UNITED STATES DEPARTMENT OF AGRICULTURE
MISCELLANEOUS CIRCULAR No. 81
SUPPLEMENT 1

WASHINGTON, D. C. OCTOBER, 1931

THE RELATIONS BETWEEN CROP YIELDS AND PRECIPITATION IN THE GREAT PLAINS AREA

SUPPLEMENT 1.—CROP ROTATIONS AND TILLAGE METHODS

By E. C. CHILCOTT, Formerly Senior Agriculturist, in Charge of Office of Dry Land Agriculture, Bureau of Plant Industry

CONTENTS

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By E. C. CHILCOTT[1]

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CONTENTS

INTRODUCTION

In Miscellaneous Circular No. 81, the average yields from about 25 plots, subjected to different methods of soil preparation and crop sequence, were used as units of measurement for studying the relations between crop yields and precipitation for each crop at each station. There are many obvious advantages in this method of using average yields rather than the yields from individual plots. In some instances it was considered advisable to use the average of composite yields from three different crops, winter wheat, spring wheat, and oats, grown each year on about 75 plots at each station. These methods of average and composite yields have made possible the presentation of many problems that can best be studied by regrouping the individual plot yields in many different ways. It now seems desirable, therefore, to present these basic figures showing about 30,000 individual yields from 23 field stations.[2]

It is believed, however, that before entering into a detailed study of this mass of statistical matter the reader's attention should be called to the nature of the problems of crop rotation and tillage methods in the

[1] Died Nov. 14, 1930.

[2] The members of the scientific staff of the Office of Dry-Land Agriculture who have participated in conducting these investigations in the field and in assembling the data in the Washington office are as follows: *Present staff.*—Washington, D. C.: J. M. Stephens, E. F. Chilcott, J. S. Cole. Mandan, N. Dak.: Robert Wilson, J. T. Sarvis, W. P. Baird, J. C. Thysell, T. K. Killand. Dickinson, N. Dak.: L. Moomaw. Assinniboine, Mont.: G. W. Morgan. Huntley, Mont.: A. E. Seamans. Belle Fourche, S. Dak.: A. Osenbrug. Ardmore, S. Dak.: O. R. Mathews, J. D. Kelso. Sheridan, Wyo.: R. S. Towle. Archer, Wyo.: A. L. Nelson. North Platte, Nebr.: L. L. Zook, H. E. Weakly. Akron, Colo.: J. F. Brandon. Colby, Kans.: B. F. Barnes. Hays, Kans.: A. L. Hallsted. Garden City, Kans.: E. H. Coles. Woodward, Okla.: L. F. Locke. Dalhart, Tex.: H. J. Clemmer. Tucumcari, N. Mex.: D. R. Burnham. Lawton, Okla.: W. M. Osborn. Big Spring, Tex.: F. E. Keating—27. *Resigned or transferred to other offices.*—Sylvester Balz, F. L. Kennard, J. E. Payne, L. E. Hazen, C. A. Jensen, H. R. Reed, W. O. Whitcomb, C. H. Plath, F. Knorr, R. W. Edwards, H. C. McKinstry, C. A. Burmeister, J. G. Lill, W. W. Burr, J. H. Jacobson, O. J. Grace, M. Pfaender, W. D. Griggs, J. E. Mundell, W. A. Peterson, H. G. Smith, L. N. Jensen, A. J. Ogaard, C. B. Brown, L. D. Willey, J. B. Kuska, C. H. Ruzicka, A. W. Schulz, W. E. Lyness, F. A. Wagner, F. E. Cobb, P. V. Cardon, N. O. Henchel, J. W. McLane, O. A. Thompson, Clarence Harris, U. G. Downey, and F. L. Kelso—38. *Deceased.*—I. J. Jensen, formerly at Moccasin, Mont.—1. Total, 66.

The field investigations at Assinniboine and Moccasin, Mont.; Williston, Dickinson, and Edgeley, N. Dak.; Archer, Wyo.; North Platte, Nebr.; and Colby, Hays, and Garden City, Kans., herein described were conducted cooperatively at field stations operated by the agricultural experiment stations of the several States, respectively.

All meteorological and soil-moisture investigations were conducted cooperatively with the biophysical laboratory, Bureau of Plant Industry, L. J. Briggs, biophysicist, J. O. Belz, associate biophysicist.

The late Charles S. Davis rendered valuable assistance in editing the text and arranging the tables and figures for publication.

Great Plains, as they differ profoundly from those of humid regions.

Much has been written on the subject, but in most instances the authors have dealt with the problems of crop rotations in regions where the soil and climatic conditions are very different from those existing in the Great Plains area. Most of their investigations have been conducted in regions of ample rainfall, where commercial fertilizers, barnyard manure, and biennial and perennial hay and forage crops are the important factors in rotation systems. On the Great Plains none of these factors are of major importance, but the conservation and utilization of the scanty rainfall is of such predominant importance as completely to eliminate some factors and to relegate all others to minor positions. Such being the case, it becomes obvious that the problems of crop rotations and tillage methods on the Great Plains must be approached from a very different standpoint and that very different methods of analysis and interpretation must be developed.

Weir[3] has digested and summarized some of the most important investigations of crop rotation in Great Britain and the United States and reaches the following conclusions:

(1) Crop rotation is so important a farm practice, especially in maintaining and increasing the yields of cereal crops, that its effectiveness may often equal or even exceed the effectiveness of the use of complete chemical fertilizer or farm manure.

(2) The conjoint effects of crop rotation and the use of fertilizers are additive, as effecting increases in crop yields.

(3) The relative efficiency of crop rotation is greater on soils naturally supplied with lime or on soils whose reactions have been altered or changed by liming than on soils that are acid in character.

The soils of the Great Plains are "naturally supplied with lime." The data in these pages contain evidence of the reaction to farm manure on these soils. Such meager evidence as is available concerning the effectiveness of commercial fertilizers is inconclusive. However, if the time ever comes when these rich virgin soils become so depleted as to respond to the application of commercial fertilizers, it may be tentatively assumed that their effects with the rotations will be additive and that the relative effectiveness of the rotations and tillage methods, as shown in the following pages, is a safe index to the effectiveness of more complex rotations that may be elaborated from them on the same general principles. If, on the other hand, it develops that this assumption is not valid and that the effects of fertilizers are not additive, the facts presented in the following pages should provide a foundation upon which to base further investigations.

CROP ROTATIONS AND TILLAGE METHODS

The systematic field investigations of crop rotations conducted by the writer may be said to have begun in the spring of 1897, at the South Dakota Agricultural Experiment Station, where he was then agriculturist and vice director. These investigations were described, and results covering six years—1897 to 1902, inclusive—were given in a publication issued in May, 1903.[4]

When the writer was called to Washington in 1905 to take charge of the dry-land agriculture investigations of the United States Department of Agriculture, he was in a position to profit by his past experience in South Dakota, the result of which was that some fundamental changes were made in the general plans of the investigations as they had been conducted at the South Dakota station.

It was realized that the major factors in the problems of dry-land agriculture are as follows: (1) Crop sequence; (2) time, method, and depth of tillage in the preparation of the seed bed: (3) the cultivation of summer-fallows and cultivated row crops; and (4) the adaptation of varieties and strains of crops and of implements and methods to the varying combinations of soil, climatic, and economic conditions—particularly cost of labor and market demands and prices—throughout a vast area of fertile land where deficient rainfall is an important factor.

In order to make this study of the basic problems of crop rotation as simple as possible, it was decided to begin with the consideration of 11 systems of crop production, as follows: (1) Continuous cropping with the same crop upon the same land every year; (2) alternate cropping and summer-fallowing with the same crop each alternate year; (3) two 3-year rotations in which a summer-fallow occurs every third year; (4) three rotations in which the corn stubble is disked instead of being plowed in preparing it for the small-grain crop that is to follow; and (5) four rotations in which the land is all plowed and all cropped every year, but with the sequence of crops differing in each instance.

The field layout of plots used for that portion of the investigations above mentioned may be briefly described as follows:

Continuous cropping.—Two plots are used for each of the four staple crops grown at each station. One of them is plowed about 8 inches deep in the fall, the other is plowed about 4 inches deep in the spring. Otherwise they are both treated in the same manner. The average of the two plots is used to represent the yields under continuous cropping at each station for each crop.

Alternate fallowing.—Two plots are used for each of the staple crops grown at each station. One of them is plowed about 8 inches deep as soon as practicable after the preceding crop is harvested and is given sufficient cultivation with disks or harrows to prevent any appreciable weed growth until the next crop is sown—a period of about 11 months.[5] The other plot is seeded in the spring in a good seed bed on the summer-fallowed land.

Rotation 1.—Three plots are used, as follows: Spring wheat seeded on disked corn stubble; oats on early fall-plowed wheat stubble; corn on early fall-plowed oat stubble.

Rotation 2.—The same crops in the same sequence are used as in rotation 1, but the ground for each crop is spring plowed.

Rotation 3.—Identical with rotation 2 except that the plots are all early fall plowed.

Rotation 4.—Identical with rotation 1 except that the oat crop is seeded on the disked corn stubble and is followed by wheat and that in turn by corn, both of the latter on early fall plowing.

Rotation 5.—Identical with rotation 1 except that summer-fallow is substituted for the corn crop.

Rotation 6.—Identical with rotation 1 except that barley is substituted for spring wheat.

Rotation 7.—Like rotation 6, wherein barley is substituted for spring wheat, but in rotation 7 barley follows the oat crop, the oat crop follows corn, and the ground is spring plowed for all three crops.

Rotation 8.—Identical with rotation 5 except that in rotation 8 the oat crop is on the fallowed land and wheat follows oats.

Rotation 9.—Identical with rotation 2 except that the oat crop follows corn in rotation 9 and wheat follows oats. All three crops are grown on spring plowing. Rotation 9 is also identical with rotation 7, except that in the latter barley is substituted for spring wheat.

It will be seen that the 39 plots above described afford an opportunity to establish the relative values of the several factors indicated as the major ones in the problems of dry-land agriculture, so far as spring wheat, oats, barley, and corn are concerned. It is true that

[3] WEIR, W. W. A STUDY OF THE VALUE OF CROP ROTATION IN RELATION TO SOIL PRODUCTIVITY. U. S. Dept. Agr. Bul. 1377, p. 67. 1926.

[4] CHILCOTT, E. C. CROP ROTATION FOR SOUTH DAKOTA. S. Dak. Agr. Expt. Sta. Bul. 79, 69 p., illus. 1903.

[5] Late spring or early summer plowing has been substituted for early fall plowing for summer-fallow at most of the stations, as it has been found that it reduces cost and usually increases yields.

a number of other crops are of importance in the agriculture of the semiarid regions and that there are many elaborations and modifications of crop sequences and tillage methods that are not represented in this group of 11 distinct systems of crop production. A study of these more complex problems has been provided for in other rotations reported in these pages. But it is believed that an intensive study of these major factors, as exemplified in the simple continuous cropping, alternate cropping, and the nine 3-year rotations, with four staple crops, will serve to bring about a better understanding of the basic principles underlying the theories and the practices of crop rotations and tillage than would result from an attempt to take up at this time the more complex phases of the subject. When the reader has mastered these relatively simple problems, he will find an abundance of material in the accompanying tables for studies of more complex ones.

THEORY AND PRACTICE OF CROP ROTATION

In order to study either the theory or the practice of crop rotation, it is necessary to establish certain relative values for the crops produced and for the cost of producing them. It is not necessary that these values be mathematically exact provided the standards of measurement are the same for all rotations, for interest lies in the relative rather than the absolute values of the different rotation and cropping systems. The studies presented in Miscellaneous Circular No. 81 have shown that through a long period of years, on a great variety of soils, and under a wide range of climatic conditions certain definite relations exist in the Great Plains area.

The relative yields and the costs of production of spring wheat, oats, and corn are as follows: One bushel of wheat is equivalent to 2 bushels of oats, or 1½ bushels of barley, or 200 pounds (total dry weight) of corn grain and stover. These crops are therefore reduced to equivalents of bushels of wheat by dividing the acre yields of oats by 2, those of barley by 1½, and the total weight of corn by 200.

The cost of the maintenance of a practical summer-fallow is one-half the acre cost of producing a crop of wheat, oats, or corn. These relative values are therefore used in the following comparisons of crop rotations.

As an example of one method of studying the theory and practice of crop rotation and tillage methods based upon these investigations covering 228 crop years, the continuous-cropping series, the alternate-fallow series, and rotations 1 to 9, inclusive, have been selected. They include 33 crops and 6 fallows each year at each of 16 field stations for an average period of 14¼ years, a total of 8,892 plots. The rotations are simple 3-year rotations, and they are so arranged as to facilitate the comparison of different crop sequences and tillage methods.

The five systems of farming under consideration in this study are as follows: (1) Continuous cropping to the same crop year after year; (2) alternate cropping and summer-fallow for each of the three crops (herein designated as "fallow" or "alternate fallow"); (3) continuous cropping of all the land, but rotating the crops so that the same crop is grown on the same land only once in three years, as is done in rotations 1, 2, 3, 4, and 9; (4) substituting a summer-fallow for the corn crop, as is done in rotations 5 and 8; and (5) substituting a barley crop for the wheat crop, as is done in rotations 6 and 7.

The first step is to reduce the four crops to a common denominator or composite crop, which is done by dividing the acre yields of oats (expressed in bushels) by 2, the barley yields by 1½, and the corn yields (expressed in pounds of dry weight of grain and stover) by 200. The values thus obtained are added, and this sum divided by the number of crops entering into each rotation, which is 3 for the continuous cropping, for the alternate fallow, and for all of the rotations except 5 and 8. The divisor for rotations 5 and 8 is 2, as only two-thirds of the land is cropped, one-third being fallowed.

Still another correction is necessary to make the rotations comparable. The acre yields obtained by dividing the sums of the yields by 3 in the case of the alternate fallow are again divided by 1½ to compensate for the cost of the summer-fallow. This process may be shortened by dividing the sum of the yields by $3 \times 1\frac{1}{2} = 4\frac{1}{2}$, instead of by first dividing by 3 and then by 1½.

The sums of the yields for rotations 5 and 8, which each contain a fallow, are divided, first by 2 as already mentioned and then by 1¼ (or by the shorter method divide the sum by $2 \times 1\frac{1}{4} = 2\frac{1}{2}$). The yields for rotations 1, 4, and 6 are divided by $3 \div 1.03\frac{1}{3} = 2.9$ to compensate for the decreased cost of disking the corn stubble instead of plowing it.

If the foregoing description is not fully understood, perhaps the following statement will make it clear:

Assume that the entire tillable land of the farm consists of 150 acres. Assume also that it costs $10 an acre to raise each crop when there is no summer-fallowing. When all the land is cropped every year, whether by changing crops or by continuous cropping to the same crop or crops, the cost of cropping 150 acres is $1,500.

When the system of alternate cropping and summer-fallowing is practiced, 75 acres are in crop each year and 75 acres are fallowed. The cost of tillage of the cropped plots is $10×75=$750, that of the fallow plots $5×75=$375. The total cost, $1,125, divided by 75 gives $15 as the acre cost for the cropped land, or one and one-half times as much per acre as under the continuously cropped system.

In the case of the 1-year fallow in three years, as practiced in rotations 5 and 8, where 100 acres are in crops and 50 acres under fallow, the cost is $10×100=$1,000, plus $5×50=$250, a total of $1,250. This when divided by 100, gives $12.50 as the cost per acre, which is one and one-fourth times the cost under rotation or continuous cropping.

The main purpose of summer-fallowing is to increase the yields of the crops which intervene between fallows in any given rotation. It is immaterial whether the increased yields are confined to the crop that follows immediately after the fallow or whether it is distributed throughout all the crops raised between fallows. The cost of the fallow, therefore, should be prorated between all the crops in the rotation cycle. In the 3-year rotations now under consideration this prorating is to the two intervening crops.

Unless the yields of these intervening crops are increased over the yields which result from continuous cropping in proportion as the cost of production is increased, the introduction of the summer-fallow has no economic justification. Alternate fallowing and cropping will increase the cost of production per acre at least 50 per cent. The yields obtained from land that has been summer-fallowed the previous year should therefore be correspondingly reduced before comparing them with yields obtained from continuous cropping. This is done by dividing them by 1½.

Where two crops intervene between fallows, the increased cost of production is only 25 per cent. The method of prorating, therefore, is to divide the average of the yields of these two crops by 1¼.

Table 19[6] gives the average yields of all of the crops grown on the continuously cropped plots, on the alternately fallowed plots, and of rotations 1 to 9, inclusive. These rotations are all 3-year rotations. Spring wheat, oats, and corn are grown on the continuously cropped plots, the alternately cropped plots, and in all rotations except 5 and 8 (in which a summer-fallow is substituted for the corn crop) and in 6 and 7 (in which barley is substituted for spring wheat). The land is all plowed each year for crops except for wheat in rotation 1, oats in rotation 4, and barley in rotation 6, which are grown on disked corn stubble.

TABLE 19.—*Average acre yields of spring wheat, oats, corn, and barley at 16 field stations in the northern Great Plains area for number of years shown*

[Arranged in geographical order from north to south. The yields in column A (except in rotations 6 and 7) indicate actual average acre yields of specified crops, which in column B are entered as equivalents of bushels of spring wheat per acre. In rotations 6 and 7 barley was substituted for wheat]

Field station and crop	Continuous cropping (total ÷3)		Alternate fallow (total ÷4½)		Rotation 1 (total ÷2.9)		Rotation 2 (total ÷3)		Rotation 3 (total ÷3)		Rotation 4 (total ÷2.9)		Rotation 5 (total ÷2½)		Rotation 6 (total ÷2.9)		Rotation 7 (total ÷3)		Rotation 8 (total ÷2½)		Rotation 9 (total ÷3)		Yield average	Years averaged
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B		
Williston:																								
Spring wheat........bushels..	.....	11.80	.....	18.60	.....	14.10	.....	14.60	.....	13.30	.....	17.30	.....	16.40	[a]23.80	15.87	[a]15.30	10.20	.....	13.60	.....	15.30	.....	.....
Oats........do....	23.60	11.80	40.60	20.30	30.10	15.05	32.00	16.00	29.90	14.95	43.00	21.50	28.40	14.20	34.10	17.05	30.50	15.25	44.80	22.40	39.90	19.95	.....	.....
Corn total........pounds..	4,430	22.15	6,205	31.03	3,751	18.75	4,267	21.33	3,279	16.39	4,481	22.41	([b])	.....	3,420	17.10	2,998	14.99	([b])	.....	4,234	21.17	.....	.....
Total........	.....	45.75	.....	69.93	.....	47.90	.....	51.93	.....	44.64	.....	61.21	.....	30.60	.....	50.02	.....	40.44	.....	36.00	.....	56.42	.....	.....
Average........	.....	15.25	.....	15.54	.....	16.52	.....	17.31	.....	14.88	.....	21.11	.....	12.24	.....	17.25	.....	13.48	.....	14.40	.....	18.81	16.07	1[illegible]
Assinniboine:																								
Spring wheat........bushels..	.....	6.70	.....	13.20	.....	9.90	.....	10.80	.....	10.00	.....	9.10	.....	13.40	[a]17.30	11.53	[a]16.40	10.93	.....	7.20	.....	9.90	.....	.....
Oats........do....	16.00	8.00	29.40	14.70	15.00	7.50	19.90	9.95	14.10	7.05	23.50	11.75	16.80	8.40	18.00	9.00	23.20	11.60	27.50	13.75	18.10	9.05	.....	.....
Corn total........pounds..	2,964	14.82	4,475	22.38	2,331	11.66	2,661	13.31	2,615	13.08	2,635	13.18	([b])	.....	2,742	13.71	2,925	14.63	([b])	.....	2,610	13.05	.....	.....
Total........	.....	29.52	.....	50.28	.....	29.06	.....	34.06	.....	30.13	.....	34.03	.....	21.80	.....	34.24	.....	37.16	.....	20.95	.....	32.00	.....	.....
Average........	.....	9.84	.....	11.17	.....	10.02	.....	11.35	.....	10.04	.....	11.73	.....	8.72	.....	11.81	.....	12.39	.....	8.38	.....	10.67	10.55	[illegible]
Moccasin:																								
Spring wheat........bushels..	.....	14.20	.....	18.90	.....	19.50	.....	18.30	.....	18.10	.....	16.90	.....	20.80	[a]22.90	15.27	[a]21.30	14.20	.....	18.80	.....	16.80	.....	.....
Oats........do....	34.10	17.05	47.10	23.55	33.90	16.95	36.70	18.35	34.20	17.10	40.80	20.40	34.20	17.10	34.00	17.00	38.20	19.10	49.30	24.65	37.10	18.55	.....	.....
Corn total........pounds..	5,199	25.99	4,863	24.32	4,447	22.21	4,936	24.68	4,375	21.88	4,468	22.34	([b])	.....	4,008	20.04	4,994	24.97	([b])	.....	4,769	23.85	.....	.....
Total........	.....	57.24	.....	66.77	.....	58.69	.....	61.33	.....	57.08	.....	59.64	.....	37.90	.....	52.31	.....	58.27	.....	43.45	.....	59.20	.....	.....
Average........	.....	19.08	.....	14.84	.....	20.24	.....	20.44	.....	19.03	.....	20.57	.....	15.16	.....	18.04	.....	19.42	.....	17.38	.....	19.73	18.52	1[illegible]
Huntley:																								
Spring wheat........bushels..	.....	10.00	.....	15.10	.....	15.90	.....	14.60	.....	14.00	.....	13.30	.....	23.50	[a]20.40	13.60	[a]15.90	10.60	.....	14.30	.....	11.40	.....	.....
Oats........do....	24.60	12.30	39.80	19.90	26.90	13.45	29.10	14.55	27.80	13.90	34.30	17.15	29.20	14.60	30.60	15.30	32.70	16.35	47.30	23.65	31.40	15.70	.....	.....
Corn total........pounds..	2,792	13.96	4,475	22.38	2,922	14.61	2,969	14.85	2,742	13.71	2,741	13.71	([b])	.....	2,814	14.07	2,930	14.65	([b])	.....	2,769	13.85	.....	.....
Total........	.....	36.26	.....	57.38	.....	43.96	.....	44.00	.....	41.61	.....	44.16	.....	38.10	.....	42.97	.....	41.60	.....	37.95	.....	40.95	.....	.....
Average........	.....	12.09	.....	12.75	.....	15.16	.....	14.67	.....	13.87	.....	15.23	.....	15.24	.....	14.82	.....	13.87	.....	15.18	.....	13.65	14.22	1[illegible]
Dickinson:																								
Spring wheat........bushels..	.....	11.80	.....	20.70	.....	19.80	.....	19.80	.....	17.40	.....	14.80	.....	20.80	[a]25.50	17.00	[a]19.10	12.73	.....	15.70	.....	14.40	.....	.....
Oats........do....	26.40	13.20	46.60	23.30	34.70	17.35	39.20	19.60	32.90	16.45	37.90	18.95	33.80	16.90	32.70	16.35	36.50	18.25	45.20	22.60	31.60	15.80	.....	.....
Corn total........pounds..	3,359	16.79	3,634	18.17	3,334	16.67	3,833	19.16	3,083	15.42	3,091	15.46	([b])	.....	3,210	16.05	3,487	17.44	([b])	.....	3,329	16.65	.....	.....
Total........	.....	41.79	.....	62.17	.....	53.82	.....	58.56	.....	49.27	.....	49.21	.....	37.70	.....	49.40	.....	48.42	.....	38.30	.....	46.85	.....	.....
Average........	.....	13.93	.....	13.82	.....	18.56	.....	19.52	.....	16.42	.....	16.97	.....	15.08	.....	17.03	.....	16.14	.....	15.32	.....	15.62	16.22	1[illegible]
Mandan:																								
Spring wheat........bushels..	.....	12.00	.....	19.90	.....	15.70	.....	16.90	.....	14.40	.....	12.80	.....	19.60	[a]22.80	15.20	[a]21.10	14.07	.....	14.60	.....	15.60	.....	.....
Oats........do....	26.40	13.20	49.90	24.95	28.70	14.35	34.50	17.25	29.10	14.55	35.60	17.80	30.00	15.00	29.70	14.85	36.60	18.30	49.90	24.95	36.40	18.20	.....	.....
Corn total........pounds..	4,425	22.13	5,149	25.75	4,011	20.06	4,208	21.04	3,766	18.83	3,885	19.43	([b])	.....	3,944	19.72	4,316	21.58	([b])	.....	4,108	20.54	.....	.....
Total........	.....	47.33	.....	70.60	.....	50.11	.....	55.19	.....	47.78	.....	50.03	.....	34.60	.....	49.77	.....	53.95	.....	39.55	.....	54.34	.....	.....
Average........	.....	15.78	.....	15.69	.....	17.28	.....	18.40	.....	15.93	.....	17.25	.....	13.84	.....	17.16	.....	17.98	.....	15.82	.....	18.11	16.66	1[illegible]
Edgeley:																								
Spring wheat........bushels..	.....	11.40	.....	13.10	.....	16.90	.....	15.80	.....	17.00	.....	14.00	.....	16.90	[a]24.20	16.13	[a]20.80	13.87	.....	14.20	30.90	14.50	.....	.....
Oats........do....	25.80	12.90	39.30	19.65	29.30	14.65	30.90	15.45	31.20	15.60	33.10	16.55	35.60	17.80	30.20	15.10	34.80	17.40	36.10	18.05	39.00	15.45	.....	.....
Corn total........pounds..	3,461	17.31	3,365	16.83	3,798	18.99	4,055	20.28	3,797	18.99	3,677	18.39	([b])	.....	3,710	18.55	4,067	20.34	([b])	.....	3,846	19.23	.....	.....
Total........	.....	41.61	.....	49.58	.....	50.54	.....	51.53	.....	51.59	.....	48.94	.....	34.70	.....	49.78	.....	51.61	.....	32.25	.....	49.18	.....	.....
Average........	.....	13.87	.....	11.02	.....	17.43	.....	17.18	.....	17.20	.....	16.88	.....	13.88	.....	17.17	.....	17.20	.....	12.90	.....	16.39	15.56	1[illegible]
Sheridan:																								
Spring wheat........bushels..	.....	13.20	.....	23.10	.....	17.80	.....	17.30	.....	18.00	.....	16.10	.....	23.60	[a]36.00	24.00	[a]35.20	23.47	.....	16.30	.....	16.00	.....	.....
Oats........do....	32.80	16.40	46.60	23.30	35.50	17.51	34.40	17.20	35.80	17.90	37.50	18.75	40.80	20.40	37.60	18.80	41.60	20.80	46.70	23.35	38.50	19.25	.....	.....
Corn total........pounds..	2,966	14.83	3,307	16.54	2,793	13.97	2,995	14.98	2,954	14.77	2,640	13.20	([b])	.....	3,050	15.25	2,983	14.92	([b])	.....	2,981	14.91	.....	.....
Total........	.....	44.43	.....	62.94	.....	49.52	.....	49.48	.....	50.67	.....	48.05	.....	44.00	.....	58.05	.....	59.19	.....	39.65	.....	50.16	.....	.....
Average........	.....	14.81	.....	13.99	.....	17.08	.....	16.49	.....	16.89	.....	16.57	.....	17.60	.....	20.02	.....	19.73	.....	15.86	.....	16.72	16.87	
Belle Fourche:																								
Spring wheat........bushels..	.....	14.70	.....	22.70	.....	17.50	.....	13.50	.....	15.60	.....	16.10	.....	22.40	[a]27.80	18.53	[a]25.60	17.07	.....	17.00	.....	15.30	.....	.....
Oats........do....	32.90	16.45	49.50	24.75	33.10	16.55	31.00	15.50	32.20	16.10	39.30	19.65	33.80	16.90	35.40	17.70	35.80	17.90	52.60	26.30	35.00	17.50	.....	.....
Corn total........pounds..	3,514	17.57	4,260	21.30	3,562	17.81	3,232	16.16	3,633	18.17	3,530	17.68	([b])	.....	3,759	18.79	3,747	18.74	([b])	.....	3,578	17.89	.....	.....
Total........	.....	48.72	.....	68.75	.....	51.86	.....	45.16	.....	49.87	.....	53.43	.....	39.30	.....	55.02	.....	53.71	.....	43.30	.....	50.69	.....	.....
Average........	.....	16.24	.....	15.28	.....	17.88	.....	15.05	.....	16.62	.....	18.42	.....	15.72	.....	18.97	.....	17.90	.....	17.32	.....	16.90	16.94	1[illegible]

