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TILLAGE INVESTIGATIONS RELATING TO WHEAT PRODUCTION

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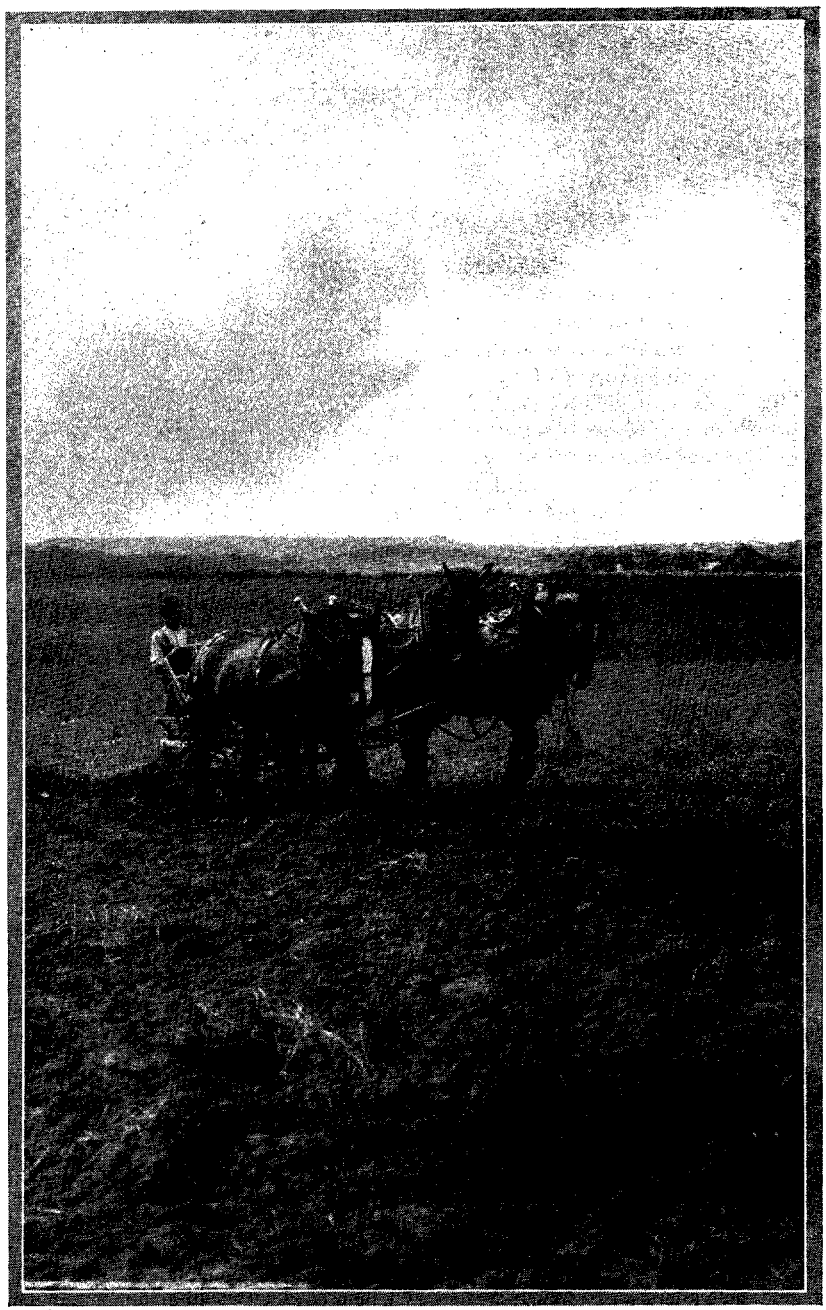

TILLAGE INVESTIGATIONS RELATING TO WHEAT PRODUCTION[1]

M. C. Sewell and L. E. Call

INTRODUCTION[2]

Tillage is the most expensive of the operations involved in crop production. Though one of the oldest agricultural practices, but little is known about how often and how deep the land should be plowed, or the reasons why certain methods give better results than others.

When farm lands were cheap and low prices prevailed the costs of misdirected tillage operations were not so important as in recent years. In the present era of higher prices for all commodities, a better understanding of the reasons for tillage and its effect on crop yield is especially desirable. In many instances, modification of present practices will no doubt lead to decreases in production costs and to increases in yield.

EXPERIMENTAL METHODS

A systematic field study of tillage has been carried on by the Kansas Agricultural Experiment Station, Manhattan, since 1909. In that year an experiment was established to determine the effect of time and depth of plowing on the yield of wheat when grown continuously on the same land, and in 1912 a similar experiment was begun in which the wheat was grown in rotation with corn and oats.

In 1919 another experiment was begun relating to the same general subject. This was located in the same field and was separated from the former by a road only. It was an outgrowth of the previous work and planned to give more definite information regarding the depth and frequency of plowing and methods of incorporating straw. The wheat was grown continuously on the same land. The general arrangement of the project is shown in figure 1.

Acknowledgments.—The investigation reported herein was outlined and established by L. E. Call. The field and laboratory work was in charge of J. G. Lill from 1910 to 1912, and C. E. Millar from 1913 to 1915. Since 1916 this work has been carried on by M. C. Sewell. The authors appreciate the aid of S. C. Salmon in preparing this manuscript for publication.

1. Contribution No. 156 from the Department of Agronomy.

2. A review of the literature relating to tillage by the senior author has been published in the Journal of the American Society of Agronomy, Vol. XI, No. 7, pages 269-290, 1919. Reports of progress of the experiment discussed herein have been presented in: (1) Director's Report—Kansas Agricultural Experiment Station, 1913, pages 42-76. (2) Journal of the American Society of Agronomy, Vol. VI, No. 6, pages 249 to 259, 1915; Vol. X, No. 1, pages 35-44, 1918. (3) Bulletin 185, Kansas Agricultural Experiment Station, "Preparing Land for Wheat," 1913.

One-tenth acre plots separated by six-foot cropped alleys were used in all cases, In the last experiment there were three plots of each treatment, but only one in each of the other two. Check plots have been used throughout.

The previous cropping history of the field is not, definitely known

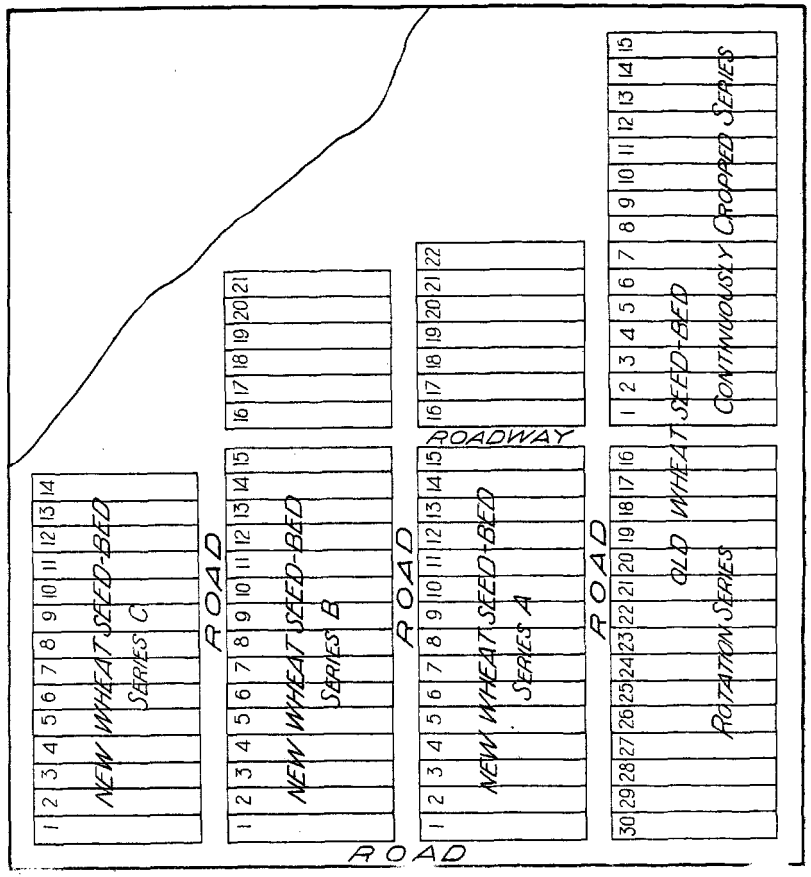

FIG. 1.—Diagram of the plots used in the tillage investigations discussed in this bulletin.

except that the land had been cropped continuously to cereals for approximately 30 years prior to the purchase of the farm in 1908 by the Agricultural Experiment Station. Corn was grown on the field in 1908 and oats in 1909.

The soil upon which the project is located is a dark brown silt loam naturally high in organic matter. The soil type shades from

the Oswego silt loam on the south half to the Derby silt loam on the north half of the area.

Moisture and nitrate determinations have been made during tillage periods, July 15 to October 1. For several years soil samples for such determinations were also taken in the spring. The purpose in each case was to find out the effect of depth and date of plowing upon the conservation of soil moisture and the development of nitrates, and the relation of these to yield.

For the first five-year period separate soil samples were taken for the moisture and for the nitrate determinations using a steel tube. A composite was made up of four samples and the data reported in the tables are averages of four such composites. For eight of the years cited a gas oven was used to dry the moisture samples to a constant weight at a temperature of 110° C. Weighings were made on a torsion balance, sensitive to 0.1 of a gram.

The samples for nitrate determinations were taken in five cores diagonally across the plots. These were mixed through a quarter-inch mesh screen and composite samples taken for the analytical work.

In the second five-year period, moisture and nitrate determinations were made from the same set of soil samples. For the last two years of this period, the moisture samples were dried in an electric oven, using 50-gram duplicate samples from composites and a balance for weighing sensitive to 0.01 of a gram.

The nitrates have been determined colorimetrically by the phenyldisulphonic acid method. A Schreiner colorimeter was used during the forepart of the work and a Dubosque colorimeter during the latter part.

To those interested in the character of the soil beyond the description of the soil type that has been given, tables will be found in the appendix stating the volume weights and moisture equivalents.

In presenting the results of the project, the data from the different experiments will be discussed separately. In each case the yields will be given first, followed by the moisture and nitrate determinations.

A study of the influence of tillage on the milling and baking qualities of wheat has been included as a part of this investigation in cooperation with the Department of Milling Industry. The results obtained will be presented in a separate publication.

CONTINUOUSLY CROPPED PLOTS: EARLY EXPERIMENTS

The different treatments in the first experiments, where wheat was grown continuously on the same land, have been as follows:

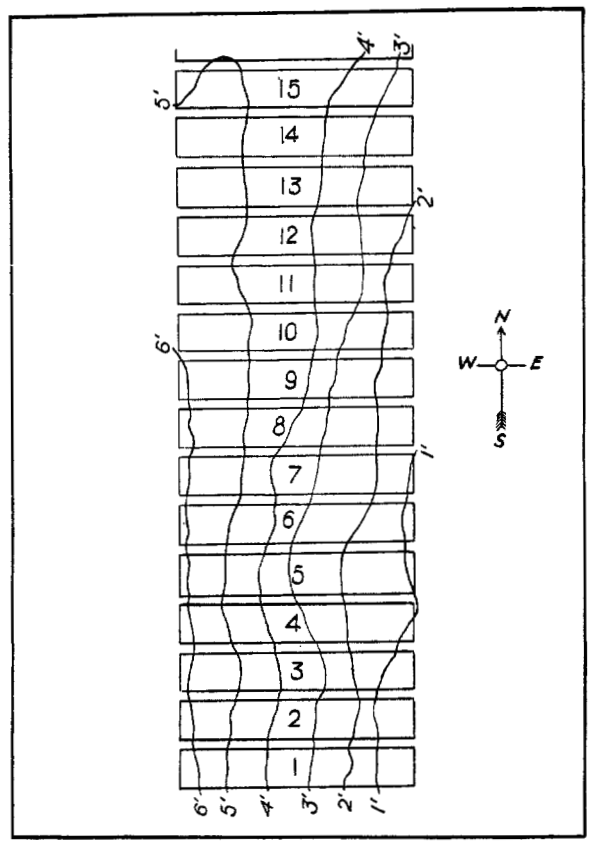

FIG. 2.—Contour map of a portion of the wheat seedbed preparation plots. The map shows the north half of the old wheat seedbed plots (plots 1 to 15), continuously cropped to wheat.

Plot No.	Treatment.
1.	Double disked just previous to seeding (weeds mowed and raked off).
2.	Plowed September 15, three inches deep.
3.	Double disked July 15; plowed September 15, seven inches deep.
4.	Double disked July 15; plowed August 15, seven inches deep.
5.	Plowed September 15, three inches deep.
6.	Listed July 15; ridges worked down.
7.	Listed July 15; ridges split August 15.
8.	Plowed September 15, three inches deep.
9.	Plowed July 15, seven inches deep.

10. Plolwed August 15, seven inches deep.
11. Plowed September 15, three inches deep.
12. Plowed August 15, seven inches deep; not worked until September 15.
13. Plowed September 15, seven inches deep.
14. Plowed September 15, three inches deep.
15. Plowed July 15, three inches deep.

It will be noted that every third plot in the series beginning with plot 2 received similar treatment. These are known as check plots. No attempt has been made to correct the yields on the basis of check-plot yields, but, as stated later, probable errors have been calculated. A contour map of this portion of the project is shown in figure 2.

All plowed plots were disked after plowing and at intervals until seeding time, except as otherwise stated, in order to control any weed growth. The plots were all drilled crosswise, usually about October 1.

The annual and average yields of wheat for the period 1911 to 1923 are presented in Tables I and 11.

TABLE I.—The effect of different tillage methods on the yield of winter wheat grown continuously on the same land.

Plot No.	TILLAGE TREATMENT.	Yields of wheat in bushels per acre.												
		1911.	1912.	1913.	1914.	1915	1916.	1917.	1918.	1919.	1920.	Av. for 10-yr. period.	1921.	1922.	1923.
1	Double disked at seeding time	6.00	4.17	13.00	21.83	4.33	3.58	6.23	5.83	7.90	4.58	7.75	4.08	9.3	6.40
2	Plowed Sept. 15, 3 inches deep	17.50	6.83	20.00	23.33	17.88	6.41	12.00	6.08	12.70	8.25	13.10	6.90	12.2	10.50
3	Double disked July 15, plowed Sept. 15, 7 inches deep	25.50	6.33	29.91	25.83	26.58	7.45	19.50	5.75	19.10	8.33	17.43	7.10	26.0	28.40
4	Double disked July 15, plowed Aug. 15, 7 inches deep	34.83	6.33	31.00	26.00	20.13	6.25	15.50	9.75	17.80	10.16	17.77	10.10 (a)	24.3 (a)	17.58
5	Plowed Sept. 15, 3 inches deep	14.50	7.83	16.33	21.67	10.29	5.62	11.83	7.16	11.40	6.83	11.35	6.08	12.1	7.00
6	Listed July 15; ridges worked down	37.66	5.33	28.58	23.42	16.77	8.62	16.33	10.70	21.70	11.25	18.04	10.75 (a)	25.6 (a)	19.00
7	Listed July 15; ridges split Aug. 15	37.16	5.75	31.00	27.17	20.02	6.66	12.33	12.16	18.20	13.50	18.30	12.66 (a)	25.0 (a)	10.80
8	Plowed Sept. 15, 3 inches deep	18.83	10.58	18.83	27.92	17.52	5.83	14.50	7.66	15.70	9.25	14.66	6.33	14.3	10.60
9	Plowed July 15, 7 inches deep	40.00	9.75	36.00	25.83	24.63	7.50	21.50	13.25	16.30	12.50	20.73 (a)	15.58 (a)	22.1 (a)	13.70
10	Plowed Aug. 15, 7 inches deep	28.00	14.33	32.50	25.58	23.10	7.41	18.00	12.10	20.00	9.58	19.06 (a)	12.50 (a)	20.4 (a)	5.30
11	Plowed Sept. 15, 3 inches deep	14.66	10.66	14.66	24.92	13.88	4.95	10.80	7.16	13.70	5.08	12.05	5.08	9.7	5.30
12	Plowed Aug. 15, 7 inches deep; not worked till Sept. 15	21.66	10.08	26.47	26.08	19.15	5.12	16.66	11.16	23.70	7.75	16.78	11.16	17.4 (a)	6.50
13	Plowed Sept. 15, 7 inches deep	10.66	9.42	14.17	23.17	13.08	5.29	12.33	4.50	17.30	6.75	11.67	7.83	12.6	8.08
14	Plowed Sept. 15, 3 inches deep	12.16	8.42	12.50	21.70	10.27	3.62	11.33	5.91	12.20	4.83	10.29	5.66	8.9	5.58
15	Plowed July 15, 3 inches deep	29.83	6.83	17.33	20.88	9.10	5.37	13.16	10.33	25.60	11.66	15.01	12.16	23.5	16.50
	Average of check plots	15.53	8.86	16.46	23.96	13.97	5.28	12.10	6.80	13.10	6.80	12.28	6.01	11.4	9.75

(a) Plots damaged with foot-rot.

