EFFECT OF CROP ROTATION AND FERTILIZER TREATMENT ON THE NITROGEN AND CARBON CONTENT OF A PRAIRIE SOIL

by

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B.S., Kansas State College
of Agriculture and Applied Science, 1952

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1957

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INTRODUCTION

Since the last land frontiers in the United States have been occupied, considerable interest has been placed upon maintaining the productivity of the land.

High productivity of a soil for a certain crop implies that large yields of that crop can be obtained in relation to the labor required or to the cost of production. Some soils may be very productive for one crop and require specialized forms of management for production of other crops. The management practices may be simple, such as building drift fences; or they may be complex and include tillage, green manuring, fertilizers, drainage, and/or irrigation. Thus soil productivity may be most clearly conceived as being response to management. Yields alone are an inadequate measure of soil productivity.

Soil fertility is included in the concept of soil productivity, but refers only to the content, balance, and availability of the chemical compounds in the soil that influence plant growth.

The fertility in a sense must include all of the characteristics of the soil itself such as: depth, acidity, content of nutrients, slope, texture, degree of erosion, plus the climate. Each soil must be understood as a complex changing thing, subject to the forces of its environment. In time, the soil approaches an equilibrium in which the forces of depletion (leaching, erosion, and removal of plant material) balance the forces of renewal (addition of minerals, organic amendments, etc. to the top or bottom of the soil).

Many changes take place slowly in nature and depend upon the management practices and soil conditions.

The Kansas Agricultural Experiment Station, Manhattan, Kansas, has conducted investigations on the subject of soil fertility, with respect to the nitrogen and carbon content of the soil, for more than forty years. The material presented in this thesis is a continuation of these investigations in the Soil Fertility Project to determine the effect of management upon the nitrogen and carbon content of the soil.

This project was located on the SE 4.8 acres of the NW 1/4 of the SE 1/4 and the SE 6 acres of the NE 1/4 of the SE 1/4 of S1 T10S R7E. The area on which this experiment was located had been under cultivation since 1864. During the time from 1864 until this experiment was started in 1909, the land was planted to corn and occasionally to oats or wheat.

The soils in this area have been called tentatively Geary silt loam. The Geary series includes the well drained, moderately dark colored, moderately fine textured, Prairie soils which have developed on the reddish brown loess or loess-like materials believed to be of post-Illinoian age.

Nitrogen and carbon may be lost from the soil through leaching, erosion, crop removal, oxidation and volatilization. Cultivation tends to reduce permeability, thereby reducing the amount of leaching. The amount of erosion that may be expected depends upon the erodibility of the soil under particular management practices, including the kinds of crops grown, the layout of the field, and the method of tillage. Cultivation tends to lower the nitrogen and carbon content of the soil, thereby lowering the amount of material that will volatilize or oxidize.

In this experiment, the losses due to leaching probably have been negligible. The losses due to erosion were increased at various rates because of the rotations used and also the slope of the ground. Finally the losses due to oxidation and volatilization probably have been low during the period of this experiment since the land had been in cultivation a number of years prior to the start of this experiment.

REVIEW OF LITERATURE

Many investigators have studied the effect of management upon the fertility of the land. Jenny (6) pointed out a definite relationship between climate and the nitrogen and carbon content of the soil and stated that deviations in nitrogen values were due to differences in soil physical and chemical makeup, age, topography, geological origin, soil temperature, vegetation, and cultivation.

Jenny (7) page 257, stated that nature's quasi equilibrium state for total nitrogen was reached with the accumulation of total nitrogen as a function of time of soil formation under conditions of constant climate, biological environment and topography. When man entered the picture, some of these environmental conditions were changed. The nitrogen level then was altered because of the variety of methods of cropping and soil management that were introduced. Continuous cropping to corn had a destructive effect on soil fertility, whereas the intensive use of strong legumes preserved the original nitrogen content and in some instances increased it.

Jenny (7) page 233, in discussing the results of a 22-year experiment dealing with the effect of cropping on the total nitrogen content of the soil, stated that the most impressive features of the results were the rapid decline of soil nitrogen during the early periods and the damped oscillations in the later years. Similar results have been reported by Lipman and Blair (9) for soils in New Jersey.

Myers, et al (13) stated that there was a continuous decrease in soil nitrogen at Hays, Colby, and Garden City throughout their experiment, but there were indications that the nitrogen level was approaching a state of equilibrium for each cropping system and station. They also stated that the extent of the nitrogen and carbon depletion was definitely associated with the cropping systems for all the systems studied. The losses of both nitrogen and carbon also were associated with the original nitrogen and carbon contents of the soil. The continuous row crop, and the alternate row crop and fallow were the most destructive cropping systems for both nitrogen and carbon for all the systems studied.

