

Different rates, dates, and directions of seeding were compared but since these subjects are discussed later average results only from comparable plots are presented in the tables (Tables V and VI) which follow. Unlike the earlier experiments the same rate of seeding was used for both methods. In 1914 and 1915 winter oats and winter barley as well as winter wheat were included in the experiments. For convenience the data secured in 1914, 1915 and 1917 are presented in Table V and for 1918, 1919, 1920, 1921 and 1922 in Table VI. Because of the very unsatisfactory work of the furrow drill the plots sown in the fall of 1915 were plowed up and no data were secured in 1916.

TABLE V.—RELATION OF SEEDING IN FURROWS TO WINTER SURVIVAL, LODGING, AND YIELDS OF GRAIN AND STRAW

(Manhattan, 1914 to 1917)

Year and crop	Winter survival percent		Lodging percent		Yield of grain bushels per acre		Yield of straw tons per acre	
	Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method
1914								
Winter wheat	96.0	95.3	0.0	0.0	37.8	37.9	2.57	3.09
Winter barley	96.0	92.5	0.0	0.0	35.0	38.1	2.00	1.90
Winter oats	86.5	7.5	0.0	0.0	26.0	12.3	1.24	1.43
1915								
Winter wheat	100.0	100.0	19.3	30.0	17.4	18.7	1.93	1.77
Winter barley	84.0	50.0	0.0	0.0	10.3	9.2	.79	1.26
Winter oats	45.0	33.3	0.0	0.0	19.7	18.3	1.31	1.65
1917								
Winter wheat	89.6	72.0	0.0	0.0	22.7	20.7	1.10	1.03

The rainfall in 1915 and in 1919 was unusually heavy, ample though not excessive in 1921 and 1922, and deficient in amount in 1917, 1918, and 1920. The winters were unusually mild except for the season of 1918. Unfortunately so far as the work here reported is concerned, there was very little winterkilling on any of the plots included in this experiment even in 1918. Ex-

TABE VI.—RELATION OF SEEDING WINTER WHEAT IN FURROWS TO STAND, WINTER SURVIVAL, YIELDS OF GRAIN AND STRAW, AND TEST WEIGHT

(Manhattan, 1918 to 1922)

Year	Culms per acre at harvest (000 omitted)		Winter survival, percent		Yield of grain, bushels per acre		Yield of straw, tons per acre		Test weight, pounds	
	Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method
1918	1634	1382	99.7	99.9	20.0	21.1	.94	1.02	61.0	60.5
1919	2594	3174	100.0	100.0	20.4	23.4	2.75	2.94	51.7	52.2
1920	2177	2016	100.0	100.0	32.4	33.3	1.91	1.97	58.7	59.2
1921	2145	2549	100.0	100.0	31.3	35.9	1.29	1.52	58.0	58.6
1922	2086	2478	100.0	100.0	34.7	35.7	1.76	1.80	58.0	58.1

cept for winter barley and winter oats therefore these later experiments at Manhattan give very little information on the relation of seeding in furrows to winter survival.

As previously mentioned the experiment was not entirely satisfactory in 1914 and 1915 because of the poor work of the drill. The yields were somewhat erratic for that reason and little dependence can be placed in the differences observed. Results in 1917 and later years are considered as reliable as usually can be expected from field plots. The yield data show no particular difference in favor of either method except in the few cases where winter injury occurred. In such cases the results were distinctly in favor of the furrow method. In other cases the differences were usually slightly in favor of the ordinary method of seeding.

The data on number of culms per acre at harvest time indicate a better stand for the ordinary method in 1919, 1921, and 1922 and better for the furrow method in 1918 and 1920.

The number of plants per acre soon after seeding was determined for the 1920 and 1921 crop. The figures, which are

ABLE VII.—SUMMARY OF YIELDS SECURED FROM SEEDING IN FURROWS

(Manhattan, 1920 to 1921)

Method of seeding	Yield, bushels per acre										
	1890	1891	1892	1893	1917	1918	1919	1920	1921	1922	Average
Furrow method	36.3	29.4	27.0	19.6	22.7	20.0	20.4	32.4	31.3	34.7	27.3
Ordinary method	29.8	31.9	27.6	11.6	20.7	21.1	23.4	33.3	35.9	35.7	27.1

not shown in the table, were 1,082,000 and 1,086,000 per acre for the furrow method and the ordinary method, respectively, in 1920, and 1,065,000 and 971,000, respectively, in 1921.

The yield of straw was slightly in favor of the ordinary method in all cases except for wheat in 1916 and in 1917. A slight difference in the average test weight was also recorded for the ordinary method in every year except in 1918.

The average yields for all seasons for which dependable data are available are presented in Table VII.

It will be seen that the average yield is practically the same for each method, being 27.3 bushels for the furrow method and 27.1 bushels for the ordinary method. There was only one season (1921) when the furrow method produced markedly less grain than the ordinary method, two seasons (1890 and 1893) when the furrow method produced much the better yield, and seven seasons when the differences were small. In only three seasons (1890, 1893, and 1918) was there material damage from winterkilling. In two seasons (1891 and 1919) the rainfall was without doubt too great for the most satisfactory results with wheat, especially when sown in furrows. Drouth appeared to be a major factor in three seasons, viz., 1893, 1917, and 1920.

It appears that the desirability of seeding in furrows at Manhattan will depend largely if not entirely upon the damage that may ordinarily be expected from winterkilling. While more winter injury can ordinarily be expected than occurred during the course of these experiments, it seems rather doubtful if the method will ever prove of sufficient value to justify its use in this area. The results, however, do support the conclusion that marked protection will be afforded for those areas where winterkilling is of common occurrence.

YIELDS AT HAYS

The first experiments with seeding in furrows at the Fort Hays Branch Experiment Station were begun in the fall of 1913. (Kiene, 1914.) Furrows were thrown out with a nursery plow and planted with a nursery drill, the plots being 6 feet wide and 8 rods long. Winter oats, winter emmer, and winter barley were included in this test. The furrows were spaced 12 inches apart. The results are given in Table VIII.

TABLE VIII.—RESULTS FROM SEEDING WINTER GRAIN IN FURROWS AT THE FORT HAYS STATION, 1914

Kind of grain and method of seeding	Stand	Survival	Yield per acre	
			Grain, bus.	Straw, lbs.
Winter oats				
Ordinary method	Poor	5	6.2	1,006
Furrow method	Good	50	21.9	2,236
Winter emmer				
Ordinary method	Fair	57	11.7	2,771
Furrow method	Good	90	19.0	3,124
Winter barley				
Ordinary method	Poor	50	21.1	1,392
Furrow method	Good	92.1	32.6	2,353

It will be seen that much better yields were secured from the grain sown in furrows, the difference apparently being due mostly to a better stand secured in the fall and to better winter survival. Germination and emergence required two days less time for the furrow plots than for the others.

Similar experiments were continued in 1915 and 1916. In 1915 so much lodging occurred that none of the plots were harvested for yield. Marked differences in germination and stand and in winter survival were secured. The Forkney light draft harrow was used for making the furrows in 1916 and an ordinary 8-inch drill with every other disk removed was used for seeding the grain, thus spacing the rows 16 inches apart. The rate of seeding was approximately one bushel per acre for the ordinary method of seeding ond one-half bushel for the furrow method. The results are given in Table IX.

