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NITROGEN AND CARBON CHANGES IN SOILS

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SUMMARY AND CONCLUSIONS

A study was made of the nitrogen and carbon changes in the 0-7 inch layer of the dry-land soils at Hays, Colby, and Garden City during the period 1916 to 1938. Particular attention was given to the effect of cropping system and soil treatment on the two soil constituents.

The relative loss of nitrogen and carbon from the soil was related to the original nitrogen and carbon content of the soil, the cropping system used, soil treatment applied, tillage method used, time of plowing, and the yield of crop.

The higher the nitrogen and carbon content of the soil in 1916, the greater the loss of the element where the other factors were more or less constant.

The cropping system bore a definite relationship to the loss of each element. Continuous small grain production, and alternate small grain and fallow caused relatively low losses. Continuous row crops, and alternate row crop and fallow produced the greatest losses. Rotations including row crops and small grain produced intermediate losses.

Both manure and straw made positive contributions to the residual nitrogen and carbon of the soil.

Spring plowing has resulted in less loss of the two constituents than fall plowing. Likewise listing has been less destructive than plowing.

There has been a tendency for the nitrogen content of the soil to approach a state of equilibrium more or less characteristic of a given cropping system and a given soil. However, as yet nitrogen compensating factors have not balanced nitrogen losses.

The nitrogen loss from the soil during the period 1916 to 1938 has been nearly equal to the removal of nitrogen by the crop for those areas several years removed from the virgin sod.

Immediately following the breaking of the virgin sod the loss of nitrogen is greatly in excess of its removal by crops.

NITROGEN AND CARBON CHANGES IN SOILS UNDER LOW RAINFALL AS INFLUENCED BY CROPPING SYSTEMS AND SOIL TREATMENT[1]

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INTRODUCTION

Nitrogen and carbon studies on cultivated soils have been the subject of numerous investigations in many parts of the world. It has been established rather definitely that the soil organic matter approaches a dynamic equilibrium characteristic of the environment imposed upon the soil. For a discussion of a part of the evidence on this point the reader is referred to the recent book by Jenny (13). In general, the trend of organic matter in cultivated soils is downward. A line representing the trend is curvilinear in nature. Under humid conditions the downward trend is associated with an increasing need for commercial fertilizers, barnyard manure, and leguminous crops. Commercial fertilizers, barnyard manure, and legumes have never had a prominent place in the agriculture of the dry-land area of the Great Plains and only a few field experiments have shown any advantage to the crop from the use of these materials on the soil. That this may not continue to be the case indefinitely was early realized by dry-land agriculturists. In response to the recognition of the need for a systematic study of the fertility balance in soils of low-rainfall regions most of the experimental plots on the dry-land projects at the Hays, Colby, and Garden City branches of the Kansas Agricultural Experiment Station were systematically sampled in the spring of 1916.[3] In 1927 and 1928 a few of the plots were sampled again and the result published (6, 21). In the spring of 1938 virtually all plots sampled in 1916 on which the treatment had continued unchanged through the period 1916 to 1938 were again resampled and the analyses made.[4] The investigation dealt only with

1. Contribution No. 355, Department of Agronomy, Contribution No. 38, Fort Hays branch station, and Contribution No. 78, Office of the Director, Kansas Agricultural Experiment Station, and the Division of Dry-Land Agriculture, Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture, cooperating.

2. Agronomist, Kansas Agricultural Experiment Station; Associate Agronomist (Hays); Associate Agronomist (Colby); and Assistant Agronomist (formerly Garden City, Kansas, now Mandan, North Dakota); Division of Dry-Land Agriculture, Bureau of Plant Industry, Soils and Agricultural Engineering, United States Department of Agriculture, respectively. Acknowledgment is hereby given H. H. Laude, Agronomist, and H. C. Fryer, Statistician, Kansas Agricultural Experiment Station, for assistance with the statistical studies.

3. It was through the initiative of C. O. Swanson, Professor of Milling Industry and L. E. Call, Director of the Kansas Agricultural Experiment Station, then Soil Chemist and Professor of Agronomy, respectively, that the samples were taken. The analyses were made under the direction of C. O. Swanson.

4. Nitrogen analyses were made by H. E. Jones, then student assistant, now assistant agricultural chemist, Indiana Agricultural Experiment Station. The carbon analyses were made under the direction of A. T. Perkins, Department of Chemistry, Kansas Agricultural Experiment Station.

changes in the nitrogen and carbon constituents of the soil. A study of the changes that occurred during the 22 years is presented in this paper. The locations of the stations are shown in Fig. 1.

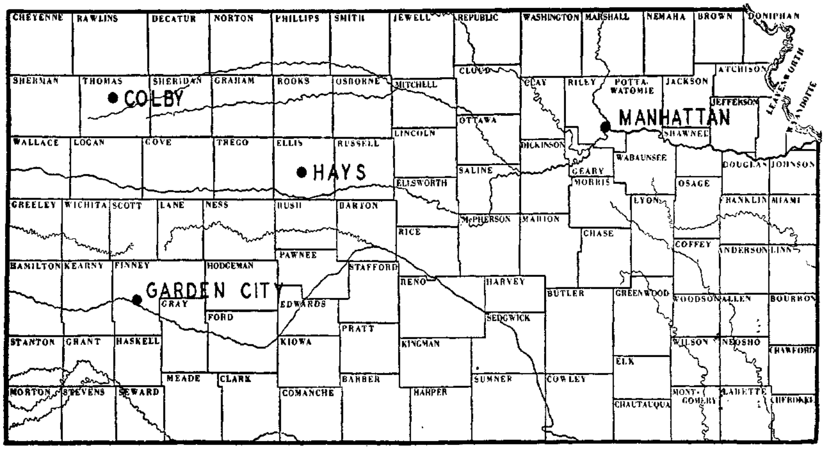

Fig. 1. A map of Kansas showing the location of the main and branch agricultural experiment stations.

Gainey, *et al.* (6) reviewed early nitrogen studies on soils under low rainfall conditions. Since that time a few other papers (2, 10, 24, 26, 27) have reported similar studies.

CROPPING HISTORY OF THE EXPERIMENTAL AREAS AND SOILS

HAYS

Available records do not show when the experimental area was broken from the native sod. The first written record of a crop was that for winter wheat harvested in 1904. An old resident, who, in the early days lived on a quarter-section of land that is now a part of the experiment station site, stated quite positively (according to his recollection) that the quarter-section on which the dry-land project was later established was not broken earlier than 1902 or 1903, probably the latter date. From this evidence it is assumed that the sod was broken in 1903 and the first crop harvested in 1904.

From the time the sod was broken until the establishment of the experimental work, winter wheat and corn were grown on the area. The experimental work was started in 1906. Other plots included in the present study were established in 1910, 1913, and 1916.

Accelerated wind erosion has not greatly influenced the experimental plots since the original soil samples were taken in 1916 according to Mr. Hallsted's observations. Dust deposition has occurred during dust storms but the extent of the accumulation has not been great enough to influence the surface elevation of any plot during the 22-year period of the study such that it can be observed.

Water erosion has had variable effects. On a part of the area the surface is nearly level and the remaining area has an increasing slope reaching a maximum of about 2 percent. The plots are laid out so that all tillage and planting have been on the approximate contour. The extent of erosion cannot be evaluated quantitatively but depth observations, both during the period and at the time the last samples were taken, indicated that erosion has not been severe.

The soil is of the Chernozem group and classed as Crete silty clay loam, with a moderate claypan, according to a recent survey. The series name has been changed since the original reconnaissance survey was made. Reports have referred to the soil on the experimental block as of the Colby series. The soil is representative of a large area of good wheat land.

COLBY

The experimental area at the Colby station had been under cultivation for several years prior to its acquisition by the station. While no records of the early cropping history of the area were kept, information that could be obtained suggested that the sod was broken about 1885. It was permitted to resod in the early '90s but was broken again in 1905. The experimental work was started in 1914. The crops grown before records were kept probably consisted of winter wheat, barley, and corn.

The soil of the area blew considerably in the spring of 1912 and at intervals since. Soil samples taken in the fall of 1914 showed variations in the depth of soil presumably the result of soil blowing. While some wind erosion has occurred since the start of the experimental work, accumulation of materials eroded from adjoining areas has been responsible for even greater changes in the plot soil. This is especially noticeable on those plots that carry standing stubble during the winter or early spring. On some of these plots the surface is distinctly higher than that of adjoining plots which are free of stubble during the winter and spring. The difference in elevation is sufficient to be readily observed.

The area has a fairly uniform slope to the east averaging about 0.75 percent. Water erosion has not been serious, although the surface drainage is good.

The soil is of the Chestnut group, now classed as Sherman silt loam, though formerly classed as Colby silt loam. A buried soil is found at a depth of about 24 inches. Calcium carbonate is found at a depth of about 15 inches.

GARDEN CITY

The complete cropping history of this experimental area is known. On the main project the buffalo grass sod was broken from March 8 to 20, 1907. The experimental work was started immediately and all crops were seeded in 1907 as scheduled. The dry-land agriculture annex was broken from buffalo sod in June, 1930. It was seeded uniformly to winter wheat in the fall of the same year. Experimental plots were laid out and treatments started the following year. The original soil samples were taken in April, 1931.

The slope of the area where the main project is located varies from about 0.3 percent to 2.75 percent. The annex is located on an area where the slope varies from 1 to 3 percent. Soil erosion has not been serious on the experimental areas. Dust deposition has probably been of greater importance than wind erosion. Water probably has removed a greater amount of soil than has wind.

The soil is in the Chestnut soil group not far from the boundary between the Chestnut and Brown soils. Several series which vary considerably in depth of profile have been mapped on the station. The series include Keith, Ulysses[5], and Colby, all very fine sandy loams. The calcium carbonate layer in the Keith series is encountered at 18 to 24 inches, in the Ulysses series from 12 to 18 inches, while in the Colby at a depth less than 12 inches.

CLIMATE

The climatic conditions for the three stations used in this study are depicted in part by data in Table 1. For greater detail

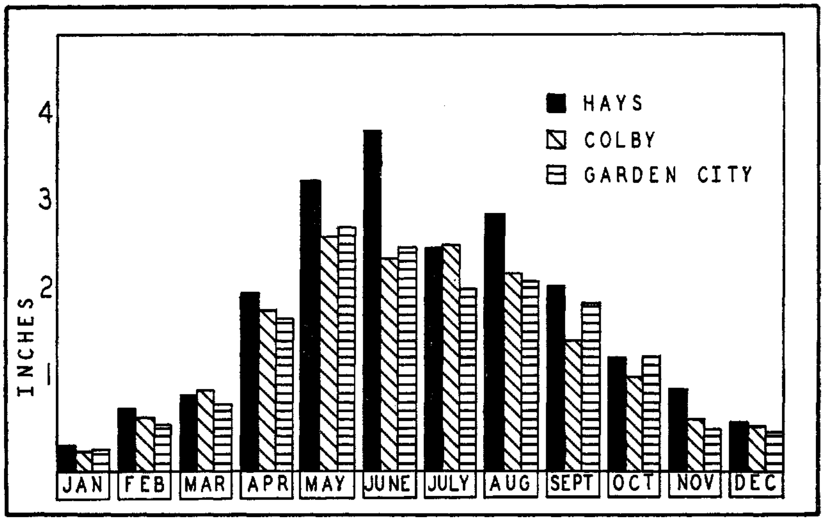

Fig. 2. The average monthly distribution of rainfall at Hays, Colby and Garden City.

5. Tentative series name.

the reader should refer to a recent study compiled by Cardwell and Flora (3). The rainfall type at all stations is typical of that for the Great Plains. Slightly more than 75 percent of the total rain falls during the 6-month period April to September as indicated graphically in Figure 2. The rainfall is highly variable with more than half of the annual periods receiving less than the long-time average. Extended periods of drought are common. Crop failures are most frequent at Garden City and least frequent at Hays. Temperature fluctuations are characteristic of a continental environment. Temperatures above 100° F. occur rather frequently. The high evaporation from the free-water surface, occurring at the time when three-fourths of the rain normally falls, indicates a low efficiency of the rainfall.

TABLE 1. CLIMATIC AND ELEVATION DATA FOR THE DRY-LAND EXPERIMENT STATIONS.

Station	Average 1916-1937		Annual mean temperature[1]	Elevation
	Annual precipitation	April to Sept. evaporation from free water surface		
	inches	inches	degrees F.	feet
Hays	21.68	48.9	54.0	2000
Colby	16.99	43.8	52.2	3138
Garden City	17.18	57.2	54.8	2836

1. Hays 40 years, Colby 45 years, and Garden City 41 years.

METHODS USED IF THE STUDY

The experimental plots were each one-tenth acre in area. Enough plots were used for each cropping system so that all crops in the rotation were grown each year. Studies reported herein were taken from the surface 7 inches.

In 1916 the soil samples were a composite of six borings per plot. In 1927, 1928, 1931, and 1938 a sample consisted of a composite of 12 cores per plot. The individual cores were taken in all cases to the depth of 7 inches in such a manner as to be fairly representative of the plot, but no effort was made to duplicate the sampling scheme of the previous period. In 1938, six samples approximately uniformly spaced over the full length were taken from the center of each half of the plot divided lengthwise.

The organic carbon was determined at each period by the Parr-bomb combustion method as outlined by Hopkins (11). The nitrogen determinations were made according to the Gunning-Hibbard procedure.

The analyst was a different individual at each period. Just how this fact affects the comparisons is unknown. The 1916, 1927, 1928, and 1931 samples were lost in a fire before the 1938 samples were taken; therefore, it was not possible to check on the old analyses.

Wheat was harvested with a binder during the early years of the experiments. No straw was returned to the plots other than the normal stubble except as indicated otherwise. During the latter part of the period the method of harvesting has been changed to the use of the combine with all the straw returned. The dates when combining was started at Hays, Colby, and Garden City were 1928, 1931, and 1932, respectively. Oats and barley have been cut with a binder with no return of straw throughout the period. The corn and sorghum crops have been harvested with a binder with only the normal stubble remaining except that milo stover was not harvested at Hays after 1936 and at Colby after 1937. Green manure crops were turned under near the stage of maximum growth for the crop until 1931, after which they were turned under at a somewhat earlier stage. The rye has been turned under about 30 days earlier than the Canada field peas.

The statistical procedure followed was that outlined by Snedecor (23). Probabilities shown in the statistical tables were obtained from tables of probabilities by Fisher and Yates (4).

