

AGRICULTURAL EXPERIMENT STATION

KANSAS STATE COLLEGE OF AGRICULTURE
AND APPLIED SCIENCE

MANHATTAN, KANSAS

Nitrogen and Organic Carbon of Soils as Influenced by Cropping Systems and Soil Treatments



PRINTED BY KANSAS STATE PRINTING PLANT
W. C. AUSTIN, STATE PRINTER
TOPEKA 1939
17-8570

TABLE OF CONTENTS.

	PAGE
INTRODUCTION.....	5
EXPERIMENTAL METHODS.....	5
EFFECTS OF CROPPING SYSTEMS.....	7
ALFALFA IN RELATION TO NITROGEN ACCRETION.....	9
EXTENT AND DURATION OF THE EFFECT OF ALFALFA ON AVAILABLE NITROGEN.....	12
CARBON : NITROGEN RATIOS.....	15
EFFECT OF FERTILIZERS, MANURE, AND LIME ON THE NITROGEN AND CARBON OF THE SOIL.....	16
16-year rotation.....	17
3-year rotation.....	19
Continuous wheat.....	20
Continuous alfalfa.....	20
DIRECT EFFECT OF MANURE AND GREEN MANURE ON SOIL NITROGEN AND CARBON.....	21
DISCUSSION.....	24
SUMMARY.....	24
LITERATURE CITED.....	26
APPENDIX.....	29

Nitrogen and Organic Carbon of Soils as Influenced by Cropping Systems and Soil Treatments¹

W. H. METZGER

INTRODUCTION

The soil-fertility field experiments of the main branch of the Kansas Agricultural Experiment Station involve comparisons of several cropping systems, and within the systems various lime, manure, and fertilizer treatments are provided. These experiments were begun in 1910. A study of the nitrogen and carbon of the soil of the various plats, after approximately 25 years of cropping, has been completed recently and is reported in this publication.

The literature dealing with the broader aspects of this subject is so voluminous that no attempt at a comprehensive review will be made. Certain publications dealing with special phases of the subject, will be cited in the appropriate succeeding paragraphs. Even with this restriction, many meritorious papers cannot be mentioned.

EXPERIMENTAL METHODS

At the time the plats were established in 1910, certain soil samples were taken; and nitrogen and organic carbon were determined. Insufficient samples were taken, however, to make possible a satisfactory comparison of the original content of these constituents with that of the present. The plats were first adequately sampled, and nitrogen and carbon determined in 1915. They were sampled again during the period 1932-1934. Not all the plats were sampled the same season since it was desired, insofar as possible, to sample the soil of the various cropping systems while under the same crop. Twelve soil cores were systematically taken from each one-tenth acre plat, and composited to provide the sample representing the plat. Such samples were taken in sections to the following depths: 0 - $6\frac{2}{3}$ inches, $6\frac{2}{3}$ - 20 inches, and 20 - 40 inches. Since the most active and the most easily changed organic matter is found in the 0 - $6\frac{2}{3}$ inch layer, only the data relating to this layer will be dealt with here.

The cropping systems include a 16-year rotation (alfalfa, four years and a corn, wheat, wheat rotation for 12 years); a three-year rotation (corn, soybeans, and wheat); continuous wheat; and continuous alfalfa. Cowpeas were used in the three-year rotation in place of soybeans until 1929. In the 16-year rotation, the 12-year

Credit is due R. I. Throckmorton for supervising the collection of samples in 1915 and 1928; C. O. Swanson, for analyzing the 1915 samples; and F. L. Duley and E. S. Lyons, for collecting samples and for a part of the data relating to nitrates from the "alfalfa-wheat" experiment. Credit is also due H. H. Laude for advice regarding statistical treatment of data.

1. Contribution No. 276, Department of Agronomy.

period was devoted to a corn, corn, wheat rotation until 1922, when a system of corn, wheat, wheat was substituted. In each of these cropping systems, there are four control plats in each series, except that in one series of the three-year rotation there are five such plats. There is included in the 16-year rotation one plat in each series which has Brome grass as the sod crop in place of alfalfa. In the three-year rotation, there is one plat in each series devoted to a corn, corn, wheat rotation, with no legume. Another plat in this series has a similar rotation, except that a green manure crop of cowpeas is grown after each wheat crop.

All samples were taken from wheat stubble land except those from the continuous alfalfa experiment, and one of the four series of the 16-year rotation, which was sampled under alfalfa sod. In all the experiments involved in these studies, all crop growth was removed, leaving only stubble and roots as residues.

Another experiment was utilized in order to study the effect of the alfalfa crop on nitrogen accretion. This experiment involved 26 plats; nine were devoted to continuous wheat culture; and 17 were utilized for a study of the effect of varying the alfalfa cropping periods upon succeeding wheat crops and upon soil nitrogen. The alfalfa cropping periods varied from one to nine years, and all except the one-year period were represented by duplicate plats. This experiment will be referred to in the succeeding pages as the "alfalfa-wheat" experiment.

The experiments are all located on the same soil type; namely, Derby silt loam. This soil is a moderately leached soil developed under a grass cover, and has a dark to very dark brown, loose, friable, and weakly granulated surface soil. The subsoil is reddish brown to bright reddish brown, moderately compact, with fragmental structure. There is no CaCO_3 , above the 36-inch level. The land on which the experiments are located is gently rolling and erosion has caused some variability in the depth of the surface soil.

The samples were digested for the nitrogen determinations according to the Gunning-Hibbard procedure, distilled into four percent boric acid, and titrated with $\text{N}/7 \text{H}_2\text{SO}_4$ in the presence of brom-cresol-green and methyl red. Carbon was determined by the Schollenberger method, using the procedure outlined by Allison (1). Through the kindly cooperation of Dr. H. G. Byers of the Bureau of Chemistry and Soils, a preliminary set of determinations was made to verify the factor 1.15 as reported by Allison to relate the values obtained by the Schollenberger method with those obtained by furnace combustion. A group of six samples analyzed in the laboratory here by the Schollenberger method were submitted to Doctor Byers and analyzed in the laboratories in Washington, using the dry combustion procedure. The average factor relating the results was in good agreement with Allison's factor; and his procedure was therefore adopted in its entirety. Since the 1915 determinations were made by furnace combustion, and the required apparatus is no

longer available, it was felt the procedure outlined by Allison offered the best available means of obtaining results comparable with those obtained in 1915.

EFFECTS OF CROPPING SYSTEMS

In a previous publication (7) the effects of the four major cropping systems upon the soil's nitrogen and carbon content, as measured from four unfertilized plats devoted to each system, were presented. The carbon determinations have since been repeated, using the method proposed by Allison (1) in place of the wet combustion method (*Methods of Analysis*, 2d edition, A. O. A. C.) used in the previous work. The values presented at that time were comparable among themselves but not comparable directly with those obtained from the samples analyzed in 1915 by the dry combustion method. Also, data from all the plats of each cropping system are now available and are summarized in Table I.