[a] Barley was substituted for wheat. [b] Fallow.

[6] The serial numbers of the tables and figures of this supplement are continuations of those in Miscellaneous Circular No. 81, issued in February, 1927.

TABLE 19.—*Average acre yields of spring wheat, oats, corn, and barley at 16 field stations in the northern Great Plains area for number of years shown*—Continued

[Arranged in geographical order from north to south. The yields in column A (except in rotations 6 and 7) indicate actual average acre yields of specified crops, which in column B are entered as equivalents of bushels of spring wheat per acre. In rotations 6 and 7 barley was substituted for wheat]

Field station and crop	Continuous cropping (total ÷3)		Alternate fallow (total ÷4½)		Rotation 1 (total ÷2.9)		Rotation 2 (total ÷3)		Rotation 3 (total ÷3)		Rotation 4 (total ÷2.9)		Rotation 5 (total ÷2½)		Rotation 6 (total ÷2.9)		Rotation 7 (total ÷3)		Rotation 8 (total ÷2½)		Rotation 9 (total ÷3)		Yield average	Years averaged
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B		
Ardmore:																								
Spring wheat.........bushels..		11.60		16.40		18.50		16.50		16.00		16.70		19.10	[a]25.90	17.27	[a]21.30	14.20		12.80		13.30		
Oats.........do....	24.30	12.15	36.70	18.35	30.10	15.05	29.60	14.80	27.80	13.90	33.70	16.85	31.00	15.50	33.30	16.65	33.90	16.95	35.80	17.90	33.00	16.50		
Corn total.........pounds..	3,488	17.44	3,645	18.23	3,162	15.81	3,097	15.49	2,883	14.42	3,163	15.82	([b])		3,304	16.52	3,012	15.06	([b])		2,877	14.39		
Total..........		41.19		52.08		49.36		46.79		44.32		49.37		34.60		50.44		46.21		30.70		44.19		
Average..........		13.73		11.77		17.02		15.60		14.77		17.02		13.84		17.39		15.40		12.28		14.73	14.87	13
Scotts Bluff:																								
Spring wheat.........bushels..		7.10		14.30		13.00		11.20		12.30		11.00		16.50	[a]15.10	10.07	[a]17.30	11.53		9.60		10.40		
Oats.........do....	16.60	8.30	25.70	12.85	18.60	9.30	23.90	11.95	18.90	9.45	20.30	10.15	20.60	10.30	18.10	9.05	20.60	10.30	27.00	13.50	26.60	13.30		
Corn total.........pounds..	2,796	13.98	3,785	18.93	3,376	16.88	3,666	18.33	3,163	15.82	3,179	15.90	([b])		3,146	15.73	3,476	17.38	([b])		3,367	16.84		
Total..........		29.38		46.08		39.18		41.48		37.57		37.05		26.80		34.85		39.21		23.10		40.54		
Average..........		9.79		10.24		13.51		13.83		12.52		12.78		10.72		12.02		13.07		9.24		13.51	11.93	9
North Platte:																								
Spring wheat.........bushels..		11.40		19.00		13.10		10.50		13.20		11.00		17.10	[a]15.90	10.60	[a]17.90	11.93		13.60		10.50		
Oats.........do....	24.00	12.00	36.00	18.00	25.90	12.95	22.30	11.15	25.80	12.90	25.00	12.50	23.30	11.65	20.10	13.05	26.10	13.05	39.60	19.80	23.80	11.90		
Corn total.........pounds..	3,796	18.98	4,323	21.62	4,076	20.38	3,383	16.91	4,056	20.28	3,802	19.01	([b])		3,885	19.43	3,814	19.07	([b])		3,874	19.37		
Total..........		42.38		58.62		46.43		38.56		46.38		42.51		28.75		43.08		44.05		33.40		41.77		
Average..........		14.13		13.03		16.01		12.85		15.46		11.66		11.50		14.86		14.68		13.36		13.92	14.04	19
Archer:																								
Spring wheat.........bushels..		8.50		13.40		12.60		11.10		8.70		9.90		13.50	[a]15.33	10.22	[a]14.10	9.40		8.50		9.00		
Oats.........do....	10.40	5.20	15.00	7.50	17.40	8.70	17.60	8.80	11.30	5.65	22.00	11.00	14.80	7.40	15.20	7.60	21.70	10.85	20.00	10.00	17.20	8.60		
Corn total.........pounds..	2,987	14.94	3,083	15.42	2,491	12.46	3,293	16.47	2,265	11.33	2,600	13.00	([b])		2,250	11.25	3,487	17.44	([b])		2,809	14.05		
Total..........		28.64		36.32		33.76		36.37		25.68		33.90		20.90		29.07		37.69		18.50		31.65		
Average..........		9.55		8.07		11.64		12.12		8.56		11.69		8.36		10.02		12.56		7.40		10.55	10.05	12
Akron:																								
Spring wheat.........bushels..		9.00		11.30		11.80		10.80		9.70		8.70		12.70	[a]19.40	12.93	[a]17.50	11.67		7.70		8.90		
Oats.........do....	19.00	9.50	32.50	16.25	17.20	8.60	20.30	10.15	17.10	8.55	20.20	10.10	16.30	8.15	18.80	9.40	24.90	12.45	25.50	12.75	19.30	9.65		
Corn total.........pounds..	2,833	14.17	3,561	17.81	2,754	13.77	2,647	13.24	2,623	13.12	2,617	13.09	([b])		2,607	13.04	2,937	14.69	([b])		2,504	12.52		
Total..........		32.67		45.36		34.17		34.19		31.37		31.89		20.85		35.37		38.81		20.45		31.07		
Average..........		10.89		10.08		11.78		11.40		10.46		11.00		8.34		12.20		12.94		8.18		10.36	10.69	17
Colby:																								
Spring wheat.........bushels..		7.00		11.20		6.90		7.50		5.70		7.40		9.40	[a]16.80	11.20	[a]19.10	12.73		7.60		6.50		
Oats.........do....	17.40	8.70	29.20	14.60	18.60	9.30	19.50	9.75	16.70	8.35	17.90	8.95	20.30	10.15	14.60	7.30	13.30	6.65	27.30	13.65	14.90	7.45		
Corn total.........pounds..	2,833	14.17	4,335	21.68	2,914	14.57	3,822	91.11	2,834	14.17	3,022	15.11	([b])		2,661	13.31	3,093	15.47	([b])		2,712	13.56		
Total..........		29.87		47.48		30.77		36.36		28.22		31.46		19.55		31.81		34.85		21.25		27.51		
Average..........		9.96		10.55		10.61		12.12		9.41		10.85		7.82		10.97		11.62		8.50		9.17	10.14	12
Hays:																								
Spring wheat.........bushels..		5.60		8.30		7.10		5.40		6.70		6.60		9.10	[a]19.00	12.67	[a]15.20	10.13		6.90		5.20		
Oats.........do....	18.00	9.00	28.30	14.15	22.50	11.25	18.40	9.20	21.60	10.80	23.10	11.55	23.60	11.80	20.90	10.45	21.00	10.50	30.10	15.05	22.10	11.05		
Corn total.........pounds..	2,777	13.89	3,864	19.32	2,933	14.67	2,827	14.14	2,799	14.00	2,852	14.26	([b])		2,948	14.74	2,438	12.19	([b])		2,862	14.31		
Total..........		28.49		41.77		33.02		28.74		31.50		32.41		20.90		37.86		32.82		21.95		30.56		
Average..........		9.50		9.28		11.39		9.58		10.50		11.18		8.36		13.06		10.94		8.78		10.19	10.26	19
Averages and total..........		13.63		12.32		15.14		14.87		13.91		15.24		12.28		15.17		14.96		12.52		14.31	13.98	228

[a] Barley was substituted for wheat.

[b] Fallow.

The figures in the 11 double-columns of Table 19 (designated "A" and "B") represent the acre yields for the continuously cropped plots, for the alternately cropped plots, and for each rotation from 1 to 9. The figures representing the wheat yields are entered directly in the right-hand or B section of each pair of columns, except those representing rotations 6 and 7 wherein barley is substituted for wheat. The figures representing the oat, corn, and barley yields are entered in the left-hand or A sections of the respective columns wherever they are used in the rotation. These figures are then each divided by the proper conversion factors, respectively, for each of the three crops—oats by 2, barley by 1½, and corn total weight by 200, which converts the figures into equivalents of bushels of wheat per acre. The quotients are entered in the B sections of their respective columns under the wheat yields and added. The totals in the columns representing continuous cropping and rotations 2, 3, 7, and 9 are divided by 3, which gives the average composite acre yield for each rotation. The total in the alternately fallowed column is divided by $3\times1\frac{1}{2}=4\frac{1}{2}$; the sums for rotations 5 and 8 are divided by $2\times1\frac{1}{4}=2\frac{1}{2}$; and the sums for rotations 1, 4, and 6 are divided by 2.9, to compensate for the difference in cost of production due to fallowing and disking, respectively, as heretofore explained. The averages of the composite yields shown for each of the 11 systems of cropping in Table 19 can then be plotted for each station as has been done in Figure 68, and the relative net productivity of the several systems, after allowing for the increased cost per acre of the systems into which summer-fallowing has been introduced and the decreased cost when disking is practiced, can be plainly seen.

It must be borne in mind that the values represented in both Table 19 and Figure 68 are relative and not absolute. The market prices of the crops raised and the cost of labor involved in their production are constantly fluctuating, both absolutely and relatively. It is therefore obvious that no fixed value can be established for any of the factors involved. It is believed, however, that this method of presenting the relative average returns that may reasonably be expected from these respective systems of farming is as trustworthy as any that has yet been devised. There are, however, other ways of interpreting the facts represented by these figures, and the reader is urged to make his own interpretation. His conclusions may not be the same as those here presented. If some better method than the one used in these computations can be developed, it will be welcomed by all truth-seeking investigators.

RESULTS AT 16 NORTHERN FIELD STATIONS COMPARED

In studying the tables and figures which follow it must be borne in mind that the lengths of the periods of the investigations at the several stations differ. At Sheridan and Scotts Bluff the period is only 9 years; at either differences in length of period or adaptability (crops. This matter is further considered on page 1 in connection with Table 24 and Figure 70, where it : shown that comparisons between the relative values (the rotations are not materially affected by these differ ences in yields at different field stations. These com parisons are between the results from different rotation at the same field station and are expressed in percent ages of the mean yields obtained at the respective fiel stations.

COMPARISON OF YIELDS OF OTHER CROPS EXPRESSED IN EQUIV LENT YIELDS OF BUSHELS OF WHEAT

In Table 19 the stations are arranged geographicall from north to south in conformity with the arrangemen

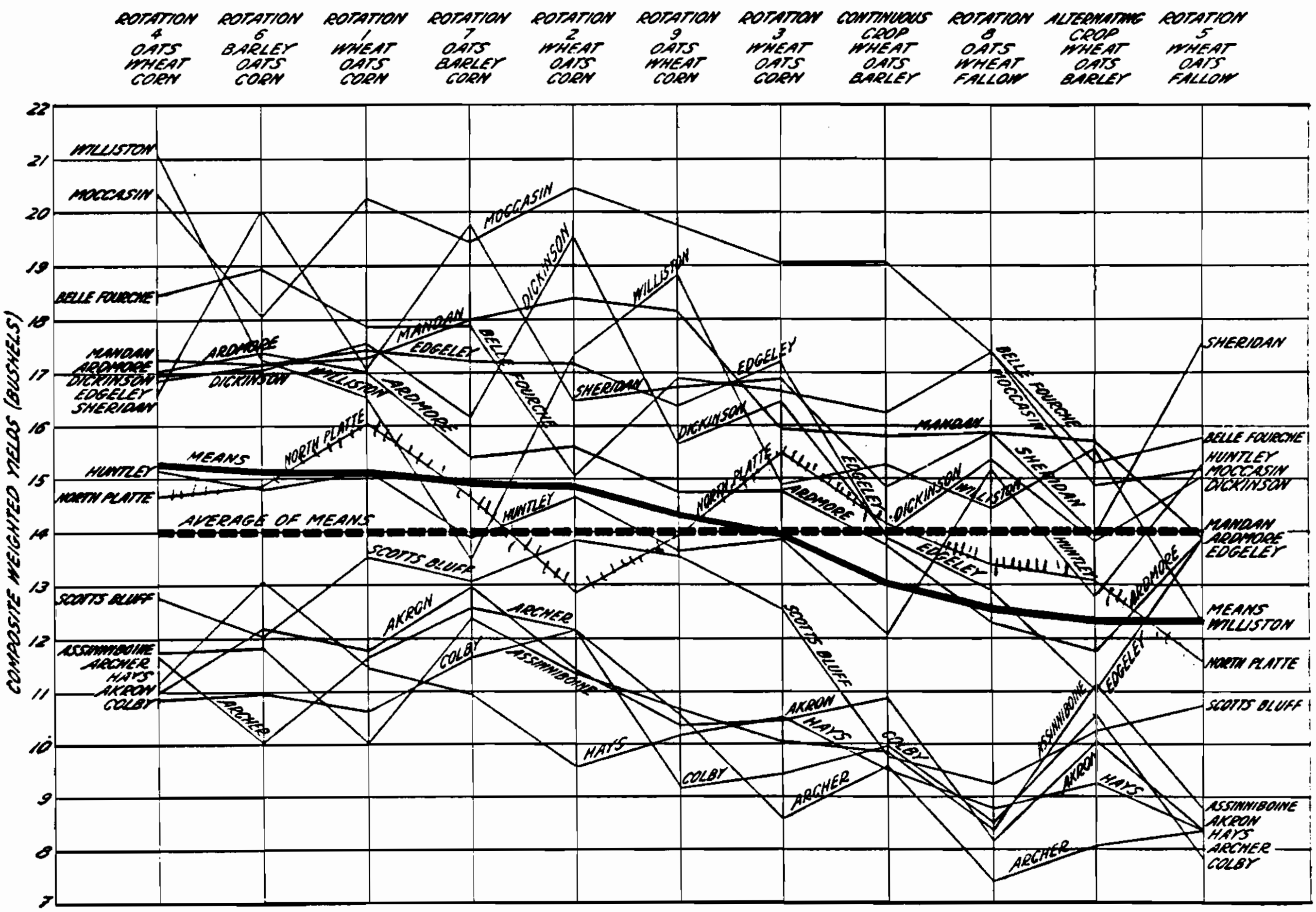

FIGURE 68.—Diagram illustrating Table 20. See text under "Comparison of yields of other crops expressed in equivalent yields of wheat," page 6

Assinniboine, 10 years; at Williston, 11 years; at Mandan, Archer, and Colby, 12 years; at Ardmore, 13 years; at Huntley, 14 years; at Edgeley, 16 years; at Akron, 17 years; at Moccasin and Belle Fourche, 18 years; at Dickinson, North Platte, and Hays, 19 years; as shown in the last column in Table 19.

It will also be noticed that there is a rather wide range in the average returns for the several stations, from 18.52 at Moccasin to 10.05 at Archer. This does not necessarily mean that these figures represent the difference in agricultural possibilities of the regions represented by the respective stations. It simply shows the relative adaptability of these particular crops to the different localities. As interest centers in the relative rather than in the absolute yields, it has not been considered desirable to attempt to weight the figures for in Miscellaneous Circular No. 81. The yield data fo the continuously cropped plots are placed in the firs figure column; next the alternately fallowed plots, an then the rotations 1 to 9 in their numerical order. Thi is not the best arrangement for comparison. More over, the composite yields from the different systems c tillage are so scattered among other figures that wer used in computing the composite yields, but have n further significance, that it is difficult to find then Table 20, therefore, has been prepared, in which th stations are arranged according to the magnitude of th average yields—the highest yields at the top and th lowest at the bottom of the table. The average shown in the right-hand column and near the bottom c Table 20 represent the same values as those in Tabl 19. It will be observed that the average returns show by stations in the right-hand column of Table 20 range from 18.52 bushels at the top to 10.05 bushels at the bottom and that these same values arranged by systems of tillage near the bottom range from 15.24 bushels at the left to 12 28 at the right, with a grand average both by stations and by systems of tillage of 13.98 bushels, as shown at the lower right-hand corner of both Tables 19 and 20.

Table 20, therefore, presents data arranged in convenient form for plotting and comparison. Figure 68 represents graphically the facts shown by the data in Table 20.

It will be noticed by the yields shown by the data at the bottom of Table 20 and by the line marked "means" in Figure 68 that there is a reasonably regular decrease in the yields for the different systems or rotations from left to right. It will also be observed that the 11 systems fall into five rather distinct groups, namely, (1) continuous cropping, (2) alternate fallow, (3) summer-fallowing once in three years, (4) wheat, oats, or barley sown on disked corn stubble in a 3-year rotation, and (5) straight 3-year rotations of corn oats, wheat, or barley sown on ground plowed every year.