TABLE II.—The effect of different tillage methods on the yield of wheat straw on land cropped continuously to wheat.

Plot No.	TILLAGE TREATMENT.	Yields of wheat straw in pounds per acre.												
		1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	Av. for 10-yr. period.	1921.	1922.	1923.
1	Double disked at seeding time	590	410	1,205	2,710	795	995	540	800	1,140	865	1,005.0	780	926	1,155
2	Plowed Sept. 15, 3 inches deep	1,450	950	1,840	3,615	2,022	1,615	1,380	865	2,115	1,025	1,687.7	950	1,039	1,280
3	Double disked July 15, plowed Sept. 15, 7 inches deep	2,120	880	2,105	3,830	3,205	1,382	2,290	1,365	2,400	1,500	2,207.7	1,050	3,320	4,505
4	Double disked July 15, plowed Aug. 15, 7 inches deep	3,010	1,120	3,480	3,320	2,295	1,655	1,950	1,445	4,410	1,630	2,431.4	1,360	(a) 3,310	(a) 2,155
5	Plowed Sept. 15, 3 inches deep	1,130	900	1,560	2,820	1,067	932	1,090	910	1,885	830	1,312.4	890	1,040	950
6	Listed July 15, ridges worked down	3,140	895	2,945	2,905	2,005	1,822	2,080	1,427	3,645	1,575	2,243.9	1,150	(a) 2,940	(a) 2,040
7	Listed July 15, ridges split Aug. 15	3,070	1,055	3,410	3,000	2,100	1,830	1,780	1,550	1,735	2,120	2,165.0	1,540	(a) 3,195	(a) 880
8	Plowed Sept. 15, 3 inches deep.	1,470	1,035	1,470	3,225	1,685	1,050	1,390	940	755	955	1,377.5	1,050	1,140	1,410
9	Plowed July 15, 7 inches deep	3,550	1,250	4,170	3,070	2,830	1,750	2,510	1,635	2,290	1,810	2,486.5	(a) 1,880	(a) 3,462	(a) 1,635
10	Plowed Aug. 15, 7 inches deep	2,320	1,540	3,250	2,415	2,692	1,285	2,180	1,480	1,560	1,575	2,029.7	(a) 1,480	(a) 2,390	(a) 990
11	Plowed Sept. 15, 3 inches deep	1,170	895	1,230	3,185	1,400	852	690	670	1,755	615	1,146.2	890	775	845
12	Plowed Aug. 15, 7 inches deep; not worked until Sept. 15	1,800	1,185	2,870	3,455	2,035	1,147	1,780	1,390	2,965	845	1,947.2	1,530	1,335	(a) 850
13	Plowed Sept. 15, 7 inches deep	940	845	1,130	3,520	1,202	782	1,020	770	490	775	1,147.4	860	1,170	445
14	Plowed Sept. 15, 3 inches deep	1,020	805	1,090	2,868	950	567	920	525	1,645	500	1,087.0	720	735	875
15	Plowed July 15, 3 inches deep	2,360	880	2,040	2,377	1,027	1,022	1,390	1,420	2,310	1,240	1,606.6	1,410	2,100	1,340

(a) Plots damaged with foot-rot.

The yields for 1921, 1922, and 1923, are not included in the average because in those years a fungus disease appeared on certain plots. The yields are given, however, to show how the disease has spread with the various treatments and the extent to which it has influenced the yields compared with the 10 previous years.

The disease appears to be a foot-rot since *Helminthosporium Sativum* P. K. B., Wojnowicia *graminis* (McAlp) Sacc. and D. Sacc., and *Ophiobolus cariceti* (B and Br) Sacc. have been found on diseased plants.[3]

To free the land of this disease it has been thought desirable to crop the area to other crops for a period of years since in other experiments where wheat has been grown in rotation there is no evidence of the disease.

PROBABLE ERRORS

The yields can be more fairly interpreted if the probable errors of the experiment are considered.[4] Since shallow September plowing is the only treatment that is replicated, the probably error of the experiment must be calculated from these plots.

Bessel's formula $E = 0.6745 \sqrt{\frac{\Sigma d^2}{n-1}}$ was used in calculating the probable error for each year and the formula for the probable error of an arithmetical mean E av. $= \frac{\sqrt{E_1^2+E_2^2+E_3^2 \ldots E_{10}^2}}{10}$ was used in calculating the error for the ten-year period. E_1, E_2, ... E_{10}, being the probable errors for the individual years. This value was found to be 0.47 of a bushel. For any comparisons which involve the average yield of the five check plots the probable error of the difference is $\sqrt{0.47^2+\left(\frac{0.47}{\sqrt{5}}\right)^2} = 0.52$ of a bushel.

For comparisons involving the yields of single plots (plots other than the checks) the probable error of the difference is $Ed = 0.47\sqrt{2} = 0.66$ of a bushel. Statistically significant differences are arbitrarily considered as differences that are 3.2 times the probable error of the difference. Accordingly any comparison of yields between checks and other treatments are statistically significant when equal to 3.2 X 0.52 or 1.6. In a similar way any comparisons of yields between single plot treatments are statistically significant when equal to 3.2 X 0.66 or 2.1.

3. Sewell, M. C., and Melchers, L. E. The effect of rotation and tillage on foot-rot of wheat in Kansas, 1920 to 1924. Jour. Amer. Soc. Agron., Vol. XVI, No. 12, pp. 768-771. 1924.

4. The probable error is calculated by a method proposed by S. C. Salmon and explained in Technical Bulletin 15 of the Kansas Agricultural Experiment Station, pp. 11 to 12.

It is well to remember in this connection that this interpretation involves the assumption that all treatments tend to vary the same as the check plots and that had the other treatments been replicated the probable errors for them would be the same as those of the check plots. This is obviously not always the case. It is believed that this interpretation is justified in the present case because the assumption referred to is in general true, and because the probable errors so calculated provide a readily comprehended measure of the variability of the soil on which the experiments were conducted. If it is recognized that a probable error so calculated cannot be applied with strict mathematical accuracy, no serious errors should be introduced by its use and the interpretation of the experiment is materially aided thereby.

RELATION OF TIME AND METHODS OF TILLAGE TO YIELD

Effect of Time of Plowing on Yield

A comparison of the yields recorded in Table I, brings out the most important fact revealed by these experiments; namely, that early plowing has been the most effective single treatment in producing high yields. Land plowed in July six to seven inches deep has produced the greatest, yield. Compared with September plowing, this treatment has increased the yield nine bushels per acre. Plowing August 15 has done practically as well. These great differences show the importance of early plowing. While the difference between July and August plowing is not statistically significant in the light of probable error, one would be justified in recommending July rather than August plowing so far as practicable since the chances are much in favor of the earlier preparation. The point most worthy of emphasis in this connection is the materially larger yields secured from August or July plowing as compared with September plowing.

Another comparison of the effect of time of plowing on yield is afforded between plots 15 and 14, plowed in July and September, respectively, three inches deep. In this case the difference in favor of early plowing is only five bushels per acre. This is somewhat less than might be expected in view of certain results to be presented later. The physical condition of the soil in this tract varies from plots 1 to 15 and chemical analyses for nitrogen and carbon made in 1915 show that the amount of nitrogen in the soil also decreases toward plot 15. These analyses are presented in the appendix. The slight discrepancy in yield between actual and expected results may possibly be due to these soil differences.

Value of Disking After Harvest

When conditions are such that plowing or listing for wheat cannot be done before the middle of August, these experiments have shown that the practice of disking the stubble in July and plowing by the middle of September is advantageous. Thus plowing seven inches deep the middle of September has given an average yield of 11.7 bushels of wheat per acre as compared with 17.4 bushels per acre for double disking the middle of July and plowing seven inches deep in September, or a difference of 5.7 bushels.

It has been observed that the results of early preparation are closely related to the precipitation in July. If rains in July start weed growth in the stubble, then July plowing is preferable. If, on the contrary, the month of July is dry and weeds do not grow, very little is gained by the early plowing. This point is discussed in detail later.

Depth of Plowing and Yields

As shown in Table I, plowing seven inches deep in July has produced larger yields than plowing three inches deep at the same time, the average yields being 20.7 and 15.0 bushels per acre, respectively. However, as stated in the preceding discussion of the effect of time of plowing, there is some doubt concerning the uniformity of the soil on plot 15, plowed three inches deep in July, as compared with the other plots on this area. Seven-inch plowing in September has produced on the average 1.38 bushels more than three-inch plowing at the same time. Other experiments in this project will be discussed later which show no material differences in the yields secured from deep and shallow plowing.

Listing Versus Plowing

The average yields of the two listed plots, Nos. 6 and 7, show that listing has given an average yield of two or two and one-half bushels per acre less than plowing on the same date. On the other hand, early listing has given an increase in yield of about seven and one-half bushels over late plowing. Since listing can be done more rapidly than plowing, it may be good farm practice to list early rather than to plow, if by plowing a part of the land must be plowed late. These results also show that splitting the listed ridges or double listing, as it is sometimes called, does not give an increase in yield over single listing sufficient to warrant the extra expense.

Value of Cultivation After Plowing

Cultivating the soil after plowing has increased the yield 2.3 bushels per acre as compared with no cultivation, as shown by comparing plots 10 and 12, both of which were plowed August 15.

RELATION OF TILLAGE TO SOIL MOISTURE

Some of the reasons for the difference in yields obtained from the various tillage methods may be found by studying the moisture relations. Moisture determinations have been made on all plots in July, August, September, and October to various depths. The most marked differences were on plots 1, 8, 9, and 15, representing the earliest and latest prepared plots. Only these will be discussed in detail. Table III gives the per cent of soil moisture in the surface foot of soil on all plots and Table IV records similar data to a depth of six feet,. Tables V and VI present the moisture data from plots 1, 8, 9, and 15, giving (1) the moisture in the surface foot of soil at monthly periods, July to October, (2) the moisture to a depth of three feet of soil at the same intervals, and (3) the amount of moisture in fractional parts of the surface soil at the time of fall seeding.

TABLE III.—Relation of tillage to moisture content of the soil to a depth of one foot at time of seeding: Per cent of moisture based on dry weight of soil.

Plot No.	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.	1922.	Average.
1	27.1	24.2	20.4	25.5	21.4	28.9	22.0	15.2	9.8	16.0	16.6	11.3	.....	19.8
2	26.8	24.6	20.4	24.9	22.3	28.0	24.9	13.3	14.6	16.2	15.6	11.3	21.7	20.3
3	26.1	26.4	21.0	25.7	24.4	27.5	24.2	15.9	19.5	20.2	16.1	17.2	23.0	22.1
4	28.7	27.5	22.0	24.8	22.7	27.7	25.3	19.7	16.9	20.5	16.1	20.0	22.6	22.6
5	26.2	26.9	21.5	26.0	23.6	26.7	25.3	15.6	16.6	15.9	16.6	14.8	21.1	21.3
6	26.2	27.3	19.6	25.2	22.6	24.0	25.3	18.3	16.9	20.0	16.5	16.2	22.2	21.5
7	26.7	26.7	18.5	25.1	22.3	26.3	25.3	19.0	17.6	19.3	16.1	18.9	21.9	21.8
8	25.5	25.3	19.2	26.0	24.1	26.8	23.1	12.0	14.4	17.7	14.4	13.5	21.4	20.2
9	26.9	26.7	19.9	26.4	24.7	26.2	23.5	19.7	19.2	18.3	16.2	17.8	24.3	22.3
10	27.9	27.1	21.5	26.4	25.0	27.6	24.2	16.9	17.5	18.3	17.1	19.1	22.8	22.4
11	25.6	25.8	21.3	25.8	24.2	26.0	24.6	14.3	17.9	17.2	19.9	18.8	20.1	21.6
12	26.0	28.1	21.0	25.9	24.9	27.1	24.2	18.0	16.9	17.0	23.3	17.4	22.0	22.4
13	25.0	26.5	21.6	26.7	24.4	27.4	21.2	10.8	12.1	16.9	21.5	20.7	20.1	21.1
14	25.2	26.0	21.2	25.7	23.9	26.3	19.7	12.9	14.3	15.9	19.1	19.4	19.1	20.6
15	25.6	25.6	20.1	24.6	22.3	24.9	21.9	20.5	14.7	19.0	22.5	18.4	21.8	21.7
Range	3.7	3.9	3.5	2.1	3.6	4.9	5.6	9.7	9.0	4.6	8.9	9.4	5.2	2.8

TABLE IV.—Relation of tillage to moisture content of the soil to a depth of six feet at time of seeding: Per cent of moisture based on dry weight of soil.

Plot No.	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	10-yr.	1920.	1921.	1922.	Average, 1910-'22
1	24.9	21.6	20.2	20.0	15.2	24.9	20.4	17.0	15.3	17.1	19.7	17.9	15.1	17.2	19.0
2	25.2	21.0	19.5	19.6	17.5	25.2	21.2	15.4	17.1	16.5	19.8	15.9	15.6	18.8	19.1
3	25.3	21.0	19.6	19.3	17.5	25.0	21.2	16.3	19.4	18.9	20.3	16.9	18.0	19.2	19.8
4	26.8	21.3	19.4	18.1	17.6	24.7	22.8	17.0	16.5	18.8	20.3	16.9	18.7	22.1	20.0
5	24.3	21.5	18.9	19.9	18.8	23.6	20.7	15.4	13.5	16.8	19.3	16.1	16.5	17.8	18.7
6	24.8	22.0	17.8	18.6	18.7	21.1	22.0	16.7	15.2	18.5	19.8	17.1	17.6	17.8	19.3
7	25.0	21.0	17.2	18.5	18.8	24.4	22.6	15.8	15.1	18.2	19.6	17.1	18.2	18.8	19.3
8	23.9	20.4	17.7	19.1	18.5	22.6	17.9	14.3	16.2	16.0	18.6	15.5	16.3	17.7	18.1
9	24.9	20.2	16.7	17.4	16.7	23.5	20.4	14.7	22.7	17.0	19.4	17.9	20.5	19.8	19.4
10	25.4	22.5	18.4	18.3	17.9	23.6	21.6	15.1	14.3	17.9	19.5	17.7	20.3	17.6	19.3
11	23.9	20.3	18.1	19.1	17.3	23.1	19.1	14.1	15.1	16.7	18.7	17.5	19.4	16.3	18.4
12	24.6	22.0	19.7	18.1	18.3	23.7	18.7	15.5	16.4	17.6	19.4	19.4	19.3	19.3	19.4
13	23.4	20.5	19.6	20.2	18.4	23.7	16.9	14.3	18.4	16.6	19.2	17.2	19.1	16.3	18.8
14	23.1	20.0	17.9	19.1	18.7	23.2	14.5	14.5	19.9	14.7	18.5	16.1	16.6	16.1	18.0
15	24.0	19.5	17.9	18.1	16.3	22.7	18.6	15.9	22.3	17.7	19.3	18.1	16.9	16.6	18.8
Range	3.7	3.0	3.5	2.8	3.6	2.6	8.3	2.9	8.4	4.2	1.8	3.9	5.4	6.0	2.0

TABLE V.—Relation of tillage to moisture content of the soil to a depth of one foot and to a depth of three feet for the summer months, July, August, September, and October: Per cent of moisture based on dry weight of soil.