Zook (19) of Nebraska reported that as the proportion of row crops decreased and the proportion of legumes plus small grain crops increased, the returns of organic matter and nitrogen usually became greater. Gosdin, et al (4) reported similar results

Salter and Green (14) found in Ohio that corn, their principal row crop, was about twice as destructive of organic matter as was wheat or oats and that legume hay crops materially reduced the annual losses. They also reported that continuous corn, oats, and wheat lowered the soil nitrogen content and that the longer a rotation containing only one legume, the higher the nitrogen loss. The results of a 10-year experiment by Lyon and Bizzel (10) in New York indicated a similar relationship between the frequency of occurrence of legume crops in rotation and soil organic matter and nitrogen content. Metzger (11) obtained substantially the same trend. He also stated that continuous alfalfa gave considerable increase in nitrogen content of the soil.

Lee and Bray (8) reported differences in organic matter in soil samples taken from fertilized and unfertilized plots. Their results indicated that organic matter could be maintained or built up, provided sufficient nitrogen and other soil nutrients were present. The inability of some of the treatments studied to maintain or increase the soil organic matter content therefore was ascribed primarily to the fact that sufficient nitrogen was not added to these otherwise fertile soils to balance crop removal and leaching. Prince, et al (15) and Puhr (16) on the other hand, reported that the additions of fertilizer materials have not prevented the decline of nitrogen and carbon in soils under various cropping systems.

While most of these investigations reported continued losses of nitrogen from the surface soil, Stewart (18) suggested three possible explanations to account for the failure of the surface soil to show a decrease in nitrogen under cultivation; (a) the translocation of nitrogen from lower levels to the surface, (b) the free fixation of nitrogen, and (c) the utilization of nitrogen by the wheat plant primarily in the lower strata, with the subsequent deposition of the nitrogen contained in the straw in the surface foot.

The results of an investigation on the subsurface soil (7-12 inches) by Miller (12) of Missouri revealed only very minor changes in the total nitrogen. Greaves and Jones (5) stated that probably there was a certain nitrogen content in some soils below which legumes may increase the soil nitrogen even where the complete crop was removed. For their soil in Utah, this nitrogen level was undoubtedly below 0.105 percent.

EXPERIMENTAL PROCEDURE

Design

The Kansas Soil Fertility Project was laid out systematically, with no previous investigations on the uniformity of the nitrogen and organic carbon content of the soil. This experiment consisted originally of ten series. Of these ten, two series were discontinued, one in 1932 and one in 1940. This study dealt with the remaining eight series. These series were arranged in two north and south columns with a road between. They were numbered beginning on the south with the odd numbered series on the east side of the road and the even numbers on the west side of the road. The first four series were occupied by a 16-year rotation consisting of alfalfa for four years and a corn, corn, wheat sequence for the remaining twelve years. This was changed in 1922 to four years of alfalfa and a corn, wheat, wheat sequence for twelve years. The next three series were occupied by a 3-year rotation consisting of corn, cowpeas, and wheat. In 1928 soybeans were substituted for cowpeas. Series VIII was seeded to wheat continuously.

Within each of the series, except Series VII, there were twelve 0.1-acre plots parallel to the center road. Series VII had fifteen plots. These plots were numbered beginning at the center road and proceeding both east and west. Plots 2, 5, 8, and 11 received no special treatments and were designated as check plots. The other plots received additions of mineral fertilizers, manure, etc.

Only the check plots and three other sets of plots received similar treatments in all rotations and for the duration of the study. Plot one in all rotations received a fertilizer treatment of phosphorus. Plot four in the 16-year rotation, and plot three in the 3-year rotation and continuous wheat were given a fertilizer treatment of phosphorus and potassium. Phosphorus, potassium and nitrogen were added to plot six in all rotations. These three treatments plus the check treatment will be referred to in the remainder of this report as treatments one, two, three, and four respectively.

Thus there were four replications of fertilizer treatments and 16 replications of the check plot in the 16-year rotation, three replications of the fertilizer treatments and 12 replications of the check plot in the 3-year rotation, and only one replication of each fertilizer treatment and four replications of the check plot in the continuous wheat system.

Sampling

As listed in the annual Soil Fertility Project reports, the first adequate sampling of these plots was accomplished in 1915. Later samplings of the plots were made in 1923, or immediately after each of the first four series was taken out of alfalfa, and in 1934, 1946, and 1956. In 1956 a composite sample consisting of twelve cores from the surface to a depth of six and two thirds inches was taken from each plot with a soil sampling tube. Care was taken not to include the surface residue in the samples. Composite samples consisting of six cores from six and two thirds inches to the depth of twenty inches were taken from the check plots in Series I and II. These samples were oven dried and ground in a Braun pulverizer.