TABLE IX.—RESULTS FROM SEEDING WINTER WHEAT AND BARLEY IN FURROWS AT THE FORT HAYS STATION, 1916

Kind of grain, preparation of ground and method of seeding	Percent survival	Spring vigor	Yield per acre		
			Grain, bus.	Straw, lbs.	Test wt.
Wheat on fallow					
Furrow method	100	Excellent	23.6	2,628	62.5
Ordinary method	100	Good	33.4	2,858	62.5
Wheat on continuously cropped land					
Furrow method	100	Excellent	27.1	2,790	62.5
Ordinary method	100	Good	29.8	3,520	62.5
Winter barley on fallow					
Furrow method	89	Good	20.7	1,981	48
Ordinary metnod	53	Poor	13.8	1,737	46
Winter barley on continuously cropped land					
Furrow method	94	Good	25.5	2,240	49
Ordinary method	68	Poor	22.1	2,080	48

It will be seen that there was no winterkilling except in the case of barley and that the differences both in yield and winter survival in this crop were in favor of the furrow method. The yields of wheat were somewhat in favor of the ordinary method. This seems clearly to have been due to the lower rate of seeding in the case of the furrow plots. Concerning the wheat sown in furrows Kiene (1916) who had charge of the experiment stated that at harvest time "it was evident the ground was not fully occupied."

The disc furrow drill later described in this paper was secured for seeding in the fall of 1916. Only wheat was included, but the experiment was enlarged to compare two directions of seeeding. Table X gives the results for this season.

TABLE X.—RESULTS FROM SEEDING WHEAT IN FURROWS AT THE FORT HAYS STATION, 1917

Method and direction of seeding	Date up	Winter survival	Percent stand May 1, estimated	Yield per acre	
				Grain, bu.	Straw, lb.
Ordinary method East and west	Oct. 17	93	80	16.6	2,149
Furrow method East and west	Oct. 15	98	65	13.9	1,803
Ordinary method North and south	Oct. 17	95	80	17.3	1,941
Furrow Method North and south	Oct. 15	98	65	14.5	1,900
Average					
Ordinary method	Oct. 17	94	80	17.0	2,045
Furrow method	Oct. 15	98	65	14.2	1,852

The grain in furrows emerged two days before the other and the winter survival was somewhat better although the amount of winterkilling was not enough in any case to influence the yields materially. The stand and yields, however, were better for the ordinary method. The records fail to disclose the reason for this difference. It seems probable that inaccuracy in the rate of seeding of the two drills—in view of the quicker germination of the furrow plots—may have been responsible for the differences in stand and also in yield. It seems probable also that there was a difference in the width of the plots, a 6-foot drill having been used for the ordinary method and a 10-foot drill for the furrow method. This might easily have greatly influenced the yields as discussed in connection with the experiments for the season of 1919. It seems therefore that these yields should not be considered seriously in arriving at conclusions relating to the effect of seeding in furrows at the Fort Hays station.

In 1918 the furrow drill was used for seeding approximately one-third of each of eight commercial fields totaling about 600 acres. Yields were determined by harvesting from

TABLE XI.—YIELD OF WHEAT SOWN WITH THE FURROW DRILL IN EIGHT COMMERCIAL FIELDS AT THE FORT HAYS STATION 1918.

Field	Yield of grain bushels per acre		Yield of straw tons per acre		Test weight	
	Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method
10-1-W	12.1	10.8	1.62	1.77	....	....
10-1-E	14.8	15.1	2.00	2.09	....	....
16-1	10.7	10.1	1.34	1.44	50.4	48.0
9-2	11.1	10.1	1.82	1.76	....	....
9-3-S	8.6	6.2	1.65	1.35	50.3	51.0
17-1-B	12.7	11.3	1.76	1.69	50.0	49.5
15-2-A	21.9	12.8	....	....	55.4	51.4
8-4	13.9	12.1	....	....	48.2	49.5
Average	13.2	11.1	1.69	1.68	50.9	49.9

each portion of each field near the dividing line ten one-thousandth acre plots. In two fields (known as 15-2 and 8-4) the yield was determined by harvesting all of each portion separately. These fields were very level but rather spotted and it appeared that the yield of the entire field would be a more reliable index of the relative value of the two methods than would be secured by harvesting the small plots. The results are given in Table XI.

The furrow drill was also used in some plot experiments to compare the two methods. The plots were one-fifth of an acre in size for the ordinary method and two-fifths of an acre for the furrow method, being twice as wide. The results are presented in Table XII.

TABLE XII.—RESULTS FROM SEEDING WHEAT IN FURROWS AT THE FORT HAYS STATION, 1918

Method and direction of seeding	Yield per acre	
	Grain, bus.	Straw, lbs.
Ordinary method, east and west	12.1	3,115
Furrow method, east and west	12.1	3,033
Ordinary method, north and south	9.9	3,880
Furrow method, north and south	13.8	3,085
Average		
Ordinary method	11.0	3,498
Furrow method	13.0	3,059

There was no injury from winterkilling or soil blowing. Low yields were due, in the main, to insufficient moisture in the spring. The yields, it will be noted, are equal for the east and west seeding but the furrow plots produced 3.9 bushels more than the ordinary method for the north and south seeding, making an average difference of approximately 2 bushels per acre in favor of the furrow method.

Assuming an alley effect, the yields of the common-drill plots are too high as compared with the furrow-drill plots since they are narrower and the effect of the alleys on yield would be greater. As in the preceding season the yields of straw were better for the ordinary method possibly indicating a better stand in the fall for that method, due apparently either to differences in rate of seeding or to germination.

In the fall of 1918 the furrow method was compared with two plots sown by the ordinary method, one with the rows spaced 8 inches apart and one 7 inches apart. Two adjoining portions of a commercial field, one having been drilled in furrows and the other in the usual way, were also harvested for a yield test. The data are shown in Table XIII.

TABLE XIII.—YIELDS OF WHEAT SOWN IN FURROWS AND IN THE USUAL WAY AT THE FORT HAYS STATION, 1919

Method of seeding	Culms per acre at harvest (000 omitted)	Yield per acre		Test weight
		Grain, bus.	Straw, lbs.	
Commercial Field Test				
Ordinary method	3,272	13.1	2,857	52
Furrow method	2,535	16.7	4,327	52
Plot Test				
Ordinary method, seven-inch spacing	2,915	13.0	5,172	50
Ordinary method, eight-inch spacing	3,404	10.7	4,504	49
Furrow method	2,474	10.2	4,113	49

The furrow method gave the best yield in the commercial fields but the lowest yield in the plots. Considering, however, that it is very unlikely that a difference of one inch in the spacing is responsible for the difference in yields of the plots spaced 7 inches and those spaced 8 inches it seems probable that the lower yield of the furrow drill plot as compared with the ordinary drilled plots with 7 inch spacing is due to experimental error.

It should also be noted that the furrow plots were 10 feet wide, the ordinary drilled plots spaced 7 inches were 5 feet wide, and the ordinary drilled plot spaced 8 inches was 6 feet wide, all with cultivated alleys surrounding them. The border rows were harvested with the plots. As has been shown by Arny (1921) the effect of cultivated alleys differs greatly in plots of different sizes. Considering that the yield of these plots was greatly reduced by drouth it seems probable that the yield of the narrow plots, i. e., the ordinary method of seeding, was much larger than would be the case had the border rows been removed before harvest. This error was no

TABLE XIV.—RESULTS FROM SEEDING WHEAT IN FURROWS AT THE FORT HAYS STATION, 1920 AND 1921

Preparation of ground and method of seeding	Plants per acre (000 omitted	Culms per acre (000 omitted)	Lodging percent	Grain, bus. per acre	Straw, tons per acre	Test weight
1920						
FALLOW						
Furrow method	779	3,760	14	36.9	2.00	58.7
Ordinary method	1097	4,066	22	37.0	2.00	59.1
STUBBLE						
Furrow method	....	....	....	34.9	1.80	....
Ordinary method	....	....	....	33.2	2.06	....
1921						
FALLOW						
Furrow method	630	2,690	....	30.4	2.93	60
Ordinary method	748	3,149	....	32.7	3.04	60
FALL PLOWING						
Furrow method	....	....	....	25.4	2.74	60
Ordinary method	....	....	....	26.1	2.56	60

doubt much less for the furrow plots which were 10 feet wide as compared with the common drilled plots which were 5 and 6 feet wide. Considering these facts and the results secured from the commercial field test it seems that the results may be interpreted at least as not unfavorable for the furrow method. It will also be noted that the number of culms per acre as determined by acutal count was considerably less for the furrow method.