TABLE 20.—*Composite acre yields of spring wheat, oats, barley, and corn at 16 field stations in the northern Great Plains area expressed in equivalent yields of bushels of wheat*

[Arranged in order of magnitude of acre yields]

Field station	Rotation 4	Rotation 6	Rotation 1	Rotation 7	Rotation 2	Rotation 9	Rotation 3	Continuous cropping	Rotation 8	Alternate fallow	Rotation 5	Total	Average
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Moccasin	20.57	18.04	20.24	19.42	20.44	19.73	19.03	19.08	17.38	14.84	15.16	203.73	18.52
Belle Fourche	18.42	18.97	17.88	17.90	15.05	16.90	16.62	16.24	17.32	15.28	15.72	186.30	16.94
Sheridan	16.57	20.02	17.08	19.73	16.49	16.72	16.89	14.81	15.86	13.99	17.60	185.76	16.87
Mandan	17.25	17.16	17.28	17.98	18.40	18.11	15.93	15.78	15.82	15.69	13.84	183.24	16.66
Dickinson	16.97	17.03	18.56	16.14	19.52	15.62	16.42	13.93	15.32	13.82	15.08	178.41	16.22
Williston	21.11	17.25	16.52	13.48	17.31	18.81	14.88	15.25	14.40	15.54	12.24	176.79	16.07
Edgeley	16.88	17.17	17.43	17.20	17.18	16.39	17.20	13.87	12.90	11.02	13.88	171.12	15.56
Ardmore	17.02	17.39	17.02	15.40	15.60	14.73	14.77	13.73	12.28	11.77	13.84	163.55	14.87
Huntley	15.23	14.82	15.16	13.87	14.67	13.65	13.87	12.09	15.18	12.75	15.24	156.46	14.22
North Platte	14.64	14.86	16.01	14.68	12.85	13.92	15.46	14.13	13.36	13.03	11.50	154.46	14.04
Scotts Bluff	12.78	12.02	13.51	13.07	13.83	13.51	12.52	9.79	9.24	10.24	10.72	131.23	11.93
Akron	11.00	12.20	11.78	12.94	11.40	10.36	10.46	10.89	8.18	10.08	8.34	117.63	10.69
Assinniboine	11.73	11.81	10.02	12.39	11.35	10.67	10.04	9.84	8.38	11.17	8.72	116.09	10.55
Hays	11.18	13.06	11.39	10.94	9.58	10.19	10.50	9.50	8.78	9.28	8.36	112.82	10.26
Colby	10.85	10.97	10.61	11.62	12.12	9.17	9.41	9.96	8.50	10.55	7.82	111.58	10.14
Archer	11.69	10.02	11.64	12.56	12.12	10.55	8.56	9.55	7.40	8.07	8.36	110.52	10.05
Total	243.66	242.77	242.16	239.32	237.91	229.03	222.56	208.44	200.30	197.12	196.42	2,459.69	----------
Average	15.24	15.17	15.14	14.96	14.87	14.31	13.91	13.03	12.52	12.32	12.28	----------	13.98
Mean rank for all stations	1	2	3	4	5	6	7	8	9	10	11	----------	----------

Groups 1 and 2 are already segregated in Tables 19 and 20, and Group 3 is represented by rotations 5 and 8. These two rotations are exactly alike except that in rotation 5 wheat follows summer-fallow and the oat crop follows wheat, whereas in rotation 8 the oat crop follows summer-fallow and wheat follows oats. As shown in Table 20, they differed in average yields for all stations and years by only 0.24 bushel. The average yields of these two rotations have been used for Group 3, as shown in Tables 22 and 23.

Group 4 is represented by rotations 1, 4, and 6. These three rotations are identical except that in rotation 1 wheat is sown on disked corn stubble and the oat crop follows wheat, in rotation 4 the oat crop is sown on disked corn stubble and wheat follows oats, and in rotation 6 barley is sown on disked corn stubble and the oat crop follows barley. As shown by Tables 19 and 20, rotations 1 and 4 differed in average yield by only 0.10 bushel, and rotation 6 yielded only 0.03 bushel more than rotation 1 and 0.07 bushel less than rotation 4. The average yields of these three rotations have been used for Group 4, as shown in Tables 22 and 23.

Group 5 is represented by rotations 2, 3, 7, and 9. These four rotations are identical except that wheat followed corn in rotations 2 and 3, barley followed oats in rotation 7, and wheat followed oats in rotation 9. Rotations 2, 7, and 9 were spring plowed, but rotation 3 was fall plowed. As shown by Tables 19 and 20, rotation 2 yielded 0.09 bushel less than rotation 7, rotation 9 yielded 0.56 bushel less than rotation 2, and rotation 3 yielded 0.40 bushel less than rotation 9. The average yields of these four rotations have been used for Group 5, as shown in Tables 22 and 23.

A careful study of Tables 19, 20, and 21 and of Figures 68 and 69, indicates that the somewhat erratic differences in yields shown therein must be due to the fact that the corn crop reacts very differently from the wheat, oats, and barley crops, in response to differences in soil, climate, tillage, and crop sequence.

It was therefore decided to reject the corn yields and use only the yields from spring wheat, oats, and barley in considering the relative efficiency of these five groups. Further reasons for rejecting the corn yields will be presented in connection with the description of Tables 25 and 26 and Figure 71, which follows on page 12.

RESULTS SHOWN BY REJECTING CORN YIELDS

Table 21 has been prepared in the same form as Table 20, but the figures are different, owing to the rejection of the corn yields. The general effect has been to reduce the values, indicating that the assumed relative value of the corn yields, as 200 pounds dry weight of total crop, including grain and stover, was too low. For the particular combination of conditions existing at these 16 stations, for these 228 crop years, with the relative frequency of occurrence of the corn crop in the rotations, the ratio should have been 257 pounds of dry weight of the corn crop, instead of 200. Neither of these figures has any permanent value as a conversion factor in reducing corn yields to equivalents of bushels of wheat, as will be shown later.

There were 27 instances out of 176 where the values were increased, 32 where they remained the same (in rotations 5 and 8 where the corn crop did not enter into the rotation), and 117 where they were reduced. The net result was to reduce the grand average from 13.98 to 13.08, a reduction of 0.90 bushel of wheat equivalents, as is seen in the lower right-hand corner of Tables 20 and 21, respectively.

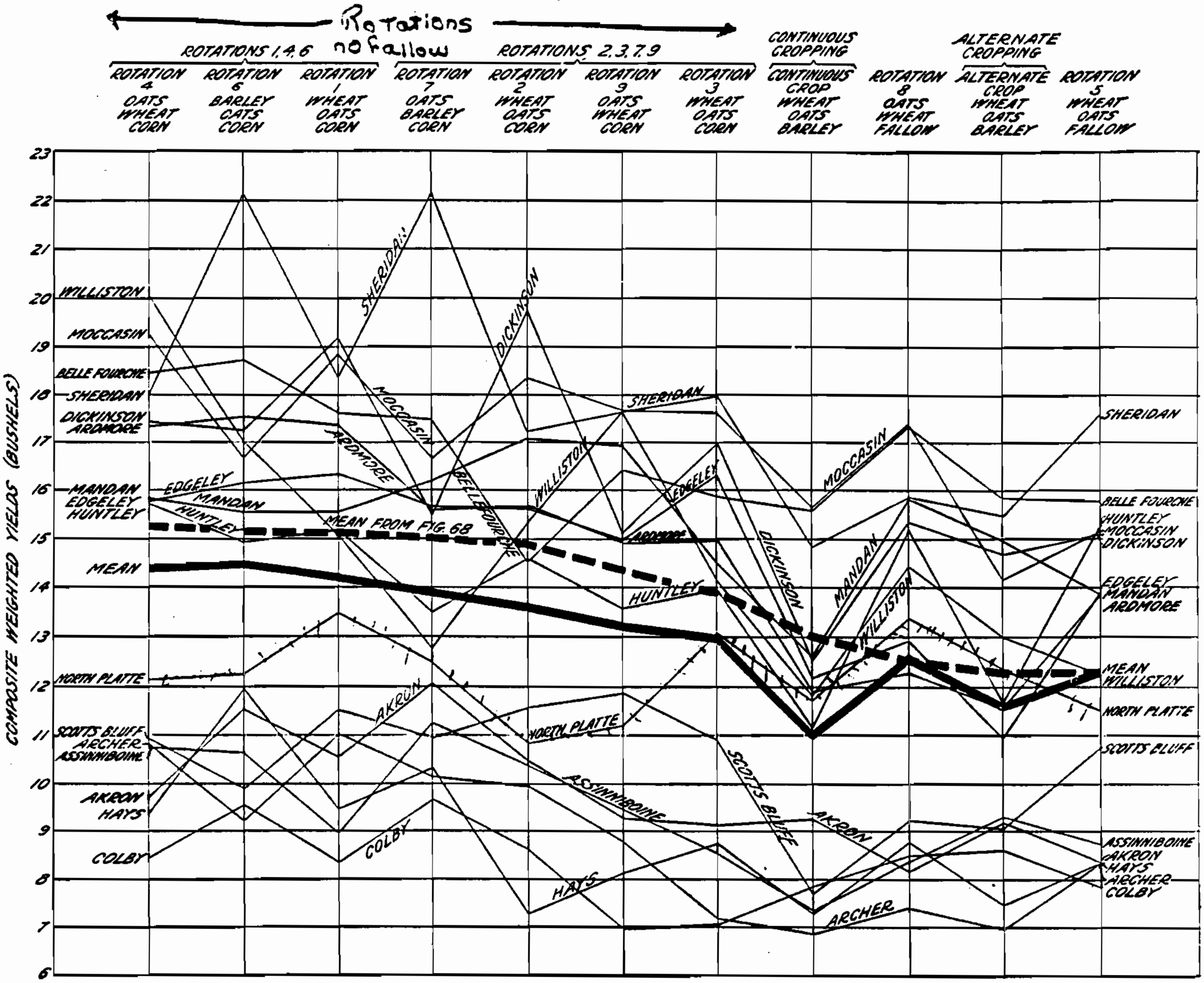

FIGURE 69.—Diagram illustrating Table 21 showing rotation groupings used in Tables 22 and 23. See text under "Group comparisons of crop yields"

TABLE 21.—*Composite acre yields of spring wheat, oats, and barley at 16 field stations in the northern Great Plains area expressed equivalent yields of bushels of wheat*

[Arranged in the same order as in Table 20 and comparable therewith, but with corn yields excluded]

Field station	Rotation 4	Rotation 6	Rotation 1	Rotation 7	Rotation 2	Rotation 9	Rotation 3	Continuous cropping	Rotation 8	Alternate fallow	Rotation 5	Total	Avera
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushe*
Moccasin	19.27	16.68	18.84	16.65	18.33	17.68	17.60	15.63	17.38	14.15	15.16	187.37	17.
Belle Fourche	18.48	18.72	17.60	17.49	14.50	16.40	15.85	15.58	17.32	15.82	15.72	183.48	16
Sheridan	18.01	22.11	18.37	22.14	17.25	17.63	17.95	14.80	15.86	15.47	17.60	197.10	17
Mandan	15.81	15.53	15.53	16.10	17.08	16.90	14.48	12.60	15.82	14.95	13.84	168.73	15
Dickinson	17.44	17.24	19.20	15.49	19.70	15.10	16.93	12.50	15.32	14.67	15.08	178.67	16
Williston	20.05	17.01	15.07	12.73	15.30	17.63	14.13	11.80	14.40	12.97	12.24	163.33	14
Edgeley	15.79	16.14	16.31	15.64	15.63	14.98	16.30	12.15	12.90	10.92	13.88	160.64	14
Ardmore	17.34	17.53	17.34	15.58	15.65	14.90	14.95	11.88	12.28	11.59	13.84	162.88	14
Huntley	15.74	14.93	15.17	13.48	14.58	13.55	13.95	11.15	15.18	11.67	15.24	154.64	14
North Platte	12.14	12.22	13.46	12.49	10.83	11.20	13.05	11.70	13.36	12.33	11.50	134.28	12
Scotts Bluff	10.93	9.90	11.52	10.92	11.58	11.85	10.88	7.70	9.24	9.05	10.72	114.29	10
Akron	9.71	11.54	10.54	12.06	10.48	9.28	9.13	9.25	8.18	9.19	8.34	107.70	9
Assinniboine	10.78	10.61	8.99	11.27	10.38	9.48	8.53	7.35	8.38	9.30	8.72	103.79	9
Hays	9.38	11.95	9.49	10.32	7.30	8.13	8.75	7.30	8.78	7.49	8.36	97.25	8
Colby	8.45	9.56	8.37	9.69	8.63	6.98	7.03	7.85	8.50	8.60	7.82	91.48	8
Archer	10.80	9.21	11.01	10.13	9.95	8.80	7.18	6.85	7.40	6.97	8.36	96.66	8
Total	230.12	230.88	226.81	222.27	217.17	210.49	206.69	176.09	200.30	185.14	196.42	2,302.38	-------
Average	14.38	14.43	14.18	13.89	13.57	13.16	12.92	11.00	12.52	11.57	12.28	----------	1[illegible]

Figure 69 represents graphically the data in Table 21. The different systems of cropping are shown at the top of the figure, indicating the crops and their sequences, continuous cropping, alternate fallowing, the numbers of the rotations 1 to 9, and their proposed groupings into five groups as heretofore explained.

It will be noted that there are two lines marked "mean." The heavy solid line is the mean of the data used in Table 21 and the broken line is the mean of the data used in Table 20 and Figure 68. The interval between these two means represents the average difference of 0.90 bushel heretofore referred to. It will be seen that these two means coincide in rotations 5 and 8 and show an extreme deviation in continuous cropping.

An intensive study of Figures 68 and 69 would reveal many other seemingly anomalous phenomena. In some instances they can be explained by local soil conditions which limit the storage of soil moisture by reason of an impervious subsoil, such as is found at Moccasin, Edgeley, and to a somewhat less extent at Belle Fourche. At these stations but little response is usually shown to summer-fallow. There are, however, many instances where it is impossible with our present knowledge to account for the peculiar behavior of crops. Reference will again be made to these problems after presenting some other important phases of the subject.

TABLE 22.—*Reduction of the composite acre yields of wheat, oats, and barley at 16 field stations in the northern Great Plains area into five groups of rotations*

[The average acre yields for each group are expressed in equivalent yields of bushels of wheat based on the data given in Table 21. The yields from continuous cropping and alternate fallow are the same as in Table 21]

Field station	Continuous cropping (Group 1)	Alternate fallow (Group 2)	Rotations: 5 and 8 (Group 3)	Rotations: 1, 4, and 6 (Group 4)	Rotations: 2, 3, 7, and 9 (Group 5)	Average
1	2	3	4	5	6	7
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Moccasin	15.63	14.15	15.16 17.38 -------- --------	18.84 19.27 16.68 --------	18.33 17.60 16.65 17.68	-------- -------- -------- --------
Average	15.63	14.15	16.27	18.26	17.57	16.38
Belle Fourche	15.58	15.82	15.72 17.32 -------- --------	17.60 18.48 18.72 --------	14.50 15.85 17.49 16.40	-------- -------- -------- --------
Average	15.58	15.82	16.52	18.27	16.06	16.45
Sheridan	14.80	15.47	17.60 15.86 -------- --------	18.37 18.01 22.11 --------	17.25 17.95 22.14 17.63	-------- -------- -------- --------
Average	14.80	15.47	16.73	19.50	18.74	17.05
Mandan	12.60	14.95	13.84 15.82 -------- --------	15.53 15.81 15.53 --------	17.08 11.48 16.19 16.90	-------- -------- -------- --------
Average	12.60	14.95	14.83	15.62	16.16	14.83
Dickinson	12.50	14.67	15.08 15.32 -------- --------	19.20 17.44 17.24 --------	19.70 16.93 15.49 15.10	-------- -------- -------- --------
Average	12.50	14.67	15.20	17.96	16.81	15.43
Williston	11.80	12.97	12.24 14.40 -------- --------	15.07 20.05 17.01 --------	15.30 14.13 12.73 17.63	-------- -------- -------- --------
Average	11.80	12.97	13.32	17.38	14.95	14.08
Edgeley	12.15	10.92	13.88 12.90 -------- --------	16.31 15.79 16.14 --------	15.63 16.30 15.64 14.98	-------- -------- -------- --------
Average	12.15	10.92	13.39	16.08	15.64	13.64
Ardmore	11.88	11.50	13.84 12.28 -------- --------	17.34 17.34 17.53 --------	15.65 14.95 15.58 14.90	-------- -------- -------- --------
Average	11.88	11.59	13.06	17.40	15.27	13.84
Huntley	11.15	11.67	15.24 15.18 -------- --------	15.17 15.74 14.93 --------	14.58 13.95 13.48 13.55	-------- -------- -------- --------
Average	11.15	11.67	15.21	15.28	13.89	13.44
North Platte	11.70	12.33	11.50 13.36 -------- --------	13.46 12.14 12.22 --------	10.83 13.05 12.49 11.20	-------- -------- -------- --------
Average	11.70	12.33	12.43	12.61	11.89	12.19
Scotts Bluff	7.70	9.05	10.72 9.24 -------- --------	11.52 10.93 9.90 --------	11.58 10.88 10.92 11.85	-------- -------- -------- --------
Average	7.70	9.05	9.98	10.78	11.31	9.76
Akron	9.25	9.19	8.34 8.18 -------- --------	10.54 9.71 11.54 --------	10.48 9.13 12.06 9.28	-------- -------- -------- --------
Average	9.25	9.19	8.26	10.60	10.24	9.51
Assinniboine	7.35	9.30	8.72 8.38 -------- --------	8.99 10.78 10.61 --------	10.38 8.53 11.27 9.48	-------- -------- -------- --------
Average	7.35	9.30	8.55	10.13	9.02	9.05
Hays	7.30	7.49	8.36 8.78 -------- --------	9.49 9.38 11.95 --------	7.30 8.75 10.32 8.13	-------- -------- -------- --------
Average	7.30	7.49	8.57	10.27	8.63	8.45
Colby	7.85	8.60	7.82 8.50 -------- --------	8.37 8.45 9.56 --------	8.63 7.03 9.69 6.98	-------- -------- -------- --------
Average	7.85	8.60	8.16	8.79	8.08	8.30
Archer	6.85	6.97	8.36 7.40 -------- --------	11.01 10.80 9.21 --------	9.95 7.18 10.13 8.80	-------- -------- -------- --------
Average	6.85	6.97	7.88	10.34	9.02	8.21
Grand average	11.01	11.57	12.40	14.33	13.39	12.54

Attention heretofore has been called to the very close agreement between the average yields of the several rotations that have been grouped together. It must, however, be constantly borne in mind that these averages almost invariably represent very wide divergences in the individual yields at the different stations from which these averages were obtained, as shown by Figures 68 and 69. Keeping these facts in mind, it is found that in order to arrive at any concrete generalization concerning the relative efficiency of the different systems of tillage and crop rotations, it will be

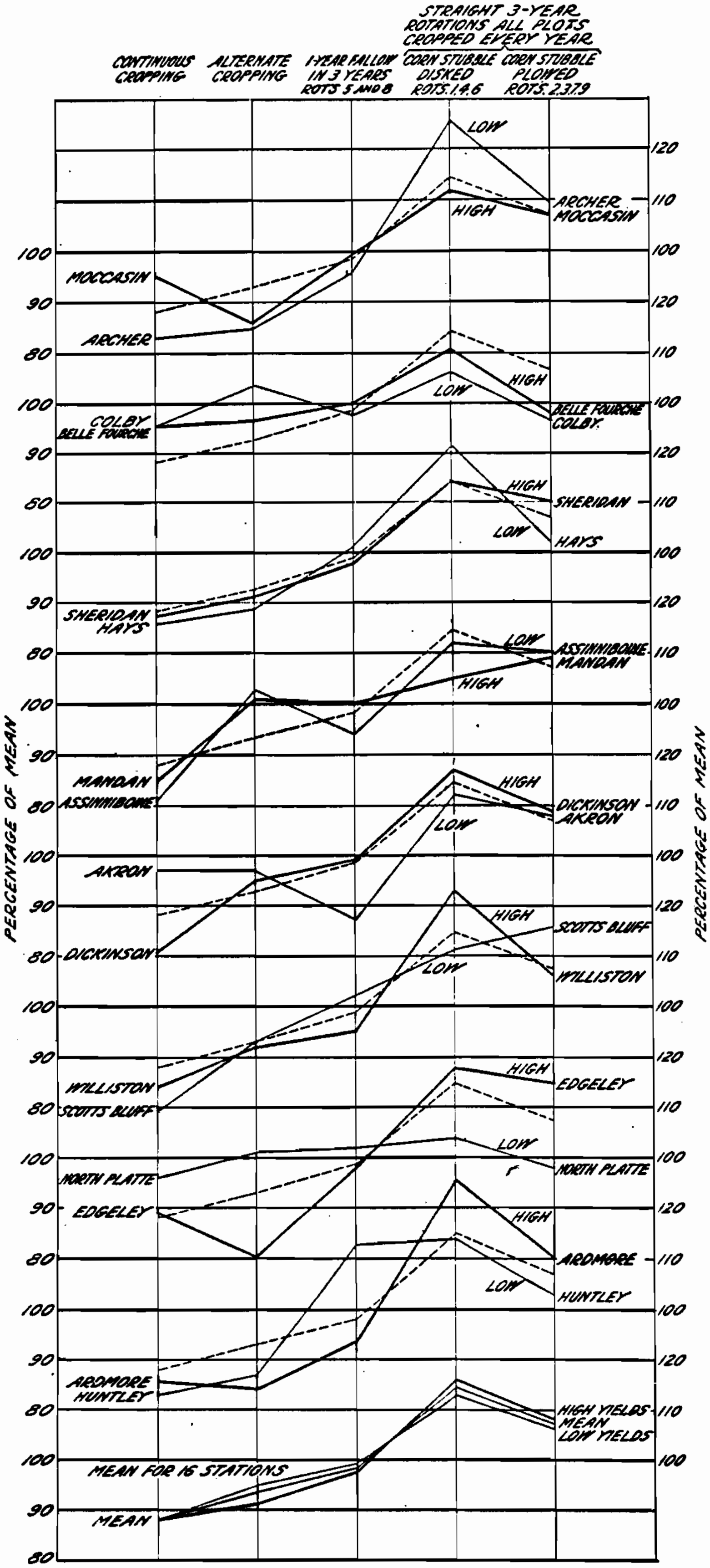

FIGURE 70.—Diagram illustrating the relative efficiency of five tillage and rotation systems by the percentages of the means for each of the five groups at 16 northern Great Plains field stations, arranged in pairs of high and low yielding stations. Percentages below the mean (100) are shown along the left margin and those above the mean along the right margin

necessary still further to concentrate the available data. The manner of reduction of the 11 different rotations and tillage methods to five groups is indicated in Figures 69 and 70.

SIMPLIFYING GROUP COMPARISONS OF CROP YIELDS BY CONCENTRATION INTO FEWER GROUPS

The figures in Table 22 are transferred from Table 21. Columns 2 and 3 contain the same figures as the columns with the same headings in Table 21. Column 4, headed "Rotations 5 and 8," contains the same figures as the respective columns in Table 21, but the average of these two quantities is used, and the footing at the bottom is the average of the two footings in Tables 20 and 21, respectively. Columns 5 and 6, headed "Rotations 1, 4, and 6" and "Rotations 2, 3, 7, and 9," are treated in the same manner as column 4. The average of the footings at the bottom of columns 2–6 and the average of the averages in column 7 give the grand average of 12.54, which is 0.54 less than 13.08, as given in Table 21. This difference is due to the averaging of the averages of 11 groups when concentrated into five groups.