Chemical Analysis and Laboratory Procedures

In the laboratory, the 1956 composite samples were analyzed for total nitrogen and carbon along with some selected samples from 1923 and 1934 which had been stored in mason jars on the Agronomy Farm.

The total nitrogen determination followed the Gunning-Hibbard procedure (2) page 32. The organic carbon was determined by Allison's modification of the Schollenberger method (1) using chromic acid. The factor of 0.115 was used to relate values obtained by this method to those obtained by the dry combustion method.

Check Plots

Four check plots were used in each series of this experiment. The results of these four check plots were totaled and the average was reported for the check treatment in each series. Since the fertilizer treatments had only one plot for each series, using the average figure for the check plots seemed reasonable. By this means the check plots were considered as another fertilizer treatment in the statistical analysis.

EXPERIMENTAL RESULTS

Nitrogen Storage Results

Since some of the soil samples taken at earlier dates were not analyzed it was necessary to determine if their analysis in 1956 would give reasonable values. To do this, some selected samples which were analyzed in 1923 and stored in mason jars were reanalyzed in 1956.

The results of these analysis showed that the 1923 results and the 1956 results agreed within the maximum permissible analytical error of 0.003 percent nitrogen.

Since there was no apparent loss of nitrogen from the stored samples, stored samples of the subsurface soil could be analyzed.

Subsurface Nitrogen Results

Although Miller (12) showed that subsurface nitrogen content did not change materially with continued cultivation, it seemed desirable to determine losses from subsoils of plots in this study. Subsoil samples were taken from the check plots of Series I and II in 1956. These samples were analyzed along with their respective counterparts taken in 1923 and 1934, and stored in mason jars.

The 1923, 1934, and 1956 results are shown graphically in Fig. 1.

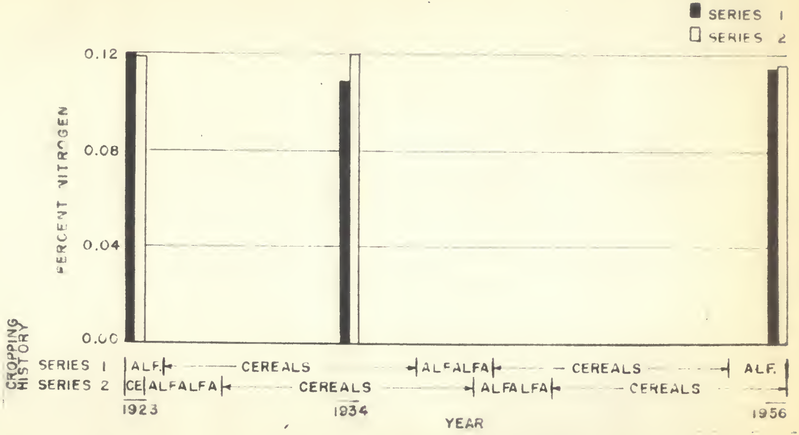

Fig. 1 The cropping history and the trend of the nitrogen content in the subsurface soil.

Series I and II were selected for investigation because they were similar in relation to the alfalfa in the rotation in 1923 and 1956. Series I was 10 years out of alfalfa in 1923. It was seeded to alfalfa in 1925 and again in 1943. By 1956, Series I was 11 years out of alfalfa. Series II in 1923 had been in alfalfa for two years. It was again seeded to alfalfa in 1939 and 1953. By 1956, Series II had been in alfalfa for three years.

The difference in amount of nitrogen in 1923 and in 1956 for Series I was 0.005 percent and for Series II was 0.002 percent. The experimental error allowed in analysis was 0.003 percent nitrogen. Series I percentage difference was slightly greater than the allowed analytical error and the Series II difference was within the analytical error.

Since both differences were so minor, it was concluded that the nitrogen content of the subsoil remained essentially the same. This plus the fact that Series VIII was terraced in the 1930's because it had been badly eroded, thus disrupting the surface and subsurface soil, made it inadvisable to continue further subsurface investigations. Therefore the remainder of this paper deals only with the surface data.

Original Data

Original data on nitrogen and organic carbon were obtained from the annual Soil Fertility Project reports for the years 1915 and 1934. Some of the data compiled in 1932, 1935, and 1936 are listed as 1934. The 1946 data were obtained from a master's thesis by Dodge (3). The 1956 data were obtained by laboratory analysis as previously described. These data are presented in Tables 1 and 2. The data are shown graphically in Plates I and II.

Table 1. Nitrogen in percent from the surface soils.

