THE EFFECT OF LONG-TIME FERTILITY TREATMENTS ON THE NITROGEN AND CARBON CONTENT OF PRAIRIE SOILS

by

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INTRODUCTION

Studies of nitrogen and carbon relationships in the soil have been the subject of intensive investigation on the Soil Fertility experiment at the Kansas Agricultural Experiment Station, Manhattan, Kansas, for more than 36 years. The material presented in this thesis is a continuation of the studies to determine the influence of cropping system and fertilizer treatments upon the trends of nitrogen and carbon in the soil and to determine the relationship between the level of nitrogen and carbon, particularly in the surface seven inches of the soil, and the ability of the soil to produce crops over a long period of years.

The area on which this experiment is located has been under cultivation since 1864. During the time from 1864 until the Soil Fertility plots were established in 1909, the land was cropped largely to corn and occasionally to oats or wheat. Some alfalfa was planted about 1890 or 1895. From the report by W. E. Grimes, foreman of the Agronomy farm in 1913, the fields on which these plots were established produced 42 bushels per acre of corn in 1905 and 38 bushels per acre in 1906. Good yields of Kharkof wheat were obtained in 1907 and 1908, indicating a fairly high level of fertility at the time the experiment was begun.

The soils in this area belong to the Prairie soils group.

The soil type[1] on the experimental plots is Geary silty clay loam and Geary silty clay loam, light colored subsoil phase. The soil was mapped and described in 1945 by Dr. J. C. Hide of Kansas State College and Dr. Claude L. Fly and Alvin W. Goke of the Soil Conservation Service. The Geary silty clay loam occupies the narrow ridge crests and more sloping well-drained areas. The soil is more friable in the deep subsoil than the light colored subsoil phase. The surface six inches is a weak brown, friable heavy silt loam with a pH of 5.5. The light subsoil phase seems to be dominant in the border areas and more gentle slopes. The surface five inches of a plowed field is weak brown, granular silty clay loam with a pH of 6.5.

Cropping systems or fertilizer treatments may or may not have a significant effect upon the loss of nutrients from the soil, depending on several factors. Both carbon and nitrogen can be lost from the soil by crop removal, by erosion, by leaching and by oxidation or volatilization. No provision was made in the design of this experiment to determine the amount of carbon or nitrogen lost from the soil by erosion, leaching or by volatilization. Leaching is probably not extensive on this soil type and, since the land had been in cultivation for a number of years prior to the establishment of the plots,

[1]Information as to soil types was secured for this paper by Paul L. Brown, Assistant Professor of Agronomy, Kansas State College.

losses by volatilization have probably been low during the period of the experiment. Erosion is a very important factor, especially on the lower slopes. Crop removal can in a small measure be correlated with changes in nitrogen and carbon but definite correlations are masked somewhat by the erosion that has taken place.

EXPERIMENTAL PROCEDURE

Arrangement and Design

Arrangement of the Soil Fertility plots is a systematic arrangement in which a 16-year rotation occupies the first four series, a 3-year rotation the next three series, and continuous wheat the eighth series. Within each series, twelve one-tenth acre plots are located lying across the length of the series which they form. The long dimension of each plot is north and south. The plots in each series are numbered from a center road between two tiers of the series. The tiers of series run north and south with numbers one, three, five, seven and nine on the east side of the road and numbers two, four, six, eight and ten on the west side of the road.

In dealing with treatments in this thesis, the check plots, superphosphate plots, superphosphate and potassium sulfate plots, and superphosphate, potassium sulfate and sodium nitrate plots are designated as F_4, F_1, F_2 and F_3, respectively.

These treatments are the only treatments studied since they were uniform throughout the experiment and lend themselves more readily to statistical analysis. In every case in the tables, the check plot data will be an average of four plots compared with one plot each for the other treatments. In the 16-year rotation plot four always had treatment F_2 (superphosphate and potassium sulfate) while in the 3-year rotation and continuous wheat, F_2 was always placed on plot three. Plots two, five, eight and eleven on all series are check plots, and plot six had the complete fertilizer containing superphosphate, potassium sulfate and sodium nitrate. The 16-year rotation was a rotation of alfalfa for four years and corn, corn, wheat rotated for 12 years. The land was then put back to alfalfa. In 1922 one year of corn was changed to wheat, making the rotation: alfalfa for four years and corn, wheat, wheat rotated for 12 years. The 3-year rotation was corn, cowpeas and wheat. In 1928 soybeans were substituted for the cowpeas.

Sampling

The annual reports of the Kansas Agricultural Experiment Station for 1910 and 1911 and a drawing from the report for 1923 showed that these plots were adequately sampled for nitrogen and carbon analysis in 1915 and again in 1932 to 1934. The 1915 figures were chosen as a base or starting point from which to observe trends in nitrogen and carbon for the period 1915 to 1934. The 1934[2] nitrogen and carbon data were used as a base to observe trends within the period 1934 to 1946. This also gives an opportunity to compare trends between periods. Sampling methods were essentially the same as those used in years previous to 1946. Twelve cores were driven six and two-thirds inches deep at a specified distance in a systematic way with a soil sampling tube. These twelve cores were pulled, composited and placed in cloth soil bags to dry in the basement of East Waters Hall.

All 1946 samples were taken in February when the plots were in wheat, alfalfa, or fall plowed for spring crops. On the 16-year rotation, Series I had a good stand of stooling wheat, Series II plowed in preparation for corn, Series III had stooling wheat and Series IV had a good stand of first-year alfalfa. For the 3-year rotation, Series V was plowed in preparation for corn, Series VI was in wheat and Series VII had been plowed in preparation for soybeans. The continuous wheat had a good stand of stooling wheat. The crop residue was removed from the surface of the soil where the sampling tube was driven so that all plant residues obtained in the soil samples were of root origin with the exception of the plowed plots in which turned-under residue was unavoidably sampled. The influence of differences in the plots at sampling time on the nitrogen and carbon content of the soil is not

[2]Contain some figures of 1932, 1933, 1934 and 1936.

discernible. In pasture management studies, Aldous (3) reported that burning did not decrease the total nitrogen or carbon content of the soil either by decreasing root development or the accumulation of top growth residue.

During March, 1946 all the composited soil samples were dried in bags in the basement of East Waters Hall. Regular turning of the soil sample bags was carried out to insure complete and uniform drying. A small A. E. Paton, Black Hawk Mill was used for grinding these composited samples to bring the dry cylindrical cores down to a 10 mesh size. A mortar and pestle was the best method found for grinding 100 grams of a mixed aliquot of the 10 mesh composite samples down to 100 mesh size. The 100 mesh samples were placed in glass vials with airtight lids to insure as little absorption of moisture as possible.

Chemical Laboratory Analysis and Procedure

In the chemical laboratory 108 composited soil samples, each composite sample representing one plot, were analyzed for total nitrogen and carbon. The results from only 56 samples were used in this thesis.

The total nitrogen determination followed the Gunning-Hibbard procedure (6) according to steps outlined in previous work by Metzger (28).

The total carbon was determined by the Schollenberger method using the reduction of chromic acid as outlined by Allison (4). The factor 1.15 used by Allison to relate values obtained by the Schollenberger method with that of oven combustion was used with satisfaction on these determinations. The factor of 1.15 was tested in 1939 by the late Dr. W. H. Metzger in cooperation with Dr. H. G. Byers, then of the Bureau of Chemistry and Soils, and was found to be reliable.