PERCENTAGE VALUES OF CROP-YIELD COMPARISONS

The average yields for the several stations as they appear in column 7 of Table 22 are now transferred to column 2 in Table 23, and in the same line with these mean yields in columns 3, 5, 7, 9, and 11 are placed the respective yields for each of the five groups, as given in Table 22.

Each of these yields is then divided by the mean yields for that station and the respective quotients placed in columns 4, 6, 8, 10, and 12 under the heading "Percentage of mean." These figures constitute the percentages of the mean for all the five tillage systems at each station, and their relative magnitudes indicate the relative efficiency of each tillage system for each station. The percentage value of any given system at any station may be compared with the percentage value of any other system at any station irrespective of the actual yields at any of the stations.

In order to determine whether the relative magnitude of the yields exerted any influence upon the relationships of different tillage methods and crop rotations as measured by the respective percentage of their mean yields, Table 23 is presented in two sections. The upper section contains the figures for the eight stations having the highest yields, and the lower section contains those having the lowest yields. The averages are given for each station and the grand averages for the entire table. The percentages of the means are the significant figures in this table, as they are the indexes of the relative efficiency of the different systems or rotations. These are presented graphically in Figure 70.

TABLE 23.—*Composite weighted acre yields of wheat, oats, and barley, expressed in equivalent yields of bushels of wheat, at 16 field stations in the northern Great Plains area, showing percentage of mean*

[The stations are arranged in the same order as in Tables 20, 21, and 22, but they are separated into two divisions, the upper containing the higher yields and the lower containing the lesser yields]

Stations—	Mean yields for all rotations	Group 1, continuous cropping		Group 2, alternate fallow		Group 3, rotation 5 and 8 (fallow)		Group 4, rotations 1, 4, and 6 (disked corn stubble)		Group 5, rotations 2, 3, 7, and 9 (plowed corn stubble)	
		Average yield	Percentage of mean	Average yield	Percentage of mean	Average yield	Percentage of mean	Average yield	Percentage of mean	Average yield	Percentage of mean
1	2	3	4	5	6	7	8	9	10	11	12
Showing high yields:	*Bu.*	*Bu.*		*Bu.*		*Bu.*		*Bu.*		*Bu.*	
Moccasin	16.38	15.63	0.95	14.15	0.86	16.27	0.99	18.26	1.11	17.57	1.07
Belle Fourche	16.45	15.58	.95	15.82	.96	16.52	1.00	18.27	1.11	16.06	.98
Sheridan	17.05	14.80	.87	15.47	.91	16.73	.98	19.50	1.14	18.74	1.10
Mandan	14.83	12.60	.85	14.95	1.01	14.83	1.00	15.62	1.05	16.16	1.09
Dickinson	15.43	12.50	.81	14.67	.95	15.20	.99	17.96	1.16	16.81	1.09
Williston	14.08	11.80	.84	12.07	.92	13.32	.95	17.38	1.23	14.95	1.06
Edgeley	13.64	12.15	.89	10.92	.80	13.39	.98	16.08	1.18	15.64	1.15
Ardmore	13.84	11.88	.86	11.59	.84	13.06	.94	17.40	1.26	15.27	1.10
Average	15.22	13.37	-----	13.82	-----	14.92	-----	17.56	-----	16.40	-----
Percentage of mean	-----	-----	.88	-----	.91	-----	.98	-----	1.16	-----	1.08
Showing low yields:											
Huntley	13.44	11.15	.83	11.67	.87	15.21	1.13	15.28	1.14	13.89	1.03
North Platte	12.19	11.70	.96	12.33	1.01	12.43	1.02	12.61	1.03	11.89	.98
Scotts Bluff	9.76	7.70	.79	9.05	.93	9.98	1.02	10.78	1.10	11.31	1.16
Akron	9.51	9.25	.97	9.19	.97	8.26	.87	10.60	1.12	10.24	1.08
Assinniboine	9.05	7.35	.81	9.30	1.03	8.55	.94	10.13	1.12	9.92	1.10
Hays	8.45	7.30	.86	7.49	.89	8.57	1.01	10.27	1.22	8.63	1.02
Colby	8.30	7.85	.95	8.60	1.04	8.16	.98	8.79	1.06	8.08	.97
Archer	8.21	6.85	.83	6.97	.85	7.88	.96	10.34	1.26	9.02	1.10
Average	9.87	8.64	-----	9.33	-----	9.88	-----	11.10	-----	10.37	-----
Percentage of mean	-----	-----	.88	-----	.95	-----	.99	-----	1.13	-----	1.06
Grand average:											
Yield	12.54	11.01	-----	11.57	-----	12.40	-----	14.33	-----	13.39	-----
Percentage of mean	-----	-----	.88	-----	.93	-----	.985	-----	1.145	-----	1.07

RELATIVE EFFECTIVENESS OF ROTATIONS OR TILLAGE METHODS AT HIGH-YIELDING AND LOW-YIELDING STATIONS

In order to make direct comparisons between those stations that would be likely to show the greatest differences, the stations have been plotted in pairs, as shown in Figure 70, the station at the top of the upper section of high yields, with that from the bottom of the lower section of low yields; the second one from the top of the upper section with the second one from the bottom of the lower section, and so on for the eight pairs. The differences in yields between the two members of the pair, expressed in the equivalents of bushels of wheat, are graphically shown in connection with the station designations at the left of the figure. The submeans for each section of Table 23 and for the entire table are shown graphically at the bottom of the figure. The latter is repeated in broken lines for each pair for more direct comparison. The figures at the bottom are the footings of Table 23, showing, respectively, the percentages and the yields for the entire table.

It is an interesting fact, but probably of little practical importance, that the four pairs having the greater differences in yields between their two members show a decidedly closer coincidence in percentages than do the four pairs having the lesser differences. It is also a rather peculiar circumstance that the Sheridan–Hays pair having the closest coincidence also have the greatest difference in yields, and the Edgeley–North Platte pair, which show the greatest discordance in percentages, differ in yields by only 1.45 bushels.

The important facts established by Figure 70 are that it furnishes no evidence that the relative effectiveness of rotations or tillage methods is influenced in any way by the differences in magnitude of the crop yields obtained at different stations and that if any such influences existed these comparisons would have revealed them. It, therefore, may be safely stated that this percentage method provides an index to the relative effectiveness as reliable as the data upon which it is based.

It must be borne in mind that the conclusions indicated in Table 23 and Figure 70 are based upon the yields from 228 crop years involving more than 5,000 determinations of individual crop yields of spring wheat, oats, and barley at 16 field stations for an average period of 14¼ years, ranging from 9 to 19 years at each station. This is a broad basis for a broad generalization. Very few broad generalizations are universally applicable. This one is no exception to the rule. It is, however, based upon long-continued and carefully interpreted experimentation and is believed to be the safest general guide to rotation practices throughout the northern Great Plains that has ever been formulated, for the very obvious reason that it is based upon vastly more reliable experimental data than have ever before been brought together. A careful study of Table 21 and Figure 69, and of the still more detailed information contained in tables which follow will be of great assistance to anyone desiring to solve local problems of crop rotation and tillage methods, which can be solved only in terms of particular farms and particular farmers, being subject also to the local soil, climatic, and economic conditions existing and prospective at any given time and place.

RELATIONS OF THE CORN CROP TO ROTATIONS IN THE NORTHERN GREAT PLAINS AREA

Corn (also known as Indian corn, or maize) is, and probably long will continue to be, one of the most important crops in the farming systems and crop rotations in the Great Plains area. The importance of the corn crop is not due to its intrinsic value as a cash crop, but rather to the beneficial influence that it has upon the small-grain crops which follow it in the rotations, and it is also one of the most dependable crops grown in this region to provide winter feed for livestock. In favorable years it often produces profitable yields of grain at many of the stations, and it seldom fails to produce more or less stover or silage in even the most unfavorable years. The altitude is too high, the season too short, and the annual rainfall too low for corn ever to become the major crop, except possibly in some few especially favored localities in the

Great Plains area. Nevertheless, it is believed, not only from evidence furnished by these investigations, but also from nearly a half century of experience and observation in the northern Great Plains, that the growing of corn and the raising of livestock should occupy a prominent place in the farming systems of that region. Such being the case, the growing of corn should be given careful consideration in any study of crop rotations on the northern Great Plains, and it seems that the corn yields should be included in estimates of the relative efficiency of all rotations in which it is used. But, as heretofore mentioned, there seem to be serious difficulties in establishing a common basis for estimating its relative value in any given rotation. This is due largely to the fact that in many instances the climatic conditions, and sometimes the tillage methods, which are most favorable to spring wheat, oats, and barley are unfavorable for the corn crop, and vice versa.

There is still another reason why "a good wheat season is a poor corn season, and a good corn season a poor wheat season." Not infrequently the small-grain crops will be seriously damaged or completely destroyed by unfavorable weather such as drought or hail during May or June. This may be followed by favorable weather during July, August, and September, and a good corn crop may be harvested. But the most discordant thing about the corn crop is that it does not respond to summer-fallowing to anywhere near the extent that wheat, oats, and barley do. In fact, continuous cropping to corn not infrequently yields higher than alternate fallowing; and it is the rule rather than the exception that the yields from corn grown continuously on the same land are higher than when grown in rotations with small-grain crops.

In order to present still more impressively the very erratic behavior of the corn crop, Tables 24, 25, and 26 have been developed from Table 19 in the same manner and the same general form as Table 23. All values in these tables are expressed in equivalents of bushels of wheat per acre.

Table 24 includes with wheat, oats, and barley the corn yields obtained by dividing the total dry weight of corn grain and stover by 200, as in Tables 19 and 20. It also includes rotations 5 and 8, as does Table 23.

Table 25 includes corn, calculated at 200 pounds as the equivalent of 1 bushel of wheat, but excludes wheat, oats, and barley. It also excludes rotations 5 and 8.

Table 26 is identical with Table 25 except that the corn yields are calculated upon the basis of 257 pounds of dry weight of corn grain and stover as being equivalent to 1 bushel of wheat, instead of 200 pounds as in Tables 19 and 20.

TABLE 24.—*Composite weighted acre yields of wheat, oats, barley, and corn, expressed in equivalent yields of bushels of wheat, a 16 field stations in the northern Great Plains area, showin percentage of mean*

[Same as Table 23, except that corn yields (obtained by dividing the total dry weig of corn and stover by 200) have been included]

Field stations—	Mean yields for all rotations	Group 1, continuous cropping		Group 2, alternate fallow		Group 3, rotations 5 and 8 (fallow)		Group 4, rotations 1, 4, and 6 (disked corn stubble)		Group 5 rotation 2, 3, 7, and 9 (plowed corn stubble	
		Average yield	Percentage of mean	Average yield	Percentage of mean	Average yield	Percentage of mean	Average yield	Percentage of mean	Average yield	Percentage
1	2	3	4	5	6	7	8	9	10	11	12
Showing high yields:	Bu.	Bu.		Bu.		Bu.		Bu.		Bu.	
Moccasin	17.88	19.08	1.07	14.84	0.83	16.27	0.91	19.55	1.09	19.66	1.
Belle Fourche	16.62	16.24	.98	15.28	.92	16.52	.99	18.42	1.11	16.62	1.
Sheridan	16.18	14.81	.92	13.99	.86	16.73	1.03	17.89	1.11	17.48	1.
Mandan	16.27	15.78	.97	15.69	.96	14.83	.91	17.23	1.06	17.61	1.
Dickinson	15.48	13.93	.90	13.82	.89	15.20	.98	17.52	1.13	16.92	1.
Williston	15.70	15.21	.97	15.54	.99	13.32	.84	18.29	1.17	16.12	1.
Edgeley	14.49	13.87	.96	11.02	.76	13.39	.92	17.16	1.18	16.99	1.
Ardmore	14.16	13.73	.97	11.77	.83	13.06	.92	17.14	1.21	15.12	1.
Average	15.85	15.33	-----	13.99	-----	14.92	-----	17.90	-----	17.07	---
Percentage of mean	-----	-----	.97	-----	.88	-----	.94	-----	1.13	-----	1.
Showing low yields:											
Huntley	13.82	12.09	.87	12.75	.92	15.21	1.10	15.05	1.09	14.01	1.
North Platte	13.80	14.13	1.02	13.03	.94	12.43	.90	15.18	1.10	14.23	1.
Scotts Bluff	11.20	9.79	.87	10.24	.91	9.08	.89	12.77	1.14	13.23	1.
Akron	10.44	10.89	1.04	10.08	.97	8.26	.79	11.66	1.12	11.29	1.
Assinniboine	10.37	9.84	.95	11.17	1.08	8.55	.82	11.17	1.08	11.11	1.
Hays	9.91	9.50	.96	9.28	.94	8.57	.86	11.90	1.20	10.30	1.
Colby	10.01	9.96	1.00	10.53	1.05	8.16	.82	10.81	1.08	10.58	1.
Archer	9.51	9.55	1.00	8.07	.85	7.88	.82	11.12	1.17	10.95	1.
Average	11.13	10.72	-----	10.64	-----	9.88	-----	12.46	-----	11.96	---
Percentage of mean	-----	-----	.96	-----	.96	-----	.88	-----	1.12	-----	1.
Grand average:											
Yield	13.49	13.03	-----	12.32	-----	12.40	-----	15.18	-----	14.51	---
Percentage of mean	-----	-----	.96	-----	.92	-----	.91	-----	1.13	-----	1.

As has been mentioned before, the relative valu assigned to corn in Tables 19 to 25 is too high as broad generalization for the average conditions th have prevailed at the 16 northern Great Plains fiel stations during the 228 crop years covered by thes investigations, as shown by the facts that the grai average of the mean composite acre yields of whea oats, and barley, as given in column 7 of Table 22 12.54 bushels; while for corn, wheat, oats, and barle as given in Table 24, the average is 13.49 bushels; a in Table 25, where the yields of corn only are give the mean acre yield is 16.11 bushels, using 200 poun dry weight as the basis of computation. It wa therefore, considered desirable to compute the co yields on the basis of 257 pounds dry weight as h been done in Table 26, which gives 12.54 bushel the same as in Table 23.

TABLE 25.—*Acre yields of corn at 16 field stations in the northern Great Plains area, expressed in equivalent yields of bushels of wheat, as given in Table 19, and grouped in the same manner as the composite yields of wheat, oats, and barley in Table 23, showing also percentage of mean as in Table 23*

[The total dry weight of corn grain and stover is divided by 200 to convert it into equivalent bushels of wheat. Rotations 5 and 8 are omitted because they contain no corn]

Field stations—	Mean yields for all rotations	Group 1, continuous cropping		Group 2, alternate fallow		Group 4, rotations 1, 4, and 6 (disked corn stubble)		Group 5, rotations 2, 3, 7, and 9 (plowed corn stubble)	
		Average yield	Percentage of mean	Average yield	Percentage of mean	Average yield	Percentage of mean	Average yield	Percentage of mean
1	2	3	4	5	6	7	8	9	10
Showing high yields:	*Bu.*	*Bu.*		*Bu.*		*Bu.*		*Bu.*	
Moccasin	22.08	25.99	1.18	16.21	0.73	22.28	1.01	23.84	1.08
Belle Fourche	17.06	17.57	1.03	14.20	.83	18.71	1.10	17.74	1.04
Sheridan	13.85	14.83	1.07	11.03	.80	14.63	1.06	14.89	1.08
Mandan	20.05	22.13	1.10	17.17	.86	20.42	1.02	20.50	1.02
Dickinson	15.67	16.79	1.07	12.11	.77	16.61	1.06	17.17	1.10
Williston	20.35	22.15	1.09	20.69	1.02	20.09	.99	18.47	.91
Edgeley	16.88	17.31	1.03	11.22	.66	19.28	1.14	19.71	1.17
Ardmore	15.26	17.44	1.14	12.15	.80	16.60	1.09	14.84	.97
Average yield	17.65	19.28		14.35		18.58		18.40	
Percentage of mean			1.09		.81		1.05		1.04
Showing low yields:									
Huntley	14.44	13.97	.97	14.92	1.03	14.62	1.01	14.26	.99
North Platte	18.10	18.78	1.04	14.41	.80	20.29	1.12	18.91	1.04
Scotts Bluff	15.10	13.98	.93	12.62	.84	16.73	1.11	17.09	1.13
Akron	13.30	14.17	1.07	11.87	.89	13.76	1.03	13.39	1.01
Assinniboine	14.13	14.82	1.05	14.92	1.06	13.26	.94	13.52	.96
Hays	13.87	13.89	1.00	12.88	.93	15.06	1.09	13.66	.98
Colby	14.75	14.17	.96	14.45	.98	14.82	1.00	15.58	1.06
Archer	12.82	14.94	1.17	10.28	.80	12.66	.99	13.39	1.04
Average yield	14.56	14.84		13.29		15.15		14.98	
Percentage of mean			1.02		.91		1.04		1.03
Grand average:									
Yield	16.11	17.06		13.82		16.80		16.69	
Percentage of mean			1.06		.86		1.05		1.04

In Figure 71 the acre yields of wheat, oats, and barley, as shown in Table 23, are also given in equivalents of bushels of wheat, the solid lines representing the wheat, oats, and barley yields, and the broken lines the corn yields, as given in Table 26. There are two mean lines showing the means by stations, one for corn only, and the other for wheat, oats, and barley. Although each of these means averages 12.54 bushels in wheat equivalents, it will be seen that they vary fantastically from each other for the individual stations, thus showing how discordant the small-grain yields are with the corn yields at the different stations. For example, at Sheridan the difference between continuous cropping for corn and for small grains is 3.26 bushels, whereas at Huntley this difference is only 0.28 bushel; for alternate fallow the respective differences are 6.89 and 0.06 bushels; for rotations 1, 4, and 6 these differences are 8.11 and 3.9 bushels; and for rotations 2, 3, 7, and 9 these differences are 7.15 and 2.89 bushels. There are many other instances where the discordance is nearly as great. In fact, discord rather than accord seems to be the rule, as is shown by the repeated crossing and recrossing of the two "mean" lines.

Figure 72, like Figure 71, is a graphic presentation of the figures given in Tables 23, 24, and 25. But in Figure 72 the percentage of mean is used instead of the acre yield as in Figure 71.

TABLE 26.—*Acre yields of corn, expressed in amended equivalent yields of bushels of wheat, at 16 field stations in the northern Great Plains area*

[This table is the same as Table 25, except that 257 (instead of 200) is used as the divisor of the total weight in the conversion of yields to wheat equivalents]

Field stations—	Mean yields for all rotations	Group 1, continuous cropping		Group 2, alternate fallow		Group 4, rotations 1, 4, and 6 (disked corn stubble)		Group 5, rotations 2, 3, 7, and 9 (plowed corn stubble)	
		Average yield	Percentage of mean	Average yield	Percentage of mean	Average yield	Percentage of mean	Average yield	Percentage of mean
1	2	3	4	5	6	7	8	9	10
Showing high yields:	*Bush.*	*Bush.*		*Bush.*		*Bush.*		*Bush.*	
Moccasin	17.18	20.23	1.18	12.62	0.74	17.34	1.01	18.55	1.08
Belle Fourche	13.27	13.67	1.03	11.05	.83	14.56	1.10	13.81	1.04
Sheridan	10.78	11.54	1.07	8.58	.80	11.39	1.06	11.59	1.08
Mandan	15.60	17.22	1.10	13.36	.86	15.89	1.02	15.95	1.02
Dickinson	12.19	13.07	1.07	9.42	.77	12.93	1.06	13.36	1.10
Williston	15.84	17.24	1.09	16.10	1.02	15.63	.99	14.37	.91
Edgeley	13.14	13.47	1.03	8.73	.65	15.00	1.14	15.34	1.17
Ardmore	11.88	13.57	1.14	9.46	.80	12.92	1.09	11.55	.97
Average yield	13.74	15.00		11.17		14.46		14.32	
Percentage of mean			1.09		.81		1.06		1.05
Showing low yields:									
Huntley	11.24	10.87	.97	11.61	1.03	11.38	1.01	11.10	.99
North Platte	14.08	14.61	1.04	11.21	.80	15.79	1.12	14.72	1.05
Scotts Bluff	11.75	10.88	.93	9.82	.84	13.02	1.11	13.30	1.13
Akron	10.35	11.03	1.07	9.24	.89	10.71	1.03	10.42	1.01
Assinniboine	11.00	11.53	1.05	11.61	1.06	10.32	.94	10.52	.96
Hays	10.79	10.81	1.00	10.02	.93	11.72	1.09	10.63	.99
Colby	11.48	11.03	.96	11.25	.98	11.53	1.00	12.12	1.06
Archer	9.98	11.63	1.17	8.00	.80	9.85	.99	10.42	1.04
Average yield	11.33	11.55		10.35		11.79		11.65	
Percentage of mean			1.02		.92		1.04		1.03
Grand average:									
Yield	12.54	13.28		10.70		13.12		12.98	
Percentage of mean			1.05		.86		1.05		1.04

Therefore, for comparison, there are three different methods of computation, namely, the percentages of the means based upon (1) the composite yields of spring wheat, oats, and barley, Table 23; (2) the yields of corn only, based on 200 pounds of total dry weight of grain and stover as equivalent to 1 bushel of wheat, Table 25; and (3) the composite yields of corn, spring wheat, oats, and barley, with 200 pounds of the dry weight of the corn grain and stover as an equivalent of 1 bushel of wheat, Table 24.

Rotations 5 and 8 are not included in Tables 25 and 26, nor in Figures 71 and 72, as the corn crop does not enter into these two rotations, summer-fallowing being substituted for corn. The percentage calculations are therefore based upon four groups of rotations and tillage methods instead of upon five, as is the case with Tables 19 to 24, inclusive, and with Figures 68, 69, and 70.

It will be observed that in Figure 72 a fourth line representing the means of the other three means for all stations has been inserted for each station. This was done to facilitate direct comparison between the three different methods of computation. Although there is no such close agreement as is found in Figure 70, it will be observed that the general relative efficiency of the different groups is not materially different under the different methods of computation, except in the case of the relations between continuous cropping and alternate fallowing. This difference is obviously due to the failure of corn to respond to summer-fallowing as the small grains do. The other discrepancies are nearly all differences in degree rather than differences in direction of deviation in these relations.

A careful study of Tables 23, 24, 25, and 26 and Figures 71 and 72 seems to indicate that, notwithstanding the erratic behavior of the corn crop as compared with wheat, oats, and barley, the methods of analyses and interpretation employed in the preceding pages lead to reliable conclusions concerning the relative efficiency of the different methods of crop rotation and tillage.

Reverting to Table 23, of which Figure 70 is a graphic illustration, attention is called to the following facts:

Rotations 1, 4, and 6, 3-year rotations with wheat, oats, or barley sown on disked corn stubble, stand No. 1 at 14 out of the 16 stations, Mandan and Scotts Bluff being the exceptions.