From the equation proposed by Salter and Green (11), $N_t = N_0K^t$ in which N_t is the nitrogen or carbon after "t" years and N_0 is the nitrogen or carbon at the beginning, "K" values were calculated for each cropping system. The "K" values for wheat and alfalfa in continuous culture were inserted into the equation for the 16-year rotation and a "K" value for corn thus obtained. Since "K" represents the fraction of the nitrogen or carbon remaining after the equivalent of a single year of cropping, the difference between 100 and the "K" values expressed as percent represents the annual percentage loss or gain. The values thus obtained are listed in Table II.

The results presented in Tables I and II offer three rather clear indications; *i. e.*, (1) alfalfa is not only soil conserving, but is distinctly a soil-building crop, especially from the standpoint of nitrogen; (2) wheat is soil depleting, but only moderately so; and (3) corn is decidedly soil depleting, being about two to three times as destructive of nitrogen and carbon as wheat or either of the two rotations. The destructive nature of the corn crop is probably accounted for by: (1) Leaching, while the plants are small and using little water from the land; (2) excessive aeration of the soil as a result of the intensive cultivation; and (3) greater erosion under the corn crop as compared to the close-planted crops. Of these factors, the latter is probably the most important under the conditions prevailing at Manhattan.

It seems rather surprising that the three-year rotation of corn, soybeans, and wheat, should not have produced greater relative losses, particularly of nitrogen, than are shown. However, it will be noted that there was less nitrogen in this soil in 1915 than in that of the 16-year rotation. It may be that there was also less nitrogen in the three-year rotation soil in 1910, or that this soil suffered a more rapid decline of nitrogen and carbon during the period 1910-1915 than those under the other cropping systems. The same may be true, to some extent at least, of the values for the soil under con-

TABLE I. NITROGEN AND ORGANIC CARBON IN THE SOIL OF UNFERTILIZED PLATS UNDER VARIOUS CROPPING SYSTEMS IN 1915 AND IN 1934. THE CHANGES AND ODDS¹ FOR THEIR SIGNIFICANCE

CROPPING SYSTEM.	Nitrogen in pounds per acre for the year indicated.		Difference.	Odds.	Organic carbon in pounds per acre for the year indicated.		Difference.	Odds.
	1915.	1934.			1915.	1934.		
16-yr. rotation ²	3,321	2,872	-449	> 10,000 to 1	38,840	34,940	-3,900	9,000 to 1
3-yr. rotation ³	3,009	2,725	-284	5,000 to 1	38,280	33,400	-4,880	>10,000 to 1
Continuous wheat ⁴	2,685	2,405*	-280	63 to 1	36,350	33,100*	-3,250	15 to 1
Continuous alfalfa ⁴	2,550	2,910	+360	27 to 1	32,050	34,775	+2,725	4 to 1

1. Student's method, using Love's tables. 2. Average of 16 plats. 3. Average of 13 plats. 4. Average of 4 plats. * 1932.

TABLE II. PERCENTAGE ANNUAL GAINS OR LOSSES OF NITROGEN AND ORGANIC CARBON OF THE SOIL AS AFFECTED BY CROPS AND CROPPING SYSTEMS

CROP OR CROPPING SYSTEM.	Percentage annual gain or loss.	
	Nitrogen.	Organic carbon.
16-year rotation.....	-0.78	-0.59
3-year rotation.....	-0.50	-0.68
Wheat, continuous.....	-0.64	-0.56
Alfalfa, continuous.....	+0.71	+0.43
Corn (calculated).....	-2.18	-1.21

tinuous wheat. However, the soils of the continuous wheat experiment and of the continuous alfalfa experiment were very probably poorer in nitrogen and carbon at the beginning than those devoted to the rotations.

The changes of nitrogen and carbon contents of the soil of each cropping system are supported by significant odds, except in the cases of the carbon changes for the continuous wheat and the continuous alfalfa plats. Extensive variability accounted for the somewhat low odds supporting the indicated carbon decline in the wheat plats. One of the four measurements of carbon change for the alfalfa plats was in reverse order from that of the remaining three. The result is very low odds to support the indicated change. This plat contained 40,200 pounds of organic carbon in 1915.

The results are similar to those obtained by Salter and Green (11) at the Ohio station. They found corn to be from two to three times as destructive of nitrogen and carbon as four other cropping systems studied. Smith, Brown, and Peevey (12) have also shown the destructive effect of corn culture on soil nitrogen and organic matter.

ALFALFA IN RELATION TO NITROGEN ACCRETION

The continuous alfalfa experiment, and the "alfalfa-wheat" experiment offer an opportunity for a rather systematic study of the effect of the growth of alfalfa upon the nitrogen content of soil. In Table II it was shown that, over a period of 19 years, alfalfa in unfertilized plats increased the nitrogen of the soil at the rate of 0.71 percent per year. Since few alfalfa stands survive that long, the question arises as to the efficiency of the crop in increasing the nitrogen content of the soil during a shorter period of growth. The soil of the continuous alfalfa experiment was sampled in 1923, in addition to the 1915 and 1934 samplings, and the nitrogen data for the three samplings furnish some evidence bearing on this point. The data for all plats of the series are presented in Table III.

The data of Table III indicate that alfalfa continued to build up the soil's supply of nitrogen throughout the 19-year period. There

TABLE III. NITROGEN IN THE SOIL UNDER CONTINUOUS ALFALFA AT DIFFERENT DATES

Plat No.	TREATMENT.	Nitrogen in pounds per acre—		
		1915.	1923.	1934.
1	Superphosphate.....	3,120	2,820	3,320
2	Check.....	3,140	3,220	3,200
3	P, K ₂ SO ₄	2,660	2,700	3,120
4	K.....	2,620	2,720	2,960
5	Check.....	2,440	3,040	2,780
6	NaNO ₃ , P, K.....	2,480	2,660	2,720
7	Rock phosphate, manure, 2½ tons.....	2,660	2,760	3,100
8	Check.....	2,200	2,620	2,800
9	Manure, 2½ tons.....	2,660	2,720	3,000
10	Manure, 5 tons.....	2,560	2,920	3,240
11	Check.....	2,420	2,480	2,860
12	Lime, manure, 2½ tons.....	2,520	2,720	3,180

are some discrepancies in the data which probably can not be satisfactorily explained; but in general there is a very definite indication that accretion of nitrogen continued beyond the first eight years. The samples taken in 1923 were stored and not analyzed until 1934, which may account for some of the variability in the 1923 values.

In the "alfalfa-wheat" experiment, nitrogen was determined on soil samples taken from each plat at the time alfalfa was seeded and again when the alfalfa sod was broken. The results from this experiment are set forth in Table IV.

TABLE IV. SOIL NITROGEN AS INFLUENCED BY THE LENGTH OF THE ALFALFA CROPPING PERIOD

ALFALFA CROPPING PERIOD, YEARS.	Number of plats.	Nitrogen in pounds per acre—			Percentage increase.
		At beginning.	At end.	Increase.	
1.....	1	3,110	3,240	130	4.18
2.....	1	3,180	3,480	300	9.43
3.....	2	3,180	3,210	30	0.94
4.....	2	3,160	3,290	130	4.11
5.....	2	3,120	3,500	380	12.17
6.....	2	3,100	3,340	240	7.74
7.....	2	3,110	3,440	330	10.61
8.....	2	3,105	3,360	255	8.21
9.....	2	3,090	3,360	270	8.73

All plats show an increase in nitrogen regardless of the length of the cropping period. The data, for some unknown reason, show rather high variability. This variability may be partially accounted for in that the samples were not analyzed until from four to thirteen years after they were collected, depending on the length of the alfalfa cropping periods. In general, however, the longer cropping periods show the greater increases. On a percentage basis, the average increase for the shorter cropping periods (one to four years) was 4.66 percent. The corresponding value for the longer cropping periods (five to nine years) was 9.44 percent.