In the determination of organic carbon, several methods may be used. The most accurate is probably the oven combustion method. Many other methods (4, 20, 37, 12, 13, 54, 7, 10, 33, 46) of the types requiring a strong oxidizing agent are used. The extent of the reduction of these agents by carbon dioxide is measured by titrating the excess amount of oxidizing agent and a factor is applied to convert this value to carbon. Limitations are evident as in the perchloric acid determination where complicated apparatus is needed. Probably the best simple method, requiring the least apparatus and the minimum of complicated procedure, is the determination of soil organic matter by the Schollenberger method (46) or Allison's chromic acid reduction method (4).

During the analysis of nitrogen and carbon in the laboratory two standard soil samples were used. One soil was a Colby silty clay loam from Hays, Kansas. It had a nitrogen content of 0.157 percent. The other soil was a Muscatine silt loam from Illinois and had a nitrogen content of 0.224 percent when tested in the Illinois Soil Laboratory as sample

No. C4761. The carbon percent was not recorded with the nitrogen on these samples. Both the Colby soil and the Muscatine soil were analyzed in the soil research laboratory at Kansas State College. The average nitrogen percent obtained for the Colby silty clay loam was 0.164 while the Muscatine silt loam gave a value of 0.223 percent. Frequent analyses for the carbon content of these soils were carried out at intervals resulting in an average carbon percent of 1.78 for the Colby and 3.29 for the Muscatine soil. Agreement of two analysts[3] in the Soils Laboratory at Kansas State College was within 0.20 percent error for carbon and 0.005 percent on nitrogen analysis.

Check Plots

In this experiment four plots in each series were designated as check plots on which only rotation practices were applied. To get a numerical value from these four plots that would represent the check plots, a simple average was taken. This practice of taking an average was reasoned as feasible in that it is proportional to the data used for other fertilizer treatments as these treatments were applied to only one plot in each series. In this way, the checks are considered as a separate fertilizer treatment and were treated as such

[3]Harold L. Stout, Cooperative Agent, Garden City Branch Experiment Station, and the author.

in the statistical analysis.

The method used by Metzger (28) to compensate for soil differences between plots within a series was to graph all carbon and nitrogen data in the same relative position as the plots occurred in the series. A straight line was drawn between the four check plots, and the value obtained at the intersection of this line with each intervening treatment plot was used as its check or base nitrogen and carbon level.

EXPERIMENTAL RESULTS

Original Data

Original data on nitrogen and carbon were obtained from the annual Experiment Station records for the years 1915 and 1934. Some of the data compiled in 1932, 1935 and 1936 appear as 1934 data. All of the data on nitrogen and carbon for 1946 were obtained by laboratory analyses as previously described.

Table 1. The carbon and nitrogen content, expressed as percent, of the surface seven inches of soil from the Soil Fertility plots, Manhattan, Kansas, obtained in 1915, 1934 and 1946 from each fertilizer treatment and cropping system studied.

Ro-	F_1			F_2			F_3			F_4		
tation	1915	1934	1946	1915	1934	1946	1915	1934	1946	1915	1934	1946
						Nitrogen						
16	.173	.139	.135	.180	.141	.139	.159	.136	.127	.170	.139	.129
	.194	.158	.148	.173	.154	.150	.187	.157	.152	.181	.158	.140
	.172	.150	.131	.168	.138	.136	.162	.142	.127	.165	.138	.129
	.157	.142	.130	.148	.147	.135	.150	.145	.143	.152	.140	.136
3	.163	.143	.134	.168	.151	.127	.162	.151	.136	.156	.143	.128
	.168	.142	.118	.163	.142	.131	.151	.130	.127	.153	.135	.128
	.165	.142	.133	.157	.146	.119	.140	.136	.120	.142	.131	.118
Wheat	.138	.137	.132	.140	.126	.133	.137	.115	.114	.133	.120	.119
						Carbon						
16	1.96	1.75	1.71	1.98	1.71	1.66	1.94	1.65	1.71	2.00	1.69	1.77
	2.23	1.88	1.77	2.04	1.89	1.77	2.09	1.84	1.78	2.04	1.80	1.75
	1.98	1.75	1.62	2.06	1.73	1.74	1.91	1.69	1.60	1.93	1.74	1.71
	1.81	1.79	1.53	1.79	1.81	1.73	1.79	1.74	1.84	1.81	1.78	1.66
3	2.10	1.89	1.74	2.00	2.02	1.68	1.94	1.92	1.85	1.94	1.73	1.59
	2.03	1.85	1.53	1.99	1.87	1.65	1.88	1.63	1.39	1.94	1.76	1.59
	2.20	1.62	1.52	2.05	1.63	1.45	1.86	1.49	1.49	1.89	1.52	1.51
Wheat	1.94	1.90	1.82	1.86	1.82	1.71	1.72	1.57	1.29	1.82	1.66	1.55

Statistical Analysis

Method for Analysis of Variance. According to the design of the experiment, the analysis of variance includes a set-up[4] to measure the percentage changes in nitrogen and carbon for the periods 1915 to 1934 and from 1934 to 1946.

The cropping systems include a 16-year rotation, a 3-year rotation and continuous wheat.

The fertilizer treatments, F_1, F_2, F_3 and F_4, as described on page 3, were applied uniformly throughout the experiment. For the 16-year rotation there are four plots that may be thought of as replications of each of the fertilizer treatments F_1, F_2 and F_3 since four series are required to make a complete rotation. The 3-year rotation has three plots and the continuous wheat has only one plot on which each fertilizer treatment was applied. Since each series in the experiment has four F_4, or check plots, there is a total of 16 F_4 plots in the 16-year rotation, 12 F_4 plots in the 3-year rotation and four F_4 plots on the continuous wheat. For the purposes of statistical analysis, the four F_4 plots from each series were averaged and these series averages for the 16-year and 3-year rotations again averaged to give a value comparable to the average of the four F_4 plots of

[4]Summary table and source of variance set-up by Dr. H. C. Fryer, Statistician, Agricultural Experiment Station.

the continuous wheat and the averages for fertilizer treatments within each rotation.

According to simple analysis of variance based on procedure by Paterson (36) variation was measured in base period 1915 and base period 1934 for nitrogen and carbon as shown in Table 2 for base nitrogen, and Table 3 in the Appendix for base carbon. Variation was also measured in percentage loss from the base year for nitrogen and carbon. The actual percentage loss is shown in Table 1 of the Appendix, while the statistical analysis of the percentage change from the base year for nitrogen is shown in Table 4. The statistical analysis of the percentage change from the base year for carbon is shown in Table 5 of the Appendix.

The variances and "F" ratios for base years on nitrogen and carbon and for percentage change from base year for nitrogen and carbon are represented in Table 2.

Table 2. The variance in nitrogen and carbon content of the surface seven inches of soil and in the yield in tons of dry matter per acre produced from the Soil Fertility plots, Manhattan, Kansas, represented by "F" ratios for each base period, and percentage change from the base period.

Source of variance	Base nitrogen 1915 with 1934	Base carbon 1915 with 1934	Change nitrogen 1915 to 34 with 1934 to 46	Change carbon 1915 to 34 with 1934 to 46	Yield 1915 with 1934
Total	2.68**	1.98*	1.38	1.17	27.34**
Systems	28.77**	1.71	2.51	2.99	147.04**
Fertilizer	2.61	4.73**	--	--	37.21**
System X Fertilizer	--	--	--	--	2.79*
Periods	62.57**	52.62**	19.24**	9.68**	1163.18**
Periods X Systems	1.30	1.29	4.37*	1.80	7.69*
Periods X Fertilizer	--	--	--	--	2.12

*Significance at the 5 percent level.
**Significance at the 1 percent level or less.