The experimental layouts at all three stations were made before attention had been directed to the statistical analysis of field-plot results. The plots were not duplicated, and even though enough plots were used to produce every crop of a rotation each year, all were located as adjacent plots. For the purpose of the studies reported in this bulletin the plots were grouped so as to have together those with similar treatment. The grouping is not always above criticism, because for certain groups factors other than the one indicated appeared to have caused some differences. As a specific example, one cropping-system group was continuous small grain. In this was placed all continuous winter wheat, spring wheat, spring barley and oats regardless of tillage treatment. It was apparent that for any one crop the tillage method had some influence on the final results. However, because of the small number of the plots for an individual crop and individual-tillage method it was considered best to group all continuous small grains together regardless of tillage method. Likewise, with the alternate summer fallow and small grain plots, the winter wheat, spring wheat, spring barley and oats plots were grouped together, along with different methods of fallow. Rotations were grouped together when they were the same except for a variation in type of row crop, type of small grain or in the sequence of the crops making up the rotation. In the rotations to which manure was applied, those receiving the same total amount per rotation were considered the same even though the manure went into the rotation at different points.

By thus grouping the plots it was possible to increase the number in any one group to a point where a reasonably satisfactory statistical analysis could be made, even though the number of individuals in each group varied. Unless it was possible to put three plots in a group, that particular treatment was omitted from the statistical analysis. Data for treatments with less than three plots are shown in Tables 4 and 5 along with others so that comparisons can be made, even though the restricted number of plots did not permit satisfactory statistical treatment of the data.

In considering the results of the statistical analysis, the above limitations must be kept in mind. It is possible that the errors of the experiment are over-estimated. Therefore, more of the differences may be statistically significant than is implied in much of the discussion that follows.

In the discussion of results, losses are attributed to various factors including cropping system, soil treatment, tillage method, etc. In addition to these causes some loss of carbon and nitrogen probably resulted from water erosion. Likewise, there has been differential dust accumulation which has played a part in the results obtained. Probably there has been a net gain on all plots as a result of dust accumulation with the greatest gain occurring on those plots which were in stubble during the principal blow season. Since deposition and erosion cannot be evaluated, changes resulting therefrom are included in differences attributed to cropping systems, soil treatment, tillage method, etc. This appears to be satisfactory for practical application since the cropping system and soil treatment determined quite largely the extent of erosion and deposition.

ACCURACY OF SAMPLING AND ANALYTICAL TECHNIC

After the 1938 soil samples had been collected and nitrogen analyses made, certain of the plots at the Garden City experiment station were resampled and nitrogen analyses made independently by H. J. Haas and A. E. Lowe as part of another study. Their samples were taken in 1939. However, crops failed in 1938 so that little or no nitrogen loss would have resulted

TABLE 2. NITROGEN CONTENT OF SURFACE SOIL ON EXPERIMENTAL PLOTS AT GARDEN CITY, KANSAS, AS REPORTED BY TWO ANALYSTS.

Cropping system	Plot	Total nitrogen reported by		
		Jones	Haas	Difference
		percent	percent	percent
M. C.[1] kafir	F	0.075	0.070	−0.005
M. C. milo	F	0.076	0.078	0.002
405 Wheat, kafir, fallow	A	0.081	0.087	0.006
405 Wheat, kafir, fallow	B	0.087	0.090	0.003
405 Wheat, kafir, fallow	C	0.084	0.086	0.002
M. C. Winter wheat	C	0.091	0.092	0.001
M. C. Winter wheat	C	0.095	0.092	−0.003
M. C. Winter wheat	F	0.090	0.093	0.003

1. Letters and numbers are designations used by the Division of Dry-Land Agriculture to identify cropping systems. M. C. = method of continuous cropping. Plot letters designate the type of tillage used. See U.S.D.A. Misc. Cir. 81, supplement 1, pp. 32-43, 1931.

from crops. The results of the two independent analyses of different soil samples are shown in Table 2.

The close agreement of the nitrogen results reported by the two analysts on different samples taken by the same method of sampling should add to the significance of the analyses reported. Of the eight samples, only one, 405 A, shows an error greater than the limit (0.005%) suggested by Robinson (18) as being considered satisfactory for laboratory analysis only. The error reported in Table 2 included both sampling error and error of laboratory analysis.

EXPERIMENTAL RESULTS

EFFECT OF CROPPING SYSTEMS ON NITROGEN AND CARBON BALANCE

The effect of cropping systems on the nitrogen and carbon content of dry-land soils at Hays, Colby, and Garden City is shown in Tables 3, 4, and 5, respectively. The carbon-nitrogen ratios for 1916 and 1938 are also shown. Every cropping system showed an average loss of nitrogen and carbon during the period 1916 to 1938 at all three stations. Every individual plot making up the averages showed a loss of carbon, except for three plots at Colby (rotation 558, plot A; continuous oats, plot A; alternate oats and fallow, plot C) and one plot at Garden City (alternate wheat and fallow, plot H). One plot each at Hays, Colby, and Garden City did not show a loss of nitrogen (continuous oats, plot F at Hays; continuous spring wheat, plot A at Colby; and alternate wheat and fallow, plot D at Garden City). Data for each plot included in the study are shown in the appendix, Table 15.

The extent of the nitrogen and carbon depletion was definitely associated with the cropping system used. The loss of both nitrogen and carbon also was associated with the original nitrogen content of the soil. Correlation coefficients of the relationship between the nitrogen content found in 1916 and the percentage lost during 1916 to 1938 were computed for all treatments for which nine or more plots were available. The results are reported in Table 6 along with the regression coefficients for the same relationship. Of the 10 cropping systems studied all showed positive values, five showed a highly significant relationship between the two variables, three showed a significant relationship, while only two failed to show a significant relationship. The close agreement of the results would appear to add to the confidence which one may have in the results. Therefore, it appeared evident that because of the variability in the average nitrogen content of the soil in 1916 under different cropping systems a satisfactory interpretation could not be made without taking this factor into consideration.

Since the rate of nitrogen and carbon losses varied with the

TABLE 3. NITROGEN AND ORGANIC CARBON CHANGES IN DRY-LAND SOILS AT HAYS, KANSAS, AS INFLUENCED BY CROPPING SYSTEMS.

Cropping systems	Number of plots	Average nitrogen		Average percentage loss 1916-1938		Average organic carbon		Average percentage loss 1916-1938		Carbon-nitrogen		
		1916	1938			1916	1938			1916	1938	Decrease
		percent	percent	actual	adjusted[3]	percent	percent	actual	adjusted[3]	ratio	ratio	
Continuous small grain[1]	19	0.156	0.137	12.4	12.7	1.83	1.46	20.4	19.[illegible]	11.7	10.7	1.0
Alternate small grain and fallow	11	0.142	0.123	12.7	16.1	1.66	1.29	21.5	24.2	11.7	10.5	1.2
Small grain, rye (green manure), small grain, row crop[2]	12	0.162	0.141	13.1	11.9	1.93	1.48	23.3	20.3	11.9	10.5	1.4
Small grain, peas (green manure), small grain, row crop	12	0.157	0.138	11.5	11.3	1.77	1.39	21.1	21.6	11.3	10.1	1.2
Spring small grain, spring small grain, row crop	9	0.149	0.129	13.0	14.4	1.65	1.36	17.5	20.4	11.1	10.5	0.6
Barley, fallow, wheat, corn	4	0.147	0.121	17.9	20.1	1.58	1.24	21.0	25.4	10.7	10.2	0.5
Barley, wheat, wheat, row crop	8	0.172	0.131	24.0	20.8	1.94	1.43	26.1	23.0	11.3	10.9	0.4
Kafir, fallow, wheat	18	0.161	0.113	29.5	28.6	1.71	1.24	26.6	28.5	10.6	11.0	-0.4
Wheat, row crop	8	0.174	0.126	27.1	23.5	1.95	1.38	29.2	25.9	11.2	11.0	0.2
Continuous row crop	10	0.149	0.111	25.7	27.2	1.76	1.19	32.5	33.1	11.8	10.7	1.1
Alternate row crop and fallow	4	0.146	0.100	31.6	34.1	1.82	1.07	40.9	40.3	12.5	10.7	1.8
Wheat, fallow, fallow, fallow	4	0.168	0.116	30.9	28.6	1.85	1.23	33.2	32.0	11.0	10.6	0.4

1. Small grain includes winter wheat, spring barley and/or oats and is used when two or more small grain crops are involved. Wheat as used here refers to winter wheat.
2. Row crop includes kafir, milo and/or corn and is used when two or more row crops are involved.
3. From regression lines assuming linear regression.

TABLE 4. NITROGEN AND ORGANIC CARBON CHANGES IN DRY-LAND SOILS AT COLBY AS INFLUENCED BY CROPPING SYSTEMS.

Cropping system	Number of plots	Average nitrogen 1916	Average nitrogen 1938	Average percentage loss 1916-1938		Average organic carbon 1916	Average organic carbon 1938	Average percentage loss 1916-1938		Carbon-nitrogen 1916	Carbon-nitrogen 1938	Decrease
		percent	percent	actual	adjusted[4]	percent	percent	actual	adjusted[4]	ratio	ratio	
Continuous small grain[1]	8	0.133	0.115	12.4	14.3	1.50	1.22	16.0	17.4	11.3	10.6	0.7
Alternate small grain and fallow	18	0.147	0.115	20.4	17.2	1.58	1.27	17.9	16.6	10.7	11.0	-0.3
Row crop[2], row crop, wheat, rye (green manure)	8	0.123	0.098	19.4	25.0	1.52	0.94	37.6	38.4	12.4	9.6	2.8
Milo, fallow, wheat, rye (green manure)	4	0.124	0.095	22.4	27.6	1.33	1.05	20.8	28.5	10.7	11.1	-0.4
Milo, fallow, wheat, peas (green manure)	4	0.143	0.105	26.8	25.1	1.65	1.03	37.2	33.4	11.5	9.8	1.7
Milo, fallow, wheat, fallow	4	0.138	0.105	23.5	23.6	1.56	1.12	27.5	26.9	11.3	10.7	0.6
Milo, fallow wheat	9	0.128	0.100	21.7	25.1	1.25	1.01	18.4	29.0	9.8	10.1	-0.3
Spring small grain, spring small grain, row crop	9	0.155	0.119	23.1	17.2	1.94	1.29	33.1	18.8	12.5	10.8	1.7
Spring small grain, spring small grain, fallow	2[3]/3[3]	0.115	0.107	7.4	15.6[4]	1.33	1.15	12.7	20.4	10.6	10.6	0.0
Continuous kafir	2	0.115	0.092	20.1	28.5[4]	1.31	0.95	27.5	35.8[5]	11.4	10.3	1.1
Alternate kafir and fallow	2	0.107	0.081	24.3	35.4[4]	1.18	0.83	29.4	42.5[5]	11.0	10.2	0.8
Virgin sod	1	0.182	0.179	1.6		2.00	2.15	-7.5		11.0	12.0	-1.0

1. See footnote 1, table 3.
2. See footnote 2, table 3.
3. Two plots for nitrogen, three plots for carbon. One 1916 nitrogen analysis missing.
4. From regression lines assuming linear regression.
5. Adjustments were made on basis of regression lines for other cropping systems.

TABLE 5. NITROGEN AND ORGANIC CARBON CHANGES IN DRY-LAND SOILS AT GARDEN CITY, KANSAS, AS INFLUENCED BY CROPPING SYSTEMS.

Cropping system	Number of plots	Average nitrogen 1916	Average nitrogen 1938	Average percentage loss 1916-1938		Average organic carbon 1916	Average organic carbon 1938	Average percentage loss 1916-1938		Carbon-nitrogen 1916	Carbon-nitrogen 1938	Decrease
		percent	percent	actual	adjusted[3]	percent	percent	actual	adjusted[3]	ratio	ratio	
Continuous small grain[1]	6	0.101	0.091	9.5	7.9	1.21	0.85	28.5	23.6	12.0	9.3	2.7
Alternate wheat and fallow	12	0.092	0.083	9.1	12.4	1.00	0.79	20.3	24.0	10.9	9.5	1.4
Kafir, fallow, wheat, wheat, rye (green manure); Kafir, fallow, wheat, rye (green manure), wheat	10	0.104	0.091	11.9	9.0	1.14	0.73	35.0	32.9	11.0	8.0	3.0
Kafir, milo sudan	3	0.110	0.090	16.9	10.5	1.12	0.94	15.7	14.3	10.2	10.4	-0.2
Kafir, fallow, wheat, wheat	4	0.099	0.087	11.5	11.2	1.14	0.72	36.5	34.5	11.5	8.3	3.2
Kafir, fallow, wheat	3	0.096	0.084	12.3	13.4	1.11	0.75	31.9	31.0	11.6	8.9	2.7
Kafir, cowpeas (rows), sudan (close drilled)	3	0.091	0.081	11.6	15.1	0.99	0.82	16.7	20.8	10.9	10.1	0.8
Continuous row crop[2]	17	0.097	0.071	24.4	24.9	1.08	0.67	32.8	33.4	11.1	9.4	1.7
Alternate corn and fallow	2	0.083	0.067	19.3	27.6[3]	0.90	0.71	18.5	26.8[4]	10.8	10.6	0.2

1. See footnote 1, table 3.
2. See footnote 2, table 3.
3. From regression lines assuming linear regression.
4. Adjustments were made on basis of regression lines for other cropping systems.

respective levels in the soil in 1916 as well as with the cropping systems used, significance of the differences reported for the various cropping systems was tested by analysis of covariance. A summary of the statistical work is shown in Table 7. The results indicated that the cropping system had a highly significant effect on both the carbon and nitrogen content in every instance except for carbon at Garden City where the analysis showed only a significant relationship.

TABLE 6. THE RELATIONSHIP OF THE NITROGEN CONTENT OF THE PLOTS IN 1916 TO THE PERCENTAGE LOSS FROM 1916-1938.

Cropping system	Station	Number of plots	Average nitrogen 1916	Average percentage decrease in nitrogen 1916-1938	Correlation coefficient	Regression coefficient
			percent			
Alternate small grain and fallow	Hays	11	0.142	12.7	0.671[1]	1.85
Continuous row crop	Hays	10	0.149	25.7	0.507	2.13
Kafir, fallow, wheat	Hays	18	0.161	29.5	0.705[2]	1.86
Rotations with green manures	Hays	24	0.159	12.3	0.640[2]	3.16
Small grain, small grain, row crop	Hays	9	0.149	13.0	0.665[1]	3.32
Alternate small grain and fallow	Colby	18	0.147	20.4	0.851[2]	3.15
Milo, fallow, wheat	Colby	9	0.128	21.7	0.730[1]	4.43
Rotations with green manures	Colby	16	0.128	22.0	0.841[2]	4.87
Alternate small grain and fallow	Garden City	12	0.092	9.1	0.215	3.03
Continuous row crop	Garden City	17	0.097	24.4	0.675[2]	3.59

1. Significant.
2. Highly significant.

Since those plots with a high original nitrogen or carbon level would have shown the greatest percentage loss of either element, even with identical cropping systems, an attempt was made to eliminate this factor for purposes of interpretation of the data by adjusting the nitrogen and carbon changes on the basis of all plots having had the same original contents. Such estimates were made from the regression lines assuming linear regression. While, in the limit, the regression would not be linear, it appears that for the period of years covered by the study that a straight line depicts reasonably well the regression found.