In 1920 a more elaborate experiment to compare the furrow method and the ordinary method of seeding in different directions and for different rates of seeding was begun. The plots were all the same size and were sown on fallow and duplicated on unplowed stubble. A similar test was conducted in 1921 except the plots were on fallow and fall plowing instead of fallow and stubble. The average results from several plots in each of the two sesaons are given in Table XIV.

There was no winterkilling in either season and there was no injury from soil blowing except two plots sown by the ordinary method in 1920. Good stands were secured in both seasons. The yields it will be observed are somewhat in favor of the furrow method. The results however are not entirely consistent nor are the differences large. The stand on the fallow ground was in all cases decidedly less for the furrow method than for the other and the yield of straw was in most cases in favor of the ordinary method indicating either that more seed was planted or that better germination took place.

Summary of Results at Hays

Except for the results secured with winter oats, winter emmer, and winter barley in 1914 and with winter barley in 1915, the yield records at Hays fail to show much advantage for the furrow method. In view of the marked differences secured with the crops just mentioned the failure to secure similar differences with wheat calls for an explanation. This is no doubt due in a large measure to the fact that no injury from winterkilling of wheat occurred in any of the experiments at this station and so far as the plot tests are concerned no differences due to soil blowing were observed. The results then with wheat are in reality a measure of what may be expected from the two methods when no disturbing factors such as winterkilling and soil blowing intervene. The experiments with wheat in 1916 should not be included in any averages so far as yield is concerned on account of differences in the rate of seeding and a clear case of not enough plants to occupy the ground in the furrow plots. Differences in the width of the plots and unexplained differences in stand in 1917, 1918, and 1919, which operated to the disadvantage of the furrow plots, decrease the confidence which may be placed in the results for those years. This leaves only the tests in commercial fields in 1918 and 1919 and the plot experiments conducted in 1920 and 1921 to be considered reliable. The averages for these experiments with wheat are summarized in Table XV.

TABLE XV.—AVERAGE YIELDS OF WHEAT SOWN IN FURROWS AT THE FORT HAYS STATION, 1918 TO 1921

	1918	1919	1920	1921	Average
Furrow method	13.2	16.7	35.9	27.9	23.4
Ordinary method	11.1	13.1	35.1	29.4	22.2

As will be seen, there is an average difference of 1.1 bushels in favor of the furrow method, practically all of which was secured in the tests on commercial fields in 1918 and 1919. Considering the rather large experimental error likely to be present in tests of this kind, this difference can hardly be considered significant. It seems, however, that the results may be safely taken as proof that no loss in yield is likely to be suffered as a result of seeding in furrows in this area. If the wider spacing of the rows has any tendency to lower the yields it is balanced by advantages for the furrow method which are not yet clearly understood. In other words, if there is a tendency to produce lower yields with the wider spacing of the rows on account perhaps of the inability of the roots to fully occupy the soil, this tendency is offset by other factors, such as greater drouth resistance or because of the conservation of moisture until most needed by the plants as is believed to occur occasionally in wide-spaced rows of corn. The experiments, however, cannot be cited as proof of any marked difference in drouth resistance in favor of the furrow method as in each of the four years drouth was a factor at some period during the season.

The results with less hardy cereals, winter barley, winter oats, and winter emmer seem to show beyond doubt that marked differences in winter survival and in yield will be secured in those seasons when winterkilling is an important factor.

YIELDS AT COLBY

Experiments with the furrow drill were first begun at the Colby Branch Experiment Station in Thomas county in the fall of 1917. A portion of three fields, one fallow, one corn ground with the stalks removed, and the third kafir ground with the stalks removed, were sown with the furrow drill, the remainder of each being sown with an ordinary disk drill for comparison. Yields were determined by harvesting an equal area approximating an acre by each method.

Good germination was secured in all cases and no winter injury or damage from soil blowing was observed. The supply of moisture, however, was distinctly limited, the low yields apparently being due to drouth. The yields of grain are shown in Table XVI.

TABLE XVI.—RESULTS FROM SEEDING WHEAT IN FURROWS AT THE COLBY STATION, 1918

Kind of ground	Yield, bushels per acre		Difference in favor of furrow method
	Furrow method	Ordinary method	
Fallow	15.4	12.2	3.2
Corn ground	13.7	9.3	4.4
Kafir ground	5.0	5.2	—0.2

The experiments were enlarged in the fall of 1918 to include different dates and directions of seeding. The earliest seeding was on September 19, which is about the normal date for the Colby area and the later seeding was on November 20. The plots were about one-fiftieth acre in size and were located on fallow. The results for the early seeding are given in Table XVII.

TABLE XVII.—RESULTS FROM SEEDING WHEAT IN FURROWS AT THE COLBY STATION, 1919
(Sown September 19)

Rate of seeding, pks. per acre	Direction of seeding	Yield of grain, bushels per acre		Test weight	
		Furrow method	Ordinary method	Furrow method	Ordinary method
1	East and west	23.1	19.1	56.0	57.0
2	East and west	23.1	15.1	58.0	55.0
3	East and west	19.3	16.3	58.0	56.0
4	East and west	22.6	17.9	57.0	57.0
Av.		22.0	17.1	57.3	56.3
1	North and south	32.6	44.6	57.0	....
2	North and south	40.4	30.8	57.0	....
3	North and south	54.2	31.6	58.0	....
4	North and south	51.4	30.9	57.0	....
Av.		44.7	34.5	57.3	....

As is seen, the furrow plots produced much the better yield in the early seeding test, the average difference being 4.9 bushels for the plots sown east and west and 10.2 bushels for the plots sown north and south or an average difference considering all plots of 7.6 bushels. The results are also consistent, the furrow plots in all cases but one producing the larger yields, this exception apparently being due to a very thin stand in the furrow plot.

The appearance of the plots at harvest time, as well as the yield record, leaves no room for doubting the superiority of the furrow method for the conditions of the test. The plants in the furrow plots measured **7.5** inches higher at harvest time, had tillered more, were more vigorous, and in every other way were much superior to those in the plots drilled in the usual way.

This unusual difference is difficult to explain. Conditions for seeding the previous fall had been unusually favorable and the wheat on all plots had an excellent stand and made a very heavy growth before winter. The winter was very mild and no winterkilling occurred so far as known. There were some heavy winds in the spring but the heavy foliage on these plots prevented any soil movement. There was a shortage of moisture early in the spring which apparently injured the ordinary drilled plots to a much greater extent than the others as indicated by their appearance at harvest time. Just why this should have occurred, however, is not entirely clear considering the lack of such differences in other tests as already mentioned.

Whether the superior yield of the furrow plots was due to superior ability to survive the severe spring drouth, to perhaps a better condition of the soil as discussed heretofore in connection with certain row tests at Manhattan, or to some unknown factor cannot be stated at this time. That the differences were actual differences, however, and related to or were caused by the method of seeding scarcely can be doubted.

In the plots sown November 20, the yields for the east and west seeding were very much in favor of the furrow plots, the difference being 9.4 bushels per acre as may be seen in Table XVIII.