Trends in Nitrogen and Carbon. These studies were mainly concerned with the trends in nitrogen and carbon. In dealing with these soil-fertility components consideration was given the loss of carbon and nitrogen from the soil, as well as the source of nitrogen and carbon. As Gustafson (19) states, carbon and nitrogen may be added in various ways. One of those ways is by the addition of fertilizers, which will be discussed later. Carbon and nitrogen may be lost from the soil in a number of ways, as pointed out by Knoblauch, Kolodny and Brill (26) and Slater and Carleton (44). The only measurable means in this experiment by which the loss of nitrogen and carbon can be explained is by calculating the tons per acre of dry matter removed in the form of grain, hay, stubble and fodder. This is a partially erroneous method as illustrated in Table 5. Another error is the unknown residual qualities of various fertilizers in the soil. With this in mind, the influence of fertilizers on the nitrogen and carbon in the soil can be weighed. Table 4 shows the total fertilizer applications for the period of the experiment as well as changes in increments of fertilizers applied.

The analysis of variance for the nitrogen content based on the period 1915 to 1934 and on the period 1934 to 1946 showed a highly significant variation between cropping systems and periods. The period 1915 to 1934 had the highest initial nitrogen content, showing that there has been a loss of nitrogen over the entire period 1915 to 1946. The 16-year rotation had the highest nitrogen content but not significantly higher than the 3-year rotation. Both rotations had a higher nitrogen content than continuous wheat. These data are shown in detail in Table 2 of the Appendix.

The analysis of variance for loss of nitrogen showed significance only for the variation between periods. The 1915 to 1934 period showed the greatest loss. The loss of nitrogen between cropping systems was non-significant as well as the variation between fertilizer treatments. The interaction between periods and systems was significant probably due to variation in the periods as given in Table 4 of the Appendix.

The base carbon content showed significant variation between periods as did the base nitrogen. Unlike nitrogen, carbon varied significantly between fertilizer applications. This is shown clearly by the data in Table 3 of the Appendix. The complete fertilizer treatment (F_3) was the lowest in base carbon and superphosphate (F_1) was the highest. This variation can be relatively correlated to yield in which the reverse of this was true. The largest amount of dry matter has been removed from the plots with F_3 treatment. Superphosphate (F_1) plots only slightly exceed the check plots in amount of dry matter removed.

Like nitrogen the variation in carbon loss was significant only between periods.

Carbon presents essentially the same picture as described for nitrogen. The average total carbon was the same for both

16-year and 3-year rotation. On the analysis of covariance in which regression was calculated for base carbon content and change in carbon content, the deviation from regression absorbed most of the variation, therefore, making the association of those paired values nonsignificant. Relative comparison can be made, however, with the graph method to note minor changes as to loss and rate of loss of carbon between different rotations and continuous wheat.

Regressions between base nitrogen and loss of nitrogen as well as between base carbon and loss of carbon were nonsignificant. Most of the variation was absorbed by deviation from regression.

Observations, largely relative, from graphic representations, as shown in Figs. 1 and 2, and general comparisons were more important than statistical analyses in this paper. The graphic method is used to represent general trends of nitrogen, carbon, production of dry matter and the application of fertilizer.

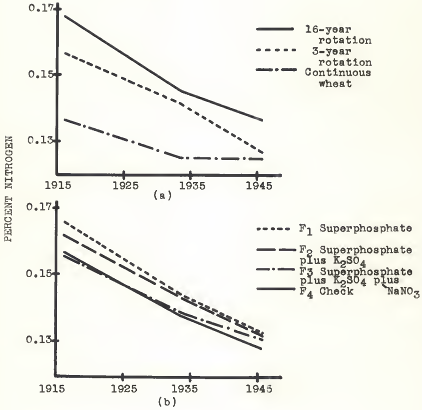

Fig. 1. Trend of total nitrogen in percent in the surface soil, Soil Fertility Experiment, Manhattan, Kansas. (a) Cropping system; (b) Fertilizer treatment.

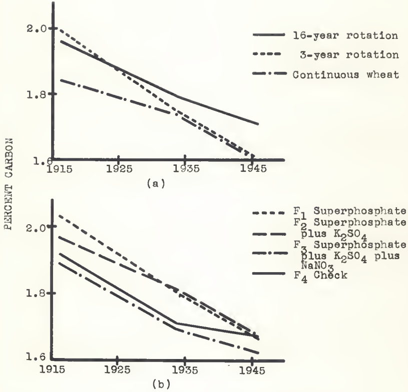

Fig. 2. Trend of total carbon in percent in the surface soil, Soil Fertility Experiment, Manhattan, Kansas. (a) Cropping system; (b) Fertilizer treatment.

Results from the graphs in Fig. 1 on base nitrogen content show highly significant variation between periods and between systems for the whole experiment. The 16-year rotation had the highest total nitrogen content but not significantly greater than the 3-year rotation. Both the 16-year and the 3-year rotations had a significantly higher total nitrogen content than the continuous wheat.

The period 1915 to 1934 had significantly higher total nitrogen in the soil than the period 1934 to 1946. This obviously shows a loss of total nitrogen over the entire 30-year period. Regardless of the fertilizer or cropping system, there has been a continual loss of carbon and nitrogen over the 30-year period 1915 to 1946. According to Figs. 1 and 2 and the statistical analyses, methods of which were taken from Paterson (36), the nitrogen content of the soil was greater in the 1915 to 1934 period than in the period 1934 to 1946.

The rate of loss for the 16-year rotation in the period 1915 to 1934 was greater than that of the 3-year rotation. In the period 1934 to 1946, the rate of loss was essentially the same on these two cropping systems.

Continuous wheat has reached the most stable position in regard to total loss of nitrogen and the rate of loss; however, there was still loss regardless of treatment. The rate of loss of nitrogen did not vary significantly between cropping systems, whereas, the total nitrogen showed a significant variation. This would indicate the rate of loss was lessening and the total nitrogen content tending to reach an equilibrium under the cultivation practices used on this type of soil.

Over the entire 30-year cropping period there was no significant difference between any of the fertilizer treatments as far as total nitrogen and loss of nitrogen was concerned.

The superphosphate (F_1) had the highest total nitrogen and highest loss of nitrogen. The superphosphate plus potassium sulfate (F_2) had the next highest total nitrogen and the next correspondingly highest loss of nitrogen. The F_3 fertilizer treatment had the third highest total nitrogen but the loss of nitrogen was less than the check plots. There is no significant difference between F_3 and F_4. These two fertilizer treatments can be considered essentially the same as far as average nitrogen was concerned and also as far as the change in nitrogen was concerned. This is in agreement with findings of other investigators, Prince, Toth, Blair and Bear (8), who found that the greatest yields resulted when nitrate of soda was added to the soil; but those soils contained the least nitrogen over a 40-year experimental period.

The 16-year rotation and the 3-year rotation had essentially the same total carbon content in 1915. The 3-year rotation had a slightly higher loss of carbon over the entire period and the rate of loss within the period 1934 to 1946 seemed to be greater for the 3-year rotation than the 16-year rotation. The rate of loss of carbon for continuous wheat during the last period, 1934 to 1946, corresponds to that of the 3-year rotation, both being greater than the 16-year rotation. This loss was probably due to the accelerated erosion that is in evidence as shown by the eroded phase of the soil type where the larger part of the 3-year rotation and continuous wheat are located.

The results of this experiment indicate that the higher the total nitrogen, the higher the total loss and the greater the rate of loss in all instances--between cropping systems, between fertilizer treatments and between periods.

The 16-year rotation was not significantly better than the 3-year when considering the initial nitrogen and carbon content and the extra amount of fertilizer needed to feed alfalfa on the 16-year rotation.