An idea frequently encountered in agronomic literature of the past is that legumes add little or no nitrogen to the soil unless the top growth is plowed under. The nitrogen used by the plant in its growth was believed to come partly from the soil and partly from the atmosphere. That which was taken from the atmosphere was believed to be about equal to that contained in the tops of the plants. If top growth was removed as hay, therefore, there was little or no addition to the soil. Data presented by Swanson and Latshaw (13) from this station indicated that alfalfa may not increase the nitrogen content of the soil even though grown for fairly long periods of time. Greaves and Hirst (5) showed that alfalfa removed as hay did not increase the nitrogen content of plat soils at the Utah station. The nitrogen content of the soil when the crop was seeded probably has been the determining factor in most such experiments, for it is evident from data recorded in the literature that it is on soils with low initial nitrogen contents that alfalfa stores the largest quantities of nitrogen. Evidence bearing on this point is contained in Table III in that plats 1 and 2, with relatively high initial nitrogen contents, showed comparatively small gains in nitrogen during the period of 19 years, while the plats with lower initial quantities of nitrogen showed larger gains. In these experiments, all top growth was removed as hay. In the process of curing and removing an alfalfa hay crop, there is always much loss of leaves. In this way, there is an appreciable return of nitrogen to the soil.

Also, recent investigations indicate that nitrogen may be excreted from the nodules of leguminous plants (6, 14, 16, 17). Whatever may be the means by which it is accomplished, it appears quite evident from the data in Tables III and IV that alfalfa may add nitrogen to the soil even though top growth is removed as hay. This is a matter of great importance to farmers since they may with confidence remove the valuable alfalfa hay crops and still benefit from the nitrogen storing ability of the crop, at least on soils in which nitrogen is deficient. It therefore appears that alfalfa should be grown on the poorest land on which a stand can be established without excessive cost, if maximum soil improvement is to be realized.

EXTENT AND DURATION OF THE EFFECT OF ALFALFA
ON AVAILABLE NITROGEN

Soil samples were collected each fall at wheat-seeding time in the "alfalfa-wheat" experiment for determinations of nitrates. Since there were nine plats which were devoted to continuous wheat culture, the effect of the alfalfa cropping periods upon nitrate accumulation could be measured by comparing the values for the alfalfa plats with those for the continuous wheat plats. However, direct comparisons between plats cropped to alfalfa for different periods of time in this experiment were of limited value. Since all alfalfa plats were seeded at the same time but broken in different years, seasonal conditions made direct comparisons impracticable. For example, the nitrate data for the first year after three years of alfalfa were obtained in 1925; while the corresponding values for six years of alfalfa were obtained in 1928. It appeared best, therefore, to obtain the ratio of the nitrates for each plat previously cropped to alfalfa, and for each year, to the nitrates of the adjoining continuous wheat plat. Since every third plat, beginning with No. 2, was devoted to continuous wheat culture, there was a wheat plat bordering every plat which grew alfalfa during the period of the experiment.

The nitrate values and the ratios are recorded in tables in the Appendix. The average ratios, however, are shown in Table V and the data are presented graphically in figure 1.

There is a great deal of variability in the nitrate data and, consequently, a corresponding variation in the ratios shown in Table V and figure 1. Such variation is natural since nitrate accumulation is affected by many factors, including temperature, moisture supply, extent of leaching, time of sampling, etc. The extent of seasonal variation is indicated by the nitrate data for 1934, the fourth year after the nine-year-old alfalfa sod was broken, fifth year after breaking the eight-year-old sod, etc. In that season, temperatures were exceedingly high and there was enough moisture in early-plowed land to insure nitrification. Furthermore, there was no leaching induced by early fall rains. Nitrate accumulation in that year was remarkably large.

In spite of some variations, the data indicate quite conclusively that the residual effect of alfalfa declines to a rather low point during a period of about six years. In only one case was a ratio attained of 2 or more, and in only six cases was a ratio of 1.5 or more attained six years or longer after the alfalfa sod was broken. It is significant, however, that nearly all plats tended to maintain a ratio somewhat greater than 1.0 for eight or nine years after the alfalfa sod was broken.

The longer periods of alfalfa cropping exhibited the same tendency as did the shorter periods; *i. e.*, a tendency toward a decline in residual effect upon nitrate-nitrogen formation in about six years. There is some evidence that cropping with alfalfa beyond three or four years may not add greatly to the soil's ability to accumulate

TABLE V. AVERAGE RATIOS OF NITRATES OF PLATS PREVIOUSLY CROPPED TO ALFALFA TO THOSE OF CONTINUOUS WHEAT PLATS. (AVERAGES OF DUPLICATE PLATS, EXCEPT IN CASE OF ONE YEAR OF ALFALFA CROPPING)

	Years of wheat cropping following alfalfa.												
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1 year alfalfa	1.49	1.38	1.54	1.22	1.39	0.55	0.98	1.63	1.00	1.34	1.29	0.97	0.74
2 years alfalfa	1.47	1.95	2.28	1.78	1.29	1.34	1.36	1.53	1.23	0.99	1.06	0.77	1.39
3 years alfalfa	1.46	3.11	1.92	1.91	1.40	1.29	1.02	1.06	0.92	1.18	0.80	0.88	.....
4 years alfalfa	1.47	2.18	1.99	2.08	1.56	1.29	1.22	1.05	1.54	1.02	1.15	.....	.....
5 years alfalfa	2.18	1.96	1.87	1.56	2.22	1.46	1.10	1.60	0.60	1.20	.....	.....	.....
6 years alfalfa	1.60	1.61	1.49	1.81	1.52	2.01	2.25	0.75	1.18	.....	.....	.....	.....
7 years alfalfa	1.06	2.12	1.05	1.68	1.11	1.00	1.42	1.30	.....	.....	.....	.....	.....
8 years alfalfa	2.52	1.73	1.97	1.76	1.98	1.10	1.62	.....	.....	.....	.....	.....	.....
9 years alfalfa	2.36	1.32	2.12	2.47	1.14	1.44	.....	.....	.....	.....	.....	.....	.....