Rotations 2, 3, 7, and 9, 3-year rotations with wheat, oats, or barley sown on plowed corn stubble, stand No. 2 at 10 stations; No. 3 at 4 stations (Belle Fourche, Huntley, North Platte, and Colby); and No. 1 at 2 stations (Mandan and Scotts Bluff).

Rotations 5 and 8, 3-year rotations of wheat, oats, and fallow (the wheat following the fallow in 5 and the oats following the fallow in 8), stand No. 3 at 9 stations; No. 2 at Belle Fourche, Huntley, and North Platte; No. 4 at Mandan, Assinniboine, and Colby, and No. 5 at Akron.

Alternate fallowing stands No. 4 at 10 stations; No. 5 at Moccasin, Edgeley, and Ardmore; No. 3 at Mandan and Assinniboine; and No. 2 at Colby.

Continuous cropping stands No. 5 at 12 stations; No. 4 at Moccasin, Edgeley, and Ardmore; and No. 3 at Akron.

The relative effectiveness of these five methods is shown in statistical form in Table 27, and graphically in Figures 73 and 74, all of which have been developed from Table 23 using the acre yields weighted for differences in tillage systems from wheat, oats, and barley as a basis and expressed in equivalents of bushels of wheat. No fixed prices for any of the grains were considered in these computations.

TABLE 27.—*Relative rank of three groups of rotations, continuous cropping, and alternate fallow at 16 field stations in the northern Great Plains area*

Field stations	Relative rank					Tota[illegible]
	Continuous cropping (Group 1)	Alternate fallow (Group 2)	Rotations 5 and 8 (Group 3)	Rotations 2, 3, 7, and 9 (Group 5)	Rotations 1, 4, and 6 (Group 4)	
Moccasin	Fourth	Fifth	Third	Second	First	
Belle Fourche	Fifth	Fourth	Second	Third	do	
Sheridan	do	do	Third	Second	do	
Mandan	do	Third	Fourth	First	Second	
Dickinson	do	Fourth	Third	Second	First	
Williston	do	do	do	do	do	
Edgeley	Fourth	Fifth	do	do	do	
Ardmore	do	do	do	do	do	
Huntley	Fifth	Fourth	Second	Third	do	
North Platte	do	do	do	do	do	
Scotts Bluff	do	do	Third	First	Second	
Akron	Third	do	Fifth	Second	First	
Assinniboine	Fifth	do	Fourth	do	do	
Hays	do	do	Third	do	do	
Colby	do	Second	Fourth	Third	do	
Archer	do	Fourth	Third	Second	do	
Total (points):						
Actual	75	63	50	34	18	[illegible]
Theoretical	80	64	48	32	16	[illegible]
Difference	−5	−1	+2	+2	+2	
Percentage:						
Actual total ÷ theoretical total	0.94	0.98	1.04	1.06	1.12	
Theoretical total ÷ actual total	1.06	1.02	.96	.94	.88	

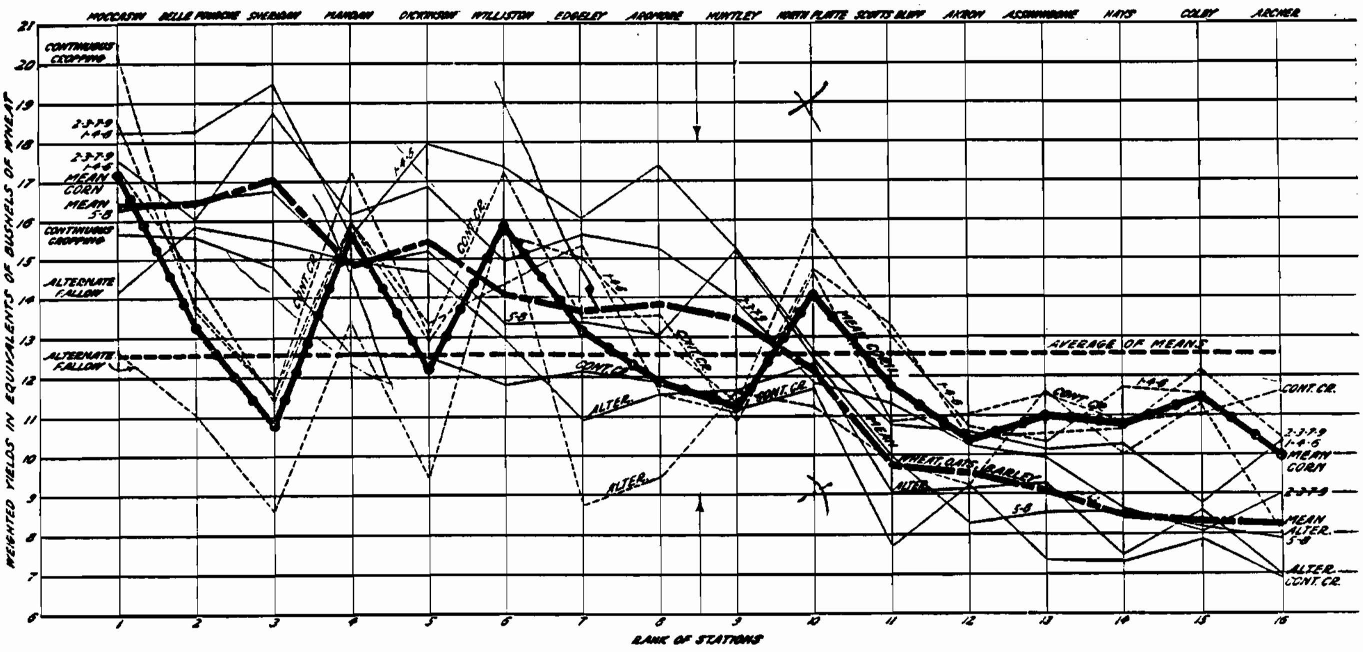

FIGURE 71.—Composite acre yields of wheat, oats, and barley, expressed in equivalents of bushels of wheat, as given in Table 23, and the acre yields of corn as given in equivalents of bushels of wheat in Table 26

By grouping the rotations as has been done in the preceding tables and figures, the effects of time and depth of plowing have been obscured. This office undoubtedly has more facts bearing upon this subject than exist in comparable form elsewhere. This material eventually will be interpreted and published, but the lack of both time and space makes it impracticable to undertake such publication at this time. The study of this material, in preparing the present publication taken in connection with what has been published previously, seems to warrant the following brief summary.

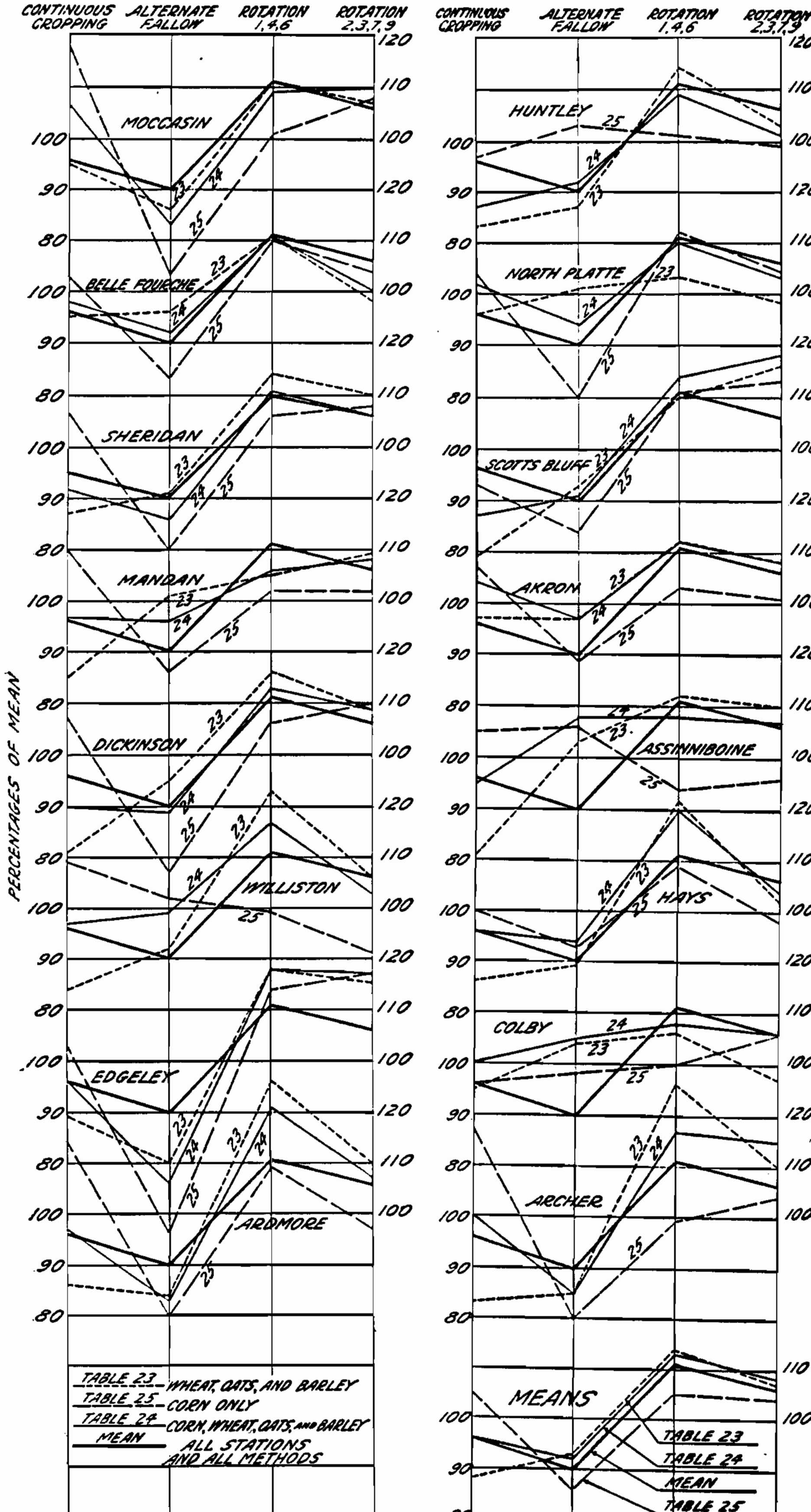

FIGURE 72.—Relative efficiency of four tillage and rotation systems as shown by the percentages of the means, computed from three bases from Tables 24, 23, and 25, respectively, composite yields of corn, wheat, oats, and barley being the base in Table 24; composite yields of wheat, oats, and barley in Table 23; and corn only in Table 25. Percentages below the mean (100) are shown along the left-hand margin and those above the mean along the right-hand margin of each section

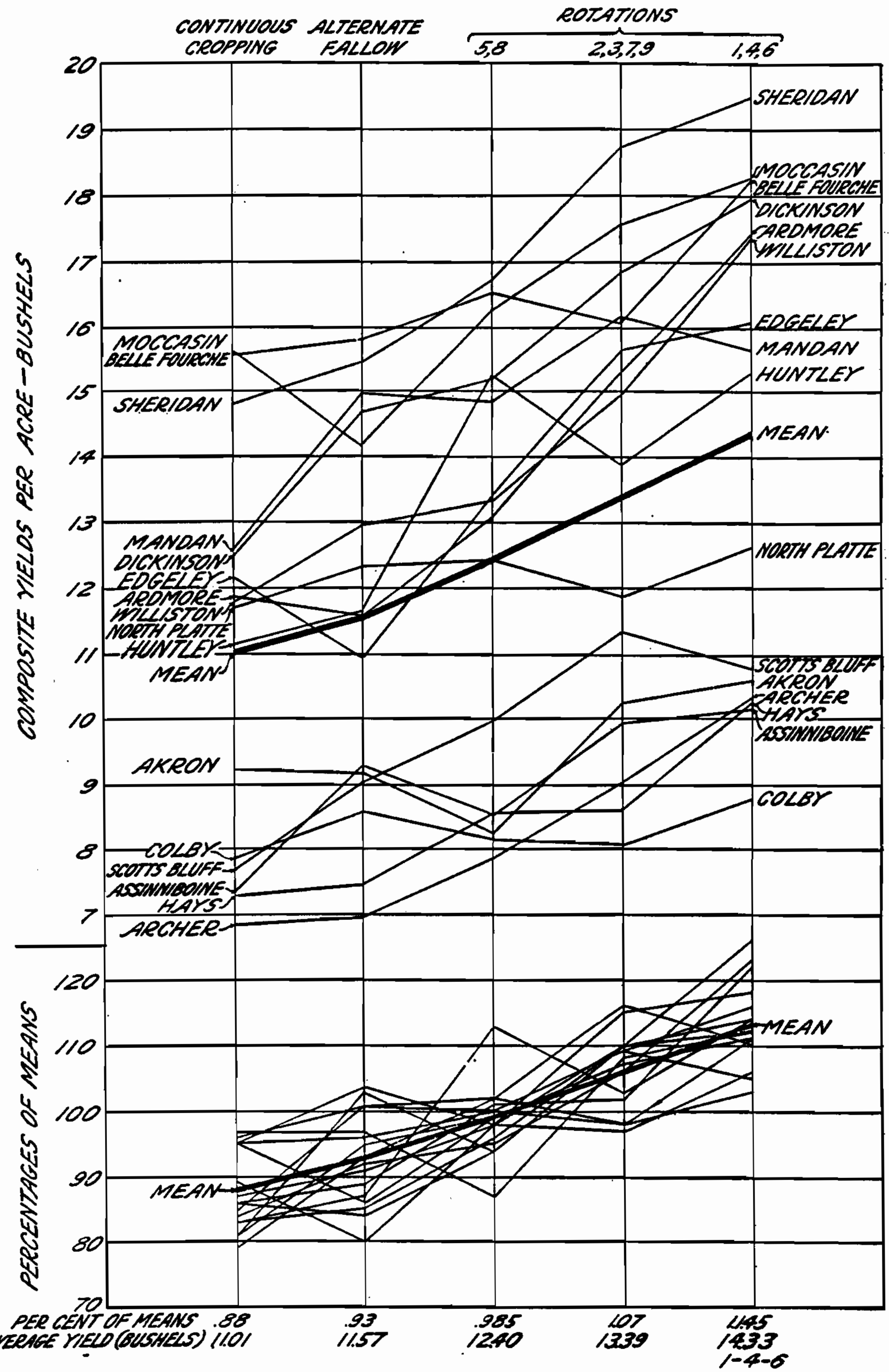

FIGURE 73.—Diagram illustrating Table 23. The composite acre yields obtained at 16 northern Great Plains field stations from wheat, oats, and barley, expressed in equivalents of bushels of wheat per acre, and the percentage of the mean for each group of rotations is shown at the bottom of the diagram. The rotations for each station are grouped as in Table 23 except that the relative positions of Groups 4 and 5 have been transposed in order to have them appear in the order of magnitude of the yields from left to right.

The time and depth of plowing, listing, disking, or duck footing the soil in the preparation of a suitable seed bed is dependent upon many local and seasonal factors, among which are the following: The character and the physical condition of the soil, and the time when the economical distribution of farm laborers, teams, tractors, disks, cultivators, and other implements can be used to the best advantage; the probable effects of climatic conditions, likely to prevail during the interval of time between the harvesting of one crop and the seeding of the next crop, such as the retention of soil moisture by the catching of snow and the retention of rainfall; soil blowing; the loss of soil moisture by weed growth; and the effects of the freezing and thawing of the soil during the winter.

The object sought in preparing the seed bed is to provide a mellow, well-tilled, but fairly compact surface layer of soil from 4 to 6 inches deep, as free as possible from ungerminated weed seeds, and with as ample a supply as possible of soil moisture at the time of seeding. How to secure these conditions at the lowest possible cost in the expenditure of labor is a perennial problem that will demand a different solution for every season, every farm, and every crop.

Each individual farmer must rely upon his knowledge of his farm, its soil, the local climate, and the adaptation of different crops and different varieties and strains of crops to the different soils of his farm. He must learn most of these facts from his own personal experience and observation or from some other farmer who has acquired his knowledge from local experience and observation.

Reducing the cost of production of farm crops and at the same time increasing the yields and the quality of these crops seems to be the most feasible if not the only way of relieving the agricultural conditions that have attracted so much attention during the last five years. Much has been accomplished toward reducing the cost of harvesting and threshing by the introduction of the small combines and other harvesting devices, but much remains to be done toward reducing the cost of preparing the seed bed and sowing the crop. The duck-foot cultivator and other similar types of implements that in a large way will replace the plow seem to be very promising. The plow has been, and probably long will be, a very useful implement, but there is nothing sacred about it. If, as now seems certain, there are other implements that can be used more economically in preparing the seed bed on the broad, level prairies of the Great Plains, there should be no hesitancy about adopting them as soon as their efficiency has been established.

Now that we know that the root zone of nearly all agricultural crops extensively grown in that region extends far deeper than the deepest plowing, that a good seed bed from 4 to 6 inches deep will produce just as good crops as one twice that depth, and that the receptivity and retentivity of the soil to water is as fully attained on most prairie soils by having the first 4 to 6 inches of the surface soils in proper condition, there is no longer any excuse for the universal use of the old-fashioned moldboard plow. The duck-foot type of cultivator as an implement for the destruction of weeds, on some soils, is more efficient than the plow, and it leaves the surface in better condition to withstand soil blowing and to catch and retain water. Ogaard[7]

[7] OGAARD, A. J. SUMMER TILLAGE IMPLEMENTS. Mont. State Col. Agr. Ext. Serv. Bul. 79, 42 p., illus. 1926.

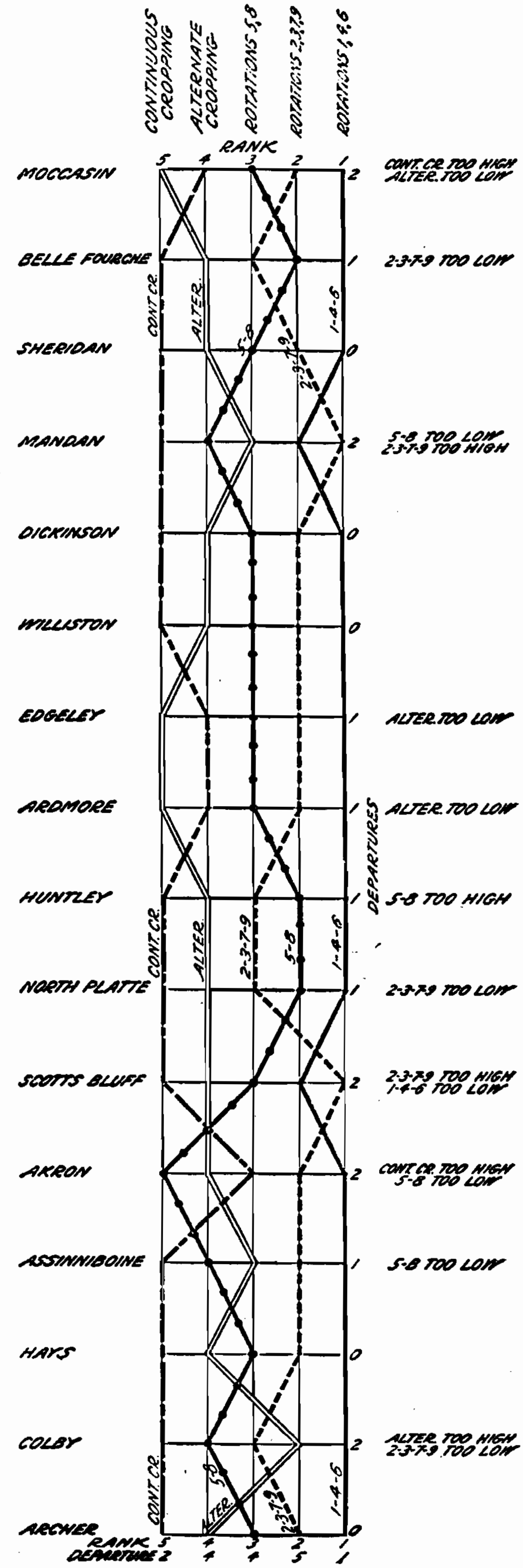

FIGURE 74.—Departures from the regular rank of certain tillage-method groups at some stations. The number of such departures for each station is given at the right hand and for each group at the bottom.

has described a large number of labor-saving tillage implements, and new ones are constantly being introduced. The farmers of the Great Plains should keep themselves posted on these new implements, for it is upon them that they must depend largely in reducing the cost of crop production.

ECONOMIC PROBLEMS

The farmers of to-day are faced with an anomalous—it seems almost an impossible—problem, that of reducing the cost of production without increasing the volume of production of some of the staple farm products. The cost of production of manufactured articles has been brought to a high state of efficiency under the stimulus of a constantly increasing demand for their products. The farmer has no such incentive. He knows that there is an overproduction of many of his products, and he sees no relief in the near future, for he has to compete in the world markets, and vast areas of agricultural land are being brought into use; and everything that lessens the cost of production or transportation anywhere in the world, except in his own immediate locality, makes his struggle more difficult. His only hope seems to be that possibly he may, by more efficient methods, implements, and managerial ability drive some other farmer out of business and convert him and his family from competitors in agricultural production into consumers of agricultural products. This is being done on an enormous scale throughout the United States at the present time.

A WORKING HYPOTHESIS FOR PLANNING ROTATION AND TILLAGE METHODS FOR THE NORTHERN GREAT PLAINS

Having presented certain facts, and certain methods of analysis and interpretation of these facts, with reference to the relative effectiveness of certain rotations and tillage methods, the next step is to present a broad generalization based upon these facts in the form of a working hypothesis that will enable the farmer to apply the results of these investigations to his problems. This is a difficult undertaking, for it is well known that no broad generalization ever quite fills any particular combination of conditions. Life-insurance companies have worked out statistical tables which enable them to state definitely just how tall the "average man" should be; how much he should weigh at certain periods of his life; how long he should live; and when, how, and why he should die; but they have never yet found the "average man" who has fully met all the specifications. But without some such working hypothesis, life insurance would be impossible. For similar reasons it is necessary for every farmer who plans a rotation system for his farm to have a working hypothesis. On the basis of the foregoing facts the working hypotheses that follow are presented.

After making allowance for the extra-labor cost per acre for summer-fallowing and for the difference in cost between disking and plowing for small grain sown on corn stubble, the relative effectiveness of the five systems considered in these groups, on the average for all of the 16 northern Great Plains field stations for 228 crop years, is as follows: System 1, continuous cropping, 1 per cent; system 2, alternate fallowing, 1.06 per cent; system 3, three-year rotations with summer-fallow every third year, 1.13 per cent; system 4, three-year rotations of corn, oats, and wheat or barley, land plowed every year, 1.23 per cent; system 5, three-year rotations the same as the preceding group, except that the corn stubble is disked instead of being plowed for the following grain crop, 1.31 per cent.