TABLE XVIII.—RESULTS FROM SEEDING WHEAT IN FURROWS AT THE COLBY STATION
(Sown November 20)

Rate of seeding pks. per acre	Direction of seeding	Yield of grain, bus. per acre		Test weight	
		Sown in furrow	Sown with single disk drill	Sown in furrows	Sown with single Disk drill
1	East and west	28.5	22.5	45.0	46.0
2	East and west	30.7	20.4	46.0	46.0
3	East and west	30.1	19.8	46.0	46.0
4	East and west	30.1	20.4	46.0	46.0
Average		29.9	20.8	45.8	46.0
1	North and south	16.3	21.9	....	....
2	North and south	19.2	20.3	....	....
3	North and south	21.1	19.5	....	....
4	North and south	21.6	21.1	....	....
Average		19.6	20.7		

These plots were injured to a considerable extent by soil blowing which apparently injured the plots sown in the ordinary manner to a much greater extent. This at least is the interpretation of the results by the superintendent of the station in charge of the experiments. The north and south plots were not damaged by soil blowing and in this case the furrow plots produced 1.1 bushels less than the others.

It should be noted that the east and west plots sown at this date were located on a different field than the north and south plots and hence the two sets are not strictly comparable, although the individual plots in each set are comparable with each other.

The experiment was repeated in 1920 and 1921 in much the same way except there was only one date of seeding. Conditions for germination were favorable, and the winters were very mild, no injury from winterkilling being observed in any case. Considerable damage from soil blowing occurred in 1920, the furrow plots apparently being injured about as much as the others. Because of labor shortage and a change in personnel, no yields were recorded in 1920. In 1921 the plots were located on ground which proved to be very uneven although apparently uniform when the grain was sown. The variations were so great and so inconsistent that little or no reliance can be placed in the results. The yields are given in Table XIX, however, for what they may be worth.

TABLE XIX.—RESULTS FROM SEEDING WHEAT IN FURROWS AT THE COLBY STATION, 1921

Rate of seeding, pecks per acre	Direction of seeding	Yield of straw, tons per acre		Yield of grain, bushels per acre	
		Furrow method	Ordinary method	Furrow method	Ordinary method
1	East and west	1.12	1.65	22.7	17.3
2	East and west	97	1.03	32.5	28.6
3	East and west	1.56	1.62	27.4	31.8
4	East and west	1.33	1.89	25.8	37.8
Av.		1.25	1.55	27.1	28.9
1	North and south	1.73	2.78	36.8	48.1
2	North and south	1.53	2.44	48.4	43.1
3	North and south	1.93	1.77	33.1	50.7
4	North and south	1.68	1.99	34.8	48.3
Av.		1.72	2.45	38.3	47.5
Av.	of all plots	1.49	2.00	32.7	38.2

The average of all plots indicates a gain for the ordinary method of seeding of 1.8 bushels per acre for the east and west seeding, 9.2 bushels for the north and south seeding, and 5.5 bushels for all plots. There is no reason, however, to expect such differences in yield with different rates of seeding as for example between the 1 peck and 2 peck rate in the east and west plots, or between the 2 peck and 3 peck rates in the north and south furrow-drill plots. These differences were clearly due to variations in the soil, there being areas including portions of several plots where the grain was dwarfed and very poor and other areas equally independent of method, rate, and direction of seeding, where the appearance of the grain indicated very high yields. There is also indicated a close relation between yields of straw and yields of grain, which would be expected with wide variations in soil.

Summary of Results at Colby.

The three years' results at Colby make it appear reasonably certain that no losses in yields will likely be suffered from the use of the furrow drill in seeding winter wheat. On the other hand, the yields in 1918 and 1919 indicate that marked advantages may be secured in some seasons. No severe injury from winterkilling was observed in any year and since winterkilling is known to occur in this area it seems that the advantages for this method will be at least no less than those recorded in the three seasons for which results are available.

YIELDS AT TRIBUNE

Yields of winter wheat have been secured at the Tribune Branch Experiment Station, located in Greeley county, in two seasons. In 1919 a variety test of wheat was sown with a Monitor double-disk drill and with a furrow drill. No damage from winterkilling or soil blowing was recorded. The grain was damaged by rabbits, however, and matured late, The yields of grain and straw, determined by harvesting and threshing ten one-thousandth acre areas from each plot are recorded in Table XX.

TABLE XX.—YIELDS OF WINTER WHEAT VARIETIES SOWN IN FURROWS AND IN THE USUAL WAY AT THE TRIBUNE STATION, 1919

Variety	Yield of straw, tons per acre		Yield of grain, bus. per acre	
	Furrow method	Ordinary method	Furrow method	Ordinary method
Kanred	1.47	1.43	11.0	12.1
Turkey............	1.32	1.30	11.4	9.2
Kharkof	1.17	1.17	9.0	9.0
Improved Turkey	1.33	1.20	9.1	7.4
Average	1.32	1.27	10.1	9.4

The slight difference in yield in favor of the furrow-drill cannot be considered significant as it is almost certainly well within the experimental error.

Winter rye was also included in this experiment, producing 12.8 bushels of grain when sown in furrows and 13.2 when sown in the usual way.

In 1921 a plot of Kanred wheat sown in furrows was located between two plots sown with a double-disk drill. As reported by Mr. Lowrey, superintendent of the station, both of the common-drill plots suffered from the effects of late spring freezes and wind storms on April 4, 5, and 6, while the wheat in furrows suffered no damage. The detailed results are presented in Table XXI.

TABLE XXI.—RELATION OF WINTER SURVIVAL, SPRING VIGOR, AND YIELD OF KANRED WHEAT TO METHOD OF SEEDING (TRIBUNE, 1920)

	Winter survival	Spring vigor	Yield of straw	Yield of grain bus. per acre
	Percent	Percent	Tons per acre	
Furrow method	100	100	2.10	26.6
Ordinary method	90	75	1.35	19.4

The results show a marked difference in winter survival and spring vigor and 7.2 bushels of grain per acre in favor of the furrow method.

SEEDING SPRING GRAIN IN FURROWS

Few observations or experimental tests are available to indicate the advantages, if any, of seeding spring grain in furrows. That the advantages are likely to be less than for winter grains is evident from the fact that much of the advantage in the latter case is due to the protection during the winter. For spring grains there remains only the possibility of better germination and early growth, protection from late spring freezes, protection from soil blowing, and resistance to drouth.

Some early experiments comparing the two methods of seeding for spring oats were conducted at the Kansas station but the drill failed to work satisfactorily, the results were considered unreliable, and the experiments were discontinued.

In the spring of 1920 some common six-row barley was sown at the Tribune station with a double-disk drill and with the furrow-drill for comparison. The yield for the barley sown in furrows was 2,436 pounds of straw and 42.9 bushels of grain and for the other 2,488 pounds of straw and 43.6 bushels of grain per acre. The test was repeated in 1921 but the nearly ripe crop was entirely destroyed by grasshoppers. According to the superintendent of the station, the barley sown with the furrow-drill "would have yielded 15 bushels, while that sown with the common drill would not have made as much as 3 bushels per acre."

In the spring of 1921 Kanota oats were sown at Manhattan on four different dates beginning March 1 and continuing every 10 days thereafter until March 31. The yields are recorded in Table XXII.