CROPPING AND SOIL TREATMENT

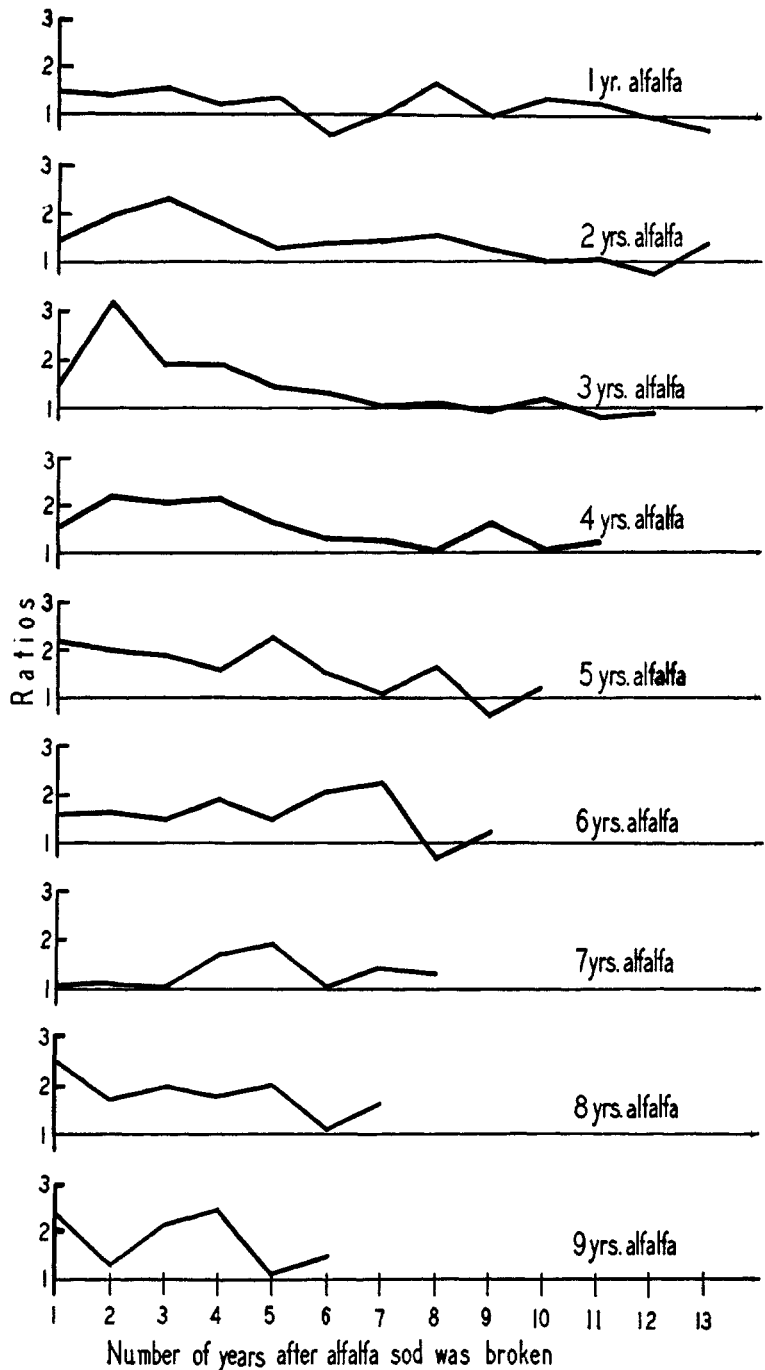


FIG. 1. Curves showing the ratios of nitrates of plots previously cropped to alfalfa to those of continuous wheat plots in succeeding years after breaking alfalfa sod.

nitrate nitrogen. The writer has shown previously (8) that the residual effect of two or more years of alfalfa cropping in this experiment was measurable in the succeeding wheat crops for a period of at least eight years. Such an effect was evident in yield, in protein content, or in both. Mirimanian (9) reported that a "prolonged" period of alfalfa cropping in Armenia produced a pronounced effect on succeeding cotton crops for three years. After that the effect declined rapidly. Nicol (10) presented data showing increased wheat yields over periods ranging from five to 12 years as a result of 20 years of previous alfalfa cropping.

CARBON NITROGEN RATIOS

The average carbon: nitrogen ratios of the unfertilized plats of the various cropping systems were calculated from the 1915 and 1934 data. These values are recorded in Table VI.

TABLE VI. AVERAGE CARBON : NITROGEN RATIOS OF UNFERTILIZED PLATS OF THE VARIOUS CROPPING SYSTEMS IN 1915 AND IN 1934, THE CHANGES AND THEIR PROBABLE SIGNIFICANCE.

CROPPING SYSTEM.	Carbon : nitrogen ratios in—		Difference of means.	Difference of means divided by P. E. (diff.).
	1915.	1934.		
16-year rotation.....	11.68 ± .094	12.15 ± .082	0.47 ± .124	3.79
3-year rotation.....	12.66 ± .211	12.26 ± .129	0.40 ± .247	1.62
Continuous wheat.....	13.55 ± .125	13.76 ± .216	0.21 ± .249	0.84
Continuous alfalfa.....	12.56 ± .245	11.96 ± .199	0.60 ± .310	1.93

There have been some alterations in the carbon: nitrogen ratios during the 19-year period. The ratio for the 16-year rotation was significantly widened. This may possibly be accounted for by the previously noted substitution of one year of wheat for one of corn in the rotation in 1922. The ratio for the three-year rotation was indicated to have narrowed somewhat but the change is of doubtful significance. The ratio for the soil under continuous wheat was widened slightly, but here the change is indicated to be of very questionable significance. The average ratio for soils under continuous alfalfa is indicated to have narrowed during the 19-year period. One of the four plats, however, showed a reverse trend and the difference of the means falls below the significant value.

The only effect of soil treatments upon the C:N ratio worthy of mention is an apparent tendency of the green manure treatments in the continuous wheat experiment to narrow the ratio. (See Table IA in the appendix.) It will be pointed out later that these plats tended to conserve nitrogen more effectively than carbon. A comparison of the ratios for the four cropping systems is recorded in Table VII.

TABLE VII. AVERAGE CARBON : NITROGEN RATIOS OF UNFERTILIZED PLATS AS AFFECTED BY CROPPING SYSTEMS

COMPARISON.	Year.	Difference of mean ratios.	Difference of means divided by P. E. (diff.).
16-year rotation with 3-year rotation	1915	0.98 ± .231	4.24
16-year rotation with continuous wheat	1915	1.87 ± .156	11.98
16-year rotation with continuous alfalfa	1915	0.88 ± .262	3.35
3-year rotation with continuous wheat	1915	0.89 ± .245	3.63
3-year rotation with continuous alfalfa	1915	0.10 ± .323	0.31
Continuous wheat with continuous alfalfa	1915	0.99 ± .275	3.60
16-year rotation with 3-year rotation	1934	0.12 ± .152	0.80
16-year rotation with continuous wheat	1934	1.62 ± .231	7.00
16-year rotation with continuous alfalfa	1934	0.18 ± .215	0.84
3-year rotation with continuous wheat	1934	1.50 ± .251	6.00
3-year rotation with continuous alfalfa	1934	0.30 ± .237	1.26
Continuous wheat with continuous alfalfa	1934	1.80 ± .293	6.20

It will be noted that there were significant differences between the ratios for each possible pair of cropping systems in 1915 except for the comparison of the three-year rotation with continuous alfalfa. In 1934, however, only the continuous wheat plats exhibited an average ratio appreciably different from the others. The continuous wheat plats also had the widest ratio in 1915. The effect of the lack of a legume in this cropping system is manifested in the carbon: nitrogen ratio.