	July.				August.				September.				October.			
Plot...	1	8	9	15	1	8	9	15	1	8	9	15	1	8	9	15
Per Cent of Moisture to a Depth of One Foot																
1910	.....	20.4	20.9	18.5	20.4	20.1	26.4	23.4	27.1	25.5	26.9	25.6	.....	.....	.....	.....
1911	8.1	9.6	9.5	10.5	11.9	14.3	19.0	17.3	12.0	11.9	23.3	22.8	24.2	25.3	26.7	25.6
1912	20.1	19.7	20.5	19.2	12.7	13.2	19.1	20.5	18.5	19.4	24.2	22.5	20.4	19.2	19.9	20.0
1913	9.0	10.4	10.4	14.6	8.3	9.9	10.5	12.0	12.2	12.4	13.2	14.2	25.5	26.0	26.4	24.6
1914	15.0	15.5	16.6	16.6	13.8	14.4	17.0	17.1	19.9	18.8	24.6	23.3	21.4	24.1	24.7	22.3
1915	24.4	25.4	23.8	22.7	22.8	20.8	25.6	23.9	16.2	16.0	25.0	22.7	28.9	26.8	26.2	24.9
1916	4.1	3.0	4.9	3.4	3.1	2.4	9.2	9.0	20.0	19.9	19.6	18.6	22.0	23.1	23.5	21.9
1917	8.1	5.5	5.2	6.5	23.1	19.0	21.9	21.4	13.1	11.9	18.7	16.3	15.2	12.0	9.7	20.5
1918	14.6	14.7	15.6	15.6	13.6	11.1	14.4	17.0	15.1	14.7	18.8	20.0	9.8	14.4	29.2	24.7
1919	8.4	7.7	15.3	14.7	9.8	9.6	16.1	15.7	12.3	15.5	19.9	19.1	16.0	17.7	18.3	19.0
Av.	12.4	13.1	12.7	14.2	13.9	13.5	17.9	17.7	14.8	16.6	21.4	20.5	20.3	20.9	23.8	22.6
Per Cent of Moisture to a Depth of Three Feet.																
1910	.....	22.4	21.9	20.1	21.2	20.7	23.5	21.5	25.9	24.7	29.9	.....	.....	.....	.....	.....
1911	15.3	15.3	14.5	13.8	18.0	17.2	18.0	16.1	17.9	16.3	19.8	19.6	22.2	21.4	22.1	21.0
1912	19.9	18.0	18.8	17.7	17.5	16.4	17.5	18.3	19.2	17.9	19.8	20.3	20.8	18.4	19.3	19.6
1913	18.7	15.1	14.2	15.0	15.0	14.4	14.6	14.6	17.1	16.2	15.5	15.9	21.9	20.8	20.5	20.3
1914	16.4	16.4	16.3	15.9	16.7	16.0	17.0	16.2	18.8	17.7	20.0	19.5	19.1	21.7	21.0	19.0
1915	23.9	24.1	23.2	21.5	24.1	22.6	24.4	23.1	20.9	20.6	23.7	22.5	27.8	25.0	25.6	23.9
1916	4.1	3.0	4.9	3.4	5.5	2.9	14.5	14.3	20.0	19.9	19.6	18.6	22.5	29.0	22.8	20.3
1917	14.1	9.9	11.4	12.1	21.3	19.0	17.9	19.1	16.1	14.1	14.9	14.4	16.8	14.1	15.2	16.1
1918	17.7	16.6	16.0	15.7	16.6	13.4	14.4	15.4	19.3	15.1	15.5	17.5	12.7	15.8	(a)	(a)
1919	14.0	14.1	18.9	16.0	14.4	14.1	17.7	17.1	19.2	17.3	23.5	15.4	17.8	16.8	19.4	18.7
Av.	16.0	18.1	16.0	15.1	17.0	15.7	17.9	17.6	19.4	17.9	20.2	18.1	20.1	19.4	20.7	19.8

(a) Error in data.

Tillage Treatments:

Plot 1.—Double disked at seeding time (about October 1) after mowing and raking off weeds.
Plot 8.—Plowed three inches deep about September 15.
Plot 9.—Plowed seven inches deep about July 15.
Plot 15.—Plowed three inches deep about July 15.

TABLE VI.—Relation of tillage to moisture content of the soil in fractional portions of the surface foot in September: Per cent of moisture based on dry weight of soil.

Plot No	1915.			1916.			1917.			1918.		1919.		Average.	
	0–3″	4″–6″	7″–12″	0–3″	4″–6″	7″–12″	0–3″	4″–6″	7″–12″	0–6″	7″–12″	0–6″	7″–12″	0–6″	7″–12″
1	16.5	18.7	19.2	13.6	15.4	17.0	12.3	11.4	15.6	13.3	17.0	18.5	15.1	15.1	16.8
8	.....	.....	.....	11.7	15.4	17.0	10.5	10.5	14.9	13.8	15.7	15.4	14.0	13.3	15.4
9	22.9	25.4	24.5	11.4	13.6	16.2	14.3	19.1	22.7	19.0	18.7	21.4	23.3	18.7	21.2
15	20.6	23.0	22.6	9.6	11.0	15.4	10.8	17.6	20.5	19.6	20.5	20.2	21.0	17.2	20.0

Tillage Treatments:
Plot 1.—Disked at seeding time (about October 1) after mowing and raking off weeds.
Plot 8.—Plowed three inches deep about September 15.
Plot 9.—Plowed seven inches deep about July 15.
Plot 15.—Plowed three inches deep about July 15.

No marked differences in the moisture content of the soil at seeding time to a depth of one foot or a depth of six feet dependent upon preparation of the ground are apparent. Thus plot 1 which is not cultivated in any way until seeding time has but 0.4 of 1 per cent less moisture to a depth of six feet than plot 9 plowed deep in July. Other comparisons show about the same result.

During the summer, however, when the moisture content is considered, marked variations are found. The differences are usually in favor of the plots receiving some form of tillage during July or August.

The first determinations have been made about July 15, which is usually from two weeks to a month after harvest. At this time there has usually been but little difference among the plots (except for the year 1919 when there was a carry over of moisture on the plots plowed in July). Since weeds are allowed to grow on the untilled land the widest variation in moisture would be expected late in the summer. This is actually the case, the greatest, differences having been recorded for the September determinations. September rains often obliterate these differences by seeding time.

The effect of tillage has been least marked in seasons such as 1910, 1913, and 1915, which were either unusually wet or unusually dry. (A precipitation record is included in the appendix.) During a dry summer there is no weed growth on any of the plots to use moisture and in a wet season the excess moisture is sufficient to overcome any differences due to tillage or weed growth.[5]

Soil samples of fractional parts of the surface foot were taken for five years, 1915 to 1919, inclusive. The results of the moisture determinations, for these three- and six-inch sections show a much wider variation than where foot sections alone are considered. (Table VI.) These differences are obscured when the soil samples are taken in foot sections and averaged for three- and six-foot depths. So far as shown by observation, there has always been sufficient moisture in the surface soil at seeding time to produce uniform germination and stand.

EFFECT OF TILLAGE ON NITRATE DEVELOPMENT

The greatest amount of nitrates in the soil at seeding time is found in those plots receiving some kind of early summer tillage. This fact is clearly illustrated in Table VII which shows the nitrates in the surface foot and the upper three feet of soil at time of seeding expressed in parts per million of dry weight of soil. Almost without

5. Gates, F. C., and Sewell, M. C. Tillage and weeds. Ecology. Vol. VI, No. 2, pages 138-142. 1925.

exception July or August tilled plots regardless of the method employed are materially higher in nitrates than those not tilled until later. August, plowing was slightly less effective in developing nitrates than July plowing, but much better than September plowing, and the latter materially better than disking at seeding time. Disking immediately after harvest has been nearly as effective in developing nitrates as was early plowing.

As a matter of fact plot 3 which has been disked July 15 and plowed September 15 has averaged more nitrates at seeding time than plot 15 which has been plowed July 15 three inches deep.

Depth of plowing seems to have had some effect on nitrification since plot 15, plowed three inches deep July 15, contains less nitrates than plot 9, plowed seven inches deep at the same time, and plot 14, plowed three inches deep September 15, has in the average somewhat less nitrates than plot 13, plowed at the same time seven inches deep. The effect, however, is much less than that caused by time of tillage as previously discussed.

Cultivation after plowing has had some effect on nitrification as shown by a comparison of plots 10 and 12, both of which are plowed in August, but only one is cultivated subeequently. The nitrates are materially greater in the cultivated plot.

Early listing has produced as much or more nitrates than plowing at the same time and considerably more than late plowing. Double listing has resulted in a somewhat greater development of nitrates than single listing. These differences are diredy correlated with yield of grain as shown in figure 3 indicating that the principal reason for higher yields following early preparation of the ground is the liberation of nitrogen in the soil.

Nitrate determination to a depth of one foot and to a depth of three feet for plots 1, 8, 9, and 15 for July, August, September, and October are recorded in Table VIII.

It will be seen that nitrates increase progressively during the summer on plots 9 and 15 which were plowed early, but on plots 1 and 8 on which weeds are allowed to grow there is very little increase on the average and in some seasons a material loss. As shown by the authors in other papers it is probable that one of the important reasons for the accumulation of nitrates during the summer on early-tilled plots and its nonaccumulation on plots which are not tilled, is growth of weeds.[6]

6. Call, L. E., and Sewell, M. C. The soil mulch. Jour. Amer. Soc. Agron. Vol. IX, No. 2, pages 49 to 61. 1917.
Call, L. E., and Sewell, M. C. Relation of weed growth to nitric nitrogen accumulation. Jour. Amer. Soc. Agron. Vol. X, No. 1, pages 35 to 44. 1918.

TABLE VII.—Relation of tillage to nitrate content of the soil to a depth of one foot and to a depth of three feet at time of seeding: Nitrates expressed as parts per million dry weight of soil.

Plot No. (a).	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.	1922.	Average.
Nitrates to a Depth of One Foot														
1	8.6	2.8	4.0	65.3	10.9	4.2	6.6	1.1	0.0	20.5	14.7	1.1	.....	11.6
2	3.5	22.7	16.2	79.4	37.9	9.1	13.0	3.1	5.5	18.5	42.7	1.1	8.5	20.1
3	6.8	15.0	59.1	64.2	99.7	14.6	29.4	21.4	86.5	104.0	51.2	12.7	56.1	47.7
4	12.8	64.8	69.8	65.8	77.1	23.1	59.2	64.3	57.7	89.4	96.7	23.6	53.4	58.3
5	5.6	20.6	14.8	58.9	29.9	1.8	23.4	2.9	10.5	5.3	16.8	1.8	6.1	15.3
6	16.4	53.9	72.8	60.6	70.9	22.7	48.2	41.5	80.5	75.8	70.7	23.9	25.1	51.0
7	10.2	58.2	114.7	44.5	89.7	1.9	124.8	34.4	84.7	122.0	59.7	28.2	24.6	66.4
8	7.9	22.0	15.2	72.8	43.9	1.7	9.8	2.6	8.8	12.6	16.7	1.7	5.4	17.0
9	11.6	80.0	83.8	52.6	71.5	25.2	6.2	32.1	43.1	126.8	47.8	53.6	22.0	50.5
10	14.7	53.0	41.3	44.8	78.8	1.6	32.8	40.9	41.7	41.5	54.1	9.2	43.2	38.3
11	0.5	10.5	9.3	59.8	27.9	1.2	13.2	2.5	6.5	6.9	6.2	3.1	6.3	11.8
12	.....	43.4	50.4	65.8	62.8	1.6	27.7	24.3	39.0	22.4	19.8	6.0	12.3	31.3
13	2.9	7.7	16.2	37.9	32.1	4.7	10.5	3.1	20.7	10.2	6.3	1.6	6.0	12.3
14	0.5	13.1	11.6	33.1	24.5	3.2	12.8	1.4	1.9	1.5	6.4	1.2	3.8	8.8
15	8.8	64.8	97.6	33.3	65.3	13.7	5.3	24.8	66.6	29.3	25.3	8.3	11.3	34.9
Nitrates to a Depth of Three Feet														
											Av.			
1	6.1	1.9	2.0	23.6	5.4	3.7	8.2	0.9	0.0	15.2	6.7	.....	.....	.....
2	6.4	8.7	6.9	29.0	15.9	4.3	10.6	1.9	1.8	9.0	9.4	.....	.....	.....
3	3.4	7.3	24.1	28.8	44.8	7.9	16.8	9.5	35.2	38.7	21.6	.....	.....	.....
4	12.8	27.0	34.8	26.0	33.5	14.1	30.7	29.7	54.9	36.7	30.0	.....	.....	.....
5	4.5	8.7	6.7	22.0	11.9	1.9	16.3	1.6	3.5	4.1	8.1	.....	.....	.....
6	13.9	22.5	33.8	23.6	29.9	9.7	37.7	16.8	35.3	28.2	25.1	.....	.....	.....
7	5.6	23.0	47.8	19.2	35.1	4.3	52.1	15.7	42.7	45.2	29.0	.....	.....	.....
8	3.6	9.5	7.0	26.7	18.7	1.6	26.1	1.7	2.9	8.5	10.6	.....	.....	.....
9	12.1	35.0	37.2	23.5	31.0	12.3	32.6	14.5	27.3	51.3	27.6	.....	.....	.....
10	8.9	22.8	22.9	17.5	34.0	4.8	20.9	16.2	19.0	18.4	18.5	.....	.....	.....
11	3.1	5.2	4.7	22.6	12.0	1.4	11.4	1.4	21.7	3.8	8.7	.....	.....	.....
12	.....	18.8	22.1	24.6	25.9	2.2	14.8	9.3	17.3	11.9	14.7	.....	.....	.....
13	3.8	3.8	6.9	14.9	12.3	2.6	8.0	2.2	11.7	4.3	7.0	.....	.....	.....
14	3.1	5.8	5.2	13.2	9.9	2.1	10.0	1.4	13.3	1.9	6.6	.....	.....	.....
15	7.7	25.5	43.5	17.3	25.7	5.6	25.9	12.0	13.7	23.4	20.0	.....	.....	.....

(a) Tillage Treatments: Plot 1.—Double disked at seeding time. Plot 2.—Plowed September 15, 3 inches deep. Plot 3.—Double disked July 15; plowed September 15, 7 inches deep. Plot 4.—Double disked July 15; plowed August 15, 7 inches deep. Plot 5.—Plowed September 15, 3 inches deep. Plot 6.—Listed July 15; ridges worked down. Plot 7.—Listed July 15; ridges split August 15. Plot 8.—Plowed September 15, 3 inches deep. Plot 9.—Plowed July 15, 7 inches deep. Plot 10.—Plowed August 15, 7 inches deep. Plot 11.—Plowed September 15, 3 inches deep. Plot 12.—Plowed August 15, 7 inches deep; not worked till September 15. Plot 13.—Plowed September 15, 7 inches deep. Plot 14.—Plowed September 15, 3 inches deep. Plot 15.—Plowed July 15, 3 inches deep.