SERIES	Treatment 1				Treatment 2				Treatment 3				Treatment 4			
	1915	1934	1946	1956	1915	1934	1946	1956	1915	1934	1946	1956	1915	1934	1946	1956
16-year rotation																
I	.173	.139	.135	.131	.180	.141	.139	.125	.159	.139	.127	.143	.170	.139	.129	.129
II	.194	.158	.148	.120	.173	.145	.150	.132	.187	.157	.152	.139	.181	.158	.140	.130
III	.172	.150	.131	.148	.168	.138	.136	.137	.162	.142	.127	.141	.165	.138	.129	.133
IV	.157	.142	.130	.137	.148	.147	.135	.139	.150	.145	.143	.138	.152	.140	.136	.135
3-year rotation																
V	.163	.143	.134	.119	.168	.151	.127	.130	.162	.151	.136	.125	.156	.143	.128	.124
VI	.168	.142	.118	.118	.163	.142	.131	.119	.151	.130	.127	.121	.153	.135	.128	.114
VII	.165	.142	.133	.122	.157	.146	.119	.116	.140	.136	.120	.108	.142	.131	.118	.111
Continuous wheat																
VIII	.138	.137	.132	.123	.140	.126	.133	.121	.137	.115	.114	.108	.133	.120	.119	.113

Table 2. Carbon in percent from the surface soils.

SERIES	Treatment 1				Treatment 2				Treatment 3				Treatment 4			
	1915	1934	1946	1956	1915	1934	1946	1956	1915	1934	1946	1956	1915	1934	1946	1956
									16-year rotation							
I	1.96	1.75	1.71	1.87	1.98	1.71	1.66	1.58	1.94	1.65	1.71	1.69	2.00	1.69	1.77	1.71
II	2.23	1.88	1.77	1.62	2.04	1.89	1.77	1.68	2.09	1.84	1.78	1.67	2.04	1.80	1.75	1.53
III	1.98	1.75	1.62	1.70	2.06	1.73	1.74	1.70	1.91	1.69	1.60	1.63	1.93	1.74	1.71	1.63
IV	1.81	1.79	1.53	1.60	1.79	1.81	1.73	1.80	1.79	1.74	1.84	1.62	1.81	1.78	1.66	1.64
									3-year rotation							
V	2.10	1.89	1.74	1.37	2.00	2.02	1.68	1.66	1.94	1.92	1.85	1.55	1.94	1.73	1.59	1.50
VI	2.03	1.85	1.53	1.38	1.99	1.87	1.65	1.51	1.88	1.63	1.39	1.48	1.94	1.76	1.59	1.44
VII	2.20	1.62	1.52	1.42	2.05	1.63	1.45	1.39	1.89	1.49	1.49	1.35	1.89	1.52	1.51	1.38
									Continuous wheat							
VIII	1.94	1.90	1.82	1.58	1.86	1.82	1.71	1.64	1.72	1.57	1.29	1.33	1.82	1.66	1.55	1.35

EXPLANATION OF PLATE I

Fig. 1 The average nitrogen contents of the three cropping systems as affected by fertilizer treatments and length of cultivation.

Fig. 2 The average nitrogen contents of the four treatments as influenced by systems and length of cultivation.

PLATE I

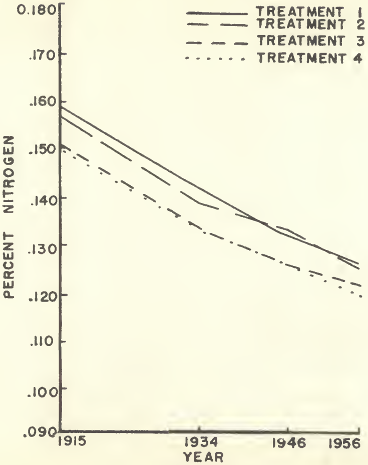

Fig. 1

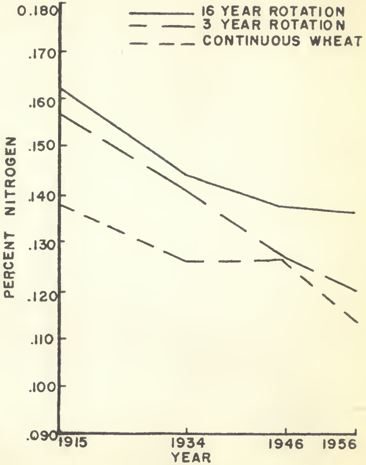

Fig. 2

EXPLANATION OF PLATE II

Fig. 1 The average carbon contents of the three cropping systems as affected by fertilizer treatments and length of cultivation.

Fig. 2 The average carbon contents of the four treatments as influenced by cropping systems and length of cultivation.