EFFECT OF FERTILIZERS, MANURE, AND LIME ON THE NITROGEN AND CARBON OF THE SOIL

In each of the cropping systems under study, various commercial fertilizer, barnyard manure, and lime treatments were included. An attempt has been made to evaluate the effects of these treatments on the soil's nitrogen and carbon. Since satisfactory data relating to nitrogen and carbon in the soil when the experiments were started are not available, some other means of evaluation was necessary. In each of the series of plats devoted to the various cropping systems, every third plat, beginning with plat No. 2, is a control plat. The control plats seemed the best source of comparison in the evaluation of the effects of the treatments. Consequently, the carbon and nitrogen values for the control plats were plotted and the corresponding values for the treated plats were read off from the straight lines connecting these points. The values so obtained were then compared with the actual values and the sur-

pluses or deficiencies, presumably attributable to the treatments, were thus determined.

Such a treatment of the data involves the assumption that natural soil variation is progressively distributed from one control plat to another. Such an assumption is doubtless not always justifiable, but since every third plat was a control plat the assumption probably approached fulfillment in large measure for most plats. The two end plats for each series were treated plats, and, since there was a control plat on only one side of each, and this control plat adjoined the treated plat, comparisons in these cases were made directly. That is, the values for plats 1 and 12, in a series of 12 plats, were compared with those for plats 2 and 11, respectively. The results for the various series in the same rotation were averaged. Thus, the results for the 16-year rotation are averages for four plats for each treatment, those for the three-year rotation are averages for three plats, while in the case of the continuous wheat and continuous alfalfa experiments only single plats were available for study.

The results obtained as outlined above are listed in Table VIII. The original data from which they were obtained and details as to treatments will be found in tables in the Appendix. In Table VIII and the succeeding discussion, plats showing more nitrogen or carbon than the value obtained from the control or check plats are said to show a surplus; if less, a deficiency.

There are numerous points of interest in the data recorded in Table VIII. In order to discuss them adequately and without confusion, the results for each cropping system will be dealt with separately.

SIXTEEN-YEAR ROTATION

All treatments resulted in a surplus of nitrogen over the checks, or control plats. In only one case was a deficiency in carbon noted, and that was the plat receiving a complete fertilizer. The indicated deficit, however, (20 pounds) is very small. The plats treated with manure and lime showed the greatest surpluses; and lime is indicated to have been quite effective in maintaining a surplus of both nitrogen and carbon. This effect of manure and lime is probably the result of both increased crop growth on the plats receiving such treatment, and greater efficiency in the utilization of atmospheric nitrogen by the alfalfa bacteria in these plats. The plats upon which Brome grass (*Byomus inermis*) was substituted for alfalfa in the rotation and which receive manure treatment showed the second largest surplus of nitrogen, though the surplus of carbon was not so large. Green manure and rock phosphate treatment was not as effective, generally speaking, in maintaining nitrogen and carbon as manure treatments but compared very favorably with the manure and superphosphate treatment. The mineral fertilizers, unaccompanied by any organic carriers, were least effective, and among these the complete fertilizer takes low rank. It is difficult to offer an ade-

TABLE VIII. SURPLUSES AND DEFICIENCIES OF NITROGEN AND CARBON PRESUMABLY PRODUCED BY SOIL TREATMENT

CROPPING SYSTEM AND SOIL TREATMENT.	Surplus or deficiency in pounds per acre.	
	Nitrogen.	Carbon.
16-year rotation:		
Superphosphate.....	31	75
Green manure; rock phosphate.....	40	782
Superphosphate; K ₂ SO ₄	14	616
Superphosphate; NaNO ₃ ; K ₂ SO ₄	20	-20*
Superphosphate; manure.....	23	915
Manure.....	64	1,082
Manure; lime.....	120	1,332
Manure; (Brome grass).....	86	530
3-year rotation:		
Superphosphate.....	-14	835
Superphosphate; K ₂ SO ₄	104	1,378
K ₂ SO ₄	-46	-428
Superphosphate; K ₂ SO ₄ ; NaNO ₃	71	398
Manure; 2½ T on wheat; 2½ T on corn.....	80	22
Manure; 5 T on corn.....	84	765
Corn, corn, wheat (no legume).....	-105	-1,488
Corn, corn, wheat; green manure.....	11	-770
†Corn, corn, wheat; green manure; 1000 lbs. rock phosphate.....	70	1,600
†Corn, corn, wheat; green manure; 500 lbs. rock phosphate.....	70	000
†Continuous wheat:		
Superphosphate.....	86	-600
Superphosphate; K ₂ SO ₄	-17	560
K ₂ SO ₄	-70	-1,950
Superphosphate; K ₂ SO ₄ ; NaNO ₃	22	340
Superphosphate; K ₂ SO ₄ ; green manure.....	118	450
Green manure.....	334	1,100
Manure.....	12	1,400
Green manure; rock phosphate.....	102	780
†Continuous alfalfa:		
Superphosphate.....	120	7,660
Superphosphate; K ₂ SO ₄	60	3,800
K ₂ SO ₄	40	-800
Superphosphate; K ₂ SO ₄ ; NaNO ₃	-68	2,100
Manure (2½ T); rock phosphate.....	308	9,480
Manure (2½ T).....	180	1,900
Manure (5 T).....	400	6,300
Manure (2½ T); lime.....	320	2,300

*(-) Sign signifies deficiency.
 † Values represent single plats.

quate explanation for this situation. Crowther (4) has reported similar results for plats fertilized with nitrogen in the continuous wheat series at the Woburn Experimental Station, but since the barley plats gave different results he attributed the results for the wheat plats to location of the unfertilized plats near a row of trees. It does not seem that positional effect could have accounted for the results in the Kansas experiments. Blair and Prince (3) reported losses of organic matter in plats under long continued treatments in all cases, except where manure and commercial fertilizers were used in combination. The rotation involved contained no legume.

THREE-YEAR ROTATION

The commercial fertilizer plats gave somewhat, erratic results. The superphosphate plus potash plats showed the largest surplus in nitrogen and the second largest in carbon. The complete fertilizer plats, in spite of a similar position with respect to the other plats in the series as in the 16-year rotation, showed an appreciable surplus of nitrogen and a small surplus of carbon. The potash plats exhibited a small deficiency but, since crops do not respond to potash fertilizer applied alone on this soil, the results are not surprising. The superphosphate plats are located at the ends of the series and have been slightly more eroded than other plats in this rotation. This may account for their failure to show a surplus of nitrogen, although they do show a surplus of carbon. The manure plats, which received the same total amounts of manure but applied differently, showed almost identical surpluses of nitrogen. Where the applications were split, practically no surplus of carbon is indicated, while a fairly small surplus is recorded for the plats on which all manure was applied on corn.

The corn, corn, and wheat rotation with no legume showed relatively large deficiencies of both nitrogen and carbon as compared to the rotation of corn, soybeans, and wheat, which occupies the major part of each of these series. In view of the destructive effect of corn culture upon nitrogen and carbon as compared to other crops and cropping systems involved, this result is to be expected. The green manure crop, in the form of cowpeas seeded after each wheat crop, maintained the nitrogen as compared to the corn, soybeans, and wheat rotation, but a moderate deficiency in carbon is indicated. Where rock phosphate was applied with the green manure surpluses of nitrogen are recorded for both treatments while only the heavier rock-phosphated plat showed a surplus of carbon.