It is believed that the adjusted values are definitely superior to the unadjusted original data when the effects of different cropping systems are to be compared because of the variable nature of 1916 carbon and nitrogen levels under the several groups.

The correlation coefficient for the relationship of the original nitrogen content to the percentage loss was a positive value for every cropping system at all stations although it was not always statistically significant. Thus the new adjusted values should in every instance be an improvement over the unadjusted values for making comparisons between cropping systems. The data for some cropping systems would be improved more than for others depending upon the relative significance of its correlation coefficient and the closeness of agreement between the regression coefficient for the individual cropping system and

TABLE 7. ANALYSIS OF COVARIANCE OF DATA SUMMARIZED IN TABLES 3, 4, and 5.[1]

Source of variation	D/F	Sum of squares	Mean squares	F	P
		Hays—nitrogen			
Total	117	7771.9			
Within cropping system	106	1751.2	16.52		
Between cropping systems	11	6020.7	547.33	33.13	0.001[2]
		Hays—carbon			
Total	117	6457.5			
Within cropping system	106	3310.3	31.23		
Between cropping systems	11	3147.2	286.11	9.16	0.001[2]
		Colby—nitrogen			
Total	62	2222.2			
Within cropping system	55	1134.0	20.61		
Between cropping systems	7	1088.2	155.41	7.54	0.001[2]
		Colby—carbon			
Total	65	5909.0			
Within cropping system	57	2155.9	37.82		
Between cropping systems	8	3753.1	469.14	12.40	0.001[2]
		Garden City—nitrogen			
Total	56	3670.4			
Within cropping system	49	1181.3	24.11		
Between cropping systems	7	2489.1	355.58	14.74	0.001[2]
		Garden City—carbon			
Total	56	3881.7			
Within cropping system	49	2780.1	56.74		
Between cropping systems	7	1101.6	157.36	2.77	0.02

1. Only those treatments with three or more plots are included in the analysis.
2. Probability is less than 0.001.

the regression coefficient representing all the systems. Adjusted values will be referred to in the discussion unless otherwise indicated.

Adjusted values are also shown for those cropping systems for which only two plots are available even though these systems did not enter into the statistical analysis. These adjustments were made with the same regression figure and average 1916 nitrogen or carbon value as were the treatments included in the statistical study. Because of the large number of plots already included, the regression coefficient and average nitrogen and carbon values would have changed only slightly if all the data had been included.

Continuous small grain production has caused a relatively low loss of nitrogen and carbon at all three stations. Alternate small grain and summer fallow has resulted in somewhat greater loss of nitrogen and carbon than continuous small grain. The only exception to this was the carbon at Colby, where the loss under continuous small grain exceeded slightly the loss under alternate small grain and fallow. Even though the fallow has increased the loss over continuous small grain production it should be recognized that the difference was not great at any station and the loss from this system did not approach the more destructive cropping systems in this respect. That fallow when used with small grains was less destructive than most cropping systems and only slightly more so than continuous small grain, is a significant fact because of the important place that fallow should occupy under western Kansas conditions. Fallow is frequently regarded as a very destructive method of soil management. This belief is probably based on erosion measurements made at several points in the humid section of the United States, which results have shown the fallow to be the most erosive system studied. In such studies continuous fallow has usually been practiced, which is far from being a practical use of the system. Furthermore, the effect of continuous fallow is not comparable to the effect of a one-year fallow.

The continuous row crop, and the alternate row crop and fallow have been the most destructive cropping systems for both nitrogen and carbon of all the systems studied. In contrast to this the continuous small grain, and the alternate small grain and fallow have been the least destructive of those studied. The only exception to this has been the carbon results at Garden City. Like in the case of small grains, the row crop alternating with fallow has increased the loss of both elements over the continuous row crop.

The other cropping systems which include row crops, small grains and fallow tended to fall between the continuous small grains and the alternate row crop and fallow on the basis of nitrogen and carbon losses. One exception to this generalization was the green manure rotations at Hays which resulted in a loss almost identical with continuous small grain production. The same was true of the nitrogen result at Garden City. The effect was the same whether the green manure crop was rye or Canada field peas. The results from the green manure crops at Colby were distinctly different from those at Hays. At Colby the results indicated that the green manure crops had made no contribution to the nitrogen and carbon contents of the soil.

The cropping systems — spring small grain, spring small grain and row crop — resulted in low losses at both Hays and Colby as did also the cropping system spring small grain, spring small grain, and fallow at Colby. The presence of the row crop in the first rotation might have been expected to cause a greater loss on the basis of other results.

The small loss for the kafir, milo, Sudan cropping system at Garden City was unexpected. No satisfactory explanation can be suggested on the basis of present knowledge.

The nitrogen and carbon changed only slightly in virgin soil at Colby during the experimental period.

A marked decrease in the carbon-nitrogen ratio from 1916 to 1938 was evident for the majority of the cropping systems at all three stations. Why a few cropping systems should have shown an increase in the carbon-nitrogen ratio is not known definitely. Because of an apparent lack of a consistent trend in the carbon-nitrogen ratio changes, it may be that experimental error was an important factor contributing to the results. The nitrogen data at the two analysis periods appeared to follow a more consistent pattern of change than did the carbon data.

EFFECT OF MANURE AND STRAW ON THE NITROGEN AND CARBON BALANCE

The influence of the application of both manure and straw on the nitrogen and carbon changes is shown in Table 8. The results of the statistical study of the data are presented in Table 9. Again adjusted values were obtained using linear regression. At both Hays and Colby the treatment showed either a significant or highly significant relationship to the changes in both elements. There was a loss of both constituents with the highest rate of manure application. However, both manure and straw made a positive contribution to the soil's supply of nitrogen and carbon.

The estimated residual soil nitrogen that could be attributed to the manure and straw added during the period 1916-1938 is shown in Table 10. For this particular study adjusted nitrogen values were used.

The manure was assumed to carry 15 pounds of nitrogen per ton, and the straw was assumed to carry 10 pounds per ton. On the basis of this assumption the calculated nitrogen recovered from the manure is in fair agreement with results presented by Salter and Schollenberger (19) for Ohio experiments but appreciably higher than those reported by Metzger (15) for experimental plots at Manhattan, Kansas. The calculated recovery from the three-ton per acre application at Colby is decided lower than the others.

At neither Hays nor Colby has the manure or straw resulted in an increase in average yield of either wheat or sorghum.

The contribution of straw and manure nitrogen to the residual nitrogen content of the soil may be indicative of the activity of the Azotobacter which has been shown by Gainey (5) to be present in virtually all western Kansas soils. While its capacity to fix nitrogen under laboratory conditions has been fully established, the contribution of the organism to the nitro-

TABLE 8. NITROGEN AND ORGANIC MATTER CHANGES IN DRY-LAND SOILS AS INFLUENCED BY MANURE AND STRAW ADDED TO ROTATIONS.

Treatment	Number of plots	Average nitrogen 1916	Average nitrogen 1938	Average percentage loss 1916-1938		Average organic carbon 1916	Average organic carbon 1938	Average percentage loss 1916-1938		Carbon-nitrogen 1916	Carbon-nitrogen 1938	Decrease
		percent	percent	actual	adjusted[1]	percent	percent	actual	adjusted[1]	ratio	ratio	
Hays—Kafir, fallow wheat												
Manure—12 tons, once in 3 years	3	0.180	0.146	18.6	17.8	1.92	1.59	16.9	15.2	10.7	10.9	-0.2
Manure—9 tons, once in 3 years	3	0.177	0.137	22.8	22.3	1.91	1.49	21.7	20.3	10.8	10.9	-0.1
Manure—6 tons, once in 3 years	6	0.178	0.127	28.6	27.9	1.94	1.37	29.2	27.0	10.9	10.8	0.1
Manure—3 tons, once in 3 years	6	0.174	0.121	30.3	30.4	1.81	1.29	28.6	29.5	10.4	10.7	-0.3
Straw—2½ tons, once in 3 years	3	0.170	0.120	29.4	29.9	1.75	1.24	28.9	31.4	10.3	10.3	0.0
Untreated	9	0.170	0.115	32.3	32.7	1.81	1.24	31.1	32.1	10.6	10.8	-0.2
Colby—Milo, fallow, wheat												
Manure—12 tons, once in 3 years	3	0.139	0.119	14.2	7.6	1.37	1.23	9.6	5.2	9.9	10.3	-0.4
Manure—9 tons, once in 3 years	3	0.139	0.115	16.7	10.3	1.37	1.16	15.1	10.1	9.9	10.1	-0.2
Manure—6 tons, once in 3 years	6	0.124	0.108	12.7	14.9	1.30	1.06	16.7	16.3	10.5	9.8	0.7
Manure—3 tons, once in 3 years	6	0.125	0.101	18.7	20.7	1.31	1.01	22.7	20.5	10.5	10.0	0.5
Straw—3 tons, once in 3 years	3	0.120	0.103	13.5	18.5	1.25	1.02	17.7	20.0	10.4	9.9	0.5
Untreated	9	0.128	0.100	21.7	21.4	1.25	1.01	18.4	21.0	9.8	10.1	-0.3
Colby—Milo, fallow, wheat, fallow												
Manure—10 tons, once in 4 years	4	0.147	0.121	18.1		1.85	1.25	32.1		12.6	10.3	2.3
Untreated	4	0.138	0.105	23.5		1.56	1.12	27.5		11.3	10.7	0.6

1. From regression lines assuming linear regression.

gen supply under field conditions is, as yet, more or less hypothetical. Jensen (14) could find little evidence to support the idea that the Azotobacter contributed an appreciable amount of nitrogen to the soil of New South Wales, Australia. Theoretically, the addition of straw and manure to the soil should make conditions more favorable for the Azotobacter to fix nitrogen than where no treatment was added. Under laboratory conditions Greaves and Bracken (8) showed that straw resulted in an increased nitrogen content of dry-land soils over

TABLE 9. ANALYSIS OF COVARIANCE OF DATA SUMMARIZED IN TABLE 8.

Source of variation	D/F	Sum of squares	Mean squares	F	P
		Hays—nitrogen			
Total	28	751.9			
Within treatment	23	176.6	7.68		
Between treatments	5	575.3	115.07	14.99	0.001[2]
		Hays—carbon			
Total	28	1078.7			
Within treatment	23	301.0	13.08		
Between treatments	5	777.7	155.53	11.89	0.001[2]
		Colby[1]—nitrogen			
Total	28	837.5			
Within treatment	23	228.8	9.95		
Between treatments	5	608.7	121.76	12.24	0.001[2]
		Colby[1]—carbon			
Total	28	2255.6			
Within treatment	23	1278.4	55.58		
Between treatments	5	977.2	195.44	3.52	0.02

1. Analysis only for those treatments with milo, fallow, wheat rotation.
2. Probability is less than 0.001.

TABLE 10. RESIDUAL SOIL NITROGEN ATTRIBUTABLE TO THE MANURE AND STRAW TREATMENTS ON THE BASIS OF ADJUSTED VALUES.

Treatment	Nitrogen lost (adjusted values) 1916-1938	Residual nitrogen resulting from treatment	Estimated nitrogen addition by treatment	Apparent recovery of nitrogen in soil (adjusted value)
	lbs./A.[1]	lbs./A.[1]	lbs./A.[1]	percent
Hays—Average nitrogen 1916 was 3140 lbs./A.[1]				
Manure, 12 tons once in 3 years	559	468	1320	35.5
Manure, 9 tons once in 3 years	700	327	990	33.0
Manure, 6 tons once in 3 years	898	129	660	19.5
Manure, 3 tons once in 3 years	951	76	330	23.0
Straw, 3 tons once in 3 years	939	88	220	40.0
Untreated	1027			
Colby—Average nitrogen 1916 was 2560 lbs./A.[1]				
Manure, 12 tons once in 3 years	195	353	1320	26.7
Manure, 9 tons once in 3 years	264	284	990	28.7
Manure, 6 tons once in 3 years	381	167	660	25.3
Manure, 3 tons once in 3 years	530	18	330	5.5
Straw, 3 tons once in 3 years	474	74	220	33.6
Untreated	548			

1. On the basis of 2,000,000 pounds of soil.

that added in the material itself. Likewise, Vandecaveye and Villanueva (25) showed increased nitrogen accretion in previously manured dry-land soils in contrast to the unmanured soils when they were studied under laboratory conditions. At both Hays and Colby, since not even all the straw and manure nitrogen could be accounted for, it is unnecessary to assign to the organism any nitrogen-fixing ability in order to explain adequately the results obtained. Therefore, it appears that at the level of fertility that existed in the experimental plots during the period 1916 to 1937, the Azotobacter has made no measurable contribution to the soil-nitrogen supply in the plots under consideration. As a result of his studies Jensen (14) concluded, ". . . . . it is obvious that the straw residues of wheat and oats crops do not represent a very valuable form of energy material for nitrogen fixation under the conditions normally existing in Australian wheat soils."

EFFECT OF TIME AND METHOD OF TILLAGE ON SOIL NITROGEN AND CARBON

Both time and method of tillage for continuous small grain production seemed to have an effect on the nitrogen losses from the soil. Data in Table 11 were grouped in an effort to measure these effects. Because of the paucity of plots no attempt was made to test statistically the significance of the data. The adjusted values were summarized from the calculations made to obtain the adjusted data presented in Tables 3 and 4. The comparison between spring and fall plowings at both Hays and Colby suggested that fall plowing was distinctly more destructive of nitrogen than spring plowing. Several factors have probably contributed to the difference. First, the accumulation of dust on the spring-plowed plots, due to the presence of stubble during the blow season, has been a factor. At the Colby station this has been a factor of considerable magnitude as indicated by the elevated surface on the spring-plowed plots. The dust accumulation at Hays has been so small that the effect cannot be noticed. Thus the dust deposit might make a logical explanation for the Colby results but would be inadequate to explain the Hays results. A second item that may have influenced the results was the difference in yield that has occurred at both stations. Fall plowing for spring small grains has produced an increase in average yield over spring plowing. Also the delay in the incorporation of the stubble into the soil, which would tend to preserve it for a longer period and thus contribute to a higher organic-matter supply in the soil probably has had its effect on the results.

Fall listing has proved to be appreciably less destructive of soil nitrogen than either fall plowing or fall plowing and subsoiling. The lister leaves the stubble only partly incorporated. This would tend to retard the rate of decomposition of the

TABLE 11. EFFECT OF TIME AND METHOD OF TILLAGE ON THE NITROGEN BALANCE IN THE SOIL UNDER CONTINUOUS SMALL GRAIN PRODUCTION.