PLATE II

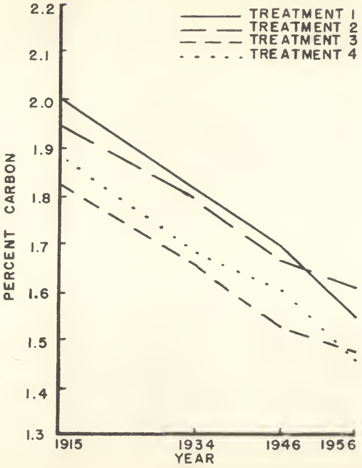

Fig. 1

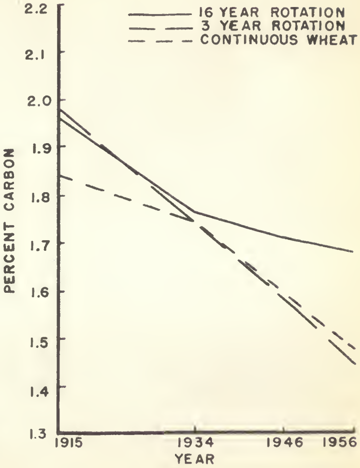

Fig. 2

Statistical Analysis of Surface Data

Justification of statistical analysis on the surface data is somewhat doubtful for the following reasons; (a) the systematic design of the experiment would bias the results, (b) one series had been terraced, (c) there was only one replication of the fertilizer treatments in the terraced series, and (d) no adequate soil investigations were conducted until six years after the experiment was started. In spite of these objections, it seemed desirable to attempt to test the significance of the differences. There are indications that the losses of nitrogen and organic carbon follow a curvilinear trend. Since there was an insufficient number of degrees of freedom to use curvilinear regression, only analyses of covariance, linear correlation and regression as described by Snedecor (17) were used to test the variance of the different cropping systems and treatments.

Nitrogen. The analysis of errors of estimate from average regression within treatments was computed for each cropping system. The results of these F tests (Table 3) indicate that the various treatments are from a homogeneous population for the three cropping systems studied. The regression coefficients (b) were computed for each treatment in the cropping systems. These are shown graphically in Plate III.

Table 3. Analysis of errors of estimate from average regression within treatments.

Sources of Variation	D/F	M.S.	F	Sign.
16-year rotation				
Deviation from individual treatment regression	11	2.89×10^{-5}	0.70	ns
Difference among treatment regression	3	2.02×10^{-5}		
3-year rotation				
Deviation from individual treatment regression	11	6.06×10^{-6}	0.39	ns
Difference among treatment regression	3	2.35×10^{-6}		

Table 3. (concl.)

Sources of Variation	D/F	M.S.	F	Sign.
Continuous wheat				
Deviation from individual treatment regression	11	$2.17X10^{-5}$	0.98	ns
Difference among treatment regression	3	$2.12X10^{-5}$		

D/F-degrees of freedom.
M.S.-mean square.
F-Fisher test.
Sign.-significance.

The analysis of covariance was computed for the treatments within the cropping systems and an F test for significance of the adjusted treatment means was made (Table 4). The results of these tests indicate that there were no significant differences between the treatments in the 16-year rotation, however, treatment one (phosphate) had the greatest rate of loss of nitrogen (Fig. 1 of Plate III). There were highly significant differences between the treatments in the 3-year rotation and in the continuous wheat series (Table 3). The regression coefficients (b) for treatments one and two (phosphate, and phosphate and potassium) were greatest in the 3-year rotation (Fig. 2 of

Table 4. Test for significance of adjusted treatment means.

Sources of Variation	D/F	M.S.	F	Sign.
16-year rotation				
Within treatments	11	$26.4X10^{-6}$	0.33	ns
For test of significance of adjusted means	3	$8.67X10^{-6}$		
3-year rotation				
Within treatments	11	$1.53X10^{-5}$	9.34	**
For test of significance of adjusted means	3	$14.3X10^{-5}$		
Continuous wheat				
Within treatments	11	$2.15X10^{-5}$	8.09	**
For test of significance of adjusted means	3	$18.3X10^{-5}$		

D/F-degrees of freedom.
M.S.-mean square.
F-Fisher's test.
Sign.-significance.

EXPLANATION OF PLATE III

Fig. 1 Regressions of percent nitrogen on years for the treatments in the 16-year rotation.

Fig. 2 Regressions of percent nitrogen on years for the treatments in the 3-year rotation.

Fig. 3 Regressions of percent nitrogen on years for the treatments in the continuous wheat.