That is to say, the annual net returns per acre from the land actually cropped, after allowing for the extra-labor cost of the summer-fallowing, on the average from alternate fallowing is about 6 per cent greater than from continuous cropping, but there are only half as many acres harvested, and the interest and taxes on the fallow land are not provided for in this estimate.

If only one-third of the land is in fallow as in system 3, the annual net returns should be about 13 per cent higher than from continuous cropping per acre of cropped land; and interest and taxes on only one-third of the farm are left unprovided for. In system 4 the entire farm is in crop, and the annual net return per acre from the entire farm should be about 23 per cent higher than from continuous cropping to the same crop, leaving no idle land for which interest and taxes must be provided. In system 5 the annual net returns should be about 31 per cent higher than from continuous cropping to the same crop. The greater return from system 5, as compared with system 4 is due mainly to two causes: (1) Slightly lower costs of production due to disking instead of plowing the corn stubble—only 3⅓ per cent allowance has been made in these estimates for this difference—; and (2) higher yields from the disked corn stubble as compared with the plowed stubble.

In the slow and devious journey from special verified facts up to this generalization many exceptions and contradictions have been noted. It therefore seems desirable to look a little closer into some of the assumptions involved in this generalization. These may have been overlooked, but they should be taken into consideration before accepting any working hypothesis as a solution of the major agricultural problems of the entire Great Plains area or any section of it.

In Table 28 the ratios of the relative effectiveness of the five systems of crop rotations and tillage methods are given, for each of the 16 northern Great Plains field stations from which the ratios of 1.00, 1.06, 1.13, 1.23, and 1.31 were developed. It will be noted that the ratio of 1.06 is the average of 16 ratios ranging from 0.90 to 1.27; that for 1.13 ranging from 0.89 to 1.36; that for 1.23 ranging from 1.02 to 1.47; and that for 1.31 ranging from 1.08 to 1.51.

TABLE 28.—*Ratios between continuous cropping and alternate fallow and between continuous cropping and three groups of crop rotations at 16 field stations in the northern Great Plains area*

[Continuous cropping is taken as a basis for the comparison of acre yields expressed in equivalents of bushels of wheat, as shown in Table 23]

Field station	Group 1, continuous cropping	Yields from alternate fallow and from various groups of rotations each divided by yields from continuous cropping			
		Group 2, alternate fallow	Group 3, rotations 5 and 8	Group 5, rotations 2, 3, 7, and 9	Group 4, rotations 1, 4, and 6
1	2	3	4	5	6
Moccasin	1	0.91	1.04	1.12	1.17
Belle Fourche	1	1.02	1.06	1.03	1.17
Sheridan	1	1.05	1.13	1.27	1.3[illegible]
Mandan	1	1.19	1.18	1.28	1.2[illegible]
Dickinson	1	1.18	1.22	1.35	1.44
Williston	1	1.10	1.13	1.27	1.4[illegible]
Edgeley	1	.90	1.10	1.29	1.3[illegible]
Ardmore	1	.98	1.10	1.29	1.4[illegible]
Huntley	1	1.05	1.36	1.25	1.3[illegible]
North Platte	1	1.05	1.06	1.02	1.0[illegible]
Scotts Bluff	1	1.18	1.30	1.47	1.4[illegible]
Akron	1	.99	.89	1.11	1.1[illegible]
Assinniboine	1	1.27	1.16	1.35	1.3[illegible]
Hays	1	1.03	1.17	1.18	1.[illegible]
Colby	1	1.10	1.01	1.03	1.1[illegible]
Archer	1	1.02	1.15	1.32	1.[illegible]
Average	1	1.06	1.13	1.23	1.3[illegible]

If one were to consult the original data it would be found that there is a similar range in the average of the 684 crop-year yields that entered into the 64 ratios shown in Table 28.

If, however, one were to study the data contained in Miscellaneous Circular No. 81, it would be found that many of the seeming inconsistencies are accounted for by the combinations of soil and climatic conditions at the several stations during different years. For instance, Table 28 shows that the ratios of alternate fallowing are below continuous cropping at Moccasin, Edgeley, Ardmore, and Akron. This is undoubtedly due largely to the very impervious character of the subsoil and the consequent low storage capacity for water at these stations. The peculiar reaction to the different systems at Huntley where there is a relatively low reaction to alternate fallowing but a high reaction to the summer-fallowing in rotations 5 and 8 where the summer-fallowing occurs once in three years instead of in alternate years, and the very small differences shown from different methods at North Platte, Akron, and Colby are undoubtedly due to local conditions. But just what these local conditions are is not so obvious as are the subsoil conditions at Moccasin, Edgeley, Ardmore, and Akron. Further study will probably explain these and some other seeming anomalies.

There are other assumptions involved in this working hypothesis that are perhaps more complex than any other feature of the subject of crop rotation. These are the relative values of the several crops entering into the rotation. In these estimates the units of measurement have been bushels of wheat, and it has been shown, so far as the crop-yielding capacity of the soil is concerned, that 1 bushel of wheat is equivalent to 2 bushels of oats and to 1½ bushels of barley. It has been assumed that the average cost of producing these three crops bears the same relations as the yield. That is to say, there is practically no difference in the cost of producing an acre of wheat, an acre of oats, or an acre of barley. Few, if any, practical farmers will question this assumption. It does, however, cost more to produce an acre of corn than it does to produce any of the small grains. But this extra cost is governed to such an extent by the way the crop is raised and the use that is made of it that it is very difficult to estimate it. Some of these variable factors are as follows: Whether it is listed or surface planted; how many times it will require cultivating to keep it free from weeds; whether the cultivating can be done with a 4-row, a 2-row, or a 1-row cultivator; how the crop is to be harvested—whether cut for silage without husking, whether cut with a corn binder, whether shocked and husked from the shock and the stover stacked or stored in barns, whether shucked from the standing stalks which are later eaten off by stock, or whether handled in several other ways.

One of the many things that these investigations have demonstrated is that corn can be profitably grown throughout the northern Great Plains if proper methods are used to reduce the cost of production and to utilize both the grain and the stalks to the fullest possible extent by converting them into beef, pork, mutton, wool, or dairy or poultry products and to provide food for work or breeding stock. Just how to accomplish this must be left for each individual farmer to decide for himself.

A goodly portion of the value of the corn crop consists of the value of the stalks for feed and the beneficial effects of this crop upon the soil in preparing it for the wheat crop that is to follow it. In Table 29, both the total dry weight of the unhusked cornstalks and the bushels of corn are given. In estimating the value of the corn crop the value of grain only is used. It is assumed that the food value of the corn stover will compensate for any difference between the cost of production and the value of the grain.

The oat crop must be considered in somewhat the same way as the corn crop in that both the grain and the straw must be converted into some kind of animal products before they are sold. The wheat crop is the only one used in this connection which can be considered as a cash crop, although a cash price is used in the estimates for both oats and corn grain. The farmer must, however, get his profits on both these crops from the animal products they afford, the manure they make, and the improved condition of the soil for raising wheat after the corn crop.

TABLE 29.—*Average annual acre yields of wheat under continuous cropping and under alternate fallowing and of wheat, oats, and corn in rotation 1 at 16 field stations in the northern Great Plains area*

[The yields here given are not weighted for tillage methods. The average yields of wheat in column 3 are based on biennial yields which have been divided by 2 in order to convert them into annual-yield equivalents]

Field stations—	Years	Wheat			Oats, rotation 1	Corn, rotation 1	
		Alternate fallowing	Continuous cropping	Rotation 1		Total	Grain
1	2	3	4	5	6	7	8
Showing normal yields:	*Number*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Pounds*	*Bushels*
Moccasin	18	9.45	14.2	19.5	33.9	4,447	--------
Belle Fourche	18	11.35	14.7	17.5	33.1	3,502	21.8
Sheridan	9	11.55	13.2	17.8	35.5	2,703	17.4
Mandan	12	9.95	12.0	15.7	28.7	4,011	28.5
Dickinson	19	10.35	11.8	19.8	34.7	3,334	16.1
Williston	11	9.30	11.8	14.1	30.1	3,751	12.7
Edgeley	16	6.55	11.4	16.9	29.3	3,708	5.7
Ardmore	13	8.20	11.6	18.5	30.1	3,162	16.2
Huntley	14	7.55	10.0	15.9	26.9	2,022	16.1
North Platte	10	9.50	11.4	13.1	25.9	4,076	20.2
Total or average	149	9.38	12.2	16.9	30.8	3,586	16.96
Showing subnormal yields:							
Scotts Bluff	9	7.15	7.1	13.0	18.6	3,376	20.1
Akron	17	5.65	9.0	11.8	17.2	2,754	12.9
Assinniboine	10	6.60	6.7	9.9	15.0	2,331	7.7
Hays	19	4.15	5.6	7.1	22.5	2,933	5.6
Colby	12	5.60	7.0	6.9	18.6	2,914	17.5
Archer	12	6.70	8.5	12.6	17.4	2,491	14.1
Total or average	79	5.98	7.3	10.2	18.2	2,798	13.0
Grand total or average	228	8.10	10.38	14.38	26.09	3,201	15.37

WILL THE WORKING HYPOTHESIS WORK?

In developing this working hypothesis it has been necessary to use composite yields, ratios, and percentages. The relative cost of producing the different crops under different systems of rotation and tillage methods has been considered, but neither the relative nor the actual market prices of the several crops have been taken into consideration.

The practical farmer is interested primarily in the net returns he will get for his labor, his managerial ability, and his investment. In order to test the validity of the working hypothesis, it must be applied to a definite farm unit, using definite prices for each of the crops in computing the annual returns.

Assuming the use of a farm unit of one section—640 acres—and (where livestock production is an important factor in the farming system) such additional land as may be necessary for grazing purposes, 40 acres of the section will be required for the farmstead, night pasture, garden, and for other crops that do not enter into the rotations, leaving 600 acres under cultivation in the general farm systems.

Assuming for the market prices those given in the Yearbook of Agriculture for 1926 as the averages received by the producer for the years 1921 to 1925, inclusive, these are, wheat $1.137, oats $0.404, corn, $0.781 per bushel. For the value per ton of the total dry weight of the corn crop, including both the grain and the stover, $9 per ton is here used. This is an estimate arrived at as follows: The average total dry weight of the corn crop for 10 field stations is 3,586 pounds. The average yield of corn grain for the same stations is 16.96 bushels. At 70 pounds per bushel this grain would weigh 1,187 pounds. Subtracting this from 3,586 pounds gives 2,399 pounds, the weight of the corn stover. The cash value of 16.96 bushels of corn at $0.781 per bushel is $13.24. The estimated value at $9 per ton of 3,586 pounds of total dry weight of grain and stover is $16.14. Subtracting $13.24, the value of the corn grain, gives $2.90 as the value of 2,399 pounds of corn stover, which is $2.41 per ton. This is believed to be a fair estimate and justifies the valuation of the total dry weight of the corn grain and stover at $9 per ton.

The acre yields from the different crops and methods are taken from Table 29, which shows that the lower six stations have abnormally low yields for wheat and oats and in some instances for corn. This is undoubtedly due largely to the fact that spring wheat and oats are not adapted to these stations. It was, therefore, decided to use the yields from all 16 stations but to segregate the 6 stations where the average spring-wheat yields were under 10 bushels and the oat yields under 24 bushels. Figures 70 and 72 show that the inclusion or exclusion of these lower yielding stations would not materially affect the relative results of the different farming systems, but in making comparisons of the gross returns per acre it seems best to treat these two groups both independently and collectively as has been done in Tables 29, 30, and 31, and in Figures 75, 76, and 77. From these it will be seen that the relative effectiveness of the different systems for the 6 stations with subnormal yields is about the same as that shown for the 10 stations having normal yields.

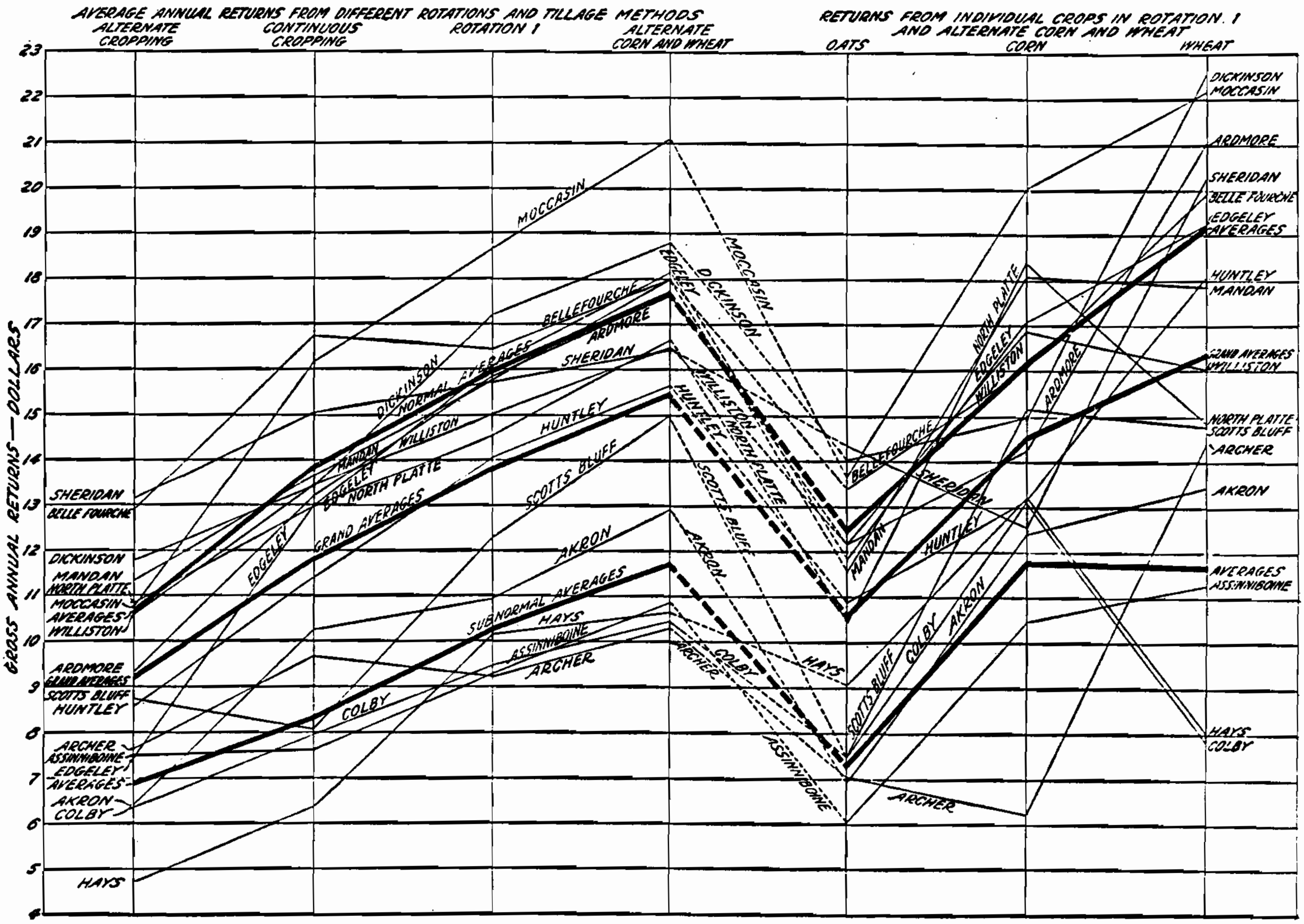

FIGURE 75.—Diagram illustrating Table 30, comparing alternate cropping to wheat and summer-fallowing, continuous cropping to wheat, rotation 1, and alternate corn and wheat. The left-hand portion of the diagram gives the annual returns in dollars per acre for the four different systems, and the right-hand portion gives returns for the individual crops in rotation 1 and in alternate cropping to corn and wheat at 16 northern Great Plains field stations

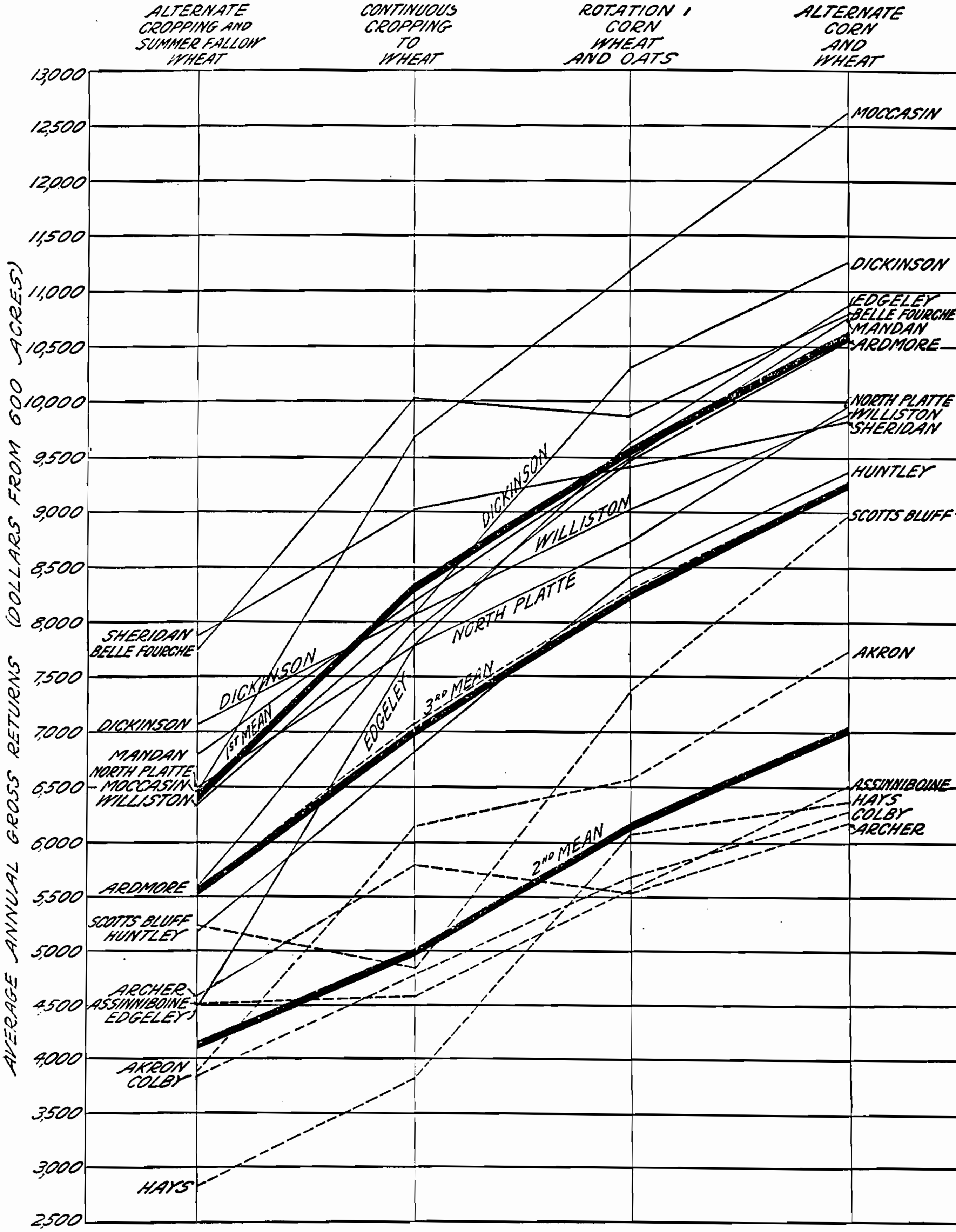

FIGURE 76.—Diagram illustrating Table 31. The estimated gross annual returns in dollars from 600 acres of cultivated land at average prices for the 5-year period, 1921 to 1925. The period for which the acre yields have been obtained is shown for each of the 16 northern Great Plains field stations in Table 19

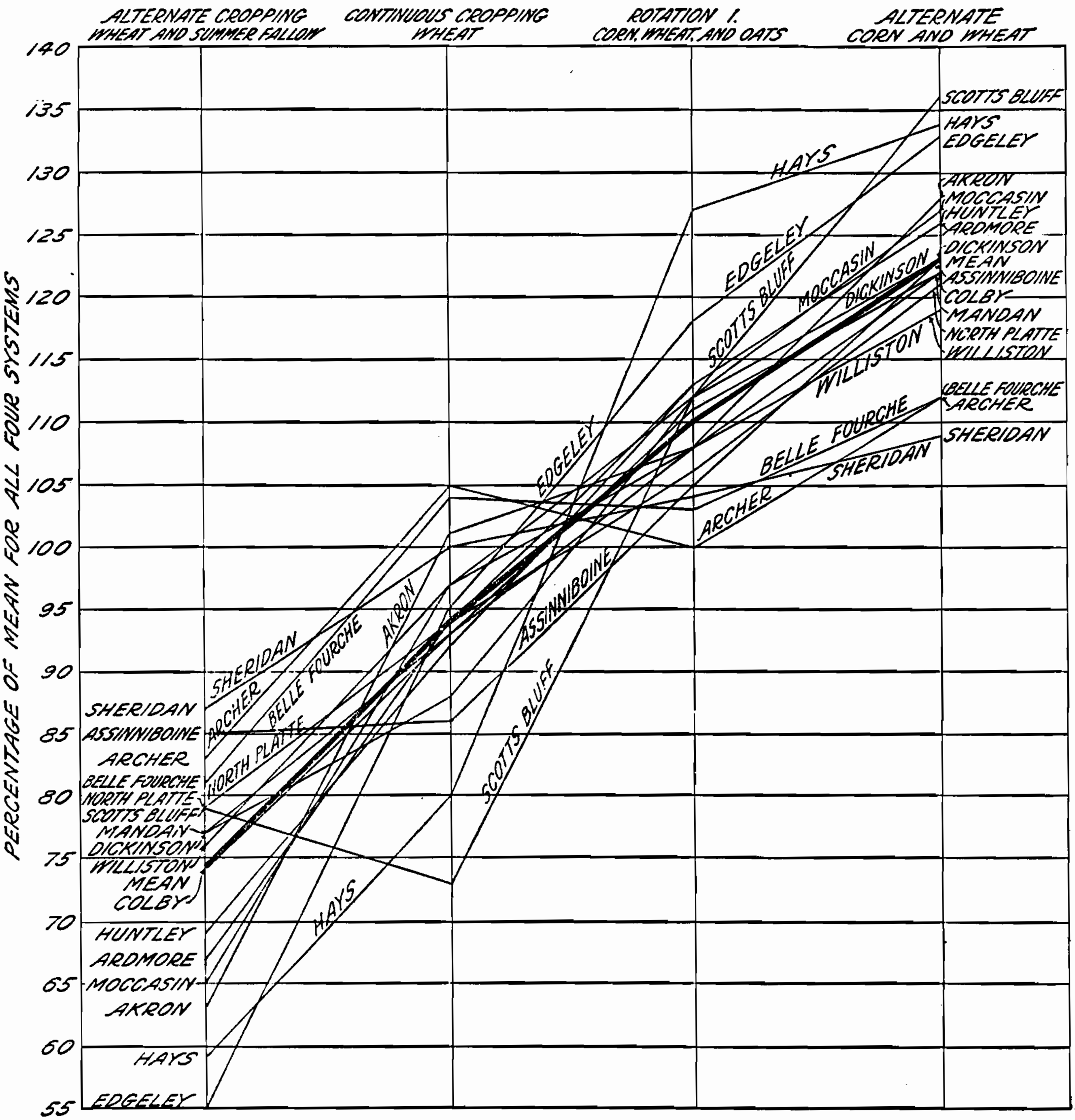

FIGURE 77.—Percentages of mean returns from each of four cropping systems, as shown in Table 31

TABLE 30.—*Gross annual returns per acre from wheat, oats, and corn at average prices for the five-year period 1921 to 1925, under different rotations and tillage systems, at 16 field stations in the northern Great Plains area*

[The returns given are based on the following prices for individual crops: Wheat $1.137 per bushel; oats, $0.404 per bushel; corn, $9 per ton of total dry weight. The average returns given in column 2 are based on biennial yields which have been divided by 2 in order to convert them into annual returns]

Field stations	Alternate fallow and wheat	Continuous cropping—wheat	Rotation 1—corn, wheat, and oats	Alternate corn and wheat	Rotation 1		
					Oats	Corn—total weight	Wheat
1	2	3	4	5	6	7	8
Showing normal yields:							
Moccasin	$10.75	$16.15	$18.63	$21.09	$13.70	$20.01	$22.17
Belle Fourche	12.90	16.71	16.43	17.97	13.37	16.03	19.90
Sheridan	13.13	15.01	15.72	16.41	14.34	12.57	20.24
Mandan	11.32	13.64	15.83	17.95	11.59	18.05	17.85
Dickinson	11.77	13.42	17.18	18.76	14.02	15.00	22.51
Williston	10.58	13.42	15.02	16.46	12.16	16.88	16.03
Edgeley	7.45	12.96	16.05	18.16	11.83	17.09	19.22
Ardmore	9.33	13.19	15.81	17.63	12.16	14.23	21.03
Huntley	8.59	11.37	14.03	15.62	10.87	13.15	18.08
North Platte	10.80	12.96	14.56	16.62	10.46	18.34	14.89
Average	10.66	13.88	15.93	17.67	12.45	16.15	19.19
Showing subnormal yields:							
Scotts Bluff	8.73	8.07	12.29	14.99	7.51	15.19	14.78
Akron	6.42	10.23	10.92	12.91	6.95	12.39	13.42
Assinniboine	7.50	7.62	9.27	10.88	6.06	10.49	11.26
Hays	4.72	6.37	10.12	10.64	9.09	13.20	8.07
Colby	6.37	7.96	9.49	10.48	7.51	13.11	7.85
Archer	7.62	9.66	9.21	10.30	7.03	6.28	14.33
Average	6.89	8.32	10.22	11.70	7.36	11.77	11.62
Grand average	9.25	11.80	13.79	15.43	10.54	14.50	16.35

FOUR SYSTEMS OF FARM ORGANIZATION COMPARED

The four systems of farm organization here compared are as follows:

SYSTEM 1

Alternating cropping to spring wheat of 300 acres each year and summer-fallowing the other 300 acres each year.