Plot		Number of plots	Station	Crop	Average nitrogen 1916	Percentage loss 1916-1938		Av. annual yield all crops 1916-1938
					percent	actual	adjusted[1]	lbs./A.
A	Spring plow	2	Hays	oats and spring barley	0.161	5.6	4.9	693
B	Fall plow	2	Hays	oats and spring barley	0.134	10.4	15.7	887
A	Spring plow	3	Colby	oats, spring barley and spring wheat	0.126	6.3	9.5	476.2
B	Fall plow	3	Colby	oats, spring barley and spring wheat	0.129	16.3	21.5	507.4
B	Fall plow	3	Hays	oats, spring barley and winter wheat	0.141	11.3	14.7	909
E	Fall plow and subsoil	3	Hays	oats, spring barley and winter wheat	0.131	11.5	16.9	963
F	Fall list	3	Hays	oats, spring barley and winter wheat	0.157	8.9	8.7	873
A	Late summer plow	1	Garden City	winter wheat	0.113	11.5	3.5	222
B	Early summer plow	1	Garden City	winter wheat	0.107	14.0	9.2	328
A	Late summer plow	1	Hays	winter wheat	0.170	7.1	4.3	576
B	Early summer plow	1	Hays	winter wheat	0.155	12.3	12.7	954
A	Late summer plow	1	Colby	winter wheat	0.166	18.1	8.1	527.2
B	Early summer plow	1	Colby	winter wheat	0.152	18.4	13.4	444.5

1. From regression lines assuming linear regression.

stubble. The results are in general agreement with data presented by Albrecht (1). He showed that clover applied to the surface resulted in a higher total nitrogen content in the soil after a period of years than did the same amount of material incorporated regularly when applied. A more complete decay of the incorporated material in comparison to that left on the surface was the suggested explanation for the results.

The effect of early- and late-fall plowing for winter wheat is similar at all stations in that the late plowing has resulted in a lower loss of both nitrogen and carbon from the soil. The late plowing might tend to preserve the crop residue more effectively due to the stubble's remaining undecomposed for a longer period. The higher yield on the early-plowed plot may have accelerated the loss of nitrogen at the Hays and Garden City stations which would be in agreement with the observations made by Sewell and Gainey (21) who showed that in continuous wheat production those systems which produced the highest yield were the ones that showed the greatest loss of soil nitrogen and *vice versa.*This cannot be the correct explanation at Colby because the late plowed plot has slightly outyielded the early-plowed plot.

EFFECT OF TYPE OF SMALL GRAIN ON NITROGEN LOSS

In order to determine the relative effect of the different types of small grain on the nitrogen loss from the soil, comparable plots for the different small grains were grouped. For each crop at Hays the plots consisted of A, B, C, D, E, and F (see appendix for treatments). At Colby, plots A, B, C, and D were used for each small grain. The results are shown in Table 12. The adjusted values indicate that the several small grains had essentially the same effect on the soil nitrogen.

TABLE 12. EFFECT OF TYPE OF SMALL GRAIN CROP ON THE NITROGEN BALANCE IN THE SOIL AT HAYS AND COLBY, KANSAS.

Crops	Station	Number of plots	Average nitrogen 1916	Percentage loss 1916-1938		Av. yield all crops 1916-1937
			percent	actual	adjusted[1]	lbs./A.
Oats	Hays	6	0.131	6.1	11.7	701
Spring barley	Hays	6	0.140	10.7	14.3	824
Winter wheat	Hays	6	0.155	11.6	11.9	860
Spring wheat	Colby	4	0.114	7.9	16.3	268.9
Oats	Colby	4	0.119	10.1	17.1	424.2
Spring barley	Colby	4	0.129	14.0	17.3	701.2
Winter wheat	Colby	4	0.156	25.0	14.9	480.3

1. From regression lines assuming linear regression.

RELATION OF SOIL-NITROGEN LOSS TO CROP REMOVAL

There is not a complete record of the nitrogen content of the harvested crops for any of the plots at the three stations. For the period 1929 to 1938, inclusive, except for the years 1935 and 1937, nitrogen data for the grain are available for several winter wheat plots at Hays. Assuming that the nitrogen content of the grain for the period 1916 to 1937 was the same as for the shorter period, the nitrogen removal by the grain crop was calculated for several selected plots at Hays. The results of the calculation are shown in Table 13.

TABLE 13. RELATION OF SOIL NITROGEN LOSSES TO THE REMOVAL OF NITROGEN BY THE WHEAT CROP AT HAYS, KANSAS.

Plot	Period 1916 to 1937, inclusive				
	Total yield wheat grain		Estimated nitrogen removed by crop[1]	Nitrogen decrease in soils[2]	Difference
	bu.	lbs.	lbs.	lbs.	lbs.
A	212	12720	329	240	89
B	350	21000	508	380	128
E	395	23700	600	560	40
F	382	22920	589	340	249
C	380	22800	620	220	400
D	194	11640	317	360	—43
		Average	494	350	144

1. On basis of nitrogen content of grain, 1929 to 1938, inclusive, except 1935 and 1937, A = 2.59 percent, B = 2.42 percent, E = 2.53 percent, F = 2.57 percent, and C and D = 2.72 percent.
2. On basis of 2,000,000 pounds.

The calculated crop removal accounted for a greater amount of nitrogen than was actually lost from the surface 7 inches of the soil for five of the six plots considered. An average of all six plots showed that 144 pounds per acre more was calculated to have been removed by the crop than was lost from the soil over the 22-year period. The wheat was cut with a binder with only the stubble returned during the period 1916-1927. It was estimated that about 80 pounds per acre of nitrogen was removed in the straw during this period. This would make a net gain of about 224 pounds per acre in 22 years or about 10 pounds per acre annually. The 10 pounds per acre would be the joint contribution of the seed wheat (3 pecks per acre), the rainfall, Azotobacter, and nitrates produced in the soil below a depth of 7 inches (and possibly other factors). Since Heller (9) has shown that Woodward, Okla., might receive about 3 pounds of nitrogen per acre annually in the rainfall and since the 3 pecks of wheat would contribute about 1 pound of nitrogen, there remains a net contribution of about 6 pounds of nitrogen per acre annually that can be assigned to the Azotobacter, the nitrates produced in the soil below a depth of 7 inches and all other sources of combined nitrogen. Since the soils at all three stations below a depth of 7 inches are supplied fairly well with organic matter it is to be expected that a considerable amount of nitrate nitrogen would be contributed by the subsurface soil. Thus the amount that it would be necessary to assign to fixation by Azotobacter or other nitrogen-fixing organisms would be less than that indicated above.

It is not possible to estimate the loss of nitrogen due to erosion, leaching and volatilization. The loss by erosion probably was not great, because of the nearly-level nature of the surface on which the plots shown in Table 13 are located. Some loss of nitrate nitrogen from the surface 7 inches by leaching would be expected since water was stored in the subsoil. Whether all the nitrate nitrogen carried from the surface gets back to the surface as a result of crop utilization cannot be answered on the basis of available data. It is known, however, that stored water is utilized completely by the growing crop except for a few seasons when summer fallow permits storage beyond the normal zone of root penetration. While the present study deals only with the surface 7 inches of soil, some data obtained at Garden City[6] for some of the plots used in the present study suggests that the loss of nitrogen from the surface soil may be in part compensated by a gain in nitrogen in the subsoil.

The loss by volatilization or leaching may be of considerable importance especially when the soil was only recently broken from the sod. The importance of this is suggested by the data presented in Table 14.

TABLE 14. NITROGEN CHANGES IN DRY-LAND SOILS AT GARDEN CITY, KANSAS, FOLLOWING THE BREAKING OF THE SOD.

Cropping system	Number of plots	Average 1931	Nitrogen 1938	Average loss 1931-1938	
		percent	percent	percent	lbs./A.
Continuous winter wheat	7	0.135	0.114	15.2	410
Fallow, winter wheat	2	0.146	0.123	15.8	461
Fallow, winter wheat, winter wheat	3	0.142	0.118	16.7	474
Fallow, winter wheat, winter wheat, winter wheat	4	0.135	0.112	17.0	459

The first samples were taken within a year after the sod was broken. During the period 1931 to 1938 one of the most severe prolonged droughts on record occurred. During the period only one good wheat crop was produced on the experimental area. That year the wheat yields ranged from 25 to 35 bushels per acre. In one other year the yields were about 5 bushels per acre. The crop was a complete failure in all other seasons. If it were assumed that the wheat crops removed about 50 pounds of nitrogen, a deficit of approximately 400 pounds per acre still remained to be explained. Some of this could have been leached below the surface 7-inch zone even though drought conditions prevailed during most of the period under consideration.

TREND OF NITROGEN

Gainey, *et al.* (6) and Sewell and Gainey (20) determined the nitrogen and carbon on a few of the plots at Hays, Colby, and Garden City in 1927 and 1928. By using only these plots and

6. Unpublished data, A. E. Lowe and H. J. Haas.

the nitrogen content at each period including that of the virgin sod at each station, it was possible to show graphically the general trend of nitrogen and carbon under cultivation. The nitrogen trend is shown in Figure 3.

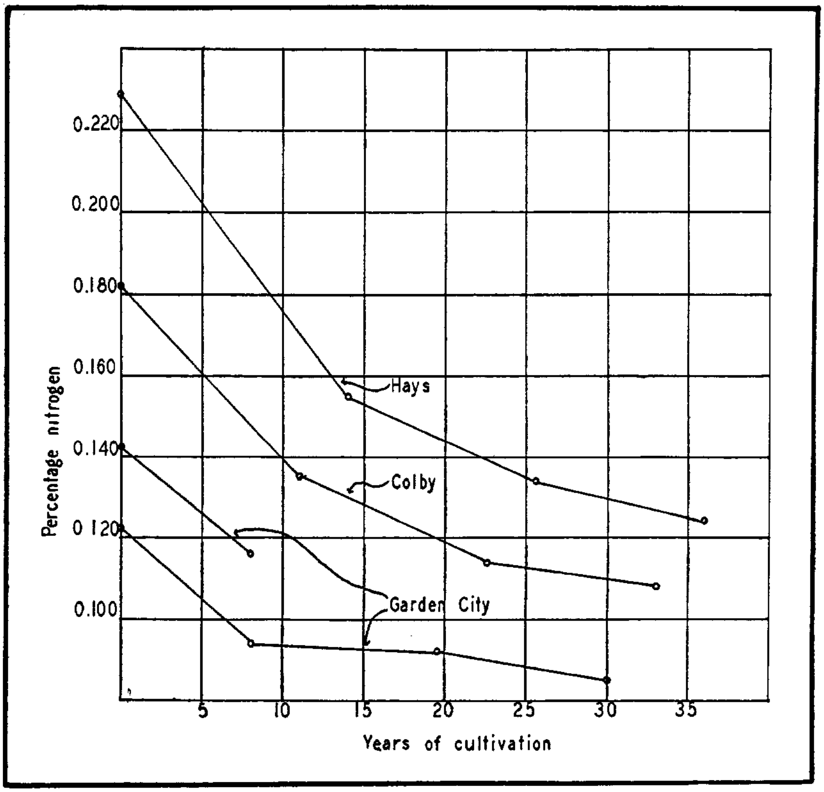

Fig. 3. Soil nitrogen equilibrium curves for Hays, Colby and Garden City.

The nitrogen content of the virgin sod was considered to be the same as that of an unbroken area near the experimental block, except for the Garden City annex data for which complete data are available for each plot.

While it is evident that the nitrogen content of the soils was approaching a state of equilibrium by 1938 the general trend continued downward. Also it is evident that the highest equilibrium value probably will be at Hays followed by Colby and Garden City, which is in the same order as the station's ranking with respect to the nitrogen contents of the virgin sod. The tendency of the soil nitrogen to approach a state of equilibrium is in agreement with the well-established principle as discussed by Jenny (13). It was thought that there were sufficient plots represented at both Hays and Colby to justify grouping them according to cropping system and treatment in order to study the trend of the nitrogen content under different systems. The average data are presented graphically in Figures 4 and 5.

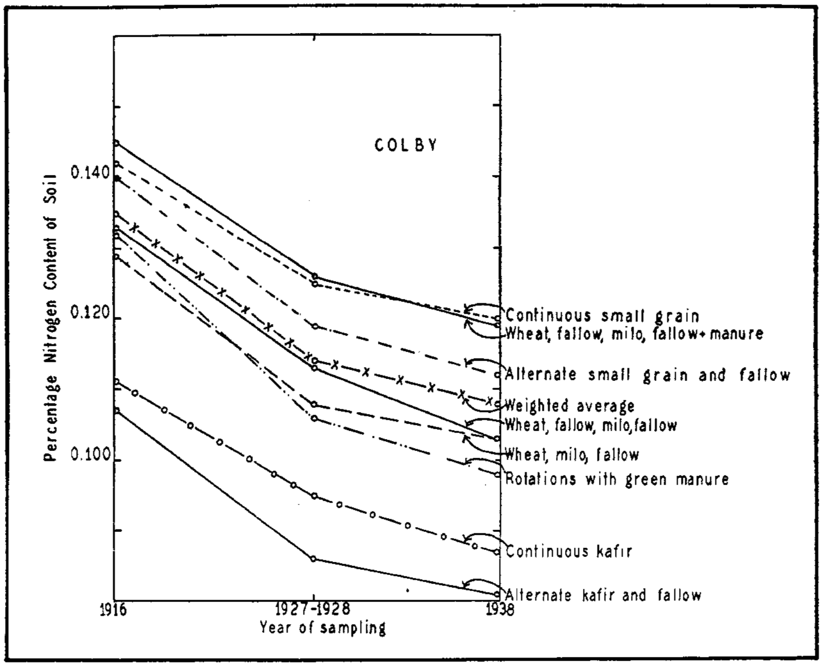

Fig. 4. Soil nitrogen equilibrium curves as influenced by cropping systems at Hays.

The different cropping systems present contrasting features at Hays (Fig. 4). Some systems such as continuous small grain and alternate small grain and fallow have tended to approach the equilibrium state more quickly and at a relatively higher nitrogen level than systems that include row crops. The influence of the cropping systems on the approach to a state of equilibrium with respect to nitrogen is not so distinct at the Colby station (Fig. 5).

The generalization made by Gainey, *et al.* (6) that the cultivated soils of western Kansas might come to equilibrium with respect to nitrogen at about 0.1 percent does not appear to be a complete picture on the basis of the evidence presented in Figures 3 and 4. The indications are that the final level will be dependent upon the region involved, the cropping system used, and the soil treatment applied.