PLATE III

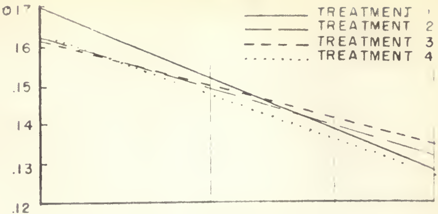

Fig. 1

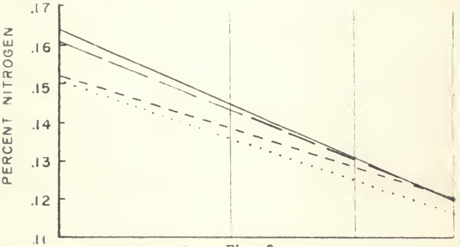

Fig. 2

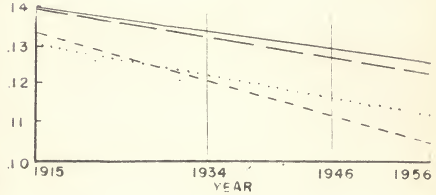

Fig. 3

Plate III) and the regression coefficient (b) for treatment three (phosphate, potassium, and nitrogen) had the greatest value in the continuous wheat series (Fig. 3 of Plate III). The fact that treatment three had the greatest regression coefficient in the continuous wheat can probably be explained, since apparently more subsurface soil was exposed on this plot than on the other plots studied.

Since there were no significant differences between the regression coefficients of the treatments within the cropping systems, these regression coefficients were plotted on a graph (Fig. 2) with respect to the original nitrogen content in 1915 of their respective plots. A regression coefficient was computed for the regression coefficients within a cropping system. The t test was used to test the significance between these regression coefficients. The results of these t tests (Table 5) indicate that the regression coefficients (rate of loss of nitrogen based upon the 1915 content) for the 16-and 3-year rotation are quite similar, but significantly different from the regression coefficient for the continuous wheat plots. This may be due to the original content of nitrogen of the various cropping systems or to the cropping system

Table 5. The t test of the regression coefficients of the regression coefficient upon the percent nitrogen in 1915.

Cropping systems compared	t	Sign.
Rate of loss of nitrogen from the 16-year rotation compared to that of the 3-year rotation	1.54	ns
Rate of loss of nitrogen from the 16-year rotation compared to that of the continuous wheat.	23.05	**
Rate of loss of nitrogen from the 3-year rotation compared to that of the continuous wheat.	14.37	**

t-t test.
Sign.-significance.

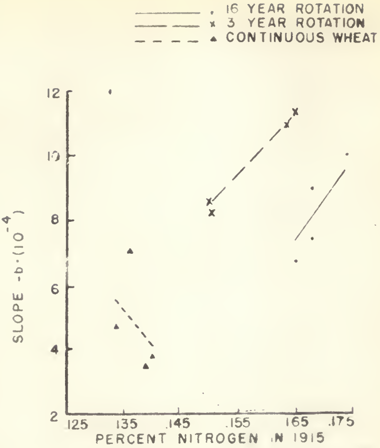

Fig. 2 Relationship of the rate of decline of soil nitrogen and the percent of nitrogen in 1915.

used. However, the regression coefficient for the 3-year rotation was the largest with the regression coefficient for the 16-year rotation next, and the regression coefficient for the continuous wheat being the smallest. This indicates that there was a greater loss of nitrogen from the 3-year rotation than from the 16-year rotation, and both of these were greater than that from the continuous wheat.

Carbon. The analysis of errors of estimate from average regression within treatments was computed for the carbon content for each of the cropping systems. The results of the F tests (Table 6) indicate that the various treatments were from a homogeneous population for the 16-year rotation and the continuous wheat, but not for the 3-year rotation.

Table 6. Analysis of errors of estimate from average regression within treatments.

Sources of Variation	D/F	M.S.	F	Sign.
16-year rotation				
Deviation from individual treatment regression	11	$4.41X10^{-3}$	1.46	ns
Difference among treatment regression	3	$6.47X10^{-3}$		
3-year rotation				
Deviation from individual treatment regression	11	$8.62X10^{-4}$	9.97	**
Difference among treatment regression	3	$86.0X10^{-4}$		
Continuous wheat				
Deviation from individual treatment regression	11	$5.01X10^{-3}$	1.27	ns
Difference among treatment regression	3	$6.37X10^{-3}$		

D/F-degrees of freedom.
M.S.-mean square.
F-Fisher's test.
Sign.-significance.

The regression coefficients (b) were computed for each treatment in the various cropping systems. These are shown graphically in Plate IV.

Since the treatments within the 3-year rotation were not from a homogeneous population, analysis of covariance could not be computed for that

EXPLANATION OF PLATE IV

Fig. 1 Regressions of percent organic carbon on years for the treatments in the 16-year rotation.

Fig. 2 Regressions of percent organic carbon on years for the treatments in the 3-year rotation.

Fig. 3 Regressions of percent organic carbon on years for the treatments in the continuous wheat.