TABLE XXII.—RESULTS OF TESTS IN METHOD AND DATE OF SEEDING OATS
(Manhattan, 1921)

Method of seeding	March 1		March 10		March 19		March 31		Av.
	Yield bus. per acre	Test wt.	Yield bus. per acre	Test wt.	Yield bus. per acre	Test wt.	Yield bus. per acre	Test wt.	
Furrow method	38.5	31	35.8	39	39.9	35.5	18.2	18.5	27.7
Ordinary method.........	41.2	29	35.4	27	32.5	25.0	20.6	18.5	28.9

The seedings of March 1 and 10, especially the latter, were injured somewhat by a sudden freeze on March 26, when the temperature dropped to 15°F. The plots sown with the common drill were injured more than the furrow plots, the damage being estimated at about 15 per cent for the former and 3 percent for the latter. Judging from the appearance of the growing grain, the oats on the furrow plots made a more rapid and vigorous growth than the other up to about the first of May. The yields, however, as may be seen from Table XXII were somewhat in favor of the ordinary method of seeding, except for the second date. The yields in this case were practically the same.

Swanson (1920) sowed common six-row spring barley and spring oats in furrows at the Fort Hays station in 1920. There was some difficulty in regulating the rate of seeding with the furrow drill and better stands were secured with the common drill as a result. The results are given in Table XXIII.

TABLE XXIII.—RESULTS FROM SEEDING SPRING GRAINS IN FURROWS AT THE FORT HAYS STATION, 1920

Crop and direction of seeding	Plants per acre (000 omitted)		Culms per acre at harvest (000 omitted)		Grain bus. per acre		Straw lbs. per acre		Test weight	
	Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method
Barley										
East and west....	548	1,189	1,219	1,437	33.8	36.2	3,872	5,020	38	38
North and south..	535	1,047	1,132	1,210	17.1	23.5	1,888	3,360	38	38
Oats										
North and south..	1,419	1,829	1,701	1,894	45.0	41.0	2,672	2,380	32	32

In the east and west seeding of barley the common drill plots produced 2.4 bushels per acre more than those sown with the furrow drill, and in the north and south plots the difference was 6.4 bushels also in favor of the common drill. The number of plants per unit area as indicated in the first and second columns of the table was only about half as much in the furrow-drill plots as in the others. In the test with oats the stand was more nearly comparable and in this case the furrow drill produced the best yield by 4 bushels per acre. Swanson (1920) observed that the "oats germinated about two days earlier in the furrow drill plots, the seed being placed in moist ground. This was an important factor as the seedbed was somewhat dry on the surface at seeding time."

TABLE XXIV.—THE EFFECT OF SPACING AND RATE OF SEEDING ON THE YIELD OF WHEAT SOWN IN FURROWS AND IN THE USUAL MANNER

(Manhattan, 1919 to 1922)

Rate of seeding pks per acre	Space between rows inches	1919		1920		1921		1922		Average	
		Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method	Furrow method	Ordinary method
1	8	23.0	25.0	17.4	22.1	26.5	10.2	35.8	37.1	25.7	23.6
1	10	33.8	22.1	17.7	18.4	30.2	9.3	36.1	31.1	29.5	20.2
1	12	29.8	34.5	20.9	20.4	31.6	7.5	34.1	34.9	29.1	24.3
1	14	31.3	25.2	18.8	21.0	32.4	12.1	36.9	37.8	29.9	24.0
1	16	22.8	22.3	18.1	16.3	28.5	7.5	32.3	33.9	25.4	20.0
Av.		28.1	25.8	18.6	19.6	29.8	9.3	35.0	35.0	27.9	22.4
2	8	14.8	23.1	26.9	27.5	37.1	22.1	66.6	43.2	28.9	29.0
2	10	20.1	32.3	22.2	26.9	32.0	18.7	34.4	39.5	27.2	29.4
2	12	31.1	25.8	25.4	17.3	31.5	20.7	34.4	44.0	30.6	27.0
2	14	29.8	25.4	28.2	22.3	34.9	19.7	37.3	39.8	32.6	26.8
2	16	28.3	22.7	22.9	21.3	30.7	20.9	36.5	32.0	29.6	24.2
Av.		24.8	25.9	25.1	23.1	33.2	20.4	35.8	39.7	29.8	27.3
3	8	31.8	15.4	25.4	19.1	40.7	22.6	40.3	41.6	34.6	24.7
3	10	27.8	20.0	26.6	26.2	33.3	24.1	42.2	42.1	32.5	28.1
3	12	30.6	19.4	23.0	21.2	40.0	29.4	42.3	44.1	34.0	28.5
3	14	25.4	25.2	20.4	23.3	32.8	26.2	41.1	40.2	29.9	28.7
3	16	25.0	23.9	17.0	14.1	33.4	27.7	38.1	44.8	28.4	27.6
Av.		28.1	20.8	22.5	20.8	36.0	26.0	40.8	42.6	31.9	27.5
4	8	26.2	19.0	18.1	24.5	43.1	22.1	44.9	46.8	33.1	28.1
4	10	20.6	21.3	19.0	37.4	37.9	17.4	42.3	44.8	29.9	30.2
4	12	25.1	25.5	11.7	10.8	14.7	28.9	44.4	43.1	24.0	27.1
4	14	30.3	20.2	15.6	29.1	35.6	26.2	42.6	39.2	31.0	28.7
4	16	27.7	20.3	13.2	21.9	28.8	30.7	42.6	39.2	28.1	28.0
Av.		26.0	21.3	15.5	24.7	32.0	25.1	43.4	42.6	29.2	28.4
6	8	29.3	24.6	36.0	28.6	40.3	23.6	48.1	39.0	38.4	29.0
6	10	26.8	24.3	34.8	20.8	34.4	21.4	42.7	38.1	34.7	26.2
6	12	30.2	22.4	35.2	24.1	33.2	18.6	45.9	38.6	36.1	25.9
6	14	24.9	21.0	35.4	21.9	34.0	27.3	42.3	37.0	34.2	26.8
6	16	28.5	24.7	32.3	22.3	29.8	25.7	39.9	35.9	32.6	27.2
Av.		27.9	23.4	34.7	23.5	34.3	23.3	43.8	37.7	35.2	27.0
8	8	29.9	28.9	24.4	26.3	39.4	28.0	41.1	36.7	33.7	30.0
8	10	43.4	34.8	35.1	31.8	36.0	24.4	46.7	51.5	40.3	35.6
8	12	39.1	32.0	28.6	30.3	36.0	27.0	45.2	43.9	37.2	33.3
8	14	31.2	21.5	27.2	25.2	37.3	29.7	41.0	42.2	34.2	29.7
8	16	27.6	26.8	28.5	22.9	31.9	28.8	35.4	34.5	30.9	28.3
Av.		34.2	28.8	28.8	27.3	36.1	27.6	41.9	41.8	35.3	31.4
12	8	25.8	21.6	25.9	29.3	38.7	29.8	44.9	44.0	33.8	31.2
12	10	17.5	23.3	21.4	20.4	39.0	28.2	39.9	44.3	29.5	29.1
12	12	18.4	31.0	24.9	21.9	37.7	31.6	39.0	40.0	30.0	31.1
12	14	23.9	20.8	27.1	23.9	35.6	32.4	39.5	38.0	31.5	28.8
12	16	19.6	26.6	22.7	18.6	35.3	32.3	37.7	36.9	28.8	28.6
Av.		21.0	24.7	24.4	22.8	37.3	30.9	40.2	40.6	30.7	29.8
Grand Av.	8	25.8	22.5	24.9	25.3	38.0	22.6	41.7	41.2	32.6	27.9
	10	27.1	25.4	25.3	26.0	34.7	20.5	40.6	41.6	31.9	28.4
	12	29.2	27.2	24.2	20.9	32.1	23.4	40.8	41.2	31.6	28.2
	14	28.1	22.8	24.7	23.8	34.7	24.8	40.1	39.2	31.9	27.7
	16	25.6	23.9	22.1	19.6	31.2	24.8	37.5	36.7	29.1	26.3
Av.		27.2	24.4	24.2	23.1	34.1	23.2	40.1	40.0	31.4	27.7

To summarize briefly, it appears that seeding spring oats and barley in furrows has produced as good yields as the ordinary method where comparable stands have been secured. The method may prove advantageous for seeding in dry soil, or in case of damage from soil blowing or from late spring freezes.