In order to measure more directly the effect of the green manure or green manure plus rock phosphate treatments, comparisons within the corn, corn, and wheat rotation should be made. When this is done we find that the insertion of a green manure crop alone maintained a surplus of 116 pounds of nitrogen and 718 pounds of carbon as compared to the same rotation without the green manure. Similar comparisons for the green manure and rock phosphate plats show surpluses of 175 and 155 pounds of nitrogen respectively for the plats

receiving 1,000 and 500 pounds of rock phosphate once in three years. For carbon, the corresponding values are 3,088 and 1,488. Thus, phosphorus treatments have aided in the maintainance of nitrogen and carbon.

CONTINUOUS WHEAT

Among the plats fertilized with commercial fertilizers, the superphosphate plat showed an appreciably larger amount of nitrogen but a slightly smaller amount of carbon than the control plats. However, this plat is so located that it has been somewhat affected by deposition of eroded soil from higher lying plats. The high nitrogen content may have arisen from this source. The superphosphate and potash plat exhibited a negligible variation from the controls in both nitrogen and carbon, while potash alone showed sizeable decreases below the controls for each constituent. This was found to be true also in the three-year rotation. The complete fertilizer plat had a higher nitrogen content and a greater amount of carbon, but the quantities are of negligible proportions. These results are similar to those for the same treatment in the 16-year rotation.

The plats receiving green manure or manure treatments all contained more nitrogen and carbon than the corresponding controls. The surplus of nitrogen for the manured plat is, however, of little or no consequence. It is interesting to note that green manuring maintained nitrogen relatively more effectively than carbon while manure treatment had the opposite effect. In the plat which was green manured but received no phosphorus or potash to balance the nitrogen furnished by the green manure, the surplus of nitrogen above the controls was rather marked while the corresponding value for carbon was appreciable but not, large.

CONTINUOUS ALFALFA

The available information indicates that the soil of the continuous alfalfa experiment was the poorest of any of the four cropping systems when the experiments were started. This, together with the fact that the land in this experiment was kept under alfalfa sod continually, probably accounts for the more consistent and larger differences favoring the fertilized plats in this series than in the other cropping systems. Superphosphate, and superphosphate and potash treated plats contained considerably more nitrogen and carbon than the check plats. The differences in carbon were especially marked. Potash alone, as in the other cropping systems, produced no marked effect on either nitrogen or carbon. The complete fertilizer plat showed somewhat less nitrogen than the controls but more carbon. With respect to the nitrogen, at least, this result is similar to that for the continuous wheat and the 16-year rotation.

All the manure treated plats showed more nitrogen and carbon than the check plats. Both rock phosphate and lime apparently

aided in the conservation of nitrogen when each was applied with manure. Rock phosphate appears to have been especially efficacious in aiding in the storage of carbon in the soil.

DIRECT EFFECT OF MANURE AND GREEN MANURE ON SOIL NITROGEN AND CARBON

In the preceding paragraphs it has been indicated that, in general, manure and green manure treatments resulted in more nitrogen and carbon in the soil than was found in the soil of the control plats. This influence of such treatments may be accounted for by either, or both, of two factors: First, the effect of the increased crop residues, provided the treatment simulated crop growth; secondly, the gradual accumulation of residual nitrogen or carbon, or both, not utilized in crop production. An attempt has been made to determine the amount of nitrogen and carbon residual from the treatments. In order to separate the two factors, the effect of the increase of crop residues in treated plats over that of the control plats had to be evaluated. To do this, it has been assumed that the nitrogen and carbon from crop residues, for any plat under consideration, is roughly proportional to the total dry matter production of the plat. Bear and Salter (2), Salter and Green (11) and the writer (7) have presented evidence supporting this assumption.

The plats treated with superphosphate plus potash in all cropping systems showed increases in total dry-matter production when compared with the control plats. They also showed more nitrogen and carbon in the soil, except in the case of the continuous wheat experiment where a very small decrease in nitrogen was recorded. The increases of nitrogen and of carbon in the 16-year rotation are also small. Since no nitrogen or carbon was applied to these plats, any increase in the nitrogen or carbon content of the soil in 1934, as compared to the control plats, may be attributed to increased crop residues. Accordingly, the excess nitrogen and carbon of the superphosphate plus potash plats over the control plats of each cropping system was divided by the corresponding increase of dry matter produced by such treatment. The results were expressed as pounds of nitrogen or carbon accumulated in the soil for each 100 pounds increase in dry matter produced. The values so obtained were applied to the dry matter increases produced by the various manure and green manure treatments. The nitrogen and carbon, presumably accumulated as a result of the increased crop residues resulting from the manure and green manure treatments, were then subtracted from the actual surplus of these elements over that contained in the soil of the control plats as determined by analysis. The remainders, if any, were assumed to be nitrogen and carbon residual from the manure and green manure treatments. This method of evaluation is essentially the same as that used by White and Holben (15). The results are shown in Table IX. (Detailed plat treatments and total dry-matter data are given in the Appendix).

TABLE IX. CALCULATED SOURCE OF THE SURPLUS NITROGEN AND CARBON OF MANURED PLATS AS COMPARED TO CHECK PLATS

CROPPING SYSTEM AND TREATMENT.	Pounds per acre of--					
	Total surplus.		N and C equivalent of increased crop residues.		Surplus from manure or green manure.	
	N.	C.	N.	C.	N.	C.
16-year rotation:						
Manure (20 T in 16 years)	64	1,080	18	800	46	280
Green manure; R. phosphate	40	780	13	607	27	173
3-year rotation:						
Manure (5 T in 3 yrs.)— $\frac{1}{2}$ on wheat, $\frac{1}{2}$ on corn.	80	22	423	5,372	0	0
Manure (5 T in 3 yrs.)—all on corn	84	765	378	4,917	0	0
Continuous wheat:						
Manure $2\frac{1}{2}$ T	12	1,400	0†	2,270	12	0
Green manure*	334	1,100	0	0	334	1,100
Green manure; superphosphate; K_2SO_4	118	450	0†	1,488	118	0
Green manure; R. phosphate	102	780	0†	1,632	102	0
Continuous alfalfa:						
Manure ($2\frac{1}{2}$ T annually)	180	1,900	123	7,770	57	0
Manure (5 T annually)	400	6,300	207	12,440	193	0
Manure ($2\frac{1}{2}$ T) rock phosphate	308	9,480	159	9,560	149	0

* Green manure treatment produced no increase in dry matter over check plat.
† The superphosphate plus potash plat showed no surplus nitrogen under continuous wheat.