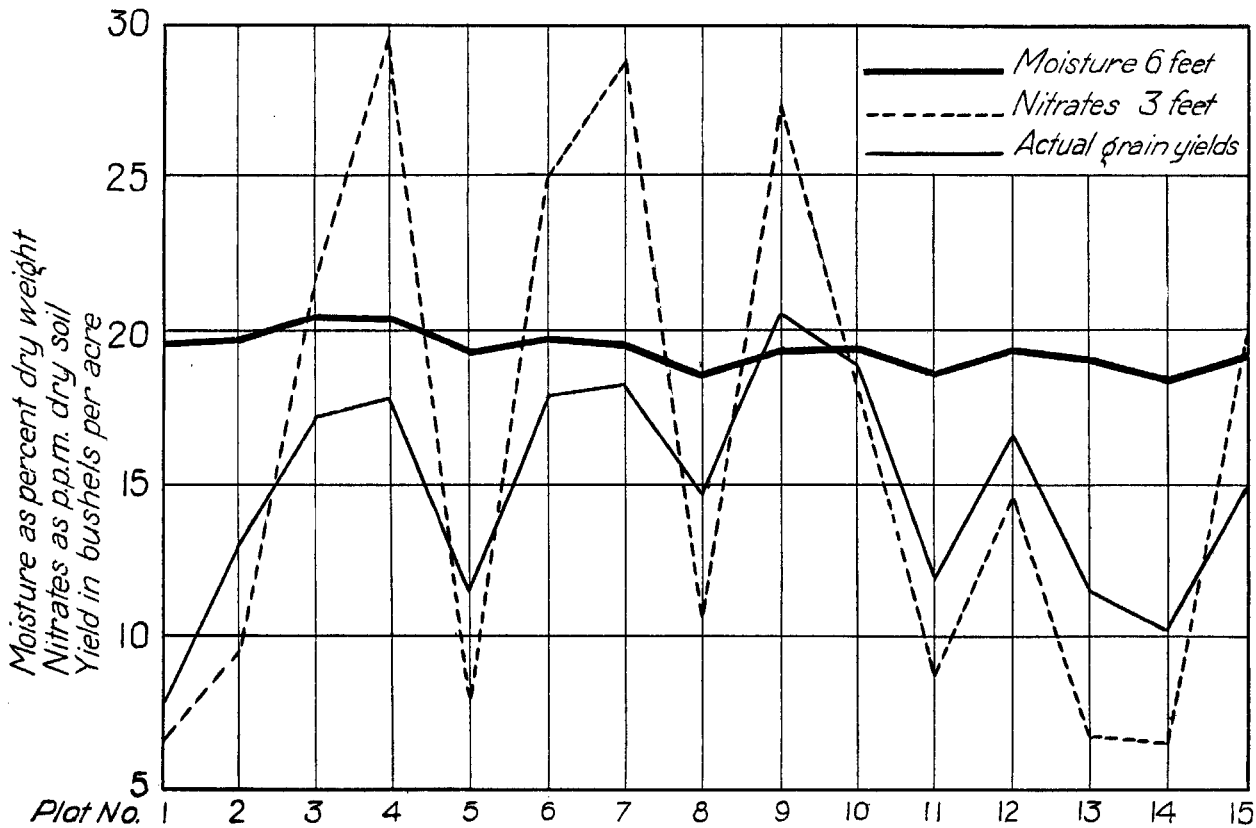

FIG. 3.—Graphs showing the per cent of moisture in the soil and the nitrates expressed as parts per million of dry weight of soil at seeding time; also average yields of the following crop. The figures show ten-year averages, 1910 to 1919, the plots being the ones shown in figure 2.

TABLE VIII.—Relation of tillage to nitrate content of the soil to a depth of one foot and to depth of three feet for the summer months, July, August, September, and October: Nitrates expressed as parts per million dry weight of soil.

	July.				August.				September.				October.			
Plot No.	1	8	9	15	1	8	9	15	1	8	9	15	1	8	9	15
Nitrates to a Depth of One Foot																
1910									8.6	7.9	11.6	8.7				
1911	8.3	10.2	7.9	5.4	14.0	22.0	49.0	13.0	5.9	7.0	54.9	43.5	2.8	22.0	79.9	64.8
1912	12.0	22.2	22.8	27.8	4.1	4.3	68.2	51.4	1.2	12.9	98.4	72.1	4.0	15.2	82.8	97.6
1913	4.5	20.5	13.4	20.5	14.1	31.5	18.9	18.2	23.5	15.1	16.0	24.0	65.3	72.8	52.6	33.3
1914	19.9	33.5	41.8	32.9	18.1	22.7	36.8	40.7	3.6	18.3	80.6	43.2	10.9	43.9	71.5	65.3
1915	1.9	3.1	6.6	7.8	1.4	2.7	16.2	14.1	1.5	5.5	28.7	29.5	4.2	1.7	25.2	13.7
1916	10.8	7.4	8.5	9.4	4.8	4.7	52.5	24.9	6.4	5.4	36.1	44.4	6.6	9.8	62.7	52.9
1917	7.6	10.2	21.8	11.5	2.7	5.1	14.1	15.2	1.7	2.4	43.3	34.4	1.9	2.6	32.1	24.8
1918	6.2	14.7	19.5	15.5	0.0	7.2	26.2	28.8	3.9	4.4	43.5	42.9	0.0	8.8	43.1	66.6
1919	4.1	6.4	22.7	15.2	6.6	6.4	46.4	30.1	4.8	3.6	73.0	34.6	20.5	12.6	126.8	48.8
Av.	8.3	14.1	16.1	14.0	7.3	11.6	36.4	26.2	6.1	8.2	48.6	37.7	12.9	21.0	64.1	51.9
Nitrates to a Depth of Three Feet																
1910									6.1	3.6	12.1	7.7	6.1	3.6	12.1	7.7
1911	4.4	5.0	4.6	3.9	6.6	10.3	10.2	11.3	3.1	3.6	20.6	16.3	1.9	9.5	35.0	25.5
1912	5.1	9.4	13.6	15.2	2.4	2.2	28.1	22.5	6.8	5.6	39.4	33.2	2.0	7.0	37.2	43.5
1913	5.2	8.4	5.8	9.0	6.0	12.0	7.5	8.8	8.6	6.0	6.9	10.2	23.6	26.7	23.5	17.3
1914	8.4	12.8	15.9	12.5	8.6	8.3	13.6	15.6	2.9	7.8	31.2	16.9	5.4	18.7	31.0	25.7
1915	1.6	2.2	3.8	4.3	1.2	2.0	7.1	6.2	1.6	3.1	11.6	21.5	3.7	1.6	12.3	5.6
1916	8.5	9.6	9.2	10.3	3.9	5.9	25.5	17.8	11.5	10.8	28.5	23.9	8.2	26.1	32.6	25.9
1917	2.5	4.6	15.0	10.3	0.9	1.7	10.9	7.6	2.0	2.7	22.7	19.7	0.9	1.7	14.5	12.0
1918	2.5	7.1	25.6	12.2	0.0	6.0	18.4	13.7	1.3	1.4	18.9	19.6	0.0	2.9	27.3	13.7
1919	2.8	3.8	9.6	10.3	3.7	4.2	19.4	13.3	2.9	3.3	33.2	14.7	15.2	8.5	51.3	23.4
Av.	4.5	7.0	11.4	9.7	3.7	5.8	14.7	12.9	4.6	4.7	22.5	18.2	6.7	10.6	27.6	20.0

Tillage Treatments:
Plot 1.—Double disked at seeding time (about October 1) after mowing and raking off weeds.
Plot 8.—Plowed three inches deep about September 15.
Plot 9.—Plowed seven inches deep about July 15.
Plot 15.—Plowed three inches deep about July 15.

A further study was made by harvesting the weeds that grew on plot 1 and determining their nitrogen content. The total amount of nitrates developed in the soil of this plot was then calculated. The data secured are presented in Table IX, which includes also the nitrates developed in plot 9, plowed in July for comparison. The determinations were made in September (at seeding time).

TABLE IX.—Nitrates in the soil and in the weeds on plots 1 and 9 in September.

YEAR.	Plot No.	Soil nitrates per acre 3 feet deep.	Weeds per acre.	Per cent nitrogen in weeds.	Total nitrogen per acre in weeds.	Nitrate nitrogen per acre in weeds.	Nitrate in both soil and weeds per acre.
		Pounds.	*Pounds.*		*Pounds.*	*Pounds.*	*Pounds.*
1915	1	18.8	3,850.0	0.883	34.0	150.0	168.8
	9	127.5	.....	.....	.....	.....	127.5
1916	1	136.0	5,360.0	.660	35.3	156.6	292.6
	9	317.9	.....	.....	.....	.....	317.9
1917	1	11.3	5,771.0	1.060	57.7	255.5	266.8
	9	160.0	.....	.....	.....	.....	160.0
1918	1	28.2	7,138.4	.590	42.1	186.4	214.6
	9	363.3	.....	.....	.....	.....	363.3
1919	1	170.9	3,791.7	(a) .800	30.3	134.2	305.1
	9	547.9	.....	.....	.....	.....	547.9
1920	1	52.4	3,366.0	1.070	36.0	159.4	211.8
	9	304.9	.....	.....	.....	.....	304.9
Average	1	69.6	4,879.4	.844	41.2	182.4	252.0
	9	303.6	.....	.....	.....	.....	303.6

(a) Estimate.

The per cent of nitrogen in the weeds varied from year to year because of differences in their maturity. The growth of weeds also varied greatly from year to year, being greatest in wet years and least, in dry years.

It will be seen that when the nitrates in the weeds are added to those in the soil of plot 1, the total production of nitrates is high and the comparison with plot 9 much different than when the nitrates in the soil only are considered. In 1915 and in 1917, plot 1 exceeded plot 9 in the calculated amount of nitrates per acre, and in 1916 the production of nitrates for the two plots was about equal. In 1918, 1919, and 1920, nitrate production in plot 9 was much

greater. For the six-year period the average nitrate production was 252.0 pounds per acre for plot 1 and 303.6 pounds for plot 9. The weed growth included in these calculations does not take into consideration the shattered leaves of those weeds which had matured when determinations were made.

Considering these facts and the limitations of the weed growth determinations, it seems probable that nitrates develop on plot 1 during the summer season as rapidly or at least, nearly as rapidly as on plot 9, but that the weeds use them about as quickly as they developed.

SOIL HORIZON IN WHICH NITRIFICATION IS MOST ACTIVE

Nitrification is most active in the surface foot of soil as shown in Table VII. Since rainfall may wash the nitrates formed in the surface soil into the subsoil, determinations were regularly made to a depth of three feet. Unpublished determinations to a depth of six feet, show that nitrates are rarely washed below the third foot. Determinations of different fractions of the surface foot have been made and the data are presented in Table X.

It will be observed that the surface six inches is the zone in which nitrification is usually most active. There is apparently but little difference between the first three and the second three inches. Table VI shows the surface three inches to be the driest fraction and the six- to twelve-inch section the wettest. Nitrates within these fractions of the surface foot are therefore not correlated with the moisture content of the soil. The proximity of moist layers of soil may, however, be a factor favoring nitrification.

RELATION OF TILLAGE TO FOOT-ROT OF WHEAT

As previously pointed out foot-rot appeared in the plots in 1921 and did so much damage that it was deemed advisable to discontinue the experiments for a time and crop the land to soybeans and oats. As illustrated in figure 4, this disease seemed to develop most rapidly on those plots which were prepared early in the summer. Possibly this is related to the fact that in such cases the stubble usually comes in contact with moist soil thus affording favorable conditions for the growth and spread of the fungus. It has been observed that there is always a greater development of foot-rot on plots plowed seven inches than in those plowed three inches deep in July. The deeper plowing probably places the stubble in contact with more moisture than the shallow plowing.

TABLE X.—Relation of tillage to nitrate content of the soil in fractional portions of the surface foot in September: Nitrates expressed as parts per million dry weight of soil.

Plot No.	1915.			1916.			1917.			1918.		1919.		Average.	
	0–3″	4″–6″	7″–12″	0–3″	4″–6″	7″–12″	0–3″	4″–6″	7″–12″	0–6″	7″–12″	0–6″	7″–12″	0–″6	7″–12″
1	3.0	2.8	1.9	8.8	10.2	15.9	2.1	1.8	1.3	7.4	0.5	4.4	2.7	5.2	7.4
8	.....	.....	.....	12.3	12.8	12.3	3.1	2.6	1.5	8.8	0.0	10.6	2.0	17.3	3.9
9	21.5	17.1	8.1	46.8	57.8	49.0	53.8	52.8	23.8	33.5	53.6	144.0	37.8	60.5	37.2
15	43.1	20.1	8.0	41.1	51.3	35.8	45.1	35.1	23.0	53.6	32.2	58.0	15.5	45.9	22.8

Tillage treatments:
Plot 1.—Double disked at seeding time (about October 1) after mowing and raking off weeds.
Plot 8.—Plowed three inches deep about September 15.
Plot 9.—Plowed seven inches deep about July 15.
Plot 15.—Plowed three inches deep about July 15.

SUMMARY

The data that have been presented indicate that when wheat is grown continuously on the same land early tillage tends to produce higher yields than late tillage. Whether the land be plowed or listed or disked and plowed seems to make but little difference. Foot-rot was favored by early tillage and hence where this disease is a limiting factor late tillage may give larger yields than early tillage.

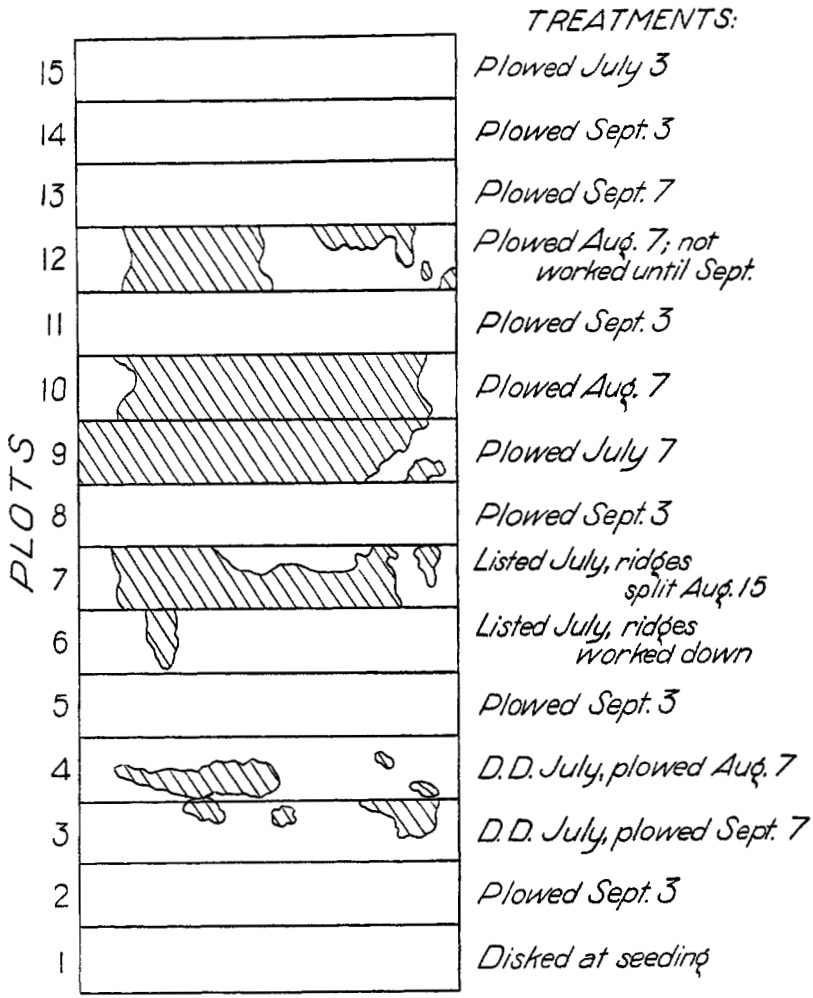

FIG. 4.—Map showing location and size of areas on the continuously cropped series of plots of the old wheat seedbed (plots 1 to 15), infected with wheat foot-rot in 1923.