The tendency for the soils to approach an equilibrium with respect to nitrogen suggests that nitrogen accretion, perhaps by Azotobacter, is an important factor. However, as suggested by Jensen (14), it still remains to be proved whether the approaching equilibrium is a result of nitrogen accretion more nearly balancing nitrogen losses or whether it is principally a

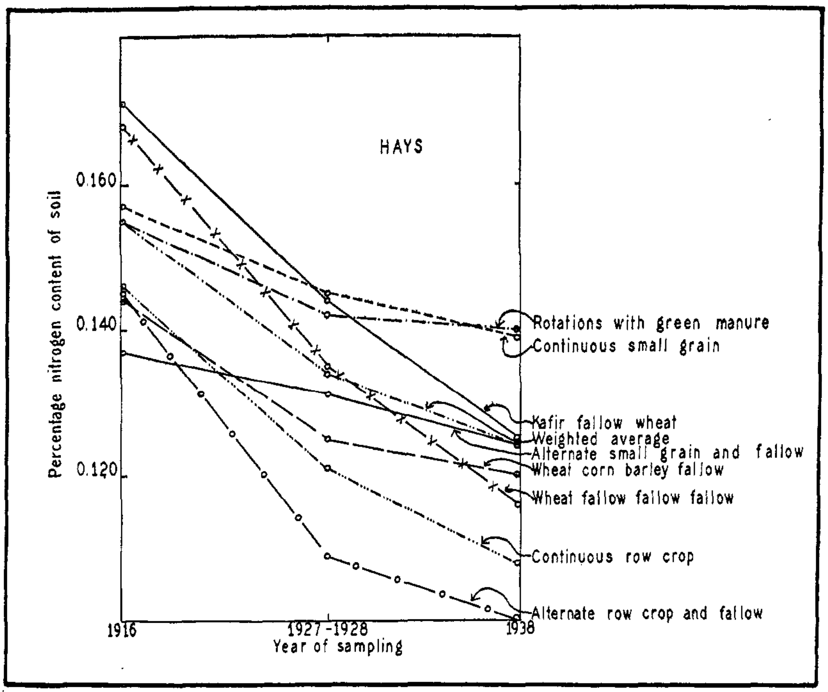

Fig. 5. Soil nitrogen equilibrium curves as influenced by cropping systems at Colby.

result of the nitrogen loss becoming less. Up to 1938, it appears to have been a case of a lower magnitude of loss due to a declining nitrogen supply in the soil.

DISCUSSION

The nitrogen and carbon losses reported for the experimental plots at the three dry-land stations probably represent conservative estimates when applied to all the cultivated fields in the area. Erosion has not been so great a factor on the plots as it has been on many farms. Therefore, it is believed that many individual areas in western Kansas would have shown even greater losses of organic matter than are herein recorded. On the stations the use of manure and nitrogenous fertilizers has not consistently shown increases in yields. The only exception has been the use of manure in an alternate milo and fallow cropping system at Garden City. There, the manure has resulted in an increased yield. On the basis of the nitrogen changes reported for similar untreated cropping systems at Garden City it appears evident that the nitrogen on the untreated plots with the alternate milo and fallow cropping system has reached a low level perhaps exceeding the critical value for milo production.

That the trend in nitrogen at all stations continued downward throughout the period of the experiment is probably a significant point. The indication is that the nitrogen level is approaching a state of equilibrium differing for each cropping system and for each station. If an equilibrium between nitrogen accretion and nitrogen loss is attained, an important question that will remain unanswered, until that period arrives, is whether the nitrogen level will be high enough to permit satisfactory production without fertilization. A study of the trend in crop yields on the various experimental plots might be expected to suggest an answer. Unfortunately, crop yields fluctuate so greatly due to weather conditions that it appears to be impossible over the period for which records are available to obtain a satisfactory picture of the trend due to soil conditions. However, there is little indication of a declining yield-level at any station. High yields of all crops are still obtained when the moisture supply is adequate. It is also true on western Kansas farms except those areas that have been badly eroded. Whether the good yields could be sustained in several consecutive seasons with favorable weather cannot be answered. The depressed nitrogen supply is probably of less importance than under humid conditions or than it would be in a sustained period of above-average rainfall in a dry-land area due to the beneficial effect of drought on the increased availability of soil nitrogen and the recurring nature of droughts in western Kansas. At present it can only be hoped that the equilibrium point between climate, cropping system, and nitrogen will be at such a level as to permit continued satisfactory crop production. That this hope may not be entirely unreasonable is suggested by the observations made by Moyer (16) in the semi-arid province of Shansi, China, where soils that have been cultivated for 40 centuries are still fertile. Also for the most part the addition of fertilizers to these soils has brought about only moderate increases in yields.

The declining level of organic matter is of importance not only because of its effect on the chemical aspects of the soil as related to plant nutrition but also because of its relation to physical features of the soil, especially its relationship to the infiltration of water. Water has been the fundamental, overall limiting factor in crop production in dry-land areas of the Great Plains. The declining organic matter content of the soil resulting in greater density, less non-capillary pore space, more easily dispersed and smaller aggregates, resulting in the formation of a less penetrable crust during rains, would reduce appreciably the rate of water infiltration and consequently the efficiency of rainfall. Fortunately, mechanical manipulations of the soil can offset to some extent this adverse feature. The greater power requirements for tillage on soils of lower organic matter content is also a factor of some importance. While no studies have been made of this item on western Kansas soils, some of the more observant older farmers have noted the increase in power needed to pull tillage implements on their own farms during their period of active operation. Closely related to the increasing tendency of crust formation is the difficulty encountered with the emergence of seedlings through the crust, consequently adding to the difficulties of obtaining satisfactory stands of crops.

Contrary to popular belief there seems to be little justification for the idea that a decreasing organic matter content of the soil increases the severity of soil blowing. On the Garden City station an area that had been broken from the sod about three years and in which the coarse root material had been decomposed was the only area on the station that caused any trouble from wind erosion in the spring of 1938. Listing the area to control the blowing was only partly effective, because it was not possible to throw up hard, more or less resistant clods. The surface soil was highly granular due to the relatively high organic matter content. On other parts of the station the soil had been in cultivation for a longer period. There the organic matter had been reduced to a considerably lower level, the soil was not so granular and it was possible, due to the less granular condition to bring resistant clods to the surface which protected the soil from blowing. Many other similar observations have been made in western Kansas. Likewise, Hopkins, *et al.* (12) have observed that the non-fibrous organic matter of the soil tended to facilitate drifting. The coarse, fibrous organic material does reduce the wind erosion hazard, and every effort should be made to maintain as much of this in the soil as possible.

The marked increases in yields obtained from the use of nitrogen fertilizers in the Palouse district of Washington (10) and the favorable response noted in certain parts of the dry-land cereal-producing belt of Australia (17) have suggested that nitrogen is a major limiting factor in crop production in those areas. The evidence from both regions suggested that the benefit from the summer fallow was due in large part to the accumulation of nitrate nitrogen. Results in these areas have prompted the generalization that such conditions might also be found in the Great Plains. Such a generalization ignores the fundamental difference in climate and soil that exists in the two major wheat-producing areas. In both Australia and Palouse wheat areas the rainfall is of the winter type. In the Great Plains the summer type of rainfall occurs. In the latter area summer rains' wetting the soil permits nitrate nitrogen to accumulate for several months prior to wheat seeding. If summer rains do not occur, thus permitting no accumulation of nitrate nitrogen, the chances for sufficient rains during the winter to permit a satisfactory wheat crop are negligible. In both Australia and the Palouse region the rains frequently start about seeding time with no previous period for nitrate accumulation. Therefore, in a continuous system of wheat culture under winter type of rainfall the crop is primarily dependent upon the nitrates formed during the period when the wheat occupies the soil, which includes a period when nitrate production would be retarded or stopped due to low temperatures.

Sievers and Holtz (22) showed that wheat-yield variations in the Palouse areas could not be interpreted satisfactorily on the basis of soil-moisture content at seeding time but were more closely related to the nitrate nitrogen supply in the soil. Hallsted[7] has shown that a high correlation coefficient existed between yield of wheat and available moisture at winter wheat-seeding time at Hays, Kansas. A correlation coefficient of virtually the same magnitude was found for the relationship of wheat yield to the nitrate nitrogen content at seeding time. By relating moisture at seeding time with nitrate nitrogen at seeding time a correlation coefficient about equal to the other two was found. These results suggest that when moisture was available at seeding time, nitrates were also present in nearly proportional amounts. It is also important to keep in mind that the favorable response from nitrogen fertilizers in the winter type rainfall areas has been reported for regions where the rainfall is high enough to produce yields of a rather high order.

There are indications from the studies of Gainey, *et. al.* (7) that a deficiency of nitrogen may be limiting wheat production in western Kansas. Extensive experiments with calcium cyanamide for the harvest seasons 1930 and 1931 showed an average increase in yield from fertilization for all of western Kansas in both seasons. While the increases were not exceptionally large, the fact that they did exist suggested that the nitrogen was a partial limiting factor in the two seasons, both of which were favorable. All but two of the tests were on non-summer fallowed fields. It is doubtful that wheat on fallow would have shown an average increase from nitrogen fertilizer owing to the accumulation of nitrate nitrogen in fallowed soils. The actual average increase in yield from nitrogen fertilizer for the two above average crop seasons in western Kansas was much less than the 13-year average increase from sodium nitrate on continuous wheat reported for the Palouse district of Washington by Holtz and Vandecaveye (10).

7. Unpublished data.

From a practical standpoint the question of the use of nitrogen fertilizers in western Kansas presents a number of important problems. First, there are frequent crop failures and years of relatively low yields when favorable response to fertilizers would not be expected. Thus there would be less certainty of obtaining a satisfactory increase in yield from a fertilizer application than there would be in the more humid sections. The more observant farmers could overcome this hazard to a considerable extent by knowing before making the application, the moisture condition of their soil and approximating the crop producing capacity for the season. However, such crop indications have been found to be more reliable in predicting failures than in estimating yield levels.

A second practical consideration concerning the use of nitrogenous fertilizers pertains to the use of the summer fallow. Summer fallow, due to the accumulation of nitrate nitrogen, will reduce the need for nitrogenous fertilizers. In both Australia and Washington (9, 16) nitrogenous fertilizer on fallowed soil has resulted in no increase in yields of wheat.

The fallow should be more extensively utilized in western Kansas. This would increase the agricultural stability in the area. Since alternate small grain and fallow is only slightly more destructive of soil organic matter than continuous small grain production, its greater use would delay the possible future need for commercial nitrogen due to the favorable effect of fallow on nitrate-nitrogen accumulation.

Since among the practical systems studied the small grains, and alternate small grain and fallow systems are the least destructive of organic matter and since these cropping systems are apparently approaching an equilibrium state with respect to nitrogen at a higher level of fertility than are the systems including row crops, a question might be raised as to whether the small grains and row crops should be grown on the same land or whether it might not be more desirable to grow each on its own area. The growing of row crops on wheat land may advance the time when a need for nitrogen fertilizer may exist for wheat. Again the question cannot be answered definitely. If a higher organic matter content is more favorable for wheat than it is for sorghum production, it would appear that the row crops should be kept off the wheat land. However, the practice of confining row crops to separate fields would hasten the loss of soil nitrogen in those fields.

Crop rotations including row crops have their greatest effect on yield at Hays. Sorghum yields have been more stimulated as a result of crop rotation than those of any other crop at all stations. Wheat yields have been consistently increased at Hays by rotations including row crops and small grains, but at both Colby and Garden City continuous wheat has outyielded wheat grown in a rotation. This may be associated with a higher nitrogen level at Hays in contrast to that at Colby and Garden City. Thus it may be at Hays that in spite of the lower nitrogen supply in the soil as a result of the growth of row crops that the nitrogen level is still above the critical point for wheat production as well as for row crop production.

At both Garden City and Colby the nitrogen level is lower than at Hays. There the inclusion of a row crop in the rotation may have been sufficient to reduce the nitrogen level below the critical point for wheat production but left it high enough to favor sorghum production over the continuous growth of this crop.

Manure made a positive contribution to the nitrogen and carbon content of the soil. It, therefore, is a conservation practice, applicable to dry-land soils. However, crop yields have not been favorably affected by manure at either of the two stations for which soil nitrogen and carbon data are given. Increased yields resulting from the application of manure have been obtained under certain conditions. Perhaps its advantage will become more evident in the future.

APPENDIX

TABLE 15. NITROGEN AND CARBON CHANGES IN DRY-LAND SOILS BY PLOT.

Rotation identification	Cropping system	Plot	Nitrogen content 1916	Nitrogen content 1927 or 1928	Nitrogen content 1938	Percentage decrease 1916-1938	Carbon content 1916	Carbon content 1927 or 1928	Carbon content 1938	Percentage decrease 1916-1938
			percent	percent	percent		percent	percent	percent	
	HAYS									
	Continuous small grain									
M.C.	Winter wheat, late plow	A	0.170	0.161	0.158	7.1	2.01		1.79	10.9
M.C.	Winter wheat, early plow	B	0.155	0.149	0.136	12.3	1.74	1.47	1.39	20.1
591	Winter wheat, stubbled in	A	0.168	0.150	0.155	7.7	1.85		1.65	10.8
M.C.	Winter wheat, early plow, annually, and subsoiled 2 years, skip 2	E	0.152	0.135	0.124	18.4	1.72		1.34	22.1
M.C.	Winter wheat, early list	F	0.161	(0.152 (0.139	0.144	10.6	1.78		1.52	14.6
606	Winter wheat, early plow annually	A	0.167		0.127	24.0	1.95		1.40	28.2
606	Winter wheat, early plow biennially, disk 1 year	B	0.167		0.131	21.6	1.94		1.50	22.7
606	Winter wheat, early plow 1 year, disk 2 years	C	0.172		0.135	21.5	1.91		1.50	21.5
606	Winter wheat, early plow 1 year, disk 3 years	D	0.169		0.141	16.6	1.91		1.62	15.2
606	Winter wheat, early plow 1 year, disk 4 years	E	0.169		0.139	17.8	1.95		1.48	24.1
606	Winter wheat, early plow as seemed necessary	F	0.166		0.141	15.1	1.89		1.56	17.5
M.C.	Spring barley, spring plow	A	0.167		0.152	9.0	2.11		1.66	21.3
M.C.	Spring barley, fall plow	B	0.132	0.131	0.115	12.9	1.80		1.15	36.1
M.C.	Spring barley, fall plow annually, and subsoiled 2 years, skip 2	E	0.131		0.118	9.9	1.66		1.13	31.9
M.C.	Spring barley, fall list	F	0.167		0.141	15.6	1.98		1.45	26.8
M.C.	Oats, spring plow	A	0.155		0.151	2.6	2.01		1.65	17.9
M.C.	Oats, fall plow	B	0.135		0.124	8.1	1.56		1.30	16.7
M.C.	Oats, fall plow annually, and subsoiled 2 years, skip 2	E	0.111		0.105	5.4	1.31		1.04	20.6
M.C.	Oats, fall list	F	0.144		0.144	0.0	1.66		1.52	8.4
	Average		**0.156**		**0.137**	**12.4**	**1.83**		**1.46**	**20.4**