The superphosphate plots had the highest total carbon content for the entire period, but not significantly higher than superphosphate plus potassium sulfate plots. The check plots had a higher total carbon content than the complete fertilizer plots.

In connection with the loss of nitrogen, other investigators, Gainey, Sewell and Latshaw (18), who observed the nitrogen balance in cultivated semi-arid soil, are in agreement with these findings that with a high nitrogen content there was a greater loss. The continuous small grain crop seemed to be conducive of the smallest changes in nitrogen content; and, the loss of nitrogen on the rotations studied was more than on the continuous grain alone.

DISCUSSION

General Discussion

Metzger (28) suggested that there was a fairly definite nitrogen and carbon level for a given soil type and climate which is characteristic of the cropping system and the tillage methods employed. Jenny (21) pointed out a definite relationship between climate and the nitrogen and carbon content of the soil. When moisture is constant, an increase in annual temperature causes soil nitrogen and organic carbon to decrease while if temperature is constant, nitrogen and carbon will increase with an increase in annual moisture. Jenny (21) also stated that deviations in nitrogen values were due to physical and chemical properties of the soil, age, topography, geological origin, soil climate, vegetation and cultivation. There was a significant negative correlation of 0.90 between soil nitrogen and temperature for semi-humid upland soils (mainly Prairie soil). This means that with precipitation and evaporation constant for each 10 degrees Fahrenheit rise in temperature, the total nitrogen and carbon decrease two to three times.

According to Figs. 1 and 2, showing trends in nitrogen and carbon, there was a tendency for a leveling off of these two factors with long-time cropping systems. In accordance with Metzger (28), it seems that the greater the extent of intertilled crops, possibly accelerating erosion, the lower the nitrogen and carbon level becomes.

Nitrogen and Carbon

The amount of nutrients and organic matter lost from the soil, thought of as trends in nitrogen and carbon, are measured by successive observations of the nitrogen and carbon content of the surface soil, amount of dry matter produced, leaching and erosion. By far the greatest factor is erosion as shown by Slater and Carleton (47), who found that organic matter loss actually measured from runoff plots was greater than was indicated by analysis of plot soil. Knoblauch, Kolodny and Brill (26) state that the average loss of organic matter from a Collington sandy loam soil by erosion was 4.2 times the loss from the check plots where no erosion occurred. The average loss of nitrogen from the eroded plots was 3.9 times that lost from the check plots. Martin (27) on the same soil type, Collington sandy loam, found that eroded material contained from three to eight times as much organic matter as the soil itself. Knoblauch, Kolodny and Brill (26) recorded that erosion is not a uniform process and that variable factors influence the amount of erosion. Among these factors the character of rainfall, type of soil, degree of slope, soil treatment and previous use are important. Collington sandy loam would be different from Geary silty clay loam, or other soil types, in the amount of organic material and nutrients removed by erosion. Nevertheless, this can be used as an illustration that larger quantities of nitrogenous complexes and hemicelluloses are found in the eroded material as compared with the original soil. This is probably due to selective erosion of certain fractions of the organic matter possibly because of differences in the specific gravities of certain fractions of the organic matter. Lighter fractions and more readily soluble fractions of organic matter would be carried away by run-off to a greater degree than the heavier materials.

In Alabama, Jones (23) found that on various cropping systems leaching was closely related to the texture of the soil, i. e., the nitrogen loss decreased as the clay content of the soil increased. Cropping decreased the amount of nitrogen that was leached but leaching was more pronounced on sandy soils.

In New York, Gustafson (19) stated that on Lordstrom silt loam and on Lansing and Dunkirk silt loams, large quantities of organic matter were lost by oxidation such as the burning of straw, weeds and stubble. This, however, would not be a cause for loss of organic matter on the soil fertility plots at Manhattan, Kansas. Organic matter and nitrogen may be added to the soil, according to Gustafson (19), by the use of lime, nitrogen, phosphorus and potassium fertilizers; pasture grasses; cover crops of legumes; plowing under green manure, farmyard manure or crop residues; and by practicing crop rotation.

The only increase in organic matter and nitrogen noted by recent data from the Soil Fertility Experiment, with regard to the aforementioned points, was from pasture grasses on Series X, which was permitted to return to grass by natural seeding in 1933 after continuous cropping of alfalfa for 22 years. Green manure, farm manure, cover crops and plowed-under residue were not studied. However, no significant increases in nitrogen and carbon due to fertilizer treatments or cropping systems in the form of 16-year and 3-year rotations were in evidence with these studies.

Due to the type of soil, amount of rainfall and the drainage factors involved on a prairie soil such as the Geary silty clay loam, it is assumed that very little leaching occurred and, therefore, all organic matter and nutrient loss was accounted for by crop removal or erosion. Volatilization of organic materials and nitrogen in the soil were not measured in this experiment. Erosion remains as the most important factor in the loss of nutrients and organic matter from the surface soil.

As reported by Smith and Vandecaveye (48) organic matter and nitrogen in wheat land soils of Eastern Washington continued to decline regardless of biennial applications of nitrogen fertilizer and crop residues alone or combined. This is in agreement with the trends of nitrogen and carbon in Eastern Kansas on Geary silty clay loam soil.

From tests with lysimeters Morgan, Jacobson and Street (30) showed that the leaching of nitrate and ammonia nitrogen was small in magnitude; however, there was a net loss of both nitrogen and carbon in all cases. This may indicate again that nitrogen losses are mainly brought about by erosion and crop removal. Olson and Roberts (35) in their studies on nonsymbiotic nitrogen fixation on a silt loam soil found that the rate of nitrogen fixation was not affected by phosphatic or potassic fertilizers. Prince, Toth, Blair and Bear (38) said that more nitrogen was removed in the harvested crop than was added when this element was applied in the form of nitrate of soda. They found nitrate of soda to be the most effective carrier of nitrogen, the yield being greater than from any other form of nitrogen applied. They also showed that soil receiving nitrate of soda contained the lowest nitrogen content over the 40-year period studied. This is in complete agreement with results from this study as shown by nitrogen equilibrium graphs in Figs. 1 and 3 and Table 9 on average soil nitrogen of the different fertilizer treatments. At Brookings, South Dakota, Puhr (40) found that loss of soil nitrogen from plots receiving nitrogen fertilizer seemed to be somewhat higher than from the check plots. The loss of nitrogen from fertilized plots was attributed largely to crop removal. Fuhr (40) also found that application of sodium nitrate did not maintain the soil nitrogen level, or that any accumulation of soil nitrogen resulted from synthesis of nitrates by soil microorganisms into organic nitrogen. The fact that sodium nitrate in combination with potassium sulfate and superphosphate did not increase soil nitrogen is in agreement with this paper. A possible explanation of this is the increased uptake of nitrogen by plants in the presence of high amounts of available nutrients, thus, resulting in an abundance of nitrogen in the soil above that required by plants. This may then stimulate a breakdown of the humus complexes in the soil nitrogen, bound in organic forms, resulting in a loss of soil nitrogen over and above that which may have been added to the soil in the form of fertilizer. As stated by White (55), liberal application of mineral nitrogen as measured by long-time field experiments has stimulated the decay of organic matter in excess of such action by mineral fertilizer without nitrogen. This is in agreement with the results obtained from the Fertility plots at Manhattan, Kansas, in that the plots with a complete fertilizer showed the lowest carbon content.