DISTANCE BETWEEN ROWS

An experiment to determine the relation between spacing, rate of seeding, and method of seeding was begun at Manhattan in 1919. In this experiment the furrows were made with a hoe and a measured quantity of grain sown by hand in each row. The rows were 16 feet long and four rows constituted a plot, with extra border rows adjoining alleys and plots widely different in spacing or rate of seeding. In the furrow plots the furrows were made as deep as the space between rows would permit. In the surafce plots the ground was leveled after seeding. The grain was ordinarily sown about September 28 to October 1. The yields of grain in bushels per acre secured in 1919, 1920, 1921, and 1922 from each rate and method of seeding for each spacing are given in Table XXIV.

The yields are somewhat erratic due in most cases to damage to the young grain by rabbits and in other cases to the loss of nearly mature grain by birds. Those plots whose appearance indicated they were greatly affected in this way were not harvested. The ground in 1920 proved to be extremely variable which accounts for most of the variations in that season. It is believed, however, that the number of plots included was large enough to balance most of the divergencies due to these causes.

The results seem to show very little tendency toward a falling off in yield with an increase in the distance between rows until this distance reaches about 12 or 14 inches. In 1919 the break seems to come at 14 inches for the furrow plots and at 12 inches for the surface plots. In 1920 both methods produced practically as good yields for 14- as for 12-, 10-, or 8-inch spacing, but there seems to be a marked drop in yield when the distance between rows is increased to 16. In 1921 the furrow plots indicate a falling off in yield when the distance is increased beyond 14 inches but the surface seeding produced the highest yields with 14- and 16-inch spacing. Averages for the three years indicate practically as good yields for 14-inch spacing as for 8-, 10- or 12-inch spacing. It would seem, therefore, that winter wheat is able to fully occupy the soil when in rows as far apart as 12 or 14 inches for the conditions of this experiment. When sown in furrows there is a marked reduction in yield when spaced 16 inches apart.

It will be noted that in each year the average yields were in favor of seeding in furrows. This difference as compared with the results from the field plots may be partly explained by the fact that in the latter experiments the wheat sown by the ordinary method is protected somewhat by the small ridges left by the drill. In the experiments just discussed the plots with which the furrow plots are compared are left perfectly smooth after seeding. Also the damage to the smooth plots in 1921 by the soil cracking as heretofore discussed has not occurred in any of the field experiments. No consistent differences depending upon rate of seeding were secured.

DIRECTION OF SEEDING

The direction of seeding with reference to the direction of prevailing winds has long been recognized as a factor of some importance with ordinary methods of seeding. For example, Mohler (1921) reports that a considerable majority of Kansas farmers prefer seeding east and west. The principal reasons given are that such seeding checks soil blowing, aids in the retention of snow, and reduces injury from alternate thawing and freezing. The probable importance of the direction of seeding in relation to winter survival has been pointed out by Redding (1899) and by Duggar and Cauthen (1913). On the other hand, most of the experiments in Kansas indicate that when grain is sown in furrows north and south it may grow more rapidly in the early spring and if not previously injured by winterkilling or soil blowing may produce larger yields than when sown east and west. Experiments to study this point have been conducted at Manhattan and Hays. Much of the data on direction of seeding have been presented in former tables but for convenience they are assembled in Table XXV.

TABLE XXV.—RELATION OF DIRECTION OF SEEDING TO YIELD AT MANHATTAN AND HAYS

	Furrow method		Ordinary method	
	North and south	East and west	North and south	East and west
Yields at Manhattan				
1915	21.3	16.4	18.9	22.0
1917	25.3	20.1	21.5	19.8
1918	20.9	19.1	21.3	20.9
1919	20.9	19.9	22.6	25.6
1920	34.0	28.6	34.4	30.4
1921	29.6	32.3	33.8	36.9
1922	36.1	28.8	37.1	30.6
Av.	26.9	23.6	27.1	26.6
Yields at Hays				
1917	14.5	13.9	17.3	16.6
1918	13.8	12.1	9.9	12.1
1920	35.7	36.1	35.6	34.5
1921	28.5	27.3	30.9	27.9
Av.	23.1	22.4	23.4	22.8

It is seen that the average yields for each station are in favor of north and south seeding where the furrow method has been used. The differences, however, while fairly consistent are of doubtful significance at Hays and are not large at Manhattan.

It probably should not be concluded that grain should be sown north and south in preference to east and west until more data are accumulated. As has been pointed out repeatedly in this bulletin, there has been less injury from winterkilling and soil blowing in these tests than may reasonably be expected for a similar series of years. It seems altogether probable that the relative yields from seeding in different directions will depend on the balance between at least two opposing factors, one the greater protection during the winter likely to be secured with east and west seeding, and the other the greater amount of sunlight and warmth likely to reach the plants early in the spring with north and south seeding.

RATE OF SEEDING IN FURROWS

In the earliest experiments conducted to compare the furrow method of seeding the rate of seeding for the furrow plots was from 1 to 1.5 pecks per acre less than for the others because of the belief that the optimum rate was somewhat less than when sown in the usual manner.

In several of the experiments conducted at Manhattan, Hays, and Colby different rates of seeding have been compared. The results are brought together and summarized in Tables XXVI, XXVII, and XXVIII.

TABLE XXVI.—RELATION OF RATE TO METHOD OF SEEDING (Manhattan, 1919 to 1922)

Rate of seeding pks. per acre	1917	1918	1919 North and South	1919 East and west	1919 North and south, sown late	1920 North and south	1920 East and west	1921 North and south	1921 East and west	1922 North and south	1922 East and west	Av. of nine trials, 1918 to 1922 (a)	Av. of eight trials, 1919 to 1922 (a)
Furrow Method													
1	......	......	22.3	......	......	18.6	......	......	......	......	......	......	......
2	......	24.9	29.0	34.2	12.9	31.6	25.1	25.5	31.5	35.3	20.9	26.6	26.8
3	......	......	25.8	......	......	32.0	......	......	......	34.5	......	......	......
4	23.1	21.7	28.4	24.3	18.0	32.8	29.5	28.9	33.9	38.3	28.8	27.9	28.6
5	......	......	26.8	......	......	34.2	......	......	......	39.6	......	......	......
6	19.9	22.1	27.6	26.3	18.7	36.3	28.1	34.5	31.8	35.5	33.5	29.2	30.1
7	......	......	21.2	......	......	36.1	......	......	......	34.2	......	......	......
8	20.4	21.0	22.3	25.5	16.5	35.4	31.8	......	......	35.1	35.1	28.3(b)	29.2(b)
9	......	......	19.7	......	......	36.6	......	35.1	......	35.0	......	......	......
10	18.3	......	25.8	27.7	12.2	......	......	......	......	......	......	......	......
Ordinary Method													
1	......	......	26.9	......	......	23.8	......	......	......	......	......	......	......
2	......	......	31.6	26.7	14.1	29.0	26.1	28.9	35.2	33.9	24.9	......	26.9
3	......	......	30.9	......	......	28.7	......	26.9	......	33.7	......	......	......
4	......	......	26.2	29.9	17.4	33.3	31.4	33.2	35.7	39.2	31.5	......	30.3
5	......	......	29.4	......	......	35.0	......	35.2	......	37.6	......	......	......
6	......	......	28.6	30.1	16.7	37.3	31.5	39.3	40.0	38.1	32.0	......	31.7
7	......	......	22.5	......	......	38.3	......	44.2	......	38.6	......	......	......
8	......	......	21.5	33.9	15.2	38.1	32.4	......	......	36.9	34.1	......	31.6(b)
9	......	......	25.5	37.6	......	38.5	......	40.8	......	37.1	......	......	......
10	......	......	......	......	11.1	......	......	......	......	......	......	......	......