PLATE IV

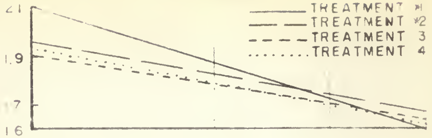

Fig. 1

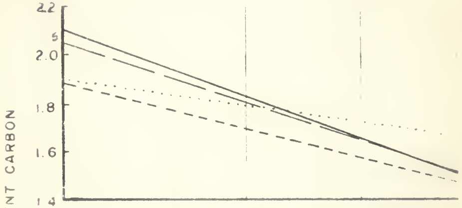

Fig. 2

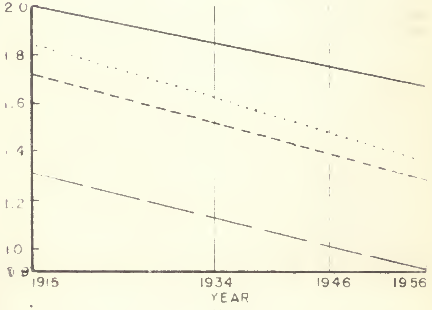

Fig. 3

cropping system. However, the analysis of covariance was computed for the treatments within the 16-year rotation and the continuous wheat plots. The F test for significance of the adjusted treatment means was computed and is shown in Table 7. The results of this test indicate that there were no significant differences between the treatments within the 16-year rotation, however, treatment one had the greatest rate of loss of carbon as shown in Fig. 1 of Plate IV. There was a significant difference between the different treatments in the continuous wheat. This again is probably due to the amount of subsurface soil exposed when this plot was terraced. This is brought out by the fact that the treatments having the greatest losses of organic carbon have a larger part of their surface covered by terraces.

Table 7. Test for significance of adjusted treatment means.

Sources of Variation	D/F	M.S.	F	Sign.
16-year rotation				
Within treatments	11	$4.91X10^{-3}$	0.90	ns
For test of significance of adjusted means	3	$4.43X10^{-3}$		
Continuous wheat				
Within treatments	11	$1.99X10^{-3}$	46.58	**
For test of significance of adjusted means	3	$92.7X10^{-3}$		

D/F-degrees of freedom.
M.S.-mean square.
F-Fisher's test.
Sign.-Significance.

The analysis of errors of estimate from average regression within cropping systems was computed for each treatment. The results of these F tests (Table 8) indicate that the cropping systems are from a homogeneous population for treatments three and four, but not for treatments one and two. The analysis of covariance was computed for the cropping systems within treatments three and four. The F test for significance of the adjusted means was

Table 8. Analysis of errors of estimate from average regression within treatments.

Sources of Variation	D/F	M.S.	F	Sign.
Treatment one				
Deviation from individual cropping systems regression	6	$3.13X10^{-3}$	9.10	**
Difference among cropping systems regression	2	$28.5X10^{-3}$		
Treatment two				
Deviation from individual cropping systems regression	6	$2.17X10^{-3}$	6.30	**
Difference among cropping systems regression	2	$13.6X10^{-3}$		
Treatment three				
Deviation from individual cropping systems regression	6	$3.27X10^{-3}$	1.67	ns
Difference among cropping systems regression	2	$5.45X10^{-3}$		
Treatment four				
Deviation from individual cropping systems regression	6	$1.11X10^{-3}$	4.61	ns
Difference among cropping systems regression	2	$5.15X10^{-3}$		

D/F-degrees of freedom.
M.S.-mean square.
F-Fisher's test.
Sign.-Significance.

computed and is shown in Table 9. These tests show highly significant differences between the cropping systems for the two treatments studied, with the 3-year rotation and the 16-year rotation having the greatest losses.

Table 9. Test for significance of adjusted treatment means.

Sources of Variation	D/F	M.S.	F	Sign.
Treatment three				
Within cropping systems	6	$5.08X10^{-3}$	16.00	**
For test of significance of adjusted means	2	$81.3X10^{-3}$		
Treatment four				
Within cropping systems	6	$3.00X10^{-3}$	9.50	**
For test of significance of adjusted means	2	$28.5X10^{-3}$		

D/F-degrees of freedom.
M.S.-mean square
F-Fisher's test
Sign.-significance.

DISCUSSION OF RESULTS

This experiment showed that the nitrogen and organic carbon levels decreased throughout the period studied for the three cropping systems and the four treatments (Plates I and II). The most rapid losses of nitrogen and organic carbon appeared in the earlier part of the experiment. Losses seemed to be related to the original level. The losses of nitrogen and organic carbon appear to be approaching an equilibrium for each cropping system and treatment. Myers, et al (13) and Lipman and Blair (9) reported similar results.