Another possible explanation for the influence of fertilizers on the trends of carbon and nitrogen in the soil is that of microbial activity, since an increase in the numbers of microorganisms may cause a reduction of nitrogenous compounds in the soil according to the conditions present. As far as the oxidation process is concerned, nitrates are oxidized to nitrites by action of heterotrophic organisms. According to Waksman (53, p.458), nitrification in the soil obeys the law of autocatalysis; i. e., the reaction at first is slow, then becomes more rapid and finally comes to a standstill as a result of accumulation of nitrates. Plants, in absorbing this nitrate supply, could keep a high speed nitrification reaction by organisms going, resulting in increased absorption of nitrates by higher plants, increased yield, increased numbers of microorganisms present and an increase in the amount of organic food that those organisms need as a source of energy. This would account for a depletion of the soil carbon content.

On Honeoye glacial till soil derived from limestone in New York, Free (16) pointed out that during the summer period erosion on a nine percent slope has been about two times that on a five percent slope. The slope variation on the Soil Fertility plots ranges from two to seven percent. If this can be used as an indication in conjunction with variations in the type of soil, the seven percent slope will have increased erosion above that of the two percent slope. Free (16) also stated that in general as the percent slope increases, the organic matter content of soils decreases and the rate of infiltration of water becomes slower. The fact that the

3-year rotation is on a steeper slope may be a plausible explanation as to why the loss of carbon was greater on the 3-year rotation of the Soil Fertility experiment than on the 16-year rotation. The slower infiltration of water on a steeper slope and its influence on the amount of water remaining in the soil for crop production may have affected yields resulting in lower yields on the 3-year rotation in comparison with the 16-year rotation than can be attributed to variations in cropping systems.

Fertilizers

The mineral fertilizers unaccompanied by any organic carriers, according to Metzger (28), were less effective than cropping systems in maintaining the nitrogen and carbon content of the soil and, among those used, the complete fertilizer took low rank. This is found to be true, in general, of mineral fertilizers; however, the nitrogen level maintained by the complete fertilizer has been increasing when compared with that of the check plots and rises slightly above that of the check plots.

The carbon content is a different story. In this case, the check plots have maintained a higher carbon percentage than complete fertilizer throughout the entire experiment. The abrupt rise in carbon content from 1934 to 1946 may be due to sampling error or possibly to an accumulation of straw through additions made at harvest time simply because a combine has been used with which more dry straw, mostly cellulose, was returned to the soil. This may also explain why the carbon content did not increase on the other mineral fertilizer plots. These plots had enough food nutrients available on which organisms could live while decomposing the added organic matter. The check plots, on the other hand, had no added nutrients and the decomposition of cellulose or straw was probably slower. Therefore, over a period of time less decomposition occurred, giving rise to more residual carbon in the soil as was evident by analyses of the soil.

Generally, speaking, there was no significant difference between fertilizer treatments where nitrogen was concerned. There was significant difference between fertilizers for carbon. That is, the superphosphate plots were significantly higher in carbon than the complete fertilizer or the check plots, but not significantly better than superphosphate plus potassium sulfate (F_2) plots.

The average pounds per year of fertilizer actually added on each series for the respective fertilizers were comparable in amounts. The 16-year rotation may appear to have had more fertilizer actually applied, but when the feeding requirement of alfalfa is considered, the effective difference is slight. The variation in amounts applied in each period was due to the uneven overlap of the different rotations from period to period. Some of this variation was caused by an increase in the rate of application of superphosphate in 1942, especially noticeable on Series VIII. The period 1934 to 1946 probably had a slightly higher application of fertilizer on all the series except Series IV. In general, fertilizer application is considered to be comparable over the entire period for all rotations. This may be more or less of an assumption but it is based upon the requirement of different plants for nutrients and is complicated by the physiology of plants in their uptake of plant food. Microbiological activity would also play a part. Therefore, for all practical purposes the fertilizer amounts applied must be considered comparable when the crops grown are considered.

Series IV had the highest actual application of all fertilizers, F_1, F_2 and F_3, in the period 1915 to 1934 on the 16-year rotation, however, it is interesting to note that the base carbon content was the lowest and the loss was less than any other series in the 16-year rotation. This is explained by White (56), who stated that a liberal application of mineral nitrogen, as measured by long-time field experiments, stimulated the decay of organic matter in excess of such action by mineral fertilizers without nitrogen. A further study could be made as to the correlation of actual amounts of different fertilizers added by various methods to the carbon content of the surface soil. In this regard, it may be possible for the addition of inorganic fertilizer to stimulate the activity of organisms enough to break down the "hard-to-decompose" humus fraction causing a net loss in total organic matter.

Table 3. The rate of fertilizer application in pounds per acre on the 16-year rotation, 3-year rotation and continuous wheat on the Soil Fertility plots, Manhattan, Kansas, in the form of superphosphate (S), potassium sulfate (K) and sodium nitrate (N) showing original application and changes in application.

Year and Fertilizer[1]	Plot	16-year rotation											
		I			II			III			IV		
		Fertilizer application pounds per acre											
		S	K	N	S	K	N	S	K	N	S	K	N
		Corn			Wheat			Corn			Alfalfa		
1916													
F_1	1	75			80			75			190		
F_2	4	75	50		80	40		75	50			180	
F_3	6	75	50	110	80	40	80	75	50	110	190	180	240
		Corn			Alfalfa			Wheat			Wheat		
1942													
F_1	1	75			190			150			150		
F_2	4	75	50		190	180		150	40		150	40	
F_3	6	75	50	110	190	180	240	150	40	80	150	40	80

Table 3 (concl.).

Year and Fertilizer[1]	Plot	3-year rotation									Continuous wheat		
		V			VI			VII			VIII		
		Fertilizer application pounds per acre											
		S	K	N	S	K	N	S	K	N	S	K	N
		Corn			Wheat			Cowpeas			Wheat		
1916													
F_1	1	75			80			90			80		
F_2	3	75	50		80	40		90	70		80	40	
F_3	6	75	50	110	80	40	80	90	70	100	80	40	80
		Wheat			Soybeans			Corn			Wheat		
1942													
F_1	1	150			90			75			150		
F_2	3	150	40		90	70		75	50		150	40	
F_3	6	150	40	80	90	70	100	75	50	110	150	40	80

[1] F_1, F_2 and F_3 represent fertilizer treatments of superphosphate; superphosphate plus potassium sulfate; and superphosphate, potassium sulfate and sodium nitrate, respectively.

Table 4. Pounds of fertilizer actually added per acre per year to the Soil Fertility plots, Manhattan, Kansas, 1915 to 1934 and 1934 to 1946 for each cropping system in the form of superphosphate (S), potassium sulfate (K) and sodium nitrate (N).

Rotation and series	Fertilizer	1915-34 F_1	1915-34 F_2	1915-34 F_3	1915-34 F_4	1934-46 F_1	1934-46 F_2	1934-46 F_3	1934-46 F_4
16-Year									
I	S	102.5	102.5	102.5		127.1	127.1	127.1	
	K		75.0	75.0			89.2	89.2	
	N			127.2				140.8	
II	S	102.7	102.7	102.7		115.3	115.3	115.3	
	K		74.4	75.0			88.3	88.3	
	N			125.5				138.3	
III	S	94.2	94.2	94.2		132.9	132.9	132.9	
	K		69.4	69.4			89.2	89.2	
	N			120.5				140.8	
IV	S	115.3	115.3	115.3		89.6	89.6	89.6	
	K		89.4	89.4			39.2	39.2	
	N			141.7				80.8	
3-Year									
V	S	81.7	81.7	81.7		93.3	93.3	93.3	
	K		53.3	53.3			53.3	53.3	
	N			96.7				96.7	
VI	S	81.7	81.7	81.7		87.5	87.5	87.5	
	K		53.3	53.3			53.3	53.3	
	N			96.7				96.7	

Table 4 (concl.).