TABLE XXVII.—RELATION OF RATE TO METHOD OF SEEDING
(Hays, 1920 and 1921)

Rate of seeding pks per acre	Furrow method					Ordinary method				
	1920 Fallow	1920 Stubble	1921 Fallow	1921 Early plowing	Average	1920 Fallow	1920 Stubble	1921 Fallow	1921 Early Plowing	Average
1	38.6	37.1	30.7	27.8	33.6	39.8	33.0	31.5	26.2	32.6
2	38.7	35.6	31.6	29.0	33.7	40.7	32.4	34.6	28.1	34.0
3	39.1	35.6	31.0	25.9	32.9	34.8	34.4	30.8	26.4	31.6
4	34.8	34.1	30.4	22.6	30.5	36.2	32.7	32.2	22.1	30.8
5	33.5	32.0	28.2	21.6	28.8	33.4	33.4	34.2	28.2	32.3

(a) Does not include east and west seeding for 1921 because of ommission of the 8-peck rate.
(b) Includes 9-peck rate for 1921.

TABLE XVXIII.—RELATION OF RATE TO METHOD OF SEEDING
(Cobly, 1919)

Rate of seeding pks. per acre	Normal date of seeding. East and west	Normal date of seeding. North & south	Late seeding. East and west	Late seeding. North & south	Average
		Furrow Method			
1	23.1	32.6	28.5	22.5	26.7
2	23.1	40.4	30.7	20.4	28.7
3	19.3	54.2	30.1	19.8	30.9
4	22.6	51.4	30.1	20.4	31.1
		Ordinary Method			
1	19.1	44.6	16.3	21.9	25.5
2	15.1	30.8	19.2	20.8	21.4
3	16.3	31.6	21.1	19.5	22.1
4	17.9	30.9	21.6	21.1	22.9

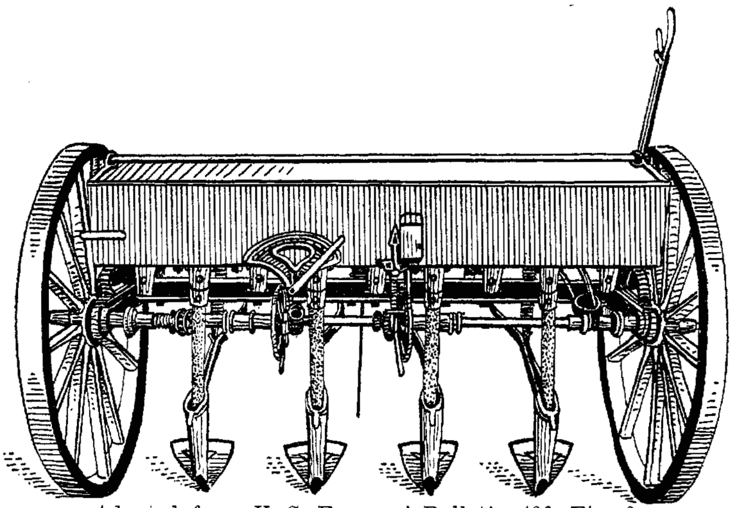
It is difficult to see in these results any marked tendency for the furrow plots to produce a maximum yield with a lower seeding rate than might with equal certainty be secured when sown in the ordinary way. In 1917 and 1918 at Manhattan the highest yields with the furrow method were secured with the lowest rates of seeding, viz., 4 pecks and 2 pecks per acre, respectively. Plots sown at different rates with an ordinary drill were not included in this experiment but in another experiment sown at approximately the same time and on similar soil the highest yields were secured with 8 pecks per acre in 1917 and 6 pecks in 1918. Since 1918 there seems to be in most cases a tendency for the yield to increase with the rate when sown with the furrow drill until a maximum of about 6 pecks is reached, beyond which there is a decrease. Plots sown in the usual manner exhibit about the same tendency but the maximum yields would perhaps be secured at a slightly higher rate than would be the case for the furrow plots.

At Hays there seems to have been a small though on the whole a rather consistent difference in favor of the 1-and 2-peck rates as compared with higher rates of seeding. This, however, is also true to some extent for the ordinary drilled plots, the highest average yield being recorded for the 2-peck rate. If the differences might be considered sufficient to indicate a tendency it would be in favor of a lower rate for the furrow method as compared with the usual method of seeding, At Colby the yields when sown in furrows increased consistently with the rate of seeding. This also was true of the ordinary drilled plots excepting the 1-peck rate which was unusually high. As the results were for one year only and that a rather favorable season which would be expected to favor the higher rates, the results cannot be given much weight so far as solving this problem is concerned.

Taking into consideration the results at all three stations and the nature of the seasons during the test, it may be said that there is some evidence for the belief that lower rates of seeding may be employed with equal chances of a maximum yield when grain is sown in furrows than when sown in the usual way. The results, however, cannot be said to prove this statement.

RELATION OF SEEDING IN FURROWS TO WEEDS

The objection has been made that seeding in furrows will permit a heavier growth of weeds than would be possible with the usual method of seeding in which the rows are closer together. Although weeds have frequently been observed in the experiments in Kansas, no consistent differences in favor of either method have been observed. In some cases there appeared to be more weeds in the furrow plots than in the others.



Adpated from U. S. Farmers' Bulletin 436, Fig. 2

Fig. 14.—Furrow drill used for seeding winter oats in the South.

On the whole it seems that the ridged condition of the ground seeded with the furrow drill would afford an unusual opportunity to destroy any weeds that did appear by harrowing the wheat in the spring.

LODGING

Differences in lodging in favor of one method or the other have been observed in a number of cases. Georgeson (1890) observes that wheat in furrows at Manhattan in 1889 showed a tendency to lodge more than that sown in the usual way. This also has been observed in later tests. On the other hand, Swanson found less lodging in commercial fields of wheat at the Fort Hays Branch Station in 1919 and it was observed that a field of spring barley sown with the furrow drill in the spring of 1919 lodged decidedly less than a portion of the field sown with a single-disk drill. At Hays in 1920 Swanson observed a slightly less endency for winter wheat to lodge (Table XIV) when sown with the furrow drill. It seems probable that on the average no marked differences in lodging may be expected in favor of either method.

DRILLS FOR SEEDING

A number of drills for seeding in furrows have been placed on the market at various times. These have for the most part been patterned after the hoe drill which was used rather extensively before the advent of the disk drill. The furrow opener of the hoe drill consisted of a small shovel and seed boot combined which opened the furrow, at the bottom of which the seed was placed. Most of the furrow or lister drills as they were frequently called differed from the hoe drill only in having somewhat broader shovels and in being spaced farther apart. The principal objections to such drills were their tendency to catch trash and their rather heavy draft in hard ground. In well-prepared ground, free from trash, they did excellent work. Some of the drills used for seeding winter oats in the South are of this type. (Fig. 14.) In the Hays lister drill which was used in western Kansas and Nebraska for.a number of years an attempt was made to overcome the tendency to catch trash by placing the hoes or furrow openers in a zigzag fashion, thus allowing more space for the trash to pass through. This proved only partly successful as there was then a tendency for the rear alignment to fill the furrows made by the front "listers." A sort of "tedder" or "kicker" was also attached to this drill for the purpose of kicking the trash from between the openers.