The greatest losses of nitrogen and organic carbon occurred under the 3-year rotation and the next greatest losses occurred under the 16-year rotation. The 3-year rotation contained one-third row crop and one-third legume while the 16-year rotation contained only one-fourth row crop and one-fourth legume. This indicates that the greatest losses were associated with the row crop, and the losses that occurred while the land was in row crop were not balanced when the land was in a legume crop for the same length of time. Similar results were reported by Zook (19) and Gosdin, et al (4).

There were losses of nitrogen and organic carbon for all treatments studied. Treatment one (phosphate) had the greatest loss of both nitrogen and organic carbon in the 3-year rotation. The complete fertilizer had the greatest loss in continuous wheat, but this can be discarded since apparently more subsoil was exposed on this plot when this series was terraced. In general the addition of the complete fertilizer tended to retard the loss of nitrogen by replacing some of the nitrogen that was utilized by the crop, and to retard the loss of organic carbon by producing more residue which was later incorporated in the soil.

The nitrogen in the subsurface layer (6 2/3 to 20 inches) did vary slightly over a period of 33 years, but this variation did not exceed 0.01 percent nitrogen. This difference occurred between samples taken from Series I when it was in the second year of alfalfa and the tenth year of cereals. This small loss apparently was made up when the series was seeded to alfalfa again. Thus it would appear that even alfalfa, in the long run, did not increase the nitrogen content of the subsoil. Miller (12) of Missouri reported similar results.

CONCLUSIONS

The results of this study on the Soil Fertility Project showed a decrease in the productivity of the soil, with respect to nitrogen and organic carbon, over the period studied.

The rate of decrease of the nitrogen and carbon content of the soil was quite rapid at first for the 16-year and the 3-year rotations, and then tended to approach an equilibrium with the new environments. The losses of nitrogen and organic carbon were smaller in the continuous wheat plots. The losses of both nitrogen and carbon tended to be associated with the original contents.

Treatments of phosphate, and phosphate and potassium tended to permit the greatest losses of both nitrogen and organic carbon, while treatment with a complete fertilizer tended to retain the highest level of productivity.

Soil samples can be stored in mason jars for several years before being analyzed without loss of nitrogen or organic matter.

Alfalfa in a rotation did not appreciably change the nitrogen content of the subsoil.

ACKNOWLEDGMENT

The author wishes to express his appreciation to his major instructor, Dr. J. A. Hobbs, for his interest and guidance during the research work and preparation of this thesis.

Acknowledgment is due Dr. H. C. Fryer for his help in the statistical analysis.

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EFFECT OF CROP ROTATION AND FERTILIZER TREATMENT ON THE NITROGEN AND CARBON CONTENT OF A PRAIRIE SOIL

by

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B.S., Kansas State College
of Agriculture and Applied Science, 1952

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1957

Since our last land frontiers have been occupied, much emphasis has been placed upon maintaining the productivity of the soil.

In 1910 an experiment was established on the Kansas State College Agronomy Farm at Manhattan, Kansas to study the effects of cropping systems and treatments upon the productivity of a Geary silt loam soil, as measured by the total nitrogen and organic carbon content.

The cropping systems included a sixteen year rotation consisting of four years of alfalfa, and a corn, wheat, wheat sequence for twelve years; a three year rotation consisting of corn, soybeans (for hay), and wheat; and continuous wheat.

There were four treatments in the study: (1) phosphate fertilizers, (2) phosphate and potassium fertilizer, (3) phosphate, potassium, and nitrogen fertilizer, and (4) no treatment or check.

Samples were taken in 1915, 1934, 1946, and 1956 from the surface soil (surface to a depth of six and two thirds inches) and from the subsurface soil (six and two thirds to a depth of twenty inches).

Samples taken in 1956 were oven dried, ground in a Braun pulvizer, and analyzed for total nitrogen and organic carbon.

These data along with the existing data were analyzed statistically by the use of covariance, correlation, and regression.

The results from this experiment indicated that losses of nitrogen and organic carbon appear to be related to the original content of nitrogen and organic carbon in the soil. Losses were most rapid in the earlier years of the study. Losses of nitrogen and organic carbon were less in the continuous wheat plots than in plots under rotation including row crops and legumes in addition to wheat. Greatest losses occurred under a three year rotation of corn, soybeans, and wheat.

Losses of nitrogen and organic carbon were similar under all fertility treatments studied except that losses of organic carbon were larger under treatments of phosphate alone and potassium and phosphate. Complete fertilizer application caused the maintenance of the highest nitrogen and organic carbon levels.

Alfalfa in a rotation did not appreciably change the nitrogen content of the subsoil.

The nitrogen content of soil samples which had been stored in mason jars for 41 years did not change during the period of storage.