VII	S	81.7	81.7	81.7	87.5	87.5	87.5
	K		53.3	53.3		53.3	53.3
	N			96.7			96.7
Continuous wheat VIII	S	80.0	80.0	80.0	103.3	103.3	103.3
	K		40.0	40.0		40.0	40.0
	N			80.0			80.0
Average		92.3	78.0	88.9	104.6	83.9	92.2

The average rates of fertilizer application in pounds per acre on the various crops as represented by the 1916 data are indicated in Table 3. These rates were followed up to 1942, when rates of application on wheat were changed from 80 to 150 pounds per acre. The legume in the 3-year rotation was changed from cowpeas to soybeans in 1928; however, the rate of application of fertilizer was not changed on these crops.

Yield

The yield data were compiled from the annual Experiment Station reports and divided into periods for statistical analysis in the same manner as the data on nitrogen and carbon, as shown in Table 6 of the Appendix. The period 1911 to 1934 was used because some of the total data on dry matter were already available. Average data for this period were considered as comparable to the average data for 1915 to 1934.

Yield data in tons per acre per year are an average value[5] obtained by using the yield per plot of the grain, straw, fodder or hay, as the case might be, in each series for the years involved. The bushels of grain were converted to pounds by multiplying by 60 for wheat and by 70 for corn. The total pounds of dry matter for each period were used to obtain the average tons of dry matter produced per acre per year

[5]Compiled from the annual report of the Experiment Station.

within a given fertilizer treatment and rotation, as seen in Table 10.

The yield in the period 1911 to 1934 was expected to be higher than in the period 1934 to 1946 for three reasons: First, the straw harvested in the 1911 to 1934 period was included in the yield, whereas due to the type of machinery used in harvesting during the period 1934 to 1946 more straw was returned to the soil; second, the drought of 1934, 1935 and 1936 decreased yields materially; and third, the failure of alfalfa crops and inability to get crop yields in 1944.

The trend in yields of crops could be an indication that the nitrogen content of the soil was coming to an equilibrium. This is not definitely shown because of so many interacting factors of soil, climate and various farming practices. H. E. Myers and H. O. Myers (32) report that nitrogen was not the only factor involved in increased yields. Other factors such as soil structure, aeration and other physical conditions may have a more lasting effect on the soil. For example, Jones (23) stated that nitrogen lost by leaching was closely related to the texture of the soil, i. e., the nitrogen loss decreased as the clay content increased. This may explain why yields are sometimes so misleading, especially over long periods of time when climatic, chemical, biological and physical factors of the substrate and the atmosphere interact.

The yield in terms of pounds of dry matter, including grain, hay, straw and fodder, was compiled in one table based on the procedure of analysis described for nitrogen and carbon on page 11 and, therefore, takes in consideration the same periods. The data used in Fig. 3 for the graphical comparisons are given in Table 5.

Table 5. The average yield per acre per year including grain, straw, fodder and hay for each fertilizer treatment on the Soil Fertility plots, Manhattan, Kansas, for the periods 1911 to 1934 and 1934 to 1946.

Rotation and series	1911-34				1934-46			
	F_1	F_2	F_3	F_4	F_1	F_2	F_3	F_4
16-Year								
I	2.51	2.67	2.76	2.47	1.53	1.75	1.86	1.53
II	2.80	2.95	3.11	2.55	1.87	2.11	2.18	1.70
III	2.29	2.47	2.68	2.19	1.46	1.41	1.60	1.18
IV	2.46	2.65	2.65	2.27	1.11	1.74	1.71	1.46
3-Year								
V	2.14	2.41	2.42	2.07	1.13	1.28	1.37	1.17
VI	2.23	2.18	2.39	1.94	1.19	1.22	1.47	1.20
VII	2.41	2.16	2.14	1.96	1.10	1.16	1.25	1.04
Wheat								
VIII	2.07	1.91	1.91	1.49	1.24	1.26	1.38	0.90

Table 6. Average annual yields of dry matter produced in tons per acre, by cropping system and fertilizer treatment during the 30-year period, 1915 to 1946, on the Soil Fertility plots, Manhattan, Kansas.

Cropping systems and fertilizer treatments	Tons dry matter produced
16-year rotation	2.12
3-year rotation	1.71
Continuous wheat	1.52
Superphosphate (F_1)	1.84
Superphosphate plus K_2SO_4 (F_2)	1.96
Superphosphate plus K_2SO_4 plus $NaNO_3$ (F_3)	2.06
Check plots (F_4)	1.69

Carbon : Nitrogen Ratio

The check plots are the best means of comparing cropping systems as stated by Metzger (28). This is done by using the carbon : nitrogen ratio. Carbon : nitrogen ratios for 1915 and 1934 were taken from Metzger (28) and the average carbon : nitrogen ratio for 1946 from laboratory analyses of 1946 soil. These data are used in table form to illustrate differences in 16-year rotation, 3-year rotation and continuous wheat and in differences between combinations of these cropping systems. Table 7 gives these data.

Table 7. The influence, as measured by the Chi-square test, of cropping systems on the ratio of carbon to nitrogen in the surface seven inches of soil from the Fertility plots, Manhattan, Kansas, for the years 1915, 1934 and 1946.

Cropping system	Carbon : nitrogen ratios				Difference of means 1915-1946	Chi-square test
	1915	1934	1946	Average		
16-year rotation	11.68	12.15	12.96	12.28	1.25	6.370
3-year rotation	12.66	12.26	12.53	12.48	-0.13	0.280
Continuous wheat	13.55	13.76	13.47	13.59	-0.06	0.023

The Chi-squared test as explained by Paterson (36) was used to test the difference between the 1915 and 1946 carbon : nitrogen ratios. The carbon : nitrogen ratio in relation to accumulation of organic matter, according to Salter (44), is one of the most changeable and yet one of the most constant relationships in the soil. On this basis and because of the fact that it is generally agreed that the carbon : nitrogen ratio fluctuates very little, a hypothesis was set up. The hypothesis was that the carbon : nitrogen ratio did not fluctuate but stayed essentially the same throughout the entire 30-year period. The expected value used was the average of the carbon : nitrogen ratios over the entire period including the 1934 figure. The Chi-squared value is listed in comparing carbon : nitrogen ratios in 1915 and 1946.

The carbon : nitrogen ratio was significantly widened over the entire period for the 16-year rotation. This change is not always explainable. Metzger (28) stated that a widened carbon : nitrogen ratio from 1915 to 1934 might possibly be accounted for by the substitution of wheat for one year of corn in the rotation in 1922. This reasoning is substantiated by Salter and Green (45), who said that a crop of corn was twice as destructive of organic matter and nitrogen as a crop of wheat. This continued widening of the carbon : nitrogen ratio in the 16-year rotation from 1934 to 1946 can be explained in the following manner: There was a relationship between carbon : nitrogen and yield as noted here. The wider ratio on the 16-year rotation was a result of an increased yield. The increase in carbon : nitrogen ratio due to the change in rotation in 1922 of wheat for corn resulted in more straw returned to the soil in the form of stubble. In later years when combines were used, still more straw was incorporated in the soil.

As a general rule, according to Rubins and Bear (42), the wider the carbon : nitrogen ratio of a substance, the less immediately available the nitrogen is to plants. This might result in a slightly higher total nitrogen percent in soil as was shown by trends in nitrogen from 1934 to 1946 for the 16-year rotation. This nitrogen was probably bound up in nitrogenous organic compounds or in the bodies of organisms, the numbers of which increase appreciably upon the addition of organic food.