TABLE 15 (continued)

Rotation identification	Cropping system	Plot	Nitrogen content 1916	Nitrogen content 1927 or 1928	Nitrogen content 1938	Percentage decrease 1916-1938	Carbon content 1916	Carbon content 1927 or 1928	Carbon content 1938	Percentage decrease 1916-1938
			percent	percent	percent		percent	percent	percent	
	Alternate small grain and fallow									
M.C.	Winter wheat, plow May 15	C	0.135	(0.136 (0.131	0.124	8.1	1.57	1.51	1.36	13.4
M.C.	Winter wheat, plow May 15	D	0.155	0.148	0.137	11.6	1.75	1.64	1.49	14.9
M.F.	Winter wheat, fall plow, replow in spring	I	0.149		0.116	22.1	1.72		1.31	23.8
M.F.	Winter wheat, fall plow	K	0.151		0.121	19.9	1.81		1.23	32.0
M.F.	Winter wheat, plow in May	M	0.155	0.136	0.136	12.3	1.87		1.32	29.4
M.F.	Winter wheat, plow in June	O	0.164		0.142	13.4	1.90		1.47	22.6
M.F.	Winter wheat, list in fall	Q	0.168		0.139	17.3	1.97		1.41	28.4
M.C.	Spring barley, plow May 15	C	0.113	0.111	0.107	5.3	1.41		1.07	24.1
M.C.	Spring barley, plow May 15	D	0.128	0.121	0.115	10.2	1.67		1.20	28.1
M.C.	Oats, plow May 15	C	0.113		0.106	6.2	1.15		1.13	1.7
M.C.	Oats, plow May 15	D	0.126		0.109	13.5	1.42		1.17	17.6
	Average		**0.142**		**0.123**	**12.7**	**1.66**		**1.29**	**21.5**
	Small grain, rye used as a green manure crop, small grain, row crop									
51	Spring barley, rye (green manure), winter wheat, corn	A	0.163		0.144	11.7	1.93		1.45	24.9
51	Spring barley, rye (green manure), winter wheat, corn	B	0.166		0.140	15.7	1.94		1.60	17.5
51	Spring barley, rye (green manure), winter wheat, corn	C	0.164		0.156	4.9	1.87		1.51	19.3
51	Spring barley, rye (green manure), winter wheat, corn	D	0.174		0.142	18.4	2.05		1.53	25.4
53	Winter wheat, rye (green manure), spring barley, corn	A	0.150	0.142	0.139	7.3	1.97		153	22.3
53	Winter wheat, rye (green manure), spring barley, corn	B	0.160		0.142	11.3	1.94		1.45	25.3
53	Winter wheat, rye (green manure), spring barley, corn	C	0.176		0.145	17.6	2.18		1.53	29.8
53	Winter wheat, rye (green manure), spring barley, corn	D	0.162	0.152	0.144	11.1	2.00		1.40	30.0
55	Spring barley, rye (green manure), winter wheat, kafir	A	0.173	0.151	0.144	16.8	2.06		1.54	25.2
55	Spring barley, rye (green manure), winter wheat, kafir	B	0.149		0.130	12.8	1.72		1.39	19.2

TABLE 15 (continued)

55	Spring barley, rye (green manure), winter wheat, kafir	C	0.147		0.132	10.2	1.77		1.42	19.8
55	Spring barley, rye (green manure), winter wheat, kafir	D	0.160		0.130	18.8	1.74		1.38	20.7
	Average		**0.162**		**0.141**	**13.1**	**1.93**		**1.48**	**23.3**
	Small grain, Canada field peas used as green manure crop, small grain, row crop									
54	Winter wheat, peas (green manure), spring barley, corn	A	0.143	0.133	0.137	4.2	1.59	1.19	1.31	17.6
54	Winter wheat, peas (green manure), spring barley, corn	B	0.158		0.138	12.7	1.71		1.40	18.1
54	Winter wheat, peas (green manure), spring barley, corn	C	0.166		0.138	16.9	1.84		1.38	25.0
54	Winter wheat, peas (green manure), spring barley, corn	D	0.143	0.134	0.131	8.4	1.59		1.32	17.0
56	Spring barley, peas (green manure), winter wheat, kafir	A	0.160	0.144	0.151	5.6	1.78		1.50	15.7
56	Spring barley, peas (green manure), winter wheat, kafir	B	0.161	0.134	0.140	13.0	1.79		1.43	20.1
56	Spring barley, peas (green manure), winter wheat, kafir	C	0.150		0.145	3.3	1.87		1.60	14.4
56	Spring barley, peas (green manure), winter wheat, kafir	D	0.150	0.146	0.135	10.0	1.89		1.26	33.3
92	Spring barley, peas (green manure), winter wheat, corn	A	0.172		0.138	19.8	1.91		1.42	25.7
92	Spring barley, peas (green manure), winter wheat, corn	B	0.163		0.138	15.3	1.80		1.35	25.0
92	Spring barley, peas (green manure), winter wheat, corn	C	0.165		0.143	13.3	1.82		1.45	20.3
92	Spring barley, peas (green manure), winter wheat, corn	D	0.148		0.125	15.5	1.63		1.28	21.5
	Average		**0.157**		**0.138**	**11.5**	**1.77**		**1.39**	**21.1**
	Spring small grain, spring small grain, row crop									
1	Spring wheat, oats, corn	A	0.160		0.127	20.6	1.72		1.36	20.9
1	Spring wheat, oats, corn	B	0.144		0.114	20.8	1.69		1.15	32.0
1	Spring wheat, oats, corn	C	0.125		0.119	4.8	1.33		1.13	15.0
9	Oats, spring wheat, corn	A	0.154		0.134	13.0	1.75		1.44	17.7
9	Oats, spring wheat, corn	B	0.144		0.133	7.6	1.58		1.35	14.6
9	Oats, spring wheat, corn	C	0.150		0.137	8.7	1.73		1.47	15.0
58	Oats, spring wheat, sorgo	A	0.171		0.142	17.0	1.86		1.51	18.8
58	Oats, spring wheat, sorgo	B	0.153		0.124	19.0	1.60		1.35	15.6
58	Oats, spring wheat, sorgo	C	0.138		0.131	5.1	1.63		1.50	8.0
	Average		**0.149**		**0.129**	**13.0**	**1.65**		**1.36**	**17.5**

TABLE 15 (continued)

Rotation identification	Cropping system	Plot	Nitrogen content 1916	Nitrogen content 1927 or 1928	Nitrogen content 1938	Percentage decrease 1916-1938	Carbon content 1916	Carbon content 1927 or 1928	Carbon content 1938	Percentage decrease 1916-1938
			percent	percent	percent		percent	percent	percent	
57	Spring barley, fallow, winter wheat, corn	A	0.142	0.123	0.121	14.8	1.46		1.21	17.1
57	Spring barley, fallow, winter wheat, corn	B	0.155		0.121	21.9	1.66		1.23	25.9
57	Spring barley, fallow, winter wheat, corn	C	0.147	0.126	0.121	17.7	1.65		1.28	22.4
57	Spring barley, fallow, winter wheat, corn	D	0.144	0.127	0.119	17.4	1.55		1.26	18.7
	Average		**0.147**		**0.121**	**17.9**	**1.58**		**1.24**	**21.0**
	Spring barley, winter wheat, winter wheat, row crop									
403	Corn, spring barley, winter wheat, winter wheat	A	0.165		0.125	24.2	1.73		1.31	24.3
403	Corn, spring barley, winter wheat, winter wheat	B	0.172		0.128	25.6	1.93		1.32	31.6
403	Corn, spring barley, winter wheat, winter wheat	C	0.161		0.128	20.5	1.82		1.37	24.7
403	Corn, spring barley, winter wheat, winter wheat	D	0.168		0.120	28.6	1.87		1.39	25.7
404	Kafir, spring barley, winter wheat, winter wheat	A	0.177		0.140	20.9	1.89		1.58	16.4
404	Kafir, spring barley, winter wheat, winter wheat	B	0.175		0.132	24.6	1.99		1.48	25.6
404	Kafir, spring barley, winter wheat, winter wheat	C	0.173		0.134	22.5	1.96		1.43	27.0
404	Kafir, spring barley, winter wheat, winter wheat	D	0.183		0.137	25.1	2.31		1.54	33.3
	Average		**0.172**		**0.131**	**24.0**	**1.94**		**1.43**	**26.1**
	Fallow, winter wheat, kafir									
501	Fallow, winter wheat, kafir	A	0.125		0.094	24.8	1.24		1.13	8.9
501	Fallow, winter wheat, kafir	B	0.118		0.101	14.4	1.14		1.13	0.1
501	Fallow, winter wheat, kafir	C	0.160		0.105	34.4	1.55		1.02	34.2
502	Fallow, winter wheat, kafir	A	0.161		0.114	29.2	1.78		1.32	25.8
502	Fallow, winter wheat, kafir	B	0.164		0.124	24.4	1.72		1.41	18.0
502	Fallow, winter wheat, kafir	C	0.164		0.118	28.0	1.67		1.19	28.7
503	Fallow, winter wheat, kafir	A	0.155		0.111	28.4	1.71		1.23	28.1
503	Fallow, winter wheat, kafir	B	0.173		0.124	28.3	1.93		1.47	23.8
503	Fallow, winter wheat, kafir	C	0.158		0.112	29.1	1.71		1.18	31.0

TABLE 15 (continued)

	Spring barley, fallow, winter wheat, corn									
551	Fallow, winter wheat, kafir	A	0.161		0.113	29.8	1.82		1.16	36.3
551	Fallow, winter wheat, kafir	B	0.182		0.122	33.0	2.00		1.27	36.5
551	Fallow, winter wheat, kafir	C	0.166		0.109	34.3	1.80		1.21	32.8
552	Fallow, winter wheat, kafir	A	0.166		0.112	32.5	1.67		1.24	25.7
552	Fallow, winter wheat, kafir	B	0.167	0.124	0.111	33.5	1.75	1.14	1.14	34.9
552	Fallow, winter wheat, kafir	C	0.180		0.121	32.8	1.91		1.31	31.4
553	Fallow, winter wheat, kafir	A	0.162	0.134	0.113	30.2	1.65		1.27	23.0
553	Fallow, winter wheat, kafir	B	0.163		0.112	31.3	1.74		1.28	26.4
553	Fallow, winter wheat, kafir	C	0.179		0.120	33.0	1.93		1.30	32.6
	Average—all		**0.161**		**0.113**	**29.5**	**1.71**		**1.24**	**26.6**
	Average—551, 552, 553		**0.170**		**0.115**	**32.3**	**1.81**		**1.24**	**31.1**
	Winter wheat, row crop									
150	Winter wheat, corn (80 inch rows)	A	0.180		0.135	25.0	1.96		1.50	23.5
150	Winter wheat, corn (80 inch rows)	B	0.179		0.128	28.5	1.95		1.39	28.7
350	Winter wheat, kafir (80 inch rows)	A	0.181		0.124	31.5	1.80		1.23	31.7
350	Winter wheat, kafir (80 inch rows)	B	0.166		0.124	25.3	1.82		1.43	21.4
149	Winter wheat, corn (40 inch rows)	A	0.181		0.129	28.7	2.08		1.38	33.7
149	Winter wheat, corn (40 inch rows)	B	0.164		0.128	22.0	1.98		1.34	32.3
349	Winter wheat, kafir (40 inch rows)	A	0.173		0.124	28.3	2.05		1.39	32.2
349	Winter wheat, kafir (40 inch rows)	B	0.164		0.119	27.4	1.92		1.35	29.7
	Average		**0.171**		**0.126**	**27.1**	**1.95**		**1.38**	**29.2**
	Continuous row crop									
M.C.	Kafir, spring plow	H	0.141		0.105	25.5	1.63		1.11	31.9
M.C.	Kafir, fall plow	B	0.138	0.125	0.109	21.0	1.66		1.14	31.3
M.C.	Kafir, fall plow and subsoiled	E	0.147	0.119	0.110	25.2	1.89		1.16	38.6
M.C.	Kafir, fall list	F	0.157		0.121	22.9	2.00		1.30	35.0
M.C.	Kafir, planted with lister, no previous cultivation	G	0.144		0.115	20.1	1.87		1.28	31.6

TABLE 15 (continued)

Rotation identification	Cropping system	Plot	Nitrogen content 1916	Nitrogen content 1927 or 1928	Nitrogen content 1938	Percentage decrease 1916-1938	Carbon content 1916	Carbon content 1927 or 1928	Carbon content 1938	Percentage decrease 1916-1938
			percent	percent	percent		percent	percent	percent	
M.C.	Milo, spring plow	H	0.142		0.104	26.8	1.72		1.31	23.8
M.C.	Milo, fall plow	B	0.145	0.127	0.108	25.5	1.85		1.19	35.7
M.C.	Milo, fall plow and subsoiled	E	0.153	0.113	0.105	31.4	1.52		1.04	31.6
M.C.	Milo, fall list	F	0.166		0.122	26.5	1.81		1.23	32.0
M.C.	Milo, planted with lister, no previous cultivation	G	0.161		0.109	32.3	1.66		1.11	33.1
	Average		**0.149**		**0.111**	**25.7**	**1.76**		**1.19**	**32.5**
			Alternate row crop and fallow							
M.C.	Kafir, spring plow	C	0.138	(0.109 (0.094	0.094	31.9	1.60		0.93	41.9
M.C.	Kafir, spring plow	D	0.145	0.121	0.100	31.0	1.83		1.13	38.3
M.C.	Milo, spring plow	C	0.151	(0.111 (0.101	0.105	30.5	1.73		1.13	34.7
M.C.	Milo, spring plow	D	0.148	0.117	0.099	33.1	2.12		1.09	48.6
	Average		**0.146**		**0.100**	**31.6**	**1.82**		**1.07**	**40.9**
			Winter wheat, fallow, fallow, fallow							
570	Winter wheat, fallow, fallow, fallow	A	0.169	0.136	0.114	32.5	1.85		1.23	33.5
570	Winter wheat, fallow, fallow, fallow	B	0.166	0.125	0.109	34.3	1.72		1.16	32.6
570	Winter wheat, fallow, fallow, fallow	C	0.166	0.142	0.118	28.9	1.88		1.24	34.0
570	Winter wheat, fallow, fallow, fallow	D	0.169	0.137	0.122	27.8	1.93		1.30	32.6
	Average		**0.168**		**0.116**	**30.9**	**1.85**		**1.23**	**33.2**
	Fallow, winter wheat, kafir rotations with straw or manure									
554	Straw, 3T/A on winter wheat	A	0.162	0.130	0.114	29.6	1.76	1.16	1.19	32.4
554	Straw, 3T/A on winter wheat	B	0.182		0.121	33.5	1.70		1.21	28.8
554	Straw, 3T/A on winter wheat	C	0.167		0.125	25.1	1.80		1.34	25.6
	Average		**0.170**		**0.120**	**29.4**	**1.75**		**1.24**	**28.9**
555	Manure, 3T/A on winter wheat	A	0.170	0.152	0.127	25.3	1.74	1.46	1.29	25.9
555	Manure, 3T/A on winter wheat	B	0.179	0.141	0.122	31.8	1.75		1.27	27.4
555	Manure, 3T/A on winter wheat	C	0.172		0.115	33.1	1.85		1.28	30.8