SYSTEM 2

Continuous cropping to spring wheat on the same 600 acres of land every year, the land to be plowed each year either in the fall or in the spring.

SYSTEM 3

The farm is divided under rotation 1 into three fields of 200 acres each. One of these fields has raised a crop of corn the previous year. The corn has been cut and fed to stock. The bare corn stubble is disked or prepared for seeding with some type of cultivator as early in the spring as the land is in suitable condition for working and is then seeded to spring wheat.

Another of the 200-acre fields has raised a crop of wheat the previous year, and had been plowed as soon after harvesting the wheat as the land was in suitable condition for plowing. This field is fitted for seeding to oats at about the same time in the spring as the field for wheat.

The third 200-acre field which had raised a crop of oats the previous year is plowed or listed and planted to corn as soon as the wheat and oat crops have been seeded. The planting and the cultivating of the corn crop is all done during the interval between the seeding and the harvesting of the wheat and oats, and the harvesting of the corn crop takes place after the harvesting and threshing of the small-grain crops have been finished.

SYSTEM 4

As will be seen later, it has been found that the relatively low price for oats that prevailed during the years 1921 to 1925 made this much the least profitable crop of the three (see Tables 30 and 31). It therefore is proposed that system 4 be used, which is as follows:

The farm is divided into two fields of 300 acres each, upon one of which a wheat crop is raised upon disked corn stubble, and upon the other a corn crop is raised on plowed or listed wheat stubble. The distribution of labor under this system would be much the same as in system 3. There would be 400 acres of small grain and 200 acres of corn in system 3 and 300 acres of small grain and 300 acres of corn in system 4.

When a definite farm unit and definite farm prices for each of the crops grown are used it is found that these and other factors not considered in the development of the first working hypothesis have very profoundly modified some of the relations between the effectiveness of the farm systems under consideration. This was foreseen and briefly referred to on pages 19-20. These factors have caused a reversal in the relative effectiveness of continuous cropping and alternate fallowing. It has, therefore, seemed desirable to change their order in Table 29 and in the tables and figures which follow, in which alternate fallowing gives lower returns than continuous cropping. The fallowing data are placed in a column at the left of continuous cropping. This arrangement facilitates the plotting of the results, as will be seen in Figure 75.

TABLE 31.—*Gross annual returns from 600 acres of cultivated land under different rotation and tillage systems for the 5-year period 1921 to 1925 at 16 field stations in the northern Great Plains area*

[The annual returns shown in this table are all obtained by multiplying the respective annual returns per acre given in Table 30 by 600]

Field stations—	Gross annual returns from—								Mean of gross annual returns from 4 systems
	System 1: Alternate fallow and wheat		System 2: Continuous cropping—wheat		System 3: Rotation 1—corn, wheat, and oats		System 4: Alternate corn and wheat		
	Value	Percentage of mean	Value	Percentage of mean	Value	Percentage of mean	Value	Percentage of mean	
1	2	3	4	5	6	7	8	9	10
Showing normal yields:									
Moccasin	$6,450	65	$9,690	97	$11,178	112	$12,645	127	$9,991
Belle Fourche	7,740	81	10,026	104	9,858	103	10,782	112	9,601
Sheridan	7,878	87	9,006	100	9,432	104	9,846	109	9,041
Mandan	6,792	77	8,184	93	9,498	108	10,770	122	8,811
Dickinson	7,062	77	8,052	88	10,308	112	11,256	123	9,170
Williston	6,318	76	8,052	97	9,012	108	9,876	119	8,322
Edgeley	4,470	55	7,776	95	9,630	118	10,896	133	8,193
Ardmore	5,598	67	7,914	94	9,486	113	10,576	126	8,394
Huntley	5,154	69	6,822	92	8,418	113	9,372	126	7,442
North Platte	6,480	79	7,776	94	8,736	106	9,972	121	8,241
Average	6,397	------	8,330	------	9,556	------	10,599	------	8,721
Percentage relation, 10 stations	------	73	------	96	------	110	------	122	------
Showing subnormal yields:									
Scotts Bluff	5,238	79	4,842	73	7,374	112	8,994	136	6,612
Akron	3,852	63	6,138	101	6,552	108	7,746	128	6,072
Assinniboine	4,500	85	4,572	86	5,562	105	6,528	123	5,291
Hays	2,832	59	3,822	80	6,072	127	6,381	134	4,778
Colby	3,822	74	4,776	93	5,694	111	6,288	122	5,145
Archer	4,572	83	5,796	105	5,526	100	6,180	112	5,519
Average	4,136	------	4,991	------	6,130	------	7,020	------	5,570
Percentage relation, 6 stations	------	74	------	90	------	110	------	126	------
Grand total	5,549	------	7,078	------	8,271	------	9,257	------	7,539
Percentage relation, 16 stations	------	74	------	94	------	110	------	123	------

It must constantly be borne in mind that these figures also leave out of consideration some important factors. Gross production only is being considered. It may be that when the cost of production is taken into consideration these figures will be materially modified. It seems, however, at this stage of the investigation that the margin in favor of rotation of crops is so large that it will not be entirely obliterated. The real purpose of these investigations is to bring plainly before the reader the many factors involved rather than to arrive at any generalization that will fit all cases.

It will be remembered that the working hypothesis postulated the relations between the yields per acre from continuous cropping, alternate fallowing, rotations 1, 4, and 6 were 1.00, 1.06, 1.31 (Table 28); whereas according to Table 31 the relations between the gross farm income from 600 acres of land under cultivation would be from continuous cropping, 1.00; from alternate fallowing, 0.76; and from rotation 1, 1.15, using the figures from stations with normal yields as given in Table 31.

This does not seem to be a very close agreement between the first working hypothesis and the facts established by 149 crop years of practical experience. These discrepancies are due to the fact that in the first instance the calculations were designed to show relations between the relative efficiency of the different systems in yield per acre of wheat and oats, expressed in equivalents of bushels of wheat after making allowances for the differences in cost of production. Thus the differences in the market prices of the different grains, the economic features of the most efficient use of the capital invested in the farm and its equipment, and the labor of the farmer and his employees were disregarded. But in the second case these latter factors have been taken into consideration. Moreover, the relative costs of production of the different crops grown under the different systems have not yet entered into the hypothetical calculations, but they will be considered later.

Table 29 was prepared from the detailed data for each year for all the 16 field stations. It gives the average yields actually obtained from wheat, oats, and corn under continuous cropping and in rotation 1. For alternate fallowing for wheat the yields given in Table 20 and in the original data have been divided by 2 for use in Table 29. This is done because the original figures represent biennial yields instead of annual. Under this system the farm is divided into two fields, one of which is fallowed and the other cropped. The next year the field cropped the previous year is fallowed, and the field that was fallowed is cropped. Thus, each field raises one crop in two years.

Table 29 is divided into two parts. The upper portion includes the 10 stations where, under continuous cropping, the average acre yields of spring wheat exceeded 10 bushels and those of oats 24 bushels. The lower portion includes the six stations where for reasons heretofore explained the yields fall below this standard. It therefore seemed desirable to keep these two groups segregated in Tables 29, 30, and 31, and in Figure 76, and to consider mainly the data from the 10 stations where conditions were more nearly normal, using the data from the other six stations for comparison.

Table 30 was developed from Table 29 by multiplying the acre yields given in Table 29 by the respective prices for each crop; namely, $1.137 per bushel for wheat. $0.404 per bushel for oats, and $9 per ton for total dry weight of corn.

The figures in columns 2 and 3 in Table 30 are calculated from those in columns 3 and 4 in Table 29, and those in columns 6, 7, and 8 in Table 30 from those in columns 6, 7, and 8 in Table 29, in the order named. The figures in column 4 of Table 30 are obtained by taking the average of returns for oats, corn, and wheat given in columns 6, 7, and 8 of Table 30, and those in column 5 are the averages of the figures given in columns 7 and 8 in Table 30.

Figure 75 is a graphic presentation of the data in Table 30. In this figure the two groups are not segregated as they are in Table 30, but the mean for each group is given, as well as that for the 16 stations collectively. It will be seen that many of the differences in the relative effectiveness of the different systems are closely related to the relative returns from the different crops. Many other interesting comparisons can also be made.

Table 31 has been developed from Table 30 by multiplying all the figures in Table 30 by 600 and transferring the products to Table 31 in the same order in which they appear in Table 30, thus presenting the gross returns in dollars from 600 acres under the different systems of tillage and rotations for each of the 16 stations and the average for each of the two groups of stations.

Columns 6, 7, and 8 in Table 30 have been omitted from Table 31, but column 10 in Table 31 has been used to represent the mean of the gross returns from the four systems. The percentage of this mean is given for each station and for each system, thus providing a means of direct comparison between the different stations and systems such as was used in developing the first working hypothesis.

Table 32 has been developed from Table 31, by dividing the yields given in columns 4, 6, and 8 by those given in column 2. This gives the ratios between alternate fallowing, used as a basis and assigned a value of 100, and the other three systems, namely, continuous cropping, rotation 1, and alternate corn and wheat.

Figures 76 and 77 are graphic presentations of the data contained in Table 31. Figure 76, like the table, is divided into two parts, representing, respectively, the 10 stations having average returns that are normal or above normal for all four systems (with three exceptions, namely, Edgeley and Huntley for alternate fallowing and Huntley also for continuous cropping) and the six stations having returns below normal for all systems.

Table 32.—*Ratios between alternate fallowing and continuous cropping and between alternate fallowing and rotation 1, and between alternate fallowing and alternate corn and wheat at 16 field stations in the northern Great Plains area*

[Alternate fallowing is taken as a basis for the comparison of the gross returns from 600 acres at prevailing prices for wheat, oats, and corn, computed from Table 31]

Field stations—	Yields from rotation 1 and from alternate corn and wheat, each divided by yields from alternate fallowing			
	Alternate fallowing	Continuous cropping	Rotation 1	Alternate corn and wheat
1	2	3	4	5
Showing normal yields:				
Moccasin	1	1.50	1.73	1.96
Belle Fourche	1	1.30	1.27	1.39
Sheridan	1	1.14	1.20	1.25
Mandan	1	1.20	1.40	1.59
Dickinson	1	1.14	1.46	1.59
Williston	1	1.27	1.42	1.56
Edgeley	1	1.74	2.15	2.44
Ardmore	1	1.41	1.69	1.89
Huntley	1	1.32	1.63	1.82
North Platte	1	1.20	1.35	1.54
Average	1	1.32	1.53	1.70
Showing subnormal yields:				
Scotts Bluff	1	.92	1.41	1.72
Akron	1	1.59	1.70	2.01
Assinniboine	1	1.02	1.24	1.1[illegible]
Hays	1	1.35	2.14	2.27
Colby	1	1.25	1.49	1.65
Archer	1	1.26	1.21	1.35
Average	1	1.23	1.53	1.77
Grand average	1	1.29	1.53	1.72

The returns for the normal group are shown in Figure 76 by solid lines, and those for the subnormal group by broken lines for the individual stations and also for the respective means. A third mean is that for all the 16 stations in the groups. There is a sufficiently close parallelism between these three means to warrant the use of any one of them in determining the relative effectiveness of the different systems, but when the subject is placed upon a quantitative basis and expressed in dollars of gross returns from a farm of definite size (600 acres) the upper mean of the 10 normal stations is the one that will provide the most reliable basis for calculations. Figure 77 is a graphic illustration of the percentages of mean returns as shown in Table 31. There is no segregation of normal and subnormal as in Figure 76, but its mean agrees with the third mean in Figure 76.

A SECOND WORKING HYPOTHESIS

The first working hypothesis having been shown to work within certain restricted limits, it has led to what will hereafter be called the second working hypothesis, some of the limitations and restrictions of which will now be considered.

Expressed in percentages of the gross returns from the system of alternate fallowing, which are the lowest, the following figures are obtained as shown in Table 32, as the average ratios for the 10 stations with normal yields: Alternate fallowing, 1; continuous cropping to wheat, 1.32; rotation 1, 1.53; and alternate corn and wheat, 1.70. These figures are very different from those of the first working hypothesis, but they are not inconsistent therewith, for they include some factors not included in the first, exclude some that were previously used, and treat other factors in a different way. The first working hypothesis was based upon yields per acre expressed in equivalents of bushels of wheat, whereas the calculations now to be considered are based upon gross returns per farm, calculated upon the prevailing prices for the whole United States for the 5-year period from 1921 to 1925, inclusive, for wheat, corn, and oats, respectively.

This hypothesis has to do with the crop-producing capacity of the soils of the Great Plains, as represented by the soils of the 16 field stations under consideration in the northern Great Plains, in reaction to the normal meteorological conditions of the region and the different systems of crop rotation and tillage methods applied to the respective crops. It also involves the actual and the relative market prices of the crops raised and the actual relative cost of the production of the different crops under the different systems. Furthermore, in the case of corn stover and all other roughage, it involves the transformation of these crops into livestock products that will sell at a price that will at least pay for the cost of conversion.

It was found that the value of the first working hypothesis consisted in its usefulness in developing a second working hypothesis that would make possible the establishment of the relative effectiveness of the different systems in producing gross returns from a farm of definite area. It is now apparent that the value of this second hypothesis depends largely upon its usefulness in developing a third hypothesis that will make possible the establishment of the relative efficiency of the different systems of crop rotation and tillage methods in producing net returns from the investment of capital and from labor performed. This is a vastly more complex problem than the developing of the first and second hypotheses, for it involves many personal equations peculiar to each individual farm and farmer and his family. The number of combinations of ever-changing conditions, such as fluctuations in the actual and relative prices not only of farm crops but also of livestock products, taken in connection with the laws of supply and demand of both farm products and labor, are beyond calculation. It is therefore obvious that no single third hypothesis that will be applicable to any considerable number of the countless combinations of conditions can be developed.

It is believed, however, that the two hypotheses herein presented will be useful to the individual farmers who must meet and solve the problems that present themselves from day to day and from year to year on each farm.

As shown by Table 31 and Figure 76, the four systems of farming under consideration differ significantly in the amounts of gross returns. Using yields from alternate fallowing as a basis of comparison, and giving this system a value of 1, as has been done in Table 32, the yields from continuous cropping would be represented by 1.32; from rotation 1, 1.53; and from alternate corn and wheat, 1.70. Expressed in dollars, from a farm with 600 acres under cultivation, the respective returns would be $6,397, $8,330, $9,556, and $10,599. This is a difference of $1,933 between the first and the second, $1,226 between the second and the third, and $1,043 between the third and the fourth. The difference between the first and the fourth is $4,202; and between the second and the fourth $2,269.

The amount of capital invested in the farm of 640 acres with its improvements, including the home of the owner, are the same for all four systems, and the taxes on them will be the same. The capital invested in implements and motive power (horses and tractors) will differ somewhat. It will be least for system 1, as only 300 acres of crop are seeded and harvested each year, instead of 600 acres under any of the other three systems. The difference in the cost of equipment necessary for the production of the crops under these four systems would not, however, vary in anything like the same proportion as the variation in the gross income. It is probable that instead of an increase in the cost of equipment being 70 per cent, as between system 1 and system 4 when the gross incomes are compared, it would be nearer 25 per cent.

If a farmer elects to adopt either the third or the fourth system, it will be necessary for him to increase his capital investment, for he must provide pasture for enough livestock to consume the roughage either from 200 acres of corn and 200 acres of oats if the third system is followed or from 300 acres of corn if the fourth system is chosen. He must also provide fences and shelter for his stock, and silos for a portion of his corn fodder, as well as some additional machinery. The kind of stock kept and the way in which the corn crop is handled will determine the nature and extent of these additional investments. In many parts of the Great Plains it is possible to rent unbroken prairie land, lying adjacent to improved farm land, for the taxes on the unbroken land. In such instances it would undoubtedly be better to rent than to buy such land, unless it can be bought at a price so low that the taxes and interest will not exceed the actual rental value of the land for pasture. Good grazing land in the northern Great Plains area can be rented for 10 to

15 cents per acre, and there is no region of comparable size in the 17 Western States that is as well suited to the production of as good quality of grass-fed beef as is found in western North Dakota and South Dakota and eastern Montana and Wyoming. This seems to indicate that grazing land in that region has a purchase value of only about $2.50 per acre, which is much below the price at which it is now being held.

How much land is necessary for grazing the livestock required to consume all the coarse grains and roughage produced on 300 or 400 acres of land? This depends, of course, upon the character of the land and the kind of livestock kept, and these would be different for each farm. It would, therefore, be a waste of time to speculate upon this subject at this time.

The extra buildings necessary for sheltering the livestock and storing the roughage for feeding can be provided at a low cash outlay by utilizing prairie sod, poles, and wheat straw for shelters, and trench silos for storing corn fodder, at least until the enterprise reaches a stage when better buildings can be constructed from the profits of the business.

In planning and also in operating a diversified grain and livestock farm, it would be well to treat the crop production and the crop conversion or livestock sections as separate enterprises as far as practicable. That is to say, a farmer operating such a farm should be at any time in position to make a rough estimate of the relative profitableness of the two branches of the business. He should be able to make a fair estimate of what it cost him to produce the feed for the livestock, and he should credit this amount to the crop-production branch and charge it against the livestock branch The gross cash returns from the crop-production branch would be represented by the receipts from the sale of wheat, and returns from the livestock branch would accrue from the sale of livestock products. These two items should be kept separate, but together they will constitute the gross income from the farm.

Expenditures should likewise be recorded in such form as to enable the farmer at any time to make a rough estimate as to the money income and outgo. The groupings of expenditures should include the following: Family living expenses; hired help; investment, interest, and taxes; equipment and repairs. An inventory of the livestock and equipment should also be kept.

The object sought is to enable the farmer to maintain a balance between his income and his outgo, or if he can not keep them in balance to know how much out of balance they are and why. In operating a combined grain and livestock farm he should also be able at any time to make a rough estimate as to whether the two branches of the business are in balance with each other. He must, in short, be constantly on the alert, watching for leaks and constantly striving to so coordinate all the activities of his organization as to yield the highest net returns either in cash, in the increased value of his investment, or in the general well-being of the organization as a whole. There must be a mutual give-and-take relationship between the family interests and the business interests of the farm.

After having adopted the system of rotation and tillage that seems best adapted to any particular farm, farmer, his family, and the local environment, including soil, climate, and marketing conditions, probably the factor most likely to necessitate frequent readjustments of the farming system is the fluctuation in the market prices of all farm products, both crop and animal. Stable conditions of these factors can not be expected; an unstable equilibrium and the ability on the part of the farmer to make prompt readjustments to meet changing conditions is all that can be hoped for It is believed that the facts recorded and the suggestions offered in these pages may be of some assistance to him

THE AMERICAN FARM HOME AND THE LABOR PROBLEM

It is in the item of labor that the most complex farm problem occurs. If all the labor on the farm could be hired at fair wages just when it is needed it would be a very simple problem to estimate the relations between labor cost and gross income, but such conditions do not, and should not, exist on any farm. A farm should be primarily a home and secondarily a place where all the members of the farmer's family may find gainful employment for such portion of the time as circumstances may permit throughout the entire year. Hired help is also usually much more satisfactory when employed by the year. These considerations lift the problems of farming out of the manufacturing class and elevate them to a class by themselves. No two families are alike, and no one family remains the same for any considerable length of time.

Every farm home is a stage upon which there is a continuous performance. The entire range of dramatic performance is covered: Tragedy, comedy, farce, and burlesque follow one another in never-ending succession. The actors are the farmer, his wife and every other member of his family, and the farm help. They provide the brains, the brawn, and the inspiration for the entire farming enterprise; and the nature of the drama they enact influences every living thing on the farm and leaves its impress upon many inanimate objects.

It is hoped that the two working hypotheses may assist the stage carpenter in setting the stage, but the analysis has now reached a point showing that the hypotheses no longer work. The actors alone can determine what the play will be.