Early plowing has given better yields than early listing, but early listing has proved better than late plowing. Listing in July produces about the same yield as disking in July and plowing in August or September. Splitting listed ridges does not increase the yield as compared with single listing.

Plowing to a depth of six or seven inches in July has given better yields than plowing to a depth of three inches at the same time, and plowing seven inches deep in September has given better yields than plowing three inches deep at the same time. The differences, however, have been slight.

Moisture and nitrate determinations show a marked relation between accumulation of nitrates in the soil and early tillage, but no marked relation between the time or method of tillage and moisture conservation.

A study of weed growth and of nitrogen stored in weeds suggests that early tillage is beneficial partly or largely because of the control of weeds which otherwise use the nitrogen available for the growing crop.

WHEAT IN ROTATION

As previously mentioned, certain methods of preparing the land for wheat grown in rotation were compared, beginning in 1913. The rotation was wheat, corn, and oats each one year. There were five plots of each crop yearly. The plots for wheat were prepared in five different ways as follows:

Plowed 12 inches deep about July 15
Plowed 7 inches deep about July 15
Plowed 3 inches deep about July 15
Plowed 7 inches deep about August 15
Plowed 3 inches deep about September 15

All plots were worked with a disk and harrow after plowing as necessary to control weeds and volunteer oats and to secure a good tilth.

The corn and oat plots were all prepared uniformly, the wheat stubble being fall plowed six to seven inches deep for corn and the oats being seeded on disked corn stubble.

The yearly and average yields of wheat, grain, and straw, are given in Table XI.

TABLE XI.—Effect of the time and depth of plowing on the yield of wheat and wheat straw when grown in rotation with corn and oats.

TILLAGE TREATMENT.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.	1922.	1923.	11-yr. average.
Yield of Grain—Bushels per Acre												
Plowed July, 12″ deep	44.0	28.1	24.6	16.2	17.5	17.5	25.7	25.4	27.6	29.0	27.3	25.7
Plowed July, 7″ deep	44.6	25.7	23.8	14.4	18.9	17.8	28.4	27.5	30.3	30.9	31.9	26.7
Plowed July, 3″ deep	41.1	31.2	24.4	14.6	18.2	17.5	29.0	30.0	27.5	29.3	29.1	26.8
Plowed August, 7″ deep	41.2	30.6	25.8	16.8	14.5	16.1	27.8	19.3	23.3	21.1	18.6	23.2
Plowed September, 3″ deep	25.5	30.5	25.6	12.7	10.2	9.7	25.9	12.6	10.6	11.6	11.9	17.0
Yield of Straw—Pounds per Acre												
Plowed July, 12″ deep	4,880	4,285	4,771	1,990	1,770	2,282	3,275	2,325	2,970	2,910	3,130	3,144
Plowed July, 7″ deep	4,400	3,460	4,613	1,315	1,566	2,052	2,925	2,340	3,050	3,427	2,935	2,917
Plowed July, 3″ deep	5,145	3,140	3,994	1,620	690	1,972	1,730	2,245	2,160	2,955	2,700	2,577
Plowed August, 7″ deep	3,660	3,815	4,644	1,820	1,350	1,885	3,350	1,480	2,070	1,590	1,895	2,505
Plowed September, 3″ deep	2,320	3,900	3,579	1,230	850	1,575	2,485	790	1,290	710	875	1,782

Time rather than depth of plowing has been the controlling factor in crop yield as was observed in the case of the continuously cropped wheat. Plowing in August has resulted in an average yield two bushels per acre less than plowing in July, and plowing in September nine to ten bushels less than from plowing in July. On the other hand plowing 12, 7, and 3 inches deep in July has produced almost identical yields, the averages being 25.7, 26.7, and 26.8 bushels per acre, respectively.

Rotating the wheat with corn and oats has produced an increase in yield of approximately six bushels per acre over that secured by the same treatment with wheat grown continuously.

The yields of corn and oats produced in rotation with the wheat are presented in Table XII. No consistent differences are apparent which can be definitely correlated with time or depth of plowing for the wheat.

SOIL MOISTURE AND NITRATE DETERMINATIONS WITH WHEAT IN ROTATION

Moisture and nitrate determinations similar to those for the continuously cropped plots were made and the data are presented in Table XIII and graphically in figure 5. As in the case of cropping wheat continuously upon the same land, nitrate development but not moisture conservation is influenced by various methods of preparing the land. September plowing has resulted in a loss of moisture as compared with earlier preparation of the land, but the difference is not large and probably not so significant in relation to yields as is the difference in nitrate development. Early plowing is evidently just as effective in producing abundant nitrification when wheat is grown in rotation as when wheat is grown continuously on the same land.

Varying the depth of plowing in July has had no consistent effect upon the moisture content of the soil. Deep plowing has resulted in a greater accumulation of nitrates than shallow plowing, but this has not been accompanied by larger yields, due perhaps to their being sufficient nitrates with all tillage treatments to produce the highest yield obtained.

SUMMARY OF ROTATION SERIES

It is apparent that, in general, rotation with corn and oats has resulted in a material increase in yields of wheat as compared with continuous cropping. Early preparation also increased the yields over late preparation, the differences being similar to those recorded for the continuously cropped plots.

TABLE XII.—Effect of different methods of preparing the ground for wheat on the yield of the corn the year following and of oats the second year following, 1913 to 1920.

TILLAGE FOR WHEAT.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.	1922.	1923.	Average.
Yield of Corn—Bushels per Acre												
Plowed July, 12″ deep	0	4.0	55.0	40.0	34.3	0	15.9	46.2	45.8	37.6	46.5	29.5
Plowed July, 7″ deep	0	2.6	50.8	41.1	40.1	0	16.2	52.5	45.6	36.7	52.7	30.7
Plowed July, 3″ deep	0	3.3	57.4	44.2	32.5	0	14.8	48.2	40.4	26.4	49.3	28.8
Plowed August, 7″ deep	0	3.5	48.5	45.0	36.6	0	18.3	36.6	42.8	29.7	47.2	28.0
Plowed September, 3″ deep	0	3.5	54.8	44.8	26.0	0	17.2	51.8	36.4	36.3	51.6	29.3
Yield of Corn Stover—Pounds per Acre												
Plowed July, 12″ deep	3,530	2,980	2,805	3,100	4,410	8,220	4,435	2,413	6,900	3,430	2,140	4,033
Plowed July, 7″ deep	4,840	3,050	2,855	3,080	4,610	8,300	4,960	2,250	7,220	1,780	3,730	4,243
Plowed July, 3″ deep	4,700	3,340	2,955	3,160	4,240	8,640	4,880	2,118	6,060	1,600	3,210	4,082
Plowed August, 7″ deep	6,600	3,850	2,775	3,060	4,400	8,530	4,740	2,329	6,240	2,510	3,590	4,420
Plowed September, 3″ deep	6,460	3,930	2,890	3,140	4,350	10,040	3,205	2,706	5,680	3,260	2,170	4,348
Yield of Oats—Bushels per Acre												
Plowed July, 12″ deep	31.5	49.8	37.5	Sudan	36.5	18.4	34.0	6.7	23.6	40.3	44.7	29.4
Plowed July, 7″ deep	35.4	55.4	37.8	grass	41.6	18.3	40.0	9.4	23.1	38.9	49.7	31.8
Plowed July, 3″ deep	38.2	50.9	38.9	planted	45.7	17.5	43.0	8.3	24.5	39.5	45.3	32.0
Plowed August, 7″ deep	36.6	61.7	39.3		50.9	16.0	37.0	7.5	22.6	35.0	43.6	31.8
Plowed September, 3″ deep	28.1	60.3	41.8		50.0	15.5	43.0	14.0	15.6	35.0	47.1	31.8
Yield of Oat Straw—Pounds per Acre												
Plowed July, 12″ deep	1,275	1,385	957	0	1,391	1,120	900	585	715	1,470	1,750	1,050
Plowed July, 7″ deep	1,300	1,500	2,020	0	1,778	1,015	615	360	1,010	1,305	1,720	1,147
Plowed July, 3″ deep	1,470	1,500	1,825	0	1,737	920	1,185	975	865	1,215	1,570	1,206
Plowed August, 7″ deep	1,625	1,675	1,342	0	2,001	1,005	1,120	660	825	1,070	1,585	1,173
Plowed September, 3″ deep	1,220	1,540	1,740	0	2,020	1,095	550	970	800	1,120	1,480	1,139

TABLE XIII.—Relation of (1) moisture content of the soil and (2) nitrates in the soil at seeding time to the time and depth of plowing ground for wheat when grown in rotation with corn and oats.

TILLAGE TREATMENTS.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.	1922.	Average.
Per Cent of Moisture to a Depth of Three Feet												
Plowed July, 12″ deep	23.2	21.9	19.9	25.1	19.1	20.9	18.6	18.9	22.6	18.7	24.3	21.2
Plowed July, 7″ deep	22.3	21.4	20.3	25.8	20.0	17.2	19.7	18.4	22.6	16.6	23.6	20.7
Plowed July, 3″ deep	22.7	21.2	20.1	25.8	20.3	16.3	19.6	19.6	27.0	15.3	23.5	21.0
Plowed August, 7″ deep	22.7	21.4	20.4	24.9	19.4	16.6	19.9	17.7	20.0	15.7	21.1	20.0
Plowed September, 3″ deep	21.7	21.2	19.4	23.8	17.6	14.2	15.7	15.5	19.5	15.1	19.1	18.4
Nitrates P. P. M. to a Depth of Three Feet												
Plowed July, 12″ deep	34.8	18.0	47.2	8.3	30.8	23.3	23.8	18.5	25.4	8.06	14.5	23.0
Plowed July, 7″ deep	26.2	14.4	51.2	11.8	22.3	13.1	20.2	18.6	24.7	8.20	11.5	20.2
Plowed July, 3″ deep	27.7	14.6	45.4	7.2	12.6	9.4	46.4	10.4	23.0	5.96	12.4	19.5
Plowed August, 7″ deep	17.5	18.3	39.6	3.9	12.3	10.2	20.3	11.0	11.4	3.36	5.8	14.0
Plowed September, 3″ deep	7.7	16.6	32.0	1.3	10.1	4.1	3.7	1.1	5.5	1.72	2.6	7.8

The acre production of wheat was approximately unchanged whether plowing in preparation was twelve, seven, or three inches deep. The yields of corn and oats in this rotation were not affected by the depth of plowing for wheat. The wheat stubble was fall plowed about seven inches deep for corn and the oats was planted on disked corn stubble. These results made evident the possibility of greater economy on tillage operations. For instance, the yields of wheat are about five bushels per acre greater in this rotation than for the same tillage treatments with wheat grown continuously on

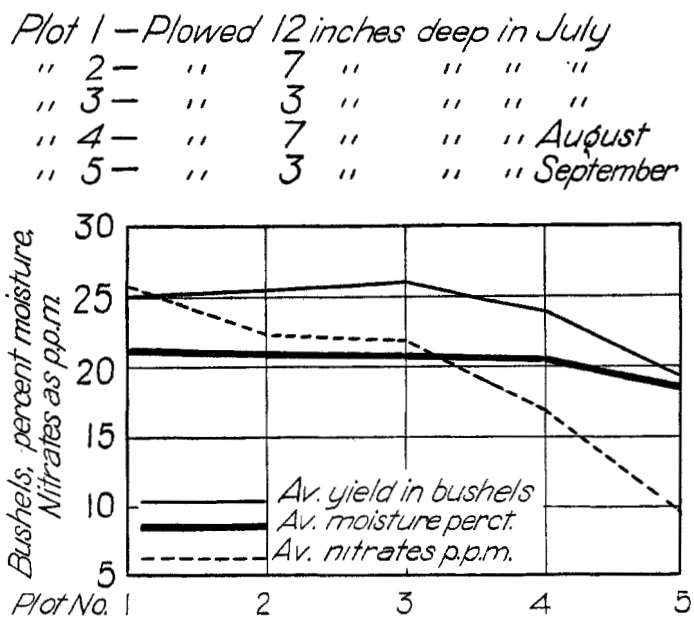

FIG. 5.—Relation of moisture and nitrate content at time of seeding to average yield of wheat in rotation series.

adjoining land. Also shallow plowing is just as effective as deeper plowing in the case of the rotated wheat. Hence in the rotation it costs less to produce a larger yield. Furthermore, the oat crop is introduced and produced cheaply by disking the corn stubble. Plowing is done only two years out of three, one year deep and one year shallow. The deep plowing is done in the fall, a more advantageous time for this work than in summer.

These ideas obtained from the old wheat seedbed plots led to the introduction in recent experiments of tillage treatments that would have a more direct bearing on the matter of frequency of plowing.

CONTINUOUSLY CROPPED PLOTS: RECENT EXPERIMENTS

As previously explained, some new experiments were begun in 1919 to clear up certain points raised in the earlier work. For example, while the older experiment furnished conclusive evidence regarding the effect of time of plowing on the yield, more infomation was needed concerning the importance of depth and frequency of plowing. It also seemed desirable to secure data relative to the effect of incorporating stubble with the soil as is done in plowing and in addition find out the effect of applying straw both before and after plowing.

TILLAGE TREATMENTS AND YIELDS

The treatments and the average yields are given in Table XIV. Foot-rot of wheat, which caused the temporary abandonment of the old wheat seed-bed project in 1923, appeared in the new wheat seedbed project in 1924. The yields for 1924 are therefore omitted from the averages. The yields as given for each year are the averages of three plots distributed over the experimental area.

The probable error of the experiment has been calculated by averaging the probable errors for each year and applying the formula for the probable error of an arithmetic mean, E av. $= \frac{\sqrt{E_1^2+E_2^2+\ldots E_n^2}}{N}$ where E_1, E_2, ... E_n are the average probable errors for each year. This comes out to be 0.65 of a bushel as the probable error for the four-year average yields. In general then it may be concluded that any differences of less than 0.65 of a bushel are probably due to experimental error while any less than 2.9 bushels ($0.65 \times \sqrt{2} \times 3.2$) are not statistically significant.

The limitations incidental to this interpretation as stated on page 12 should be kept in mind. On the other hand, it may be observed that the ground on which this experiment is located is somewhat rolling and hence more variable in yield than that of the earlier experiment. This has resulted in a high probable error. Most of the plots which are compared directly, however, lie near each other and hence the comparisons for the most part are more accurate than is indicated by the probable error.

Deep Versus Shallow Plowing

Shallow and deep plowing in July for the four years in which comparisons are made have been equally effective in the production of wheat. The average yields are 27.2 and 27.6 bushels per acre, respectively. Shallow plowing has also produced as large yields as

TABLE XIV.—The effect of different methods of tillage and application of straw on the yield of winter wheat grown continuously on the same land.