Another type also said to be used extensively in the South is a modified shoe drill. (Fig. 15.) The furrow openers are comparable to disk furrow openers sometimes used on corn planters in which the furrow is opened by a shoe fitted with concave disks on either side which assist in opening the furrow and throwing out the dirt. Like the hoe or lister type, this drill clogs easily in trashy ground but does excellent work in well-prepared ground. Some difficulty has been experienced in getting drills of this type to seed deep enough when the ground is rather compact.

In a new drill recently designed at the Kansas Agricultural experiment Station, an attempt has been made to avoid these difficulties by using the well-known advantages of the rolling disk in reducing draft and in cutting through trash and compact soil. In this drill each furrow is opened by a disk gang, the

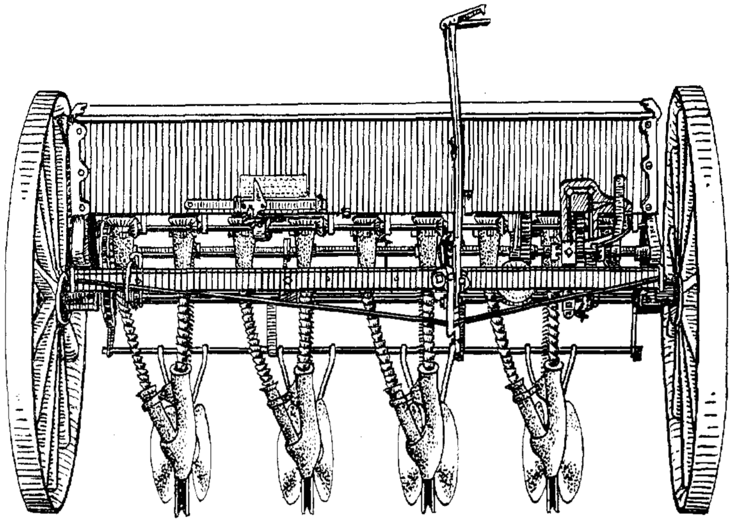


Fig 15.—Combined fertilizer and furrow drill used for seeding winter oats in the South.

disks being placed one directly behind the other and set to throw the earth in opposite directions. (Fig. 16.) The front disk cuts through the trash, if any, and opens a shallow furrow. The rear disk deepens this furrow and .the seed is deposited immediately behind it in the bottom of the furrow with a seed boot of the usual pattern. The grain may be covered by drag chains or press wheels as desired.

Drills of this general type have been used for seeding about 200 acres each year since 1918 at the Fort Hays Station, and almost exclusively since 1918 for seeding at the Colby station. They have been used also by a number of farmers. Some minor mechanical difficulties have been overcome and it is altogether likely that further improvements will be found desirable. Enough has been done, however, to show beyond doubt that the disk principle can be used to advantage especially for seeding in trashy or poorly prepared ground.

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6. The author desires to acknowledge valuable assistance from Prof. W. W. Carlson and Prof. D. E. Lynch of the Engineering Division of the Kansas State Agricultural College in designing and constructing this drill. This drill has been patented and the patent assigned to the people of the United States for public use.

Fig. 16.-Tandem disk furrow attachments on an ordinary grain drill. The rear disk of each gang is set to operate lower than the front disk and deepens the furrow made by the latter, throwing the soil out in the opposite direction. The seed is deposited in the furrow immediately behind the rear disk. The principal advantages observed for this type as compared with other furrow drills are lighter draft and better operation in trashy, weedy, or hard ground.

RELATIVE DRAFT OF FURROW DRILLS

It has been pointed out that one of the principal objections to the earlier types of furrow drills is the greater power required to pull them. The substitution of a disk gang for opening the furrows as in the new drill designed at the Kansas station has overcome this objection to a considerable extent. Observations at the Fort Hays Branch Experiment Station where several hundred acres have been seeded with the furrow drill indicate that in well-prepared ground about 10 percent more land can be covered in a given time with a common disk drill than with a furrow drill of the same size and with the same number and size of horses. The relative draft and acreage that may be seeded will depend of course upon the depth of seeding and the condition of the soil. In order to secure the advantages of the furrow method it is sometimes necessary to seed deeper and to move more soil than is the case with the common drill. If the ground is unplowed this soil may be harder to move and this of course means increased draft. Such observations as have been made indicate that the differences are not sufficient to prevent the use of the furrow method in those areas where larger yields may be expected from its use.

SUMMARY AND CONCLUSIONS

The investigations reported in this Bulletin seem to show beyond a reasonable doubt that considerable losses of winter cereals from winterkilling and soil blowing may be prevented by seeding in furrows somewhat deeper and farther apart than is usually the case. Marked protection from winterkilling especially has been observed. Much protection is afforded by preventing the drifting of snow from the fields, and perhaps by reducing the exposure of the plants to cold, drying winds. Temperature records show a marked difference in minimum winter temperatures in favor of the furrow method, the difference increasing with the depth of the furrows. There is some evidence to show that under certain conditions better and more certain germination will be obtained and there is at least a possibility that grain sown in this manner is able to endure drouth somewhat better. The data are not sufficient to show in what areas the furrow method will or will not prove advantageous. It appears that in the Colby area and northward and westward the dangers of winterkilling, soil blowing, and drouth are sufficient to justify more extended trials of this method on a field scale.

The results at Manhattan would not seem to justify any extended use of the method in this area. Also, the average yields at Hays are perhaps not sufficient to justify the slightly greater expense of seeding, but as winterkilling is believed to occur somewhat more frequently than during the course of the experiments, judgment on this point must be reserved. Since winterkilling is seldom an important factor south of Hays, the use of the furrow method in this territory can be expected to be advantageous only as it protects the grain from soil blowing and drouth and insures better germination. Since no experiments have been conducted in this area and since the importance of these factors cannot be foretold and probably vary with differences in soil and climate, it would not be wise to use this new method extensively at the present time.

It appears probable that seeding in furrows may result in lower yields where winters are mild and rainfall high. Erosion would no doubt be increased on sloping soils where the furrows extend up and down the slope. There is good reason to believe, however, that in subhumid areas where heaving is an important factor the furrow method may have some value.

Experiments so far reported are altogether too meager to permit any conclusions regarding the value of the new method for spring grains.

The relative importance of seeding east and west as compared with seeding north and south will depend, it seems, upon which direction affords the best protection during the winter and perhaps also the relative rate of growth in the spring. Observations at Manhattan indicate a tendency for the grain in north and south furrows to grow more rapidly in the early spring than that sown in east and west furrows.

Experiments so far conducted fail to demonstrate any marked differences in the rate of seeding that should be employed as compared with the usual method. At the Fort Hays station there is a slight indication that a smaller amount of seed may be used with the furrow method than with the usual method of seeding. Data on this point are too meager to permit of final conclusions.

Experiments conducted at Manhattan for four years seem to show that the furrows may be spaced as far apart as 12 or 14 inches without material loss in yield. Since temperature records indicate greater protection with increase in depth of furrows which in turn depends upon the space between furrows, it would seem that the furrows should be no closer together than is necessary to secure the maximum yield when no injury from winterkilling occurs. However, four years' records are not sufficient to determine this point and it will be safest perhaps to space the rows no farther apart than 12 inches until more complete data are secured.

A number of drills for seeding in furrows have been placed on the market at various times. Most of these drills have proved unsatisfactory principally because they do not operate to advantage in trashy ground or because of heavy draft. These difficulties have been reduced, avoided, or overcome with a new type of drill which utilizes disks for opening the furrows. While some minor difficulties in operating this drill have been encountered, they seem to be of such a nature as to be easily corrected.

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