There was no significant change in the carbon : nitrogen ratio in the 3-year rotation and in the continuous wheat plots or on the check plots for the entire 30-year period.

To compare the carbon : nitrogen ratios between cropping systems, a comparison was made between the 16-year and 3-year rotations, 16-year rotation and continuous wheat and the 3-year rotation with continuous wheat by the Chi-squared method already explained.

The carbon : nitrogen ratio as shown by Table 8 was wider on continuous wheat than either 16- or 3-year rotations when compared.

Table 8. Comparison of the carbon : nitrogen ratios between various cropping systems on the Soil Fertility plots, Manhattan, Kansas, using the Chi-squared method.

Comparison of averages within period 1915 to 1946	Chi-squared
16-year rotation with 3-year rotation	0.17
16-year rotation with continuous wheat	6.64*
3-year rotation with continuous wheat	4.72*

*Significant.

Comparisons of Average Yield
of Dry Matter from Fertilizer Treatments and Crop Rotations
with the Loss of Total Nitrogen and Carbon, Rate of Carbon
and Nitrogen Losses and the Carbon : Nitrogen Ratios

The original nitrogen content of the soil was higher on the plots with the 16-year rotation than on those with any other cropping system and, due to cultivation and other factors, tended to have a greater loss. The soil with the 3-year rotation, on the other hand, had a lower original nitrogen and a correspondingly lower loss; therefore, over the entire period the rate of loss of nitrogen was the same for the 16-year and 3-year rotation.

Loss of nitrogen on the continuous wheat plots has nearly reached an equilibrium according to these data; however, there was still a slight loss.

On this basis, the original percent of nitrogen being the same on either rotation, the 16-year and 3-year rotations can be considered to be the same with respect to nitrogen trends. Further comparison reveals that more dry matter actually was removed on an average from the 16-year rotation. This difference shows up because of greater tonnage of alfalfa removed during the rotation when alfalfa had three crops per year for four years. This probably is not a fair comparison with soybeans or cowpeas in the 3-year rotation and partially brings out the fallacy that must exist in yield comparisons between cropping systems such as these.

Table 9. Comparisons of average yield of dry matter with total nitrogen, loss of nitrogen, total carbon, loss of carbon and carbon : nitrogen ratios, for fertilizer treatments and crop rotations on the Soil Fertility plots, Manhattan, Kansas.

	Av. yield tons per acre per year	Av. total nitrogen	Av. loss nitrogen	Av. total carbon	Av. loss carbon	Average carbon : nitrogen ratio of all plots
		Percent				
Fertilizer treatment						
F_1	1.84	0.155	0.017	1.92	0.19	12.38
F_2	1.96	0.153	0.015	1.89	0.15	12.35
F_3	2.06	0.148	0.013	1.79	0.14	12.09
F_4	1.69	0.147	0.014	1.82	0.14	12.38
Rotations						
16-year	2.12	0.157	0.016	1.86	0.13	11.85
3-year	1.71	0.149	0.015	1.86	0.20	12.48
Continuous wheat	1.52	0.131	0.009	1.79	0.12	13.66

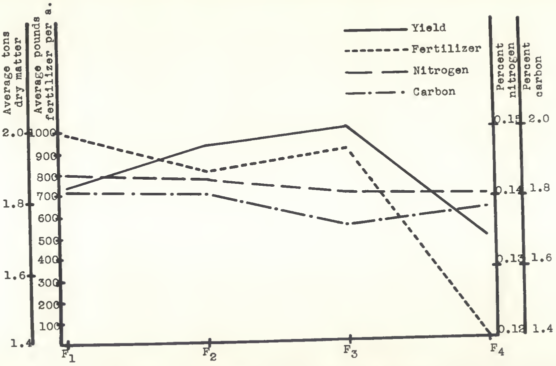

Fig. 3. Comparison of total fertilizer added for a 30-year period with average yearly production of dry matter; average total nitrogen and average percent carbon of the surface soil from the Soil Fertility Experiment, Manhattan, Kansas.

In each case where fertilizer was used, the yield was higher than on the check plots as shown by yield data in Table 9 and Fig. 3. Yield in tons of dry matter per acre per year was the highest where complete fertilizer was used. A possible explanation is that more nitrogen was available for plant growth as well as for the decomposition of organic matter and did not remain in the soil. The relationship of $NaNO_3$ and K_2SO_4 to the superphosphate of the fertilizer treatment F_3 may be the explanation. As Coleman (14) determined in greenhouse experiments, when nitrogen was adequately supplied, plants not only responded to phosphorus but required large amounts of nitrogen. This is a possible explanation for the fact that the plots on which the fertilizer F_3 was applied were lowest in total carbon and nitrogen contents. It also had the least loss of carbon and nitrogen which would be expected generally when the total contents of these elements are less. The yield was high on F_3, however, and may be explained by physiological relationships of the plants to nitrogen and phosphorus in the soil. As Miller (29, p. 306) stated, nitrogen and phosphorus in the soil together will result in greater synthesis of nitrogenous organic compounds. Possibly, for these reasons, F_3 was more completely utilized than the other fertilizers in the production of nitrogenous organic compounds; hence, it stimulated less accumulation of nitrogen and carbon in the soil.

The plots where the complete fertilizer was used, F_3, gave a slightly narrow nitrogen : carbon ratio and a correspondingly higher yield of dry matter per acre; but, on the other hand, had a lower total nitrogen content than any of the plots with other fertilizer treatments. The fact that nitrogen was added in F_3 may explain the higher yield over other fertilizers. In obtaining the yields shown by the plots with the F_2 fertilizer treatment, some nitrogen must have been supplied by nitrogen fixing organisms. The addition of extra organic matter to any of these plots did not result in an added fixation of organic carbon by an increased nitrogen addition. In the F_2 treated plots the carbon : nitrogen ratio was a little wider than in the plots with F_3 treatment, indicating that larger amounts of organic carbon were fixed in the soil where the source of nitrogen was from microbial activity rather than from commercial fertilizer.

The residual effect of commercial nitrogen in the soil in the form of $NaNO_3$ was indicated to be less than where nitrogen was supplied by the activity of microorganisms. In general, all the fertilizers used, except F_3, may be considered as giving an increase in nitrogen and carbon because the losses where these fertilizers, F_1 and F_2, were applied are less than on the check plots. Also, as a general observation, one component of nitrogen and carbon cannot be added and retained in the soil unless the other component is also supplied. The carbon : nitrogen ratios of the soils from the various plots remained generally the same regardless of fertilizer treatment.

Table 10 gives the average amounts of fertilizers added per acre per year as calculated from Table 4 in which the average values for each fertilizer used by period is given. This represents as nearly as possible an amount of fertilizer comparable to that added under field conditions to each fertilizer treatment in the experiment.

Table 10. Average annual application by periods in pounds per acre of fertilizers used on the Soil Fertility plots, Manhattan, Kansas.

	F_1	F_2	F_3	F_4
1915 - 1934	92.3	78.0	88.9	0
1934 - 1946	104.6	83.9	92.2	0
Average for 1/10 acre	98.75	80.95	90.55	0
Average for 1 acre	984.5	809.5	905.5	0

SUMMARY

Nitrogen and carbon studies of the surface seven inches of a prairie soil have been conducted since 1911 on the Soil Fertility plots at the Kansas Agricultural Experiment Station, Manhattan, Kansas. This thesis contains the results of 1946 samplings on these plots. Comparisons were made of long-time trends in nitrogen and carbon with fertilizer applications, crop rotations, yields of dry matter, carbon : nitrogen ratios and climatic conditions. This study has resulted in the following conclusions:

1. There has been a continual over-all loss of nitrogen and carbon over the entire 30-year cropping period studied regardless of cropping system or fertilizer treatment.