TILLAGE TREATMENT.	1920.	1921.	1922.	1923.	1924 (a).	Average, 1920–'23.
Plowed shallow in July	29.5±0.29	25.2±0.94	33.7±1.35	20.4±1.08	9.2	27.2
Plowed deep in July	26.5±0.23	27.7±1.28	33.6±2.29	22.8±1.55	7.2	27.6
Plowed deep and shallow alternate years, deep, 1919	28.7±1.06	26.4±0.87	36.7±1.14	22.9±0.74	10.0	28.7
Plowed deep in July every third year, deep, 1919	24.3±0.39	25.7±1.68	35.2±1.48	22.5±1.55	11.1	26.9
Plowed deep in July every sixth year, deep, 1919	25.4±1.22	24.8±2.22	33.8±0.81	18.2±2.16	11.5	25.6
Disked during the summer, not plowed	23.8±2.15	18.2±2.29	26.0±2.43	13.8±1.08	8.1	20.4
Disked during the summer, plowed shallow, September	24.7±1.25	18.3±1.55	23.5±2.02	17.1±1.68	8.3	20.9
Disked during the summer, plowed deep, September	21.6±1.16	16.6±1.35	21.4±1.75	16.9±1.81	10.7	19.1
Weeds allowed to grow; disked at seeding time	12.1±0.74	4.3±0.33	4.7±0.60	3.8±0.33	2.2	6.2
Scraped; disked at seeding time	22.6±2.75	15.6±1.48	21.9±1.95	13.6±3.30	9.4	18.4
Plowed shallow in September	19.0±2.01	9.1±0.94	11.5±0.40	10.1±0.28	4.5	12.4
Plowed deep in September	17.5±1.14	11.8±1.08	12.8±0.80	10.4±0.67	6.9	13.1
Plowed shallow in August	24.5±0.47	20.5±1.41	28.9±2.56	13.8±0.13	9.3	21.9
Stubble burned; plowed deep in July	27.3±0.39	23.7±2.49	31.6±1.21	18.3±0.87	11.3	25.2
Stubble burned; plowed shallow in July	29.3±0.74	23.9±1.08	31.3±0.47	19.6±2.49	10.7	26.0
Straw applied before plowing; plowed deep in July	29.5±0.39	29.7±1.75	34.5±1.89	21.6±2.63	15.5	28.8
Straw applied before plowing; plowed shallow, July	32.1±0.35	27.1±0.58	33.2±1.01	19.4±1.88	13.2	28.0
Straw applied after plowing; plowed deep in July	29.0±0.94	30.7±2.42	35.9±0.47	19.8±2.63	13.1	28.8
Straw applied during winter; plowed deep in July	26.1±1.28	28.8±2.02	29.1±3.77	19.0±3.91	6.9	25.7

(a) Foot-rot of wheat in 1924 materially injured many of the plots and hence the yields for this year are not included in the averages.

deep plowing which had straw applied before and after plowing, respectively. These results are in accord with those obtained in the wheat grown in rotation previously discussed, but do not conform entirely to the earlier experiments where wheat was grown continuously.

Frequency of Plowing

The yields indicate that deep plowing (seven inches) once in three years with shallow plowing in other years may produce yields equal to those from annual deep plowing. For the four years, the yields have been 27.6 bushels for the annual deep plowing, 28.7 for the deep plowing every alternate year, and 26.9 bushels for deep plowing once in three years.

Straw Treatments

Burning the stubble resulted in a slight decrease in yield, the differences for the two comparisons being 1.6 and 2.4 bushels. Applying approximately 3,000 pounds of straw per acre and turning it under or applying this amount after plowing and disking it into the soil, seemed to have no material effect as far as the data show. Applying the straw as a top dressing during the winter, decreased the yield 1.9 bushels per acre. While the differences noted above are so small as to be of doubtful significance, the data as a whole must be taken to indicate a definite relation between yield and utilization of straw. As a matter of fact, the difference in yield between the plot on which straw is plowed under and that in which the stubble is burned, is more than five times the probable error of the experiment. It would seem therefore that there are good reasons to believe that straw used in the proper way tends to increase the yield and that burning the stubble tends to decrease the yield. At the same time it should be recognized that an experiment of four years duration is not sufficient to settle this question.

Necessity of Plowing

That the control of weed growth during the summer is one of the principal beneficial effects of preparing the land early in the summer is shown by the fact that where weeds were allowed to grow, the yield was 6.2 bushels per acre, whereas when the weeds were kept down by scraping the average yield was 18.4 bushels, the land being prepared in each case by disking. Disking during the summer and at seeding time keeps down weeds and produces about the same average yield as the summer scraping. Since plowing in July pro-

duced an approximate yield of 27 bushels per acre it is apparent that plowing is necessary for reasons other than controlling weed growth.

METHODS EMPLOYED IN SOIL SAMPLING

Soil samples for moisture and nitrate determinations were taken at three monthly periods during the summer on eight different treatments. The depth of sampling was 0 to 6 inches, 7 to 12 inches, 12 to 24 inches, and 24 to 36 inches. Cores were taken with steel tubes and determinations for the surface 6-inch and 7- to 12-inch samples were based upon composites from five cores. Three cores taken diagonally across the plots made up the second- and third-foot samples. The data presented for each treatment are the averages of triplicate plots.

SOIL MOISTURE

The average moisture content for the period of the experiment for eight different tillage treatments are presented in Table XV. Table XXIII in the appendix shows the moisture data for individual years.

There is more moisture in soil plowed in July than in soil plowed in September. The difference during August is 8 per cent, comparing the moisture in the surface six inches. Nitrification is most active in the surface soil and increases with the higher per cents of moisture. Hence it is important to take into consideration the differences in moisture in the surface soil in July plowing and September plowing rather than only the averages that are given for a depth of three feet.

The average moisture in a depth of three feet shows that there is 2 to 3 per cent more moisture during August and 4 per cent more during September, in the soils receiving July rather than September plowing.

The July moisture determinations are made just before the plots receive the designated tillage treatments. There is at this time a consistent slight difference in moisture favoring the soils that had received July tillage treatments the previous summer.

The correlation of the soil moisture with nitrates and yields is shown in figure 6.

Depth of plowing in reference to four- and seven-inch depths has not caused any noteworthy difference in soil moisture. The average mean probable error in moisture determinations is 0.35 of 1 per cent. A statistically significant moisture difference would be $0.35 \times \sqrt{2} \times 3.2$, or 1.58 per cent. This calculation is based upon the application of Bessel's formula as explained in the discussion of the probable error in yields of grain.

TABLE XV.—Average per cent of moisture to a depth of three feet, 1920 to 1924.

TILLAGE (a).	July.						August.						September.					
	0''-6''	7''-12''	Av. 1st foot.	Av. 2d foot.	Av. 3d foot.	Av. in 3 feet.	0''-6''	7''-12''	Av. 1st foot.	Av. 2d foot.	Av. 3d foot.	Av. in 3 feet.	0''-6''	7''-12''	Av. 1st foot.	Av. 2d foot.	Av. 3d foot.	Av. in 3 feet.
1	20.2	22.5	21.3	20.9	17.0	19.7	22.4	23.6	23.0	22.8	19.9	21.9	20.0	22.4	20.2	23.3	20.5	21.3
2	20.3	21.8	21.0	21.2	17.0	19.7	21.4	24.5	22.9	23.0	20.5	22.1	20.1	23.6	21.8	23.0	20.8	21.9
3	17.7	19.9	18.8	19.8	17.5	18.7	14.4	16.9	15.6	18.2	19.2	17.7	16.5	19.0	17.7	18.1	16.9	17.6
4	19.6	21.9	20.7	19.4	18.5	19.5	18.8	21.9	20.3	20.3	21.1	20.6	19.0	22.7	20.8	20.8	19.3	20.3
5	18.0	20.8	19.4	19.1	17.6	18.7	14.5	18.5	16.5	19.0	20.2	18.6	16.5	18.3	17.4	17.5	18.7	17.9
6	20.4	22.2	21.3	21.0	16.9	19.7	17.0	19.5	18.2	21.4	20.7	20.1	19.4	22.8	21.1	20.9	19.7	20.6
7	20.6	22.8	21.7	21.7	16.6	20.0	21.7	24.7	23.2	23.0	20.6	22.3	22.0	22.5	22.2	23.1	20.6	22.0
8	20.8	23.6	22.2	22.0	18.2	20.8	22.6	24.9	23.7	23.8	21.9	23.1	20.4	25.2	22.8	24.2	21.3	22.8

(a) The tillage treatments on which moisture data were obtained are as follows:
1.—Plowed shallow in July.
2.—Plowed deep in July.
3.—Weeds allowed to grow; disked at seeding time.
4.—Scraped; disked at seeding time.
5.—Plowed shallow in September.
6.—Plowed shallow in August.
7.—Stubble burned; plowed shallow in July.
8.—Straw applied before plowing; plowed shallow in July.

The scraped plots in Table XV contain about 1 per cent less moisture than the plots plowed in July. This difference may be due to experimental error, but more probably to a greater surface run off on the plots that were scraped.

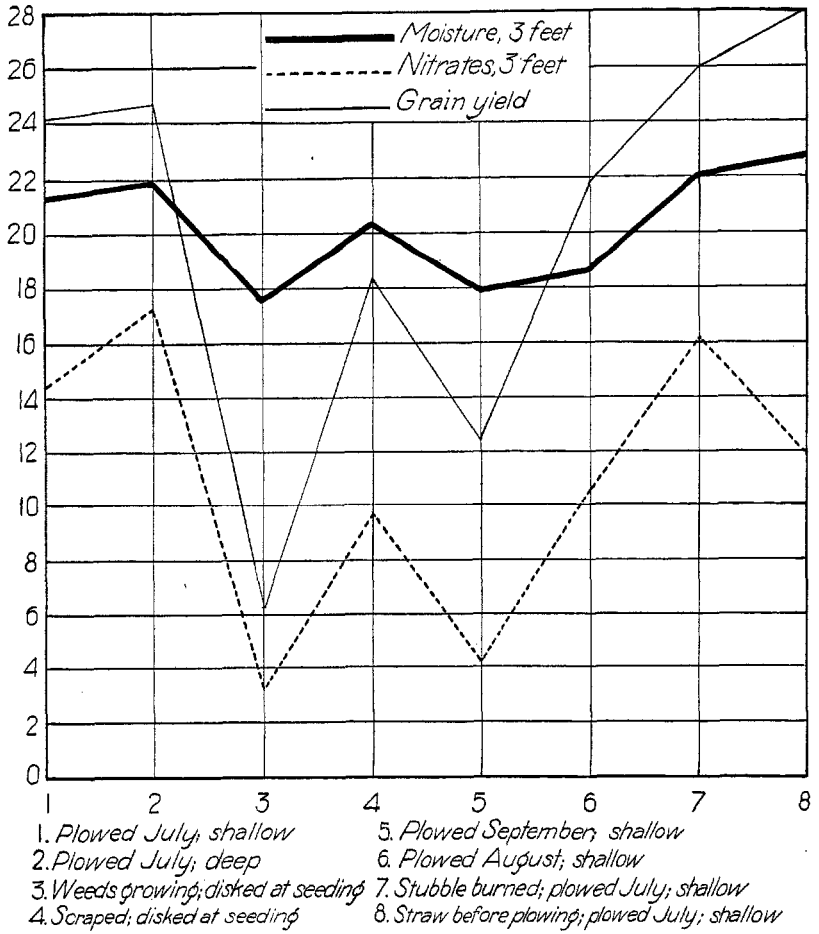

FIG. 6.—Relation of moisture and nitrate content of the soil September 15, to yield of the following crop. The figures give four-year averages, 1920 to 1923, on land cropped continuously to wheat.

SOIL NITRATES

Time of plowing is a most important factor in the development of the supply of nitrates in the soil. In the surface six inches of soil at the time of September sampling there is a difference of 35 parts per million of nitrates in favor of the soil plowed in July in com-

parison with soil plowed in September. The difference is about 16 parts per million for the 7- to 12-inch horizon of soil. The probable error in the nitrate determinations has been 1.6 parts per million, hence a statistically significant difference would be $3.2 \times \sqrt{2} \times 1.6$, or 7.1 parts per million. The nitrate data are presented in Table XVI.

Depth of plowing is a factor in nitrification though secondary to time of plowing. The average nitrates in the surface foot of soil during the middle of September have been 34.2 parts per million in the soil plowed seven inches in July and 29.2 parts per million for four-inch July plowing. This difference though not great enough to be statistically significant is sufficient to show that nitrification is slightly greater in the case of deeper plowing. Since the plots that were surface scraped during the summer and disked at seeding contained only 19.0 parts per million nitrates in September, some stirring of the soil is evidently beneficial for nitrification if the soil is not plowed occasionally.

The application of straw before plowing, 3,000 pounds per acre, and turning it under has caused a slight decrease in nitrification. This treatment resulted in an average of 27.5 parts per million of nitrates and the same tillage without straw of 38.0 parts per million in the surface soil.

The burning of stubble does not show any noteworthy difference in nitrification compared with turning under the stubble the same date and depth. The difference that does exist is no greater than the probable error of 1.6 parts per million.

The amount of nitrification is directly related to moisture as brought out in figure 6. There is also a decided correlation between the amount of nitrates and yield with the exception of the treatment which includes the application of straw before plowing. At this station Scott[7] found that the incorporation of two tons of straw in the soil in the late fall caused a depression in nitrification but in the following spring, April determinations showed as high nitrification as in the plots receiving no straw. In the light of these straw experiments, the apparent lack of correlation between nitrates and yield in the case of the straw treatment, is because the nitrate samples were taken in September when nitrification was still depressed by the effect of the straw. The following spring nitrification was probably active and increased sufficiently to have shown a correlation with the yield.

7. Scott, Herschel. The influence of wheat straw on the accumulation of nitrates in the soil. Jour. Amer. Soc. Agron. Vol. XIII, No. 6-7, pages 233 to 258. 1921.

TABLE XVI.—Average nitrates, expressed as parts per million dry soil, in depth of three feet, 1920 to 1924.

TILLAGE (a).	July.						August.						September (b).					
	0"-6"	7"-12"	Av. 1st foot.	Av. 2d foot.	Av. 3d foot.	Av. in 3 feet.	0"-6"	7"-12"	Av. 1st foot.	Av. 2d foot.	Av. 3d foot.	Av. in 3 feet.	0"-6"	7"-12"	Av. 1st foot.	Av. 2d foot.	Av. 3d foot.	Av. in 3 feet.
1	23.1	13.7	18.4	5.6	5.4	9.8	37.9	22.6	30.2	9.3	5.2	14.9	38.0	20.4	29.2	8.5	5.9	14.5
2	21.9	20.1	21.1	10.3	12.2	14.5	27.9	22.0	24.9	10.9	5.9	13.9	43.1	25.3	34.2	10.4	7.0	17.2
3	8.7	7.7	8.2	3.5	3.5	5.1	16.5	7.6	12.0	2.8	2.7	5.8	3.8	3.1	3.4	3.2	3.0	3.2
4	15.2	15.5	15.3	4.6	7.6	9.2	24.1	19.1	21.6	7.6	9.1	12.8	24.8	13.3	19.0	5.4	4.7	9.7
5	11.8	8.8	10.3	2.8	3.5	5.5	10.2	10.4	10.3	3.5	2.9	5.6	5.0	4.1	4.5	4.2	3.5	4.1
6	19.8	17.5	18.6	6.1	3.3	9.3	23.6	20.3	21.9	7.8	6.9	12.2	21.9	14.8	18.4	9.4	3.9	10.6
7	20.4	14.1	17.2	13.3	4.1	11.5	34.9	24.2	29.5	9.4	8.5	15.8	35.7	20.9	28.3	10.9	9.0	16.1
8	15.4	16.4	15.9	7.8	4.5	9.4	26.1	18.5	22.3	9.3	5.4	12.3	27.5	16.6	22.0	8.3	5.4	11.9

(a) Tillage treatments on which moisture data were obtained are as follows:
1.—Plowed shallow in July.
2.—Plowed deep in July.
3.—Weeds allowed to grow; disked at seeding time.
4.—Scraped; disked at seeding time.
5.—Plowed shallow in September.
6.—Plowed shallow in August.
7.—Stubble burned; plowed shallow in July.
8.—Straw applied before plowing; plowed shallow in July.
(b) September data were obtained only from 1921 to 1924.