TABLE 15 (continued)

557	Manure, 3T/A before kafir	A	0.169		0.118	30.2	1.65		1.29	21.8
557	Manure, 3T/A before kafir	B	0.170		0.116	31.8	1.87		1.21	35.3
557	Manure, 3T/A before kafir	C	0.182		0.128	29.7	2.01		1.40	30.3
	Average		**0.174**		**0.121**	**30.3**	**1.81**		**1.29**	**28.6**
556	Manure, 6T/A on winter wheat	A	0.179	0.149	0.124	30.7	1.87		1.30	30.5
556	Manure, 6T/A on winter wheat	B	0.172	0.137	0.123	28.5	1.83		1.32	27.9
556	Manure, 6T/A on winter wheat	C	0.187		0.127	32.1	2.17		1.35	37.8
558	Manure, 6T/A before kafir	A	0.173		0.130	24.9	1.92		1.47	23.4
558	Manure, 6T/A before kafir	B	0.172		0.125	27.3	1.82		1.30	28.6
558	Manure, 6T/A before kafir	C	0.187		0.135	27.8	2.02		1.47	27.2
	Average		**0.178**		**0.127**	**28.6**	**1.94**		**1.37**	**29.2**
559	Manure, 9T/A before kafir	A	0.160	0.151	0.130	18.8	1.73		1.44	16.8
559	Manure, 9T/A before kafir	B	0.179	0.148	0.128	28.5	1.89		1.44	23.8
559	Manure, 9T/A before kafir	C	0.193		0.152	21.2	2.11		1.59	24.6
	Average		0.177		0.137	22.8	1.91		1.49	21.7
560	Manure, 12T/A before kafir	A	0.167	0.160	0.139	16.8	1.71	1.51	1.54	9.9
560	Manure, 12T/A before kafir	C	0.188	0.157	0.143	23.9	1.98		1.51	23.7
560	Manure, 12T/A before kafir	B	0.184		0.156	15.2	2.06		1.71	17.0
	Average		**0.180**		**0.146**	**18.6**	**1.92**		**1.59**	**16.9**

	Nitrogen content 1940
	percent
Unbroken sod sample taken in southeast corner of Fort pasture near where the soil moisture samples have been taken, tested for nitrogen only.	0.242
Re-established sod sample taken from an area that had been cropped for several years and then turned back to sod in 1911, tested for nitrogen only.	0.168

TABLE 15 (continued)

Rotation identification	Cropping system	Plot	Nitrogen content 1916	Nitrogen content 1927 or 1928	Nitrogen content 1938	Percentage decrease 1916-1938	Carbon content 1916	Carbon content 1927 or 1928	Carbon content 1938	Percentage decrease 1916-1938
			percent	percent	percent		percent	percent	percent	
	COLBY									
	Continuous small grain									
M.C.	Spring wheat, spring plow	A	0.108	0.110	0.110	-1.8	1.26	0.96	1.15	8.7
M.C.	Spring wheat, fall plow	B	0.112	0.105	0.098	12.5	1.30	0.94	0.99	23.8
M.C.	Oats, spring plow	A	0.126		0.123	2.4	1.28		1.34	-4.7
M.C.	Oats, fall plow	B	0.117		0.097	17.1	1.07		1.07	0.0
M.C.	Spring barley, spring plow	A	0.143		0.122	14.7	1.54		1.29	16.2
M.C.	Spring barley, fall plow	B	0.136	0.113	0.112	17.6	1.40		1.18	15.7
M.C.	Winter wheat, late plow	A	0.166	(0.141 (0.142	0.136	18.1	2.30		1.39	39.6
M.C.	Winter wheat, early plow	B	0.152	(0.133 (0.131	0.124	18.4	1.86	1.47	1.33	28.5
	Average		**0.133**		**0.115**	**12.4**	**1.50**		**1.22**	**16.0**
	Alternate small grain and fallow									
M.C.	Spring wheat, spring plow	C	0.118	0.107	0.109	7.6	1.39	0.95	1.18	15.1
M.C.	Spring wheat, spring plow	D	0.117	0.116	0.103	12.0	1.31	1.14	1.12	14.5
M.C.	Oats, spring plow	C	0.117		0.109	6.8	1.05		1.12	-6.7
M.C.	Oats, spring plow	D	0.115		0.098	14.8	1.24		1.03	16.9
M.C.	Spring barley, spring plow	C	0.123	0.111	0.112	8.9	1.20		1.20	0.0
M.C.	Spring barley, spring plow	D	0.112	0.106	0.096	14.3	1.05		1.05	0.0
M.C.	Winter wheat, spring plow	C	0.157	(0.127 (0.120	0.115	26.8	1.89	1.51	1.13	40.2
M.C.	Winter wheat, spring plow	D	0.138	(0.117 (0.117	0.113	18.1	1.68		1.21	28.0
M.F.	Winter wheat, fall plow, work done in fall	H	0.171		0.110	35.7	1.76		1.34	23.9
M.F.	Winter wheat, fall plow, work done in fall	I	0.163		0.116	28.8	1.50		1.32	12.0
M.F.	Winter wheat, fall plow	J	0.169		0.115	32.0	1.81		1.33	26.5
M.F.	Winter wheat, fall plow	K	0.161		0.131	18.6	1.70		1.37	19.4
M.F.	Winter wheat, May plow	L	0.168	0.132	0.118	29.8	1.75		1.33	24.0
M.F.	Winter wheat, May plow	M	0.167	0.141	0.129	22.8	1.66		1.40	15.7
M.F.	Winter wheat, June plow	N	0.162		0.125	22.8	1.74		1.41	19.0
M.F.	Winter wheat, June plow	O	0.168		0.137	18.5	1.88		1.51	19.7

TABLE 15 (continued)

M.F.	Winter wheat, fall list	P	0.154		0.116	24.7	1.72		1.31	23.8
M.F.	Winter wheat, fall list	Q	0.167		0.126	24.6	2.05		1.42	30.7
	Average		**0.147**		**0.115**	**20.4**	**1.58**		**1.27**	**17.9**
	Row crop, row crop, winter wheat, rye used as a green manure crop									
152	Milo, corn (80 inch row), winter wheat, rye (green manure)	A	0.116	0.104	0.094	19.0	1.48		0.91	38.5
152	Milo, corn (80 inch row), winter wheat, rye (green manure)	B	0.126		0.094	25.4	1.67		0.83	50.3
152	Milo, corn (80 inch row), winter wheat, rye (green manure)	C	0.129		0.094	27.1	1.70		0.90	47.1
152	Milo, corn (80 inch row), winter wheat, rye (green manure)	D	0.147	0.112	0.100	32.0	1.58		0.93	41.1
153	Corn (80 inch row), milo, rye (green manure), winter wheat	A	0.114		0.101	11.4	1.43		0.93	35.0
153	Corn (80 inch row), milo, rye (green manure), winter wheat	B	0.120		0.095	20.8	1.29		0.93	27.9
153	Corn (80 inch row), milo, rye (green manure), winter wheat	C	0.110		0.101	8.2	1.40		1.09	22.1
153	Corn (80 inch row), milo, rye (green manure), winter wheat	D	0.119		0.106	10.9	1.60		0.98	38.8
	Average		**0.123**		**0.098**	**19.4**	**1.52**		**0.94**	**37.6**
	Milo, fallow, winter wheat, rye used as green manure crop									
151	Milo, fallow, winter wheat, rye (green manure)	A	0.117	0.098	0.094	19.7	1.14		0.97	14.9
151	Milo, fallow, winter wheat, rye, (green manure)	B	0.119		0.094	21.0	1.34		0.96	28.4
151	Milo, fallow, winter wheat, rye (green manure)	C	0.117		0.098	16.2	1.28		1.09	14.8
151	Milo, fallow, winter wheat, rye (green manure)	D	.0.141	0.104	0.095	32.6	1.55		1.16	25.2
	Average		**0.124**		**0.095**	**22.4**	**1.33**		**1.05**	**20.8**
	Milo, fallow, winter wheat, Canada field peas used as green manure crop									
154	Milo, fallow, winter wheat, peas (green manure)	A	0.143	0.107	0.099	30.8	1.66	0.92	0.95	42.8
154	Milo, fallow, winter wheat, peas (green manure)	B	0.146		0.102	30.1	1.70		1.00	41.2
154	Milo, fallow, winter wheat, peas (green manure)	C	0.146		0.113	22.6	1.75		1.12	36.0
154	Milo, fallow, winter wheat, peas (green manure)	D	0.136	0.113	0.104	23.5	1.47		1.05	28.6
	Average		**0.143**		**0.105**	**26.8**	**1.65**		**1.03**	**37.2**

TABLE 15 (continued)

Rotation identification	Cropping system	Plot	Nitrogen content 1916	Nitrogen content 1927 or 1928	Nitrogen content 1938	Percentage decrease 1916-1938	Carbon content 1916	Carbon content 1927 or 1928	Carbon content 1938	Percentage decrease 1916-1938
			percent	percent	percent		percent	percent	percent	
	Milo, fallow, winter wheat, fallow									
155	Milo, fallow, winter wheat, fallow	A	0.129	0.114	0.107	17.1	1.45		1.18	18.6
155	Milo, fallow, winter wheat, fallow	B	0.145		0.108	25.5	1.75		1.13	35.4
155	Milo, fallow, winter wheat, fallow	C	0.143		0.108	24.5	1.60		1.10	31.3
155	Milo, fallow, winter wheat, fallow	D	0.134	0.112	0.098	26.9	1.42		1.07	24.6
	Average		**0.138**		**0.105**	**23.5**	**1.56**		**1.12**	**27.5**
	Winter wheat, milo, fallow									
551	Winter wheat, milo, fallow	A	0.127		0.098	22.8	1.39		0.87	37.4
551	Winter wheat, milo, fallow	B	0.114		0.102	10.5	1.19		1.07	10.0
551	Winter wheat, milo, fallow	C	0.149		0.100	32.9	1.45		1.02	29.7
552	Winter wheat, milo, fallow	A	0.120	0.098	0.097	19.2	1.29	0.79	0.89	31.0
552	Winter wheat, milo, fallow	B	0.112		0.095	15.2	1.14		1.03	9.6
552	Winter wheat, milo, fallow	C	0.122		0.101	17.2	1.11		0.99	10.8
553	Winter wheat, milo, fallow	A	0.132		0.103	22.0	1.23		1.08	12.2
553	Winter wheat, milo, fallow	B	0.127		0.105	17.3	1.31		1.11	15.3
553	Winter wheat, milo, fallow	C	0.153		0.095	37.9	1.10		0.99	10.0
	Average		**0.128**		**0.100**	**21.7**	**1.25**		**1.01**	**18.4**
	Spring small grain, spring small grain, row crop									
6	Spring barley, oats, corn	A	0.156		0.119	23.7	1.96		1.24	36.7
6	Spring barley, oats, corn	B	0.161		0.119	26.1	1.98		1.26	36.4
6	Spring barley, oats, corn	C	0.152		0.114	25.0	1.77		1.25	29.4
7	Oats, spring barley, corn	A	0.163		0.118	27.6	1.84		1.30	29.3
7	Oats, spring barley, corn	B	0.156		0.118	24.4	1.81		1.26	30.4
7	Oats, spring barley, corn	C	0.145		0.122	15.9	1.86		1.44	22.6
9	Oats, spring wheat, corn	A	0.143		0.115	19.6	2.18		1.22	44.0
9	Oats, spring wheat, corn	B	0.147		0.117	20.4	2.06		1.34	35.0
9	Oats, spring wheat, corn	C	0.168		0.125	25.6	1.98		1.30	34.3
	Average		**0.155**		**0.119**	**23.1**	**1.94**		**1.29**	**33.1**

TABLE 15 (continued)

	Spring small grain, spring small grain, fallow									
8	Oats, spring barley, fallow	A	0.111		0.102	8.1	1.15		1.07	7.0
8	Oats, spring barley, fallow	C	0.119		0.111	6.7	1.29		1.19	7.8
8	Oats, spring barley, fallow	B			0.114		1.54		1.18	23.4
	Average		**0.115**		**0.107**	**7.4**	**1.33**		**1.15**	**12.7**
	Continuous kafir									
C.C.	Kafir, spring plow	A	0.118		0.096	18.6	1.41		0.96	31.9
C.C.	Kafir, fall plow	B	0.111	0.095	0.087	21.6	1.21		0.93	23.1
	Average		**0.115**		**0.092**	**20.1**	**1.31**		**0.95**	**27.5**
	Alternate kafir and fallow									
C.C.	Kafir, spring plow	C	0.108	0.086	0.081	25.0	1.21		0.86	28.9
C.C.	Kafir, spring plow	D	0.106	0.086	0.081	23.6	1.14		0.80	29.8
	Average		**0.107**		**0.081**	**24.3**	**1.18**		**0.83**	**29.4**
	Virgin sod									
Weather station	Buffalo sod		0.182		0.179	1.6	2.00		2.15	-7.5
	Fallow, winter wheat, milo rotations with straw or manure									
554	Straw 3T/A on winter wheat	A	0.119	0.103	0.103	13.4	1.29	0.80	0.96	25.6
554	Straw 3T/A on winter wheat	B	0.114		0.102	10.5	1.15		1.07	7.0
554	Straw 3T/A on winter wheat	C	0.126		0.105	16.7	1.31		1.04	20.6
	Average		**0.120**		**0.103**	**13.5**	**1.25**		**1.02**	**17.7**
555	Manure 3T/A on wheat	A	0.121	0.099	0.100	17.4	1.31	0.92	0.91	30.5
555	Manure 3T/A on wheat	B	0.114		0.092	19.3	1.23		0.97	21.1
555	Manure 3T/A on wheat	C	0.123	0.102	0.101	17.9	1.31		0.99	24.4
557	Manure 3T/A before kafir	A	0.134		0.101	24.6	1.47		1.06	27.9
557	Manure 3T/A before kafir	B	0.125		0.102	18.4	1.23		1.05	14.6
557	Manure 3T/A before kafir	C	0.131		0.112	14.5	1.30		1.07	17.7
	Average		**0.125**		**0.101**	**18.7**	**1.31**		**1.01**	**22.7**
556	Manure 6T/A on wheat	A	0.137	0.111	0.104	24.1	1.48		1.01	31.8
556	Manure 6T/A on wheat	B	0.128		0.109	14.8	1.31		1.08	17.6
556	Manure 6T/A on wheat	C	0.110		0.105	4.5	1.06		0.95	10.4
558	Manure 6T/A before kafir	A	0.137		0.106	22.6	1.64		1.05	36.0
558	Manure 6T/A before kafir	B	0.118		0.115	2.5	1.14		1.15	-0.9
558	Manure 6T/A before kafir	C	0.116		0.107	7.8	1.15		1.09	5.2
	Average		**0.124**		**0.108**	**12.7**	**1.30**		**1.06**	**16.7**