In attempting to estimate the cost of any given farm system, or the accomplishment of any object, one must have some standard of comparison in order to evaluate correctly the capital used, the labor performed, or the time consumed by any human being, animal, implement, or machine. Of course, there are no absolute standards with which any of these things can be compared and evaluated. All that can be hoped for is to make a few tentative comparisons that may serve to indicate some relative values.

This is not the proper place to sentimentalize farm life; our literature from Vergil down to Hamlin Garland is overflowing with it. No phase of farm life has been overlooked, from the best to the worst. It is, therefore, axiomatic that in no other business does sentiment exert so strong an influence as in farming. This fact can not be ignored in considering any of the problems of cost of production of farm products; nor should it be forgotten that human lives and human happiness can not be estimated in dollars and cents.

The sentiment that impels a large proportion of every civilized race to desire to own farms, to establish homes, and to rear families upon the farms has been one of the most powerful forces in civilization. It might well be called an instinct, for it is so closely associated with the instincts of self-preservation and the perpetuation of the species that it is difficult to disassociate it from them. Considered together, they constitute, for many people, the strongest incentives in life. Greater sacrifices have been and will continue to be made in their defense than in defense of any other sentiment or instinct known to humanity.

THE PROBLEM OF MARGINAL PRODUCTION

Leaving out of consideration, for the present, the farm products that are put on the market which have been produced at a loss to the producer, owing to the fact that either yields or prices, or both, are below the average, every year enormous quantities of all kinds of farm products are grown which the producer knows beforehand will yield him no direct profit. Producers of this class are mainly sentimentalists, although many of them would not recognize themselves as such. They include all sorts and conditions of men, from millionaire business men with country estates to the peasant farmers of Europe, Asia, and Africa, the latter eking out a miserable existence upon some small patch of land that they have inherited from their ancestors.

Then there is another class of producers who are not actuated by sentimental notions. Their motives are strictly utilitarian. They raise some particular crop, knowing that it will not in itself yield them a direct profit, but believing that it will indirectly benefit them. Perhaps winter wheat is as good an example as any of this practice. Over extensive regions in the United States the yields of winter wheat are not sufficient to insure a profit, but where the profitable products are corn, hay, and livestock, it has been found that by sowing winter wheat upon corn stubble and seeding down the land at the same time to clover and timothy, or some other grass, the farmers can get a small return from the winter wheat without interfering with the corn-grass rotation. If they did not raise winter wheat, they would receive no return whatever from the field during the year of its conversion into a meadow or pasture. An unprofitable winter-wheat crop is better than no crop.

In the northern Great Plains area it has been found profitable to introduce an unprofitable corn crop between two wheat crops, because the increased profits from the wheat crop following corn will more than compensate for the loss on the corn crop. Many other like instances could be cited to show that practically all staple crops have to meet the competition of large quantities of that particular commodity, or of substitutes for that commodity which are produced without any direct profit to the producer.

When manufacturers have to meet the competition of by-products from other factories, they usually find means of adjusting, evading, or overcoming such competition, through their organizations; but the farmers, who are not organized and who have no such control over either the production or the distribution of their products, are not likely to find any such remedy.

A manufacturer with his factory and a given quantity of raw material, and the necessary labor available, at the beginning of the year can make a very close estimate of just how much finished product he can turn out during the year, what it will cost him, and what he can sell it for in order to realize a given profit per unit of his product.

A farmer on the Great Plains, with his farm, his equipment, his seed, and his supply of labor and provisions for the year, can not at the beginning of the year estimate with any degree of probability within 100 per cent below the average or 250 per cent above what his output will be. His cost of production per unit of his product and the price at which he would have to sell it to realize a given profit are equally uncertain. He must simply trust to luck and the weather as to the quantity of his product, and what he will receive per unit of such crops as he may happen to produce will depend upon world prices. (See Table 7, p. 75, Miscellaneous Circular No. 81.)

Table 33 has been prepared from the data heretofore presented in these pages and from statistics published in the Yearbook of Agriculture for 1926. It is so arranged as to show very plainly the conjoint effects of fluctuations of the price and the yields of wheat and oats. The average acre yields of wheat in the Great Plains for the 16-year period were 1.4 bushels higher than for the United States as a whole, and the acre value was $1.28 higher. Although the yields of oats were also very slightly higher, 0.2 bushel, the acre values were 58 cents lower. This is due mainly to the fact that the price of wheat during the five years from 1916 to 1920, inclusive, was above the average for the 16-year period. The acre yields of wheat in the Great Plains area for that 5-year period were 13.8 bushels, which is 2.1 bushels below the average for the 16-year period. The price for oats was not as much higher during the war period as was that of wheat, and it extended over but four years, 1916 to 1919, and acre yields were 25.6 bushels, which is 6.7 bushels below the average for the 16-year period. As a result of these conditions the acre value of wheat on the Great Plains for the war period was $24.29, which is $5.52 above the 16-year average, whereas the acre value of oats for the same 5-year war period was $16.06, which is only $1.95 above the 16-year average. This is only one of many comparisons that may be made to show what queer pranks the fluctuations of prices and yields can play with profits in farming.

TABLE 33.—*Price per bushel and acre yields and values of wheat, oats, and corn in the United States for the 16-year period 1909 to 1924, compared with wheat and oats at 16 field stations in the northern Great Plains area for the same years*

Year	Wheat					Oats					Corn		
	Price per bushel, United States	Acre yields		Acre values		Price per bushel, United States	Acre yields		Acre values		Price per bushel, United States	Acre yields, United States	Acre values, United States
		Great Plains	United States	Great Plains	United States		Great Plains	United States	Great Plains	United States			
	Cts.	*Bu.*	*Bu.*	*Dol.*	*Dol.*	*Cts.*	*Bu.*	*Bu.*	*Dol.*	*Dol.*	*Cts.*	*Bu.*	*Dol.*
1909	98.4	23.4	15.8	23.03	15.57	40.6	40.8	30.4	10.00	12.34	58.6	26.1	15.32
1910	88.3	11.4	13.9	10.07	12.28	34.4	22.8	31.0	7.84	10.88	48.0	27.7	13.31
1911	87.4	5.2	12.5	4.54	10.96	45.0	10.4	24.4	4.68	10.98	61.8	23.9	14.70
1912	76.0	13.8	15.9	10.94	12.12	31.9	27.6	37.4	8.86	11.93	48.7	29.2	14.20
1913	79.9	14.8	15.2	11.83	12.16	39.2	29.6	29.2	11.60	11.45	69.1	23.1	15.99
1914	98.6	17.9	16.6	17.65	16.41	43.8	35.8	29.7	15.68	12.99	64.4	25.8	16.65
1915	91.9	32.8	17.0	30.14	15.58	36.1	65.6	37.8	23.68	13.65	57.5	28.2	16.22
1916	160.3	20.7	12.2	33.18	19.50	52.4	41.4	30.1	21.69	15.80	88.9	24.4	21.66
1917	200.8	8.8	14.1	17.67	28.35	66.6	17.6	36.6	11.72	24.37	127.9	26.3	33.58
1918	204.2	13.3	15.6	27.16	31.80	70.9	26.6	34.7	18.86	24.59	136.5	24.2	32.70
1919	214.9	7.7	12.8	16.55	27.48	70.4	15.4	29.3	10.84	20.66	134.5	28.9	38.91
1920	143.7	18.7	13.6	26.87	19.58	46.0	37.4	35.2	17.20	16.20	67.0	31.5	21.14
1921	92.6	11.9	12.8	11.01	11.85	30.2	23.8	23.7	7.19	7.16	42.3	29.6	12.50
1922	100.7	18.4	13.9	18.53	14.02	39.4	36.8	29.8	14.50	11.74	65.8	28.3	18.58
1923	92.3	15.1	13.4	13.94	12.34	41.4	30.2	31.9	12.50	13.20	72.6	29.3	21.25
1924	129.9	21.0	16.5	27.28	21.38	47.7	42.0	35.7	20.03	17.03	98.2	22.9	22.47
Average	122.5	15.9	14.5	18.77	17.50	46.0	31.9	31.7	14.11	14.69	77.6	26.8	20.60

It was found impracticable to include the yields of corn in the Great Plains area in this table, owing to the fact that the corn yields include the stover as well as the grain, while no comparable data are available for the United States as a whole.

Figure 78 is a graphic illustration of the data contained in Table 33. The upper portion shows the relations between the yields per acre, expressed in bushels per acre, of wheat and oats in the Great Plains and the corresponding yields in the entire United States.

The lower portion illustrates the relative values per acre, as given in Table 33, for the United States and the Great Plains.

A careful study of Table 33 and Figure 78 will not only reveal the complexity of the problems of crop rotations but it will also assist in explaining some seeming anomalies.

Perhaps the most impressive feature of this table and its accompanying illustration is the remarkable similarity of the average results obtained at 16 northern Great Plains field stations and for the entire United States. These respective data were, of course, obtained independently of each other, and were never before brought together for comparison. The data for the 16 field stations are much more accurate than those for the whole United States, for they represent actual measurements of both the land and the crop, while those for the United States are what they purport to be, crop estimates. On the other hand, the enormously larger number of the estimates, as compared with the actual determinations, give the estimates a higher relative value than the actual determinations. The result of this comparison is to inspire greater confidence in both sets of figures.

INSURANCE AGAINST TOTAL FAILURE OF CROP

Many advocates of summer-fallowing lay great stress upon the insurance features of this practice. It is true that danger of complete crop failure when summer-fallowing is practiced is less than with continuous cropping, but it is far from being what can be called insurance. It is at best but a slight reduction of the hazard. A crop following summer-fallow may be as completely destroyed by hail, disease, or insect pests as one grown by continuous cropping or in rotations.

Table 34 has been prepared from the records of the Office of Dry Land Agriculture and shows what has been the experience in this respect in the Great Plains area for 149 crop years, with three crops and three systems, amounting to 1,341 independent determinations. It is self-explanatory. It shows the number of seasons when the yields of wheat, oats, and corn fall below the point of possible profit in their production, at each station for each of the three crops, as grown under each of the three systems, (1) continuous cropping, (2) alternate fallowing, and (3) in rotation 1.

If the percentages of practical crop failures are subtracted from 100 in each instance, it shows that under continuous cropping the crop yield above the standards set for each crop was 70 per cent for wheat and oats and 94 per cent for corn; for alternate fallowing it was 89 per cent for wheat and oats and 96 per cent for corn; and for rotation 1 it was 77 per cent for wheat, 75 per cent for oats, and 94 per cent for corn.

For rotation 1 the average of the three crops would be $77+75+94\div3=82$ per cent, and for alternate wheat and corn it would be $77+94\div2=86$ per cent.

TABLE 34.—*Number of years in which wheat yielded less than 5 bushels, oats less than 10 bushels, and corn less than 1,000 pounds total weight at 10 field stations in the northern Great Plains area, for each of three systems of farming, with percentages for each station, crop, and system*

Field station and comparison factors	Number of years in which wheat yielded less than 5 bushels under—			Number of years in which oats yielded less than 10 bushels under—			Number of years in which corn yielded less than 1,000 pounds under—			Years at each station
	Continuous cropping	Alternate fallow	Rotation 1	Continuous cropping	Alternate fallow	Rotation 1	Continuous cropping	Alternate fallow	Rotation 1	
Moccasin:										
Years	3	2	2	3	2	3	0	0	0	18
Percentage	17	11	11	17	11	17	0	0	0	
Belle Fourche:										
Years	6	2	5	5	2	4	2	1	2	18
Percentage	33	11	28	28	11	22	11	6	11	
Sheridan:										
Years	2	0	2	2	1	2	1	1	1	9
Percentage	22	0	22	22	11	22	11	11	11	
Mandan:										
Years	4	3	3	4	0	3	0	0	0	12
Percentage	33	25	25	33	0	25	----	----	----	
Dickinson:										
Years	6	1	3	7	2	4	1	1	1	19
Percentage	32	5	16	37	11	21	5	5	5	
Williston:										
Years	4	1	3	5	1	4	0	0	0	11
Percentage	36	8	27	45	9	36	----	----	----	
Edgeley:										
Years	5	1	4	4	1	3	0	0	0	16
Percentage	31	6	25	25	6	19	----	----	----	
Ardmore:										
Years	5	2	3	4	3	4	2	1	1	13
Percentage	38	15	23	31	23	31	15	8	8	
Huntley:										
Years	3	2	3	4	2	3	2	1	3	14
Percentage	21	14	21	29	14	21	14	7	21	
North Platte:										
Years	6	2	6	7	2	7	1	1	1	19
Percentage	32	10	32	37	10	37	5	5	5	
Total years	44	16	34	45	16	37	9	6	9	149
Average percentage	30	11	23	30	11	25	6	4	6	

It is therefore obvious that the chance of obtaining an average yield above the standard for alternate wheat and summer-fallowing would be 89 per cent; whereas for the three crops, wheat, oats, and corn, in rotation 1 it would be 82 per cent; a ratio of $89\div82$ gives 1.09 per cent in favor of alternate fallowing; and with alternate wheat and corn the ratio would be $89\div86=1.03$ per cent. As an offset against these greater hazards of 9 and 3 per cent, respectively, there are the increased gross returns of 53 and 70 per cent, respectively. (See Table 32.) Moreover, the additional livestock which would be owned by the farmer under either of the rotation systems would in itself be a much better safeguard against total failure of crops than summer-fallowing. Sufficient winter feed for the livestock should be carried over from year to year, so as to insure an income from that source sufficient to feed the farmer's family even in years of total failure of crops.

It is therefore obvious that the summer-fallowing system as an insurance against total loss of crops is a myth, while crop rotation and livestock are realities.

It is rather difficult to understand why anyone should advocate or practice summer-fallowing for wheat in a region where corn can be grown as successfully as it can be in the northern Great Plains area. Of course,

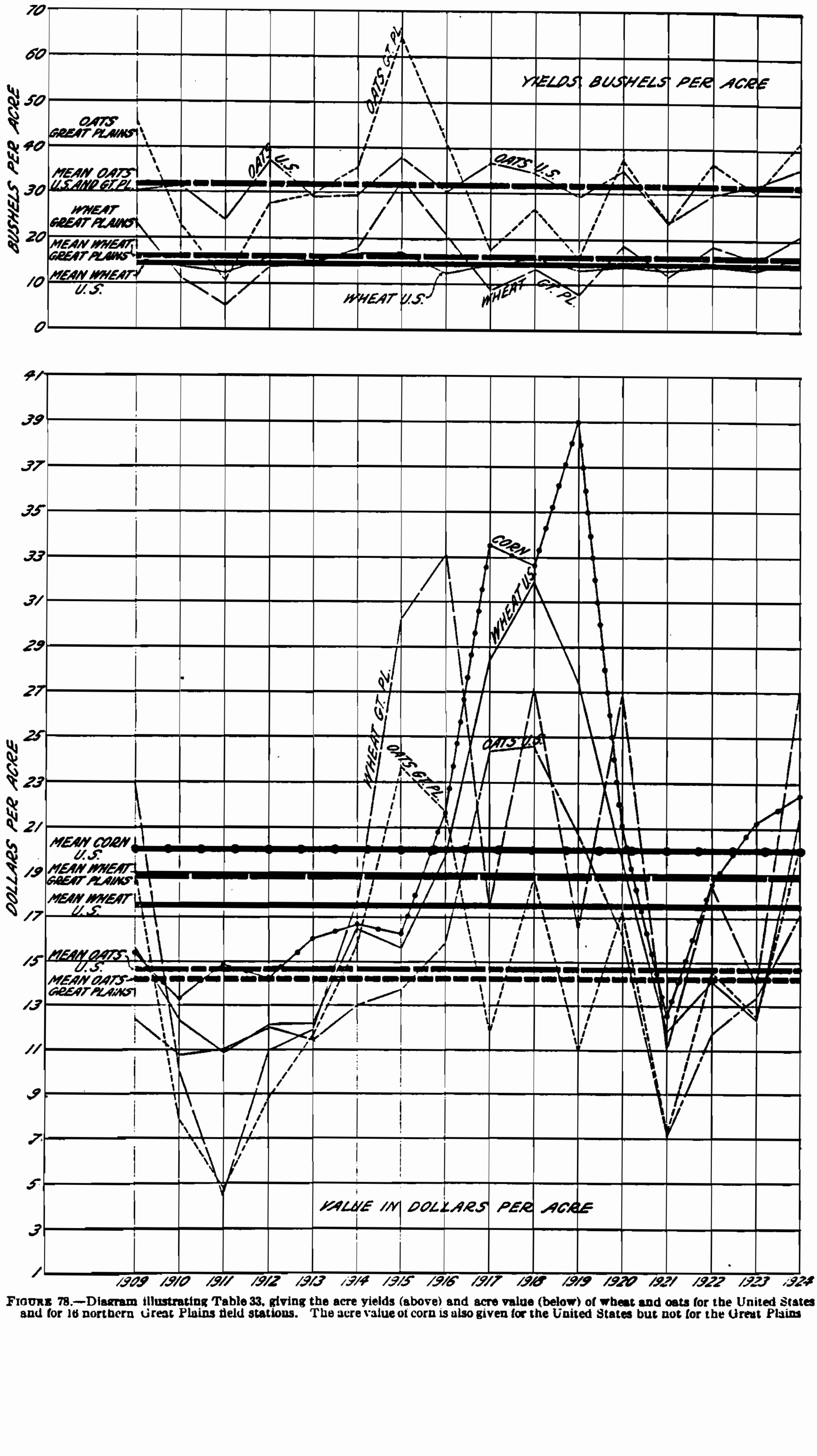

FIGURE 78.—Diagram illustrating Table 33, giving the acre yields (above) and acre value (below) of wheat and oats for the United States and for 16 northern Great Plains field stations. The acre value of corn is also given for the United States but not for the Great Plains

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the growing of corn in this region involves also the keeping of sufficient livestock to convert all the roughage and the corn grain into animal products of some kind. But that ought not to be an obstacle in the way of the agricultural development of the Great Plains. It is true that it requires more capital to finance a grain and stock farm than is required for a 1-crop system of grain raising. But, on the other hand, both the cash capital and the managerial ability invested in a grain and livestock farm are much more profitably and continuously employed. It is a much safer business, and labor is more economically and continuously employed.

Possibly sentiment may have something to do with the raising of wheat on summer-fallowed land. Any farmer likes to raise big crops. He gets much more satisfaction out of watching a 30-bushel crop of wheat grow than to watch a 20-bushel crop, but under a summer-fallow system he has only half as many acres of crop and the 30-bushel crop may cost, and probably does cost, more per bushel to raise than the 20-bushel crop.

COMMENTS AND SUGGESTIONS CONCERNING CROP ROTATIONS AND TILLAGE METHODS IN THE GREAT PLAINS AREA

The men who have conducted these investigations had no pet theories which were to be demonstrated. If they had proved nothing, they would not necessarily have failed. They have certainly established certain facts and certain relations between these facts that must be recognized in any intelligent study of some very important farm problems. These facts are hereby made available to the general public, and the preceding analysis and discussion of these facts have demonstrated some of the complexities of the problems involved in the present agricultural situation. The statistical data which follow will add to the complexity of the problems, but they also furnish additional material for studying them.

The writer is fully aware of the fact that his treatment of the material may not be the best that might be developed. Most readers will doubtless agree with him upon this point. The inadequacy of the treatment of the material by the writer therefore requires no further discussion. What is needed is better treatment. It is a subject that lies close to the foundation of our American civilization and is worthy of consideration by the best minds of the country. It is the hope of the writer that it may receive such consideration.

Crop rotation is an essential feature of the agricultural development of the Great Plains if the American farm home is to be preserved in that area.

Corn is the most important crop in the rotation in the northern Great Plains. It is also one of the most difficult to correctly evaluate. This is due mainly to two causes. It is very erratic and discordant in its reaction to changes in soil and climatic conditions when compared with wheat and oats. It must be fed on the farm where it is produced. This introduces the factor of its profitable conversion into animal products. These investigations have demonstrated its place and its value in the rotation. Its profitable conversion is a problem for the study of practical stockmen and investigators of animal industry.

The problems of tillage and the preparation of the seed bed are so dependent upon local and seasonal soil and climatic conditions that they must be left largely to the individual practical farmers for ultimat solution.

It should be borne constantly in mind that one of th most important objects sought by the rotation of cro and by tillage methods is the prevention of the growt of weeds. Whatever system of farming is adopted, i success or failure will depend largely upon how ef ciently it prevents the loss of soil water by the growt of weeds. This is a local and seasonal problem tha must be met and solved by the farmer under condition existing at any particular time and place. In fact, th entire problem of the tillage of row crops is usually th problem of weed destruction. Any cultivation of ro crops in excess of that necessary to prevent weed growt is usually a waste of time and labor. The time an method of preparing the seed bed for all crops is als largely a matter of the control of weed growth.

Although the adoption of a rotation system whic includes a corn crop is indicated as the most profitabl by the results of these investigations, it is obvious tha such a system can not, for various reasons, be adopte by all farmers in the Great Plains area. The knowledg of the relations of the different systems of farming t one another and to the gross returns that can reasonabl be expected from each, however, should be of value t anyone interested in the agricultural development o the Great Plains area.

The agricultural problems of the United States ar becoming recognized as among the gravest problem now before the American people. Their solution wi require the combined efforts of the most able sociol ogists, economists, financiers, and statesmen, as well a that of the agriculturists.

It seems impossible that the present disparity betwee the prosperity of the people engaged in agriculture an those engaged in manufactures and commerce ca continue for any great length of time. How they ar to be brought into equilibrium is a problem that doe not come within the scope of these investigations There are, however, certain probabilities that, for th purpose of these investigations, may be considered a certainties. Among these are the following: Th United States of America will have a permanent agri culture for many generations to come. The agricultur of the Great Plains will increase in national importanc as time goes on. The agriculture of the future mus rest upon a far firmer scientific basis than that of th past or the present. Pertinent facts are essential as basis for scientific reasoning. These pages contain record of facts pertinent to the agricultural developmen of the Great Plains such as can not be found elsewhere This record is becoming more valuable every year tha these investigations are continued. Before facts ca be utilized they must be interpreted and analyzed Methods of interpretation and analysis must be devel oped from which generalizations can be made. It i hoped that the generalizations herein presented will b of some value. It is still more confidently believed tha the methods of interpretation and analysis used wi prove of great value, even though it be only to show how the facts ought not to be used. Of the value o the facts presented there can be no reasonable doubt It is hoped that these facts will be fully utilized b other investigators, and that both the methods and th generalizations of the writer will be frankly and freel criticized. The problems of crop rotation are muc more complex than is generally realized, and but littl scientific work has been done upon them.

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THE RELATIONS BETWEEN CROP YIELDS AND PRECIPITATION IN THE GREAT PLAINS AREA

SUPPLEMENT 1.—CROP ROTATIONS AND TILLAGE METHODS

By E. C. CHILCOTT, Formerly Senior Agriculturist, in Charge of Office of Dry Land Agriculture, Bureau of Plant Industry

CONTENTS

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