The result of the nitrate determinations on the new wheat seedbed project are in accord with the nitrate studies of the earlier tillage experiments, except that in the latter case nitrates increased up to the time of seeding, October 1. The earlier tillage experiment did not include a scraped surface treatment, although reference has been made previously to nitrification studies conducted on small plots. The results from surface scraping on these plots had indicated that nitrification might be as great as in the soil cultivated deep or shallow. However, in this instance the scraped surfaces were spaded in the fall prior to planting wheat and a new series of plots were used the next spring. The scraped plots in this new wheat seedbed were only disked at seeding time and received the same treatment year after year without any alternate years of tillage.

The importance of eliminating weed growth during the summer from fields that are to be planted to fall wheat is brought out by comparing the nitrates in the surface soil where weeds are growing and where the surface has been scraped. In September there has been an average of 24.8 parts per million of nitrates in the surface six inches of soil on the scraped plots, and 3.8 parts per million where weeds are allowed to grow. In the 7- to 12-inch horizon of the soil, the difference has been 10.2 parts per million in favor of the scraped treatment.

SUMMARY

By way of briefly summarizing the results it may be pointed out that shallow three- to four-inch plowing in July has given as good grain yields as seven-inch plowing at the same time and that deep plowing (seven inches) once in three years has produced yields equal to those from annual deep plowing. Some plowing of the soil seems to be necessary for maximum yields. The control of weed growth is but one of the principal effects of plowing.

The incorporation of approximately 3,000 pounds of straw per acre at the time of summer plowing consistently increased the yield of wheat more than one bushel per acre.

Burning the stubble or applying 1.5 tons of straw as a top dressing during the winter decreased the yield.

GENERAL DISCUSSION AND SUMMARY

The results of three separate experiments relating to the preparation of the ground for wheat have been presented. It seems desirable to bring together at this point all the data pertaining to each cultural operation.

TABLE XVII.—Relation of time of plowing to the yield of winter wheat.

TILLAGE TREATMENT.	Wheat continuously; early experiments; average for 10 years.			Wheat in rotation; average for 11 years.			Wheat continuously; recent experiments; average for 4 years.		
	Yield in bushels per acre.	Per cent moisture at seeding time (a).	Nitrates PPM at seeding time (a).	Yield in bushels per acre.	Per cent moisture at seeding time (a).	Nitrates PPM at seeding time (a).	Yield in bushels per acre.	Per cent moisture at seeding time (a).	Nitrates PPM at seeding time (a).
Plowed in July, 7" deep.....	20.7	23.5	58.9	26.7	22.3	39.8	27.6	21.8	34.2
Plowed in August, 7" deep.....	19.0	23.6	39.1	23.2	22.0	27.4	(b) 21.9	21.1	18.3
Plowed in september, 7" deep.....	11.6	21.1	19.7	(b) 17.0	18.6	13.5	13.1	17.4	4.5

(a) In surface foot of soil. (b) Shallow plowing.

TIME OF PLOWING

In order to show clearly the effect of time of plowing on yield, the data bearing upon this problem have been assembled in Table XVII.

Early plowing has in all cases produced a much larger yield than late plowing. The difference between July and September plowing is 9.1 bushels, 9.7 bushels, and 14.5 bushels, respectively, in the three phases of the experiment. The difference between July and August plowing is 1.7 bushels, 3.5 bushels, and 5.7 bushels, respectively.

Greenhouse work on soil from this area has shown that the soil of the more recently established experiments responds more to nitrogen than the older plots. It is natural to expect the land deficient in nitrogen to respond to a greater degree to early preparation and the data bear out this supposition.

The higher yields resulting from early plowing are no doubt largely due to the greater accumulation of nitrates in the soil. There is a difference in moisture content of the soil at the time of fall seeding, in favor of early plowing. The variations, however, are not as closely correlated with yield as are the nitrates.

The difference in the amount of moisture in the surface soil may be a contributing cause to the difference in yield between early and late plowing, but the difference in nitrate accumulation is probably the principle reason. Wheat germinates well on September-plowed land, but does not stool out as much as wheat on the land receiving early summer plowing and is always a yellow green in color. This color effect is very noticeable in the spring. This is rather a decisive indication that the benefit of early summer plowing is largely due to the increase in nitrate accumulation.

DEPTH OF PLOWING

A comparison of the effectof various depths of plowing on yield is presented in Table XVIII in which deep and shallow July treatments are contrasted.

Plowing evidently is beneficial for reasons other than killing weed growth. The yield has been 18.4 bushels per acre where there has not been any plowing but where weed growth has been prevented by surface scraping. Where summer disking was practised to prevent weed growth, the average yield increased two bushels per acre. With plowing three inches deep in July the yield increased 8.8 bushels per acre. Approximately the same increase occurred with seven-inch July plowing.

TABLE XVIII.—Effect of depth of plowing upon yield.

TILLAGE TREATMENT.	Wheat continuously; early experiments; average for 10 years.			Wheat in rotation; average for 11 years.			Wheat continuously; recent experiments; average for 4 years.		
	Yield in bushels per acre.	Per cent moisture at seeding time (a).	Nitrates PPM at seeding time (a).	Yield in bushels per acre.	Per cent moisture at seeding time (a).	Nitrates PPM at seeding time (a).	Yield in bushels per acre.	Per cent moisture at seeding time (a).	Nitrates PPM at seeding time (a).
Plowed 12" deep in July	.....	.....	.....	25.7	23.0	46.2	.....	.....	.....
Plowed 7" deep in July	20.7	23.5	57.7	26.7	22.3	41.5	27.6	21.8	34.2
Plowed 3" deep in July	15.0	23.3	45.7	26.8	22.1	37.5	27.2	21.2	29.2
Disked during summer to prevent weed growth	.....	.....	.....	.....	.....	.....	20.4	.....	.....
No plowing; surface scraped during summer and disked at seeding time	.....	.....	.....	.....	.....	.....	18.4	20.8	19.0
Disked at seeding time	7.7	20.3	12.4	.....	.....	.....	6.2	17.7	3.4
Plowed 7" deep in September	11.7	21.1	12.3	.....	.....	.....	.....	.....	.....
Plowed 3" deep in September	12.2	20.8	14.6	.....	.....	.....	.....	.....	.....

(a) In surface foot of soil.

Since land disked at seeding time with no previous tillage produced a yield of only 6.2 bushels per acre and the land scraped during the summer to prevent weed growth and disked at seeding yielded 18.4 bushels, the difference, 12.2 bushels, must be due to the elimination of weed growth.

The additional benefit of plowing beside checking weed growth may be due to increased aeration and greater bacterial development. This seems to be the case if the rate of nitrification is a measure of chemical and bacterial activities. The nitrate accumulation is much greater for the four-year period on land plowed in July than on the land scraped during the summer and disked at seeding time. As regards soil moisture there is practically no difference.

As to the question of what depth it is necessary to plow for maximum yields, the evidence favors a medium depth of plowing. In the case of wheat in rotation the average yield for 11 years has been approximately the same as for 12-, 7-, and 4-inch plowing. The yields of the succeeding crops of corn and oats are no less on the land plowed shallow in July for wheat than on the land plowed at greater depths for wheat. In this rotation all the land is fall plowed about 6 inches deep for corn once in three years.

In the earlier experiment the yields from shallow and deep July plowing show a wide difference; namely 5.7 bushels per acre in favor of deep July plowing. In this case there are 15 plots with 5 check plots. If the yields from 10 different treatments are corrected by a graph system according to the average and actual yields of the check plots, the difference in yield between deep and shallow plowing is not so great. When corrected in the manner indicated, the average yield from July 7-inch plowing is 19.2 bushels per acre and from July 3-inch plowing, 17.5 bushels per acre. The difference then is only 1.7 bushels per acre in favor of the deeper plowing. Considering all phases of the work it is rather clear that deep plowing has had no material effect on yield as compared with shallow plowing.

At the time of fall seeding, there is very little difference in the amount of moisture in the surface foot of soil among the various depths of July plowing. Nitrate accumulation is greater with the deeper depths of plowing, though apparently ample with the shallow July plowing.

FREQUENCY OF PLOWING

The results of treatments dealing with this question show that there is no appreciable difference in yield between deep and shallow plowing annually, alternate years, or deep once in three years. The

alternate deep and shallow treatments gave an actual increase of one bushel per acre compared with deep plowing annually, a difference but slightly greater than the probable error.

CONCLUSIONS

1. Decreases in crop production costs can be made by timely tillage and by the use of crop rotations.

2. The time of tillage is the most important factor in the preparation of land for wheat. An average difference between July and September plowing of approximately 11 bushels per acre was recorded.

3. Depth of plowing has not varied the yield in two out of three different tillage experiments.

4. Yields of wheat can be maintained without deep plowing every year. Once in three years may be sufficient for maximum yields.

5. Early summer tillage increases the amount of soil moisture and nitrates in comparison with late summer tillage.

6. Depth of plowing does not cause any variation of soil moisture. Seven-inch compared with three-inch plowing, has shown an increase in nitrate accumulation.

7. Plowing in July resulted in greater nitrification and higher yields than no plowing but scraping the soil to eliminate weeds. Hence plowing is beneficial for reasons other than the killing of weeds.

8. Plowing under about 3,000 pounds of straw per acre in July or disking the straw into land immediately after plowing in July, has occasioned a slight increase in yield of wheat. The practice of applying straw as a top dressing during the winter has decreased the yield. Burning the stubble before plowing has also decreased yield.

9. When wheat is grown continuously upon the same land, even with the practice of the best known methods of seedbed preparation, the crop is subject to plant diseases and insect attack.

APPENDIX

Data of value in a careful study and analysis of the investigations are herein tabulated. These data include: (1) Volume weights of soil. (2) Moisture equivalents of soil. (3) Nitrogen and carbon analyses of soil. (4) Precipitation record. (5) Moisture and nitrate data in detail: Recent experiments.

TABLE XIX.—Volume weights of soil.

DEPTH.	Number of determinations.			Average.
	1.	2.	3.	
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
1st foot	82.46	83.07	80.83	82.13
2d foot	87.34	89.63	.....	88.48
3d foot	92.43	94.37	94.47	93.76
4th foot	89.38	90.96	91.97	90.77
5th foot	90.24	92.28	.....	91.26
6th foot	94.21	95.28	.....	94.74

TABLE XX.—Moisture equivalents of soil.

Plot No. (a).	Upper end of plots—depth in feet.							Lower end of plots—depth in feet.						
	1.	2.	3.	4.	5.	6.	Average.	1.	2.	3.	4.	5.	6.	Average.
1	27.0	31.3	31.0	26.7	27.7	27.0	28.5	27.6	32.7	32.1	29.2	28.4	28.4	29.7
2	25.8	31.4	31.4	30.2	28.8	26.3	29.0	27.5	30.9	32.9	31.9	28.6	28.2	30.0
3	26.2	31.7	29.5	28.0	27.3	25.0	28.0	25.6	31.7	31.7	28.8	27.6	27.7	28.8
4	29.2	30.2	30.0	30.2	28.3	25.2	28.9	26.9	31.1	31.8	29.9	26.1	28.1	29.0
5	27.4	31.7	26.5	28.7	26.4	25.9	27.8	28.6	32.2	31.6	29.1	27.1	27.8	29.4
6	26.4	31.2	31.3	29.9	28.2	26.0	28.9	26.7	31.5	31.8	27.9	25.4	25.9	28.2
7	27.1	32.0	29.7	29.3	29.5	29.5	29.6	26.9	32.2	31.0	28.5	26.6	25.6	28.5
8	26.9	32.9	28.8	27.9	25.8	23.1	27.6	27.4	34.1	29.7	24.7	23.4	25.1	27.4
9	24.0	30.6	31.2	26.8	25.1	.....	27.6	29.2	33.1	31.2	27.5	23.3	25.0	28.2
10	26.4	33.6	.....	28.3	26.0	27.7	28.4	25.5	29.0	27.8	26.2	27.6	26.2	27.1
11	29.5	27.7	28.3	25.8	26.0	25.7	27.2	26.4	31.4	27.4	.....	25.5	24.6	27.1
12	28.8	31.7	28.3	.....	.....	26.8	28.9	25.1	27.8	26.7	27.0	24.3	25.3	26.1
13	27.6	30.4	27.6	27.3	27.1	27.0	27.9	25.4	29.6	28.1	26.8	25.2	24.8	26.7
14	27.4	26.1	28.2	25.3	24.7	24.3	26.0	25.0	32.4	27.0	25.7	25.0	26.2	26.9
15	27.9	30.6	27.6	26.4	26.0	25.0	27.3	26.1	30.6	26.4	25.1	24.6	23.6	26.1

(a) Tillage treatments: Plot 1.—Double disked at seeding time. Plot 2.—Plowed September 15, 3 inches deep. Plot 3.—Double disked July 15; plowed September 15, 7 inches deep. Plot 4.—Double disked July 15; plowed August 15, 7 inches deep. Plot 5.—Plowed September 15, 3 inches deep. Plot 6.—Listed July 15; ridges worked down. Plot 7.—Listed July 15; ridges split August 15. Plot 8.—Plowed September 15, 3 inches deep. Plot 9.—Plowed July 15, 7 inches deep. Plot 10.—Plowed August 15, 7 inches deep. Plot 11.—Plowed September 15, 3 inches deep. Plot 12.—Plowed August 15, 7 inches deep; not worked till September 15. Plot 13.—Plowed September 15, 7 inches deep. Plot 14.—Plowed September 15, 3 inches deep. Plot 15.—Plowed July 15, 3 inches deep.

TABLE XXI.—Total nitrogen and carbon analyses of soil.

Plot No.	Depth.	TILLAGE TREATMENT.	1915.		1916.	
			Per cent nitrogen.	Per cent carbon.	Per cent nitrogen.	Per cent carbon.
1*	0–3″	Double disked at seeding time	0.164	2.00	0.166	2.05
1	4–7″	Double disked at seeding time	.171	1.99	.159	1.86
2	0–3″	Plowed September 15, 3″ deep	.161	2.04		
2	4–7″	Plowed September 15, 3″ deep	.171	2.05		
3	0–7″	Double disked July 15; plowed September 15, 7″ deep	.166	2.06		
4	0–7″	Double disked July 15; plowed August 15, 7″ deep	.158	1.90		
5	0–3″	Plowed September 15, 3″ deep	.157	1.87		
5	4–7″	Plowed September 15, 3″ deep	.160	1.94		
6	0–7″	Listed July 15; ridges worked down	.156	1.94		
7	0–7″	Listed July 15; ridges split August 15	.161	1.95		
8	0–3″	Plowed September 15, 3″ deep	.157	1.91	.150	1.70
8	4–7″	Plowed September 15, 3″ deep	.159	1.97	.146	1.65
9	0–7″	Plowed July 15, 7″ deep	.152	1.98	.158	1.61
10	0–7″	Plowed August 15, 7″ deep	.163	1.98		
11	0–3″	Plowed September 15, 3″ deep	.153	1.84		
11	4–7″	Plowed September 15, 3″ deep	.154	1.95		
12	0–7″	Plowed August 15; not worked until September 15	.149	1.77		
13	0–7″	Plowed September 15, 7″ deep	.145	1.72		
14	0–3″	Plowed September 15, 3″ deep	.149	1.73		
14	4–7″	Plowed September 15, 3″ deep	.151	1.73		
15	0–3″	Plowed July 15, 3″ deep	.136	1.53	.140	1.39
15	4–7″	Plowed July 15, 3″ deep	.145	1.58	.129	1.44
16	0–7″	Plowed July 15, 12″ deep	.159	1.90		
17	0–7″	Plowed July 15, 7″ deep	.175	2.01		
18	0–7″	Plowed July 15, 3″ deep	.163	2.13		
19	0–7″	Plowed August 15, 7″ deep	.154	1.88		
20	0–7″	Plowed September 15, 3″ deep	.163	1.91		
21	0–7″	Plowed July 15, 12″ deep	.155	1.90		
22	0–7″	Plowed July 15, 7″ deep	.159	1.90		
23	0–7″	Plowed July 15, 3″ deep	.154	1.82		
24	0–7″	Plowed August 15, 7″ deep	.159	1.86		
25	0–7″	Plowed September 15, 3″ deep	.151	1.79		
26	0–7″	Plowed July 15, 12″ deep	.154	1.80		
27	0–7″	Plowed July 15, 7″ deep	.150	1.84		
28	0–3″	Plowed July 15, 3″ deep	.148	1.86		
28	4–7″	Plowed July 15, 3″ deep	.154	1.88		
29	0–7″	Plowed August 15, 7″ deep	.139	1.95		
30	0–3″	Plowed September 15, 3″ deep	.156	1.96		
30	4–7″	Plowed September 15, 3″ deep	.153	1.97		

Plots 1 to 15 were cropped continuously to wheat.
Plots 16 to 30 were cropped in a rotation of corn, oats, and wheat, five plots to each crop.