TABLE 15 (continued)

Rotation identification	Cropping system	Plot	Nitrogen content 1916	Nitrogen content 1927 or 1928	Nitrogen content 1938	Percentage decrease 1916-1938	Carbon content 1916	Carbon content 1927 or 1928	Carbon content 1938	Percentage decrease 1916-1938
			percent	percent	percent		percent	percent	percent	
559	Manure 9T/A before kafir	A	0.147		0.115	21.8	1.33		1.24	6.8
559	Manure 9T/A before kafir	B	0.133		0.114	14.3	1.43		1.05	26.6
559	Manure 9T/A before kafir	C	0.136		0.117	14.0	1.36		1.20	11.8
	Average		**0.139**		**0.115**	**16.7**	**1.37**		**1.16**	**15.1**
560	Manure 12T/A before kafir	A	0.151	0.133	0.115	23.8	1.55	1.28	1.28	17.4
560	Manure 12T/A before kafir	B	0.136		0.119	12.5	1.34		1.21	9.7
560	Manure 12T/A before kafir	C	0.130		0.122	6.2	1.21		1.19	1.7
	Average		**0.139**		**0.119**	**14.2**	**1.37**		**1.23**	**9.6**
			Milo, fallow, wheat, fallow							
156	Milo, fallow, wheat, fallow, manure 10T/A before second fallow	A	0.154	0.131	0.117	24.0	2.03		1.23	39.4
156	Milo, fallow, wheat, fallow, manure 10T/A before second fallow	B	0.147		0.124	15.6	1.68		1.28	23.8
156	Milo, fallow, wheat, fallow, manure 10T/A before second fallow	C	0.148	0.135	0.126	14.9	1.84		1.32	28.3
156	Milo, fallow, wheat, fallow, manure 10T/A before second fallow	D	0.140	0.113	0.115	17.9	1.85		1.17	36.7
	Average		**0.147**		**0.121**	**18.1**	**1.85**		**1.25**	**32.1**
			GARDEN CITY							
			Continuous small grain							
M.C.	Spring barley, fall plow	B	0.093[1]	0.097	0.088	5.4	1.07[1]		0.82	23.4
M.C.	Oats, fall plow	B	0.094[1]		0.086	8.5	0.96[1]		0.80	16.7
M.C.	Winter wheat, late plow	A	0.113	0.112	0.100	11.5	1.59		0.99	37.7
M.C.	Winter wheat, early plow	B	0.107	(0.104	0.092	14.0	1.34	0.94	0.93	30.6
M.C.	Winter wheat, early plow and subsoiled	E	0.096	(0.105	0.091	5.2	1.06		0.75	29.2
M.C.	Winter wheat, early list	F	0.103	0.095	0.090	12.6	1.21		0.81	33.1
	Average		**0.101**		**0.091**	**9.5**	**1.21**		**0.85**	**28.5**

1. Plot locations at Garden City were changed since 1916 samples were taken. The data given are for the plots now occupied by continuous barley and oats. The change in location became effective with 1922 crop. The new locations were plots for which 1916 analyses were available. Because of the crops grown on the plots from 1916 to 1921 it was thought that the major cause of the change in nitrogen and carbon could be logically assigned to the barley and oats.

TABLE 15 (continued)

	Alternate winter wheat and fallow									
M.C.	Winter wheat, spring plow	C	0.092	(0.105 (0.095	0.091	1.1	1.25	0.76	0.83	33.6
M.C.	Winter wheat, spring plow	D	0.088	(0.095 (0.095	0.095	-8.0	1.06	0.81	0.90	15.1
M.F.	Winter wheat, fall plow, replow in June	H	0.083		0.078	6.0	0.75		0.83	-10.7
M.F.	Winter wheat, fall plow, replow in June	I	0.084		0.076	9.5	0.92		0.72	21.7
M.F.	Winter wheat, fall plow	J	0.082		0.079	3.7	0.91		0.72	20.9
M.F.	Winter wheat, fall plow	K	0.093		0.082	11.8	0.90		0.80	11.1
M.F.	Winter wheat, May plow	L	0.094	0.093	0.079	16.0	0.99		0.72	27.3
M.F.	Winter wheat, May plow	M	0.099		0.085	14.1	0.99		0.72	27.3
M.F.	Winter wheat, June plow	N	0.100	0.092	0.092	8.0	1.05		0.77	26.7
M.F.	Winter wheat, June plow	O	0.101	0.098	0.092	8.9	1.22		0.89	27.0
M.F.	Winter wheat, fall list	P	0.095		0.076	20.0	1.01		0.81	19.8
M.F.	Winter wheat, fall list	Q	0.090		0.074	17.8	0.98		0.75	23.5
	Average		**0.092**		**0.083**	**9.1**	**1.00**		**0.79**	**20.3**
	Rotation with rye as a green manure crop									
331	Kafir, fallow, wheat, wheat, rye (green manure)	A	0.107		0.102	4.7	1.22		0.89	27.0
331	Kafir, fallow, wheat, wheat, rye (green manure)	B	0.100		0.091	9.0	1.13		0.74	34.5
331	Kafir, fallow, wheat, wheat, rye (green manure)	C	0.104		0.088	15.4	1.05		0.73	30.5
331	Kafir, fallow, wheat, wheat, rye (green manure)	D	0.090	(0.085 (0.084	0.079	12.2	0.96	0.65	0.65	32.3
331	Kafir, fallow, wheat, wheat, rye (green manure)	E	0.094		0.082	12.8	0.91		0.71	22.0
332	Kafir, fallow, wheat, rye (green manure), wheat	A	0.123		0.104	15.4	1.44		0.78	45.8
332	Kafir, fallow, wheat, rye (green manure), wheat	B	0.117		0.090	23.1	1.45		0.77	46.9
332	Kafir, fallow, wheat, rye (green manure), wheat	C	0.106		0.094	11.3	1.14		0.77	32.5
332	Kafir, fallow, wheat, rye (green manure), wheat	D	0.093	(0.096 (0.090	0.085	8.6	1.01	0.69	0.60	40.6
332	Kafir, fallow, wheat, rye (green manure), wheat	E	0.099		0.093	6.1	1.08		0.67	38.0
	Average		**0.103**		**0.091**	**11.9**	**1.14**		**0.73**	**35.0**

TABLE 15 (continued)

Rotation identification	Cropping system	Plot	Nitrogen content 1916	Nitrogen content 1927 or 1928	Nitrogen content 1938	Percentage decrease 1916-1938	Carbon content 1916	Carbon content 1927 or 1928	Carbon content 1938	Percentage decrease 1916-1938
			percent	percent	percent		percent	percent	percent	
	Kafir, milo, Sudan									
213	Kafir, milo, Sudan	A	0.096	0.093	0.092	4.2	1.00		0.95	5.0
213	Kafir, milo, Sudan	B	0.109		0.087	20.2	1.14		0.91	20.2
213	Kafir, milo, Sudan	C	0.125		0.092	26.4	1.23		0.96	22.0
	Average		**0.110**		**0.090**	**16.9**	**1.12**		**0.94**	**15.7**
	Kafir, fallow, winter wheat, winter wheat									
324	Kafir, fallow, winter wheat, winter wheat	A	0.101	0.096	0.091	9.9	1.04		0.77	26.0
324	Kafir, fallow, winter wheat, winter wheat	B	0.097		0.085	12.4	1.28		0.72	43.8
324	Kafir, fallow, winter wheat, winter wheat	C	0.097		0.085	12.4	1.15		0.69	40.0
324	Kafir, fallow, winter wheat, winter wheat	D	0.099	0.088	0.088	11.1	1.08	0.76	0.69	36.1
	Average		**0.099**		**0.087**	**11.5**	**1.14**		**0.72**	**36.5**
	Kafir, fallow, winter wheat									
405	Kafir, fallow, winter wheat	A	0.099		0.081	18.2	1.21		0.71	41.3
405	Kafir, fallow, winter wheat	B	0.099	0.095	0.087	12.1	1.01		0.78	22.8
405	Kafir, fallow, winter wheat	C	0.090	0.093	0.084	6.7	1.11		0.76	31.5
	Average		**0.096**		**0.084**	**12.3**	**1.11**		**0.75**	**31.9**
	Kafir, cowpeas (rows) Sudan (close drilled)									
83	Kafir, cowpeas, Sudan	A	0.088	0.095	0.081	8.0	0.90		0.81	10.0
83	Kafir, cowpeas, Sudan	B	0.090		0.080	11.1	0.97		0.80	17.5
83	Kafir, cowpeas, Sudan	C	0.096		0.081	15.6	1.11		0.86	22.5
	Average		**0.091**		**0.081**	**11.6**	**0.99**		**0.82**	**16.7**

TABLE 15 (concluded)

			Continuous row crops						
C.C.	Corn, spring plow	A	0.079		0.064	19.0	0.85	0.68	20.0
C.C.	Corn, fall plow	B	0.079		0.062	21.5	0.92	0.63	31.5
C.C.	Corn, fall plow and subsoiled	E	0.082		0.065	20.7	0.78	0.69	11.5
C.C.	Corn, fall list	F	0.086		0.074	14.0	0.69	0.68	1.4
C.C.	Corn, no tillage, list at planting time	G	0.083		0.073	12.0	0.73	0.63	13.7
C.C.	Kafir, spring plow	A	0.085	0.076	0.074	12.9	0.74	0.68	8.1
C.C.	Kafir, fall plow	B	0.084	(0.074	0.065	22.6	0.80	0.58	27.5
				(0.071					
C.C.	Kafir, fall list	F	0.091	0.073	0.075	17.6	0.88	0.66	25.0
C.C.	Milo, spring plow	A	0.089		0.075	15.7	1.16	0.64	44.8
C.C.	Milo, fall plow	B	0.086		0.073	15.1	0.99	0.58	41.4
C.C.	Milo, fall list	F	0.085		0.076	10.6	0.97	0.59	39.2
Seedbed		1	0.118		0.070	40.7	1.38	0.67	51.4
Seedbed		2	0.117		0.075	35.9	1.41	0.77	45.4
Seedbed		3	0.108		0.071	34.3	1.54	0.74	51.9
Seedbed		4	0.132		0.073	44.7	1.68	0.70	58.3
Seedbed		17	0.133		0.074	44.4	1.60	0.72	55.0
Seedbed		18	0.113		0.076	32.7	1.17	0.80	31.6
	Average		**0.097**		**0.071**	**24.4**	**1.08**	**0.67**	**32.8**
			Alternate corn and fallow						
C.C.	Corn, spring plow	C	0.087		0.068	21.8	1.03	0.69	33.0
C.C.	Corn, spring plow	D	0.078		0.065	16.7	0.76	0.73	3.9
	Average		**0.083**		**0.067**	**19.3**	**0.90**	**0.71**	**18.5**

TABLE 16. CHANGES IN PERCENTAGE OF NITROGEN CONTENT AND CARBON CONTENT BETWEEN 1931 AND 1938, GARDEN CITY DRY-LAND ANNEX.

			Nitrogen content		Percentage change	Carbon content		Percentage change
			1931	1938	1931-1938	1931	1938	1931-1938
			percent	percent		percent	percent	
Soil studies[1]	Continuous winter wheat, stubble burned, early plow	1	0.150	0.120	20.0	1.56	1.15	26.3
	Continuous milo, early spring list	2	0.141	0.113	19.9	1.44	1.05	27.1
	Fallow, winter wheat, milo	3	0.136	0.106	22.1	1.34	1.06	20.9
	Rye (green manure), winter wheat	4	0.146	0.117	19.9	1.48	1.26	14.9
	Vetch (green manure), winter wheat	5	0.145	0.120	17.2	1.50	1.21	19.3
	No average							
Continuous winter wheat seedbed	Fall list	1	0.140	0.114	18.6	1.44	1.08	25.0
	Fall list, split ridges	2	0.134	0.115	14.2	1.43	1.02	28.7
	Early plow, 7 inches	3	0.135	0.114	15.6	1.41	1.23	12.8
	Early plow, 3 inches	4	0.136	0.117	14.0	1.47	1.14	22.4
	Early one-way	5	0.136	0.113	16.9	1.43	1.12	21.7
	Late plow, 3 inches	6	0.132	0.115	12.9	1.35	1.08	20.0
	Late one-way	7	0.129	0.111	14.0	1.31	1.14	13.0
	Average		**0.135**	**0.114**	**15.2**	**1.41**	**1.12**	**20.5**
267	Fallow, winter wheat	A	0.142	0.125	12.0	1.39	1.20	13.7
267	Fallow, winter wheat	B	0.149	0.120	19.5	1.49	1.15	22.8
	Average		**0.146**	**0.123**	**15.8**	**1.44**	**1.18**	**18.3**
566	Fallow, winter wheat, winter wheat, winter wheat	A	0.133	0.110	17.3	1.33	1.01	24.1
566	Fallow, winter wheat, winter wheat, winter wheat	B	0.133	0.109	18.0	1.40	1.03	26.4
566	Fallow, winter wheat, winter wheat, winter wheat	C	0.135	0.116	14.1	1.37	1.18	13.9
566	Fallow, winter wheat, winter wheat, winter wheat	D	0.140	0.114	18.6	1.37	1.04	24.1
	Average		**0.135**	**0.112**	**17.0**	**1.37**	**1.07**	**22.1**
567	Fallow, winter wheat, winter wheat	A	0.139	0.115	17.3	1.34	1.10	17.9
567	Fallow, winter wheat, winter wheat	B	0.147	0.121	17.7	1.55	1.17	24.5
567	Fallow, winter wheat, winter wheat	C	0.140	0.119	15.0	1.47	1.15	21.8
	Average		**0.142**	**0.118**	**16.7**	**1.45**	**1.14**	**21.4**
571	Continuous winter wheat stubbled in	A	0.149	0.121	18.8	1.44	1.26	12.5

1. After the 1931 samples were taken soil studies plots 2, 3, 4, and 5 were disturbed mechanically in order to level an old prairie trail. For this reason the 1931 data for the four plots should not be given too much attention.

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