The figures indicating the pounds of nitrogen and carbon residual from the manure and green manure treatments are, on the whole, very small. In the three-year rotation, no nitrogen or carbon could be attributed directly to either of the manure treatments. The quantities indicated as residual from manure and green manure treatments in the 16-year rotation are quite small, but proportionately more nitrogen was conserved than carbon. Under continuous wheat, manure treatment left no significant quantity of nitrogen or carbon but all green manure treatments left appreciable nitrogen. Where supplemented with phosphorus or phosphorus and potash, green manure left no residual carbon but where used alone considerable carbon remained in the soil. Green manure treatment alone resulted in no increase in dry matter production in the continuous wheat experiment. Since wheat responds well to phosphorus in this experiment, it appears that perhaps an unbalanced condition has been created in the soil of this plat, a shortage of phosphorus allowing nitrogen and, to a lesser extent, carbon from the green manure additions to accumulate in the soil. In the plats where the green manure was supplemented by phosphorus, or phosphorus and potash, rather large increases in dry matter were realized and much less nitrogen

and no carbon remained which could be attributed directly to the green manure.

In the continuous alfalfa experiment, no residual carbon is indicated from any of the manure treatments. A surplus of nitrogen, however, was left from each treatment. Rather large increases of dry matter were produced by these treatments and it appears that the high nitrogen content of the residues produced so narrow a carbon:nitrogen ratio that carbon was dissipated in the decay processes before all the nitrogen was utilized.

The nitrogen in the soil, residual from the manure and green manure treatments, represents but a small part of the nitrogen thus incorporated in the soil. Analyses of the manure applied were made each year for several years. In these analyses, nitrogen was determined, but determinations of carbon were not made. No data are available for the nitrogen content of the green manure, but the amount of dry matter incorporated was estimated with reasonable accuracy from results obtained from hoop samples harvested in certain years, and the nitrogen content of cowpea hay is available from various other sources. Using these various data, the total nitrogen incorporated in the soil through each manure and green manure treatment was calculated and the percentage of this nitrogen residual in the soil was estimated. The values thus obtained for the various treatments are listed in Table X.

TABLE X. NITROGEN APPLIED IN MANURE AND GREEN MANURE AND THE PERCENTAGE OF APPLIED NITROGEN RESIDUAL IN THE SOIL

CROPPING SYSTEM AND TREATMENT.	Nitrogen incorporated into the soil during 24 years, lbs. per acre.	Percentage of incorporated nitrogen residual in the soil.
16-year rotation:		
Manure.....	434	10.6
Green manure, rock phosphate.....	270	10.0
Continuous Wheat:		
Manure.....	877	1.4
Green manure.....	480	70.0
Green manure, K ₂ SO ₄ , and superphosphate.....	470	25.0
Green manure, rock phosphate.....	486	21.0
Continuous alfalfa:		
Manure, 2½ tons.....	877	6.5
Manure, 5 tons.....	1,754	11.0
Manure, 2½ tons; rock phosphate.....	877	17.0

The percentage of the total nitrogen incorporated remaining in the soil is relatively small except, in the case of the green manure treatments in the soil under continuous wheat. The results for

manure are somewhat lower than those obtained by White and Holben (15) but fairly similar to those obtained by Salter and Green (11).

DISCUSSION

In interpreting the data presented in the preceding pages, emphasis has been limited to fairly large differences produced by treatments. Most of the data discussed are derived data rather than original results and certain assumptions are involved in the treatment of the data. The number of control plats is different in the different series, and in two cropping systems each fertilizer treatment is represented by only one plat. In these two series, furthermore, there is considerable variability in soil, as indicated by the data relating to total dry-matter production in the Appendix. For these reasons, no attempt has been made to establish limits of error for that part of the data dealing with the effects produced by soil treatments.

The data suggest that there is 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. The more cultivation of the soil involved in the cropping system, the lower is this level. In other words, the greater the extent to which inter-tilled crops are introduced into the cropping system, the lower the nitrogen and carbon level falls. On the other hand, the larger the percentage of the crop cycle occupied by biennial or perennial legumes or sod crops, the higher will be this level. Use of fertilizers and lime, if they stimulate crop growth, particularly a legume crop, will maintain a higher level of nitrogen and carbon than that of soil not so treated. The same may be said of manure. If a legume is used as a green manure, supplemented, if needed, by phosphorus or phosphorus and potash, and subsequent crop growth is thereby stimulated, it may aid in maintaining a higher level of nitrogen though, apparently, not necessarily more carbon.

If soil is very low in nitrogen and carbon, a good legume such as alfalfa may increase the quantity of these constituents in the soil even though top growth is regularly removed as hay.

SUMMARY

Nitrogen and organic carbon have been determined from samples recently taken from the soil fertility plats at the Kansas Agricultural Experiment Station. The plats were established in 1910. These plats were first adequately sampled and nitrogen and carbon determined in 1915. By comparison with the data obtained in 1915 it was possible to establish rates of loss or gain for the period intervening between 1915 and the recent samplings. On this basis it was shown that a 16-year rotation, a three-year rotation, and continuous wheat, produced fairly similar losses of nitrogen and carbon. The 16-year rotation lost nitrogen more rapidly than the other two cropping systems, but the three-year rotation led in rate of loss

of carbon. Alfalfa grown continuously increased the soil's supply of nitrogen and carbon at the rate of 0.71 percent and 0.43 percent per year, respectively. Calculated values for corn indicated that its culture dissipates these soil constituents at a rate two to three times as great as that of the rotations or continuous wheat.

Alfalfa in continuous culture appeared to continue to add to the soil's supply of nitrogen over a period of 19 years. In an experiment where alfalfa cropping periods varied from one to nine years, there was some indication that the average increase in nitrogen for plats cropped five to nine years was about twice that for plats cropped for one to four years. Alfalfa increased the nitrogen content of the soil in spite of the fact that all top growth was regularly removed as hay.

Studies of the nitrate content of wheat land previously cropped to alfalfa indicate a rather marked decline in nitrate accumulating capacity in about six years after breaking the alfalfa sod. This was true of alfalfa cropping periods up to nine years, though the plats cropped to alfalfa for the shorter periods declined to lower levels. Residual effects in nitrate accumulating capacity were evident, however, for eight years or more on all plats cropped to alfalfa for two years or longer.

Continuous wheat culture maintained a wider carbon: nitrogen ratio in the soil than the rotations or continuous alfalfa. Within the continuous wheat experiment, green manuring tended to narrow the ratio.

In general, manure and green manure treatments maintained higher soil nitrogen and carbon levels than control plats. Commercial fertilizers tended to produce similar results, but they were much less marked. In most cases, the surplus of carbon in treated over untreated plats could apparently be accounted for by increased crop residues. Much or all of the nitrogen in most cases could be accounted for in like manner. A very notable exception was the green manure treatment in the continuous wheat experiment. Of the nitrogen calculated to have been applied in the manure and green manure treatments, the following portions were indicated to have remained in residual form in the soil: *16-year rotation*, manure, 10.6 percent; green manure and rock phosphate, 10 percent; *continuous wheat*, manure, 1.4 percent; green manure, 70 percent; green manure plus K_2SO_4 plus superphosphate, 25 percent; green manure and rock phosphate, 21 percent; *continuous alfalfa*, manure (2 $\frac{1}{2}$ tons), 6.5 percent; manure (5 tons), 11 percent; and, manure and rock phosphate, 16 percent. In the three-year rotation, no nitrogen or carbon could be attributed directly to the manure treatments.