TABLE XXII.—Annual precipitation in inches by months, 1909 to 1923.

YEAR.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April.	May.	June.	Total.	Average.
1909	9.57	0.59	5.21	1.60	7.98	2.19	0.22	1.27	3.40	2.07	4.41	5.00	43.51	3.63
1910	5.83	10.70	2.79	0.90	0.20	0.56	1.46	0.30	0.01	0.51	8.71	1.84	33.81	2.82
1911	2.13	5.52	4.49	1.55	1.05	2.37	0.61	5.78	0.85	1.89	2.18	0.10	28.52	2.38
1912	3.23	3.38	3.50	3.37	0.05	0.41	0.30	2.47	6.49	1.40	1.93	3.53	30.06	2.51
1913	0.17	0.65	5.69	2.61	1.92	3.84	0.75	2.25	0.56	2.96	7.18	1.55	30.13	2.51
1914	1.17	2.67	4.27	1.31	0.00	0.71	0.08	0.37	1.57	1.45	2.41	3.94	26.31	2.19
1915	12.01	3.07	3.92	2.71	0.63	0.76	2.35	3.48	1.27	2.19	9.25	7.43	50.82	4.24
1916	2.15	0.59	8.07	2.86	3.48	1.10	2.04	0.12	1.46	1.72	6.81	7.48	37.22	3.10
1917	0.68	6.92	1.63	1.06	0.10	0.15	0.30	0.05	0.72	4.59	5.04	4.80	26.04	2.17
1918	2.07	2.81	2.42	4.83	1.24	2.78	0.43	0.41	0.70	4.70	5.15	1.59	29.13	2.43
1919	1.17	1.89	2.33	0.70	3.23	0.13	0.05	1.38	4.97	3.06	3.13	4.91	26.95	2.25
1920	4.76	6.18	4.25	1.20	2.27	1.42	0.20	0.47	0.57	4.47	1.75	2.14	29.68	2.47
1921	4.63	7.80	3.17	1.38	T	0.34	1.18	0.12	0.15	2.93	3.60	5.32	30.62	2.55
1922	6.08	0.10	4.95	2.14	5.86	0.18	0.35	1.30	3.96	5.13	3.70	3.52	37.27	3.11
1923	8.31	1.83	1.00	2.76	1.08	0.26	0.01	0.36	1.69	2.67	3.07	6.64	29.68	29.68
Total	63.96	54.70	57.69	30.98	29.09	17.20	10.33	20.13	28.37	41.74	68.32	59.79	489.75	.....
Average	4.26	3.65	3.85	2.07	1.94	1.15	0.69	1.34	1.89	2.78	4.55	3.99	32.65	.....

TABLE XXIII.—Average per cent of moisture in the soil.

(Recent experiments.)

TILLAGE (a).	1920.	1921.	1922.	1923.	Average.	1920.	1921.	1922.	1923.	Average.	1920.	1921.	1922.	1923.	Average.
	SURFACE 6 INCHES IN JULY.					SURFACE 6 INCHES IN AUGUST.					SURFACE 6 INCHES IN SEPTEMBER.				
1	22.1	22.5	21.3	14.9	20.2	24.8	26.6	20.5	17.5	22.4	18.2	23.2	20.1	18.5	20.0
2	20.6	20.8	23.0	16.9	20.3	24.6	25.6	20.6	14.8	21.4	17.8	24.3	20.9	17.5	20.1
3	19.8	14.5	21.1	15.5	17.7	19.3	17.0	10.7	10.7	14.4	15.5	18.2	21.5	10.7	16.5
4	21.7	19.5	21.1	16.0	19.6	20.6	22.6	16.9	15.1	18.8	17.7	22.2	20.4	15.8	19.0
5	22.1	14.9	20.0	14.9	18.0	18.4	17.8	10.1	11.9	14.5	14.4	19.5	20.9	11.2	16.5
6	22.3	20.7	22.9	15.9	20.4	22.6	20.0	13.0	12.5	17.0	20.0	23.7	21.6	12.5	19.4
7	21.5	21.4	23.3	16.1	20.6	21.9	25.3	20.3	19.3	21.7	19.3	26.4	21.6	20.7	22.0
8	21.3	22.2	22.4	17.3	20.8	22.3	27.1	21.6	19.2	22.6	19.1	25.0	21.7	16.0	20.4
	7- TO 12-INCH DEPTH, JULY.					7- TO 12-INCH DEPTH, AUGUST.					7- TO 12-INCH DEPTH, SEPTEMBER.				
1	23.3	22.6	22.4	21.6	22.5	25.4	23.6	21.6	23.7	23.6	23.2	23.9	23.0	19.5	22.4
2	22.1	20.9	22.6	21.7	21.8	25.2	27.3	21.8	23.6	24.5	22.8	24.1	22.9	24.5	23.6
3	20.9	16.3	20.2	22.2	19.9	18.9	17.4	15.7	15.8	16.9	19.2	16.3	24.6	15.9	19.0
4	22.5	21.9	20.9	22.2	21.9	23.5	23.6	19.5	21.1	21.9	23.7	22.4	21.2	23.3	22.7
5	21.8	17.3	21.5	22.5	20.8	20.5	17.8	16.8	18.8	18.5	19.8	16.5	20.2	16.8	18.3
6	22.4	20.6	22.9	23.1	22.2	21.5	21.3	17.1	18.4	19.5	24.2	25.4	23.0	18.7	22.8
7	23.4	21.4	23.9	23.1	22.8	24.6	26.3	21.7	26.1	24.7	20.5	25.8	23.5	20.3	22.5
8	23.3	23.6	24.4	23.0	23.6	24.5	27.8	22.4	24.9	24.9	24.6	26.6	25.1	24.7	25.2
	SECOND FOOT IN JULY.					SECOND FOOT IN AUGUST.					SECOND FOOT IN SEPTEMBER.				
1	19.7	22.5	20.1	21.5	20.9	23.9	24.5	20.0	22.9	22.8	21.9	19.3	29.0	23.0	23.3
2	19.0	22.7	21.2	22.1	21.2	23.0	24.4	21.1	23.4	23.0	22.7	22.6	24.0	22.6	23.0
3	17.1	19.1	20.8	22.3	19.8	16.2	18.8	18.2	19.7	18.2	17.2	16.9	20.6	17.8	18.1
4	16.0	20.1	18.7	22.9	19.4	18.0	21.1	19.5	22.8	20.3	20.1	20.2	20.5	22.6	20.8
5	15.8	17.7	20.4	22.6	19.1	17.7	16.9	18.5	22.8	19.0	17.4	16.7	18.2	17.4	17.5
6	17.0	21.9	21.0	24.0	21.0	22.2	21.0	19.9	22.6	21.4	20.4	23.0	20.7	19.5	20.9
7	20.8	21.2	21.1	23.7	21.7	23.3	23.8	21.6	23.3	23.0	22.9	24.5	21.8	23.0	23.1
8	20.8	22.4	22.3	22.5	22.0	24.1	25.0	22.6	23.7	23.8	24.0	24.2	25.0	23.7	24.2
	THIRD FOOT IN JULY.					THIRD FOOT IN AUGUST.					THIRD FOOT IN SEPTEMBER.				
1	14.1	17.1	17.7	19.2	17.0	18.7	18.2	17.4	20.0	18.6	17.7	17.0	19.2	20.4	18.6
2	15.1	17.9	16.0	19.0	17.0	17.2	17.4	17.9	20.5	18.3	17.6	17.2	20.9	20.7	19.1
3	14.9	16.8	18.2	20.2	17.5	15.1	16.4	20.1	18.6	17.5	16.0	21.7	19.5	17.6	18.7
4	14.2	16.3	15.5	20.1	18.5	13.6	14.2	19.1	21.1	17.0	16.8	15.8	19.3	19.3	17.8
5	15.3	15.9	17.8	20.5	17.6	14.7	15.6	18.2	20.2	17.2	15.4	16.3	15.5	18.8	16.5
6	13.9	16.6	15.9	21.0	16.9	16.4	15.9	19.6	20.7	18.1	14.9	16.6	17.6	19.8	17.2
7	13.8	15.3	16.5	20.8	16.6	14.9	17.2	19.7	20.6	18.1	18.1	19.3	22.1	20.6	20.0
8	14.8	16.7	20.3	21.1	18.2	18.4	18.7	19.1	21.9	19.5	19.9	19.3	21.9	21.3	20.6

TABLE XXIV.—Average nitrates expressed as parts per million dry soil.

(Recent experiments.)

TILLAGE (a).	1920.	1921.	1922.	1923.	Average.	1920.	1921.	1922.	1923.	Average.	1920.	1921.	1922.	1923.	Average.
	SURFACE 6 INCHES IN JULY.					SURFACE 6 INCHES IN AUGUST.					SURFACE 6 INCHES IN SEPTEMBER.				
1	18.9	24.4	21.9	27.0	23.1	50.0	30.9	25.4	45.3	37.9	36.7	26.8	32.1	5.6	38.0
2	21.9	22.9	18.5	24.4	21.9	31.1	27.1	15.6	37.9	27.9	67.3	26.2	40.5	38.4	43.1
3	15.2	0	13.4	6.3	8.7	5.2	3.0	8.5	4.3	16.5	3.8	2.3	5.7	3.4	3.8
4	26.1	9.1	18.8	7.0	15.2	45.0	14.9	22.5	14.2	24.1	32.5	18.6	22.8	25.3	24.8
5	23.9	3.7	7.8	11.9	11.8	29.0	0	8.3	3.7	10.2	4.3	2.0	8.8	5.0	5.0
6	23.3	20.1	17.8	18.0	19.8	38.0	19.2	23.8	13.4	23.6	42.6	21.6	18.0	5.6	21.9
7	18.1	25.7	21.0	16.9	20.4	48.5	32.1	28.6	30.2	34.9	60.1	23.8	30.0	28.7	35.7
8	14.9	18.6	15.1	13.0	15.4	48.6	16.4	13.9	25.4	26.1	34.6	25.3	25.8	24.5	27.5
	7- TO 12-INCH DEPTH, JULY.					7- TO 12-INCH DEPTH, AUGUST.					7- TO 12-INCH DEPTH, SEPTEMBER.				
1	16.4	12.7	13.1	12.7	13.7	40.3	19.8	14.7	15.7	22.6	26.6	17.9	27.0	10.3	20.4
2	22.9	15.3	14.5	27.8	20.1	51.3	15.4	10.6	10.7	22.0	45.3	17.3	29.9	8.6	25.3
3	9.9	3.2	12.1	5.8	7.7	5.4	0	5.4	18.8	7.6	2.1	2.7	3.6	4.0	3.1
4	20.2	4.9	15.0	5.8	11.5	46.3	8.0	14.9	7.3	19.1	20.3	7.2	16.5	9.2	13.3
5	17.7	0	8.5	8.8	8.8	31.4	0	7.5	2.8	10.4	3.4	1.4	7.7	4.1	4.1
6	21.4	11.6	23.5	13.5	17.5	52.7	8.0	14.5	5.8	20.3	33.0	5.8	14.9	5.3	14.8
7	14.1	13.8	20.4	7.9	14.1	41.7	21.7	20.8	12.8	24.2	31.4	18.4	24.8	8.9	20.9
8	15.1	12.0	20.9	17.6	16.4	27.3	13.9	22.9	10.1	18.5	23.5	15.6	19.2	8.2	16.6
	SECOND FOOT IN JULY.					SECOND FOOT IN AUGUST.					SECOND FOOT IN SEPTEMBER.				
1	5.6	3.0	5.1	8.6	5.6	20.6	3.5	5.5	7.6	9.3	11.3	2.8	13.4	6.3	8.5
2	7.8	2.7	4.8	26.0	10.3	23.7	3.4	6.5	10.0	10.9	15.8	3.3	14.9	7.2	10.4
3	2.2	0	7.2	4.8	3.5	4.9	0	2.3	3.9	2.8	3.0	2.3	3.3	4.1	3.2
4	3.1	2.9	5.7	6.6	4.6	11.4	3.1	7.2	7.8	7.6	7.1	2.4	5.6	6.5	5.4
5	2.6	0	3.2	5.6	2.8	6.5	0	3.5	4.2	3.5	6.7	1.8	4.1	4.3	4.2
6	3.5	5.9	3.6	11.3	6.1	13.7	4.2	7.3	4.9	7.8	25.4	3.2	4.4	4.6	9.4
7	7.2	5.0	8.2	6.2	13.3	20.7	3.0	6.3	7.7	9.4	16.9	5.4	13.7	7.6	10.9
8	5.0	4.5	8.2	13.3	7.8	13.3	3.0	5.1	7.0	9.3	14.6	5.1	8.5	5.1	8.3
	THIRD FOOT IN JULY.					THIRD FOOT IN AUGUST.					THIRD FOOT IN SEPTEMBER.				
1	3.0	2.8	4.2	11.5	5.4	8.9	2.0	3.2	6.8	5.2	5.7	3.2	8.2	6.5	5.9
2	4.4	2.7	4.1	37.8	12.2	6.5	2.6	6.7	7.7	5.9	7.0	2.1	10.6	8.3	7.0
3	3.0	2.0	5.5	3.4	3.5	5.9	0	1.2	3.7	2.7	4.1	0	3.8	4.0	3.0
4	3.5	3.3	15.0	8.4	7.6	13.8	4.5	10.1	8.2	9.2	4.9	2.8	5.5	5.5	4.7
5	2.5	3.5	2.8	5.3	3.5	4.1	0	2.8	4.8	2.9	4.6	2.2	3.8	3.6	3.5
6	2.9	2.4	4.3	3.8	3.3	15.6	2.5	5.3	4.4	6.9	5.0	2.4	4.5	3.8	3.9
7	3.2	2.4	5.3	5.6	4.1	12.6	3.5	11.4	6.6	8.5	10.6	3.4	15.3	6.7	9.0
8	2.8	0	4.5	11.8	4.5	7.9	2.1	5.5	6.0	5.4	8.1	4.5	4.7	4.2	5.3

FOOTNOTE

The following footnote should be considered a part of both Tables XXIII and Table XXIV:

(*a*) Tillage treatments on which moisture and nitrate data were obtained are as follows:

1. **Plowed shallow in July.**
2. **Plowed deep in July.**
3. **Weeds allowed to grow; disked at seeding time.**
4. **Scraped; disked at seeding time.**
5. **Plowed shallow in September.**
6. **Plowed shallow in August.**
7. **Stubble burned; plowed shallow in July.**
8. **Straw applied before plowing; plowed shallow in July.**

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