2. Plots with the highest nitrogen content at the beginning of the experiment have shown the greatest loss.

3. There was no significant difference between fertilizer treatments, F_1, F_2, F_3 and F_4, with respect to soil nitrogen.

4. None of the fertilizer treatments have maintained soil nitrogen.

5. The loss of nitrogen was essentially the same on the 16-year and 3-year rotations while continuous wheat has nearly reached an equilibrium.

6. Plots treated with superphosphate had the highest carbon content compared with other fertilizer treatments, F_2,

F_3 and F_4.

7. The loss of carbon has been greatest on the 3-year rotation and continuous wheat as compared with the 16-year rotation.

8. The average carbon : nitrogen ratio on check plots remained unchanged throughout the 30-year experiment.

9. The carbon : nitrogen ratio of the 16-year rotation has widened slightly due to the substitution of wheat in the rotation for one year of corn in 1922.

10. The yield of total dry matter was highest for complete fertilizer (F_3) application and lowest on the check plots (F_4).

11. The yield of total dry matter was highest on the 16-year rotation and lowest on the continuous wheat.

12. The influence of erosion upon the loss of nitrogen and carbon has not been measured but has played an unmistakable part, especially on the lower slopes.

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APPENDIX

Table 1. The nitrogen and carbon for base periods 1915 and 1934 and the loss of nitrogen and carbon from period 1915 to 1934 and period 1934 to 1946 on the Soil Fertility plots, Manhattan, Kansas.

Rotation	1915–34								1934–46							
	F_1		F_2		F_3		F_4		F_1		F_2		F_3		F_4	
								Nitrogen*								
16-year	173	34	180	39	159	23	170	31	139	4	141	2	136	9	139	10
	194	36	173	19	187	30	181	23	158	10	154	4	157	5	158	17
	172	22	168	30	162	20	165	27	150	19	138	2	142	15	138	9
	157	15	148	1	150	5	152	9	142	12	147	12	145	2	140	7
3-year	163	20	168	17	162	11	156	13	143	9	151	24	151	15	143	15
	168	26	163	21	151	19	153	18	142	24	142	11	130	3	135	7
	165	23	127	11	140	4	142	11	142	9	146	27	136	16	131	13
Wheat	138	1	140	14	137	22	133	16	137	5	126	7	115	1	120	4
								Carbon**								
16-year	196	21	198	27	194	29	200	31	175	4	171	5	165	6#	169	8#
	223	35	204	15	209	25	204	23	188	11	189	12	184	6	180	6
	198	23	206	33	191	22	193	21	175	13	173	1#	169	9	174	0
	181	2	179	2#	179	5	181	3	179	26	181	8	174	10#	178	13
3-year	210	21	200	2#	194	2	194	22	189	15	202	34	192	7	173	13
	203	18	199	12	188	25	194	18	185	32	187	22	163	24	176	17
	220	58	205	42	186	37	189	37	162	10	163	18	149	0	152	1
Wheat	194	4	186	4	172	15	182	16	190	8	182	11	157	28	166	8

*To obtain percent nitrogen, divide each figure by 1,000.
**To obtain percent carbon, divide each figure by 100.
#Increase in carbon.

Table 2. Analysis of variance summary for comparing the variation in base nitrogen in 1915 with base nitrogen in 1934 on the Soil Fertility plots, Manhattan, Kansas.

Source of variance	D/F	S.S.	Variance	Calculated "F"	Table "F" 5%	Table "F" 1%
Total	63	15850.74	251.59**	2.68	1.56	1.77
Systems	2	4399.40	2699.70**	28.77	3.20	5.10
Fertilizer	3	735.55	245.18	2.61	2.81	4.24
System X Fertilizer	6	227.24	37.87	-	-	-
Periods	1	5871.27	5871.27**	62.57	4.05	7.21
Periods X System	2	244.77	122.38	1.30	3.20	5.10
Periods X Fertilizer	3	55.92	18.64	-	-	-
Error	46	4316.47	93.83	-	-	-

*Significant.
**Highly significant.

Table 3. Analysis of variance summary for comparing the variation in base carbon in 1915 with base carbon in 1934 on the Soil Fertility plots, Manhattan, Kansas.

Source of variance	D/F	S.S.	Variance	Calculated "F"	Table "F" 5%	Table "F" 1%
Total	63	15157.00	240.59*	1.98	1.56	1.77
Systems	2	417.17	208.59	1.71	3.20	5.10
Fertilizer	3	1725.38	575.13**	4.73	2.81	4.24
System X Fertilizer	6	611.55	101.91	-	2.30	-
Periods	1	6400.00	6400.00**	52.62	4.05	7.21
Periods X System	2	312.93	156.47	1.29	3.20	5.10
Periods X Fertilizer	3	95.37	31.79	-	2.81	-
Error	46	5594.60	121.63	-	-	-

*Significant.
**Highly significant.

Table 4. Analysis of variance summary for comparing the variation in loss of nitrogen in the period 1915 to 1934 with the period 1934 to 1946 on Soil Fertility plots, Manhattan, Kansas.

Source of variance	D/F	S.S.	Variance	Calculated "F"	Table "F" 5%	Table "F" 1%
Total	63	5627.75	89.33	1.38	1.56	1.77
Systems	2	324.82	162.41	2.51	3.20	5.10
Fertilizer	3	152.63	50.88	-	2.81	4.24
System X Fertilizer	6	345.51	57.59	-	2.30	3.22
Periods	1	1242.56	1242.56**	19.24	4.05	7.21
Periods X System	2	564.01	282.01*	4.37	3.20	5.10
Periods X Fertilizer	3	18.31	6.10	-	2.81	4.24
Error	46	2970.91	64.58	-	-	-

*Significant.
**Highly significant.

Table 5. Analysis of variance summary for comparing the variation in loss of carbon in the period 1915 to 1934 with the period 1934 to 1946 on the Soil Fertility plots, Manhattan, Kansas.

Source of variance	D/F	S.S.	Variance	Calculated "F"	Table "F" 5%	Table "F" 1%
Total	63	11112.94	176.40	1.17	1.56	1.77
Systems	2	904.85	452.43	2.99	3.20	5.10
Fertilizer	3	280.57	93.52	-	2.80	4.24
System X Fertilizer	6	591.07	98.51	-	-	-
Periods	1	1463.07	1463.07	9.68**	4.05	7.21
Periods X System	2	543.00	271.50	1.80	3.20	5.10
Periods X Fertilizer	3	375.30	125.10	-	-	-
Error	46	6955.08	151.20	-	-	-

*Significant.
**Highly significant.

Table 6. Analysis of variance summary for comparing variation of average yield in tons of dry matter per acre in the period 1911 to 1934 with the period 1934 to 1946 on Soil Fertility plots, Manhattan, Kansas.

Source of variance	D/F	S.S.	Variance	Calculated "F"	Table "F" 5%	Table "F" 1%
Total	63	204781.74	3250.50	27.34**	1.56	1.77
Systems	2	34962.78	17481.39	147.04**	3.20	5.10
Fertilizer	3	11487.55	3829.18	37.21**	2.81	4.24
System X Fertilizer	6	1988.08	331.35	2.79*	2.30	3.22
Periods	1	138291.02	138291.02	1163.18**	4.05	7.21
Periods X System	2	1828.02	914.01	7.69**	3.20	5.10
Periods X Fertilizer	3	755.54	251.85	2.12	2.81	4.24
Error	46	5468.75	118.89	-	-	-

*Significant.
**Highly significant.