LITERATURE CITED

- (1) ALLISON, L. E.
1935. ORGANIC SOIL CARBON BY REDUCTION OF CHROMIC ACID.
Soil Sci. 40:4:311-320.
- (2) BEAR, F. E., AND SALTER, R. M.
1916. THE RESIDUAL EFFECTS OF FERTILIZERS. W. Va. Agr. Expt. Sta. Bul. 160.
- (3) BLAIR, A. W., AND PRINCE, A. L.
1936. SOME EFFECTS OF LONG-CONTINUED MANURE, FERTILIZER AND LIME TREATMENTS ON THE COMPOSITION OF CROPPED SOIL. N. J. Agr. Expt. Sta. Bul. 604.
- (4) CROWTHER, E. M.
1936. PART IV OF THE BOOK, "FIFTY YEARS OF FIELD EXPERIMENTS AT THE WOBURN EXPERIMENTAL STATION," BY E. J. RUSSELL AND J. A. VOELCKER. 392 p., illus; Longmans, Green and Co., London.
- (5) GREAVES, J. E., AND HIRST, C. T.
1936. INFLUENCE OF ROTATION AND MANURE ON THE NITROGEN, PHOSPHORUS AND CARBON OF THE SOIL. Utah Agr. Expt. Sta. Bul. 274.
- (6) LUDWIG, C. A., AND ALLISON, F. E.
1937. EXPERIMENTS CONCERNING DIFFUSION OF NITROGENOUS COMPOUNDS FROM HEALTHY LEGUME NODULES OR ROOTS. Bot. Gaz. 98:4:680-695.
- (7) METZGER, W. H.
1936. NITROGEN AND ORGANIC CARBON OF SOILS AS AFFECTED BY CROPS AND CROPPING SYSTEMS. Jour. Amer. Soc. Agron. 28:3:228-233.
- (8) _____,
1935. THE RESIDUAL EFFECT OF ALFALFA CROPPING PERIODS OF VARIOUS LENGTHS UPON THE YIELD AND PROTEIN CONTENT OF SUCCEEDING WHEAT CROPS. Jour. Amer. Soc. Agron. 27:8:653-659.
- (9) MIRIMANIAN, K. P.
1934. THE DURATION OF THE FAVORABLE INFLUENCE OF ALFALFA ON THE COTTON FIELDS OF ARMENIA. Jour. Amer. Soc. Agron. 26:6:475-480.
- (10) NICOL, HUGH.
1933. ROTHAMSTED EXPERIMENTS ON RESIDUAL VALUE OF LEGUME CROPS. Empire Jour. Expt. Agr. 1:1:22-32.
- (11) SALTER, R. M., AND GREENE, T. C.
1933. FACTORS AFFECTING THE ACCUMULATION AND LOSS OF NITROGEN AND ORGANIC CARBON IN CROPPED SOILS. Jour. Amer. Soc. Agron. 25:9:-622-630.
- (12) SMITH, F. B., BROWN, P. E., AND PEEVEY, W. G.
1937. EFFECT OF LONG CONTINUED TREATMENT ON THE ORGANIC MATTER, NITROGEN AND PHOSPHORUS CONTENT OF CLARION LOAM. I. Continuous corn. Iowa State Coll. Jour. Sci. 11:4:379-395.
- (13) SWANSON, C. O., AND LATSHAW, W. L.
1919. EFFECT OF ALFALFA ON THE FERTILITY ELEMENTS OF THE SOIL IN COMPARISON WITH GRAIN CROPS. Soil Sci. 8:1:1-39.
- (14) VIRTANEN, A. I., VON HANSEN, S., AND LAINE, T.
1937. INVESTIGATIONS ON THE ROOT NODULE BACTERIA OF LEGUMINOUS PLANTS. XIX. Influence of various factors on the excretion of nitrogenous compounds from the nodules. Jour. Agr. Sci. 27:3:332-348.

- (15) WHITE, J. W., AND HOLBEN, F. G.
1925. RESIDUAL EFFECTS OF FORTY YEARS CONTINUOUS MANURIAL TREATMENTS: II. Effect of caustic lime on soil treated with barnyard manure. *Soil Sci.* 20:313-327.
- (16) WILSON, P. W.
1937. EXCRETION OF NITROGEN BY LEGUMINOUS PLANTS. *Nature* 140:3534:-154-155.
- (17) WINOGRADSKI, S., AND WINOGRADSKI, HELENE.
1936. ETUDES SUR LA MICROBIOLOGIE DU SOL. 8. Reserches sur less bacteries radicales des leguminenses. *Ann. Inst. Pasteur (Paris)* 56:3:-221-250.

Note: P. 28 and 29 have no content, and are omitted.

Appendix

TABLE IA. NITROGEN, ORGANIC CARBON AND THE C:N RATIO OF THE SOIL, AND TOTAL DRY MATTER PRODUCTION OF OLD FERTILITY PLATS

CROPPING SYSTEM.	Plat.	Soil treatment.	Year sampled.	Pounds per acre of—		C / N	Total dry matter 1911-'34, inclusive.
				N.	C.		
16-year ¹ rotation: SERIES I.....	1	Superphosphate.....	1936	2,780	34,900	12.55	116,589
	2	Check.....		2,872	34,740	12.10	116,826
	3	Green manure, ³ rock phosphate after second year wheat.....		2,980	36,000	12.08	126,141
	4	Superphosphate, K ₂ SO ₄		2,832	34,260	12.02	122,601
	5	Check.....		2,712	32,640	12.03	109,312
	6	Superphosphate, K ₂ SO ₄ , NaNO ₃		2,720	32,920	12.10	126,831
	7	Manure 5 tons on corn and third year alfalfa, superphosphate.....		2,820	36,140	12.82	124,938
	8	Check.....		2,780	34,320	12.34	112,405
	9	Manure 5 tons on corn and third year alfalfa.....		2,880	35,580	12.35	121,335
	10	Manure 5 tons on corn and third year alfalfa, lime.....		2,800	35,300	12.61	130,070
	11	Check.....		2,740	33,200	12.12	116,236
	12	Manure 5 tons on corn and third year sod, Brome grass.....		3,000	36,560	12.18	106,298
SERIES II.....	1	Superphosphate.....	1932	3,164	37,540	11.86	128,766
	2	Check.....		3,146	37,200	11.82	119,760
	3	Green manure, ³ rock phosphate after second year wheat.....		3,028	37,600	12.42	137,983
	4	Superphosphate, K ₂ SO ₄		3,078	37,680	12.24	135,774
	5	Check.....		3,164	35,600	11.25	123,014
	6	Superphosphate, K ₂ SO ₄ , NaNO ₃		3,146	36,820	11.70	143,230
	7	Manure 5 tons on corn and third year alfalfa, superphosphate.....		3,146	37,600	11.95	147,931
	8	Check.....		3,250	36,400	11.20	117,245
	9	Manure 5 tons on corn and third year alfalfa.....		3,096	36,800	11.88	139,011
	10	Manure 5 tons on corn and third year alfalfa, lime.....		3,112	37,000	11.89	145,952
	11	Check.....		3,044	35,000	11.51	109,218
	12	Manure 5 tons on corn and third year sod, Brome grass.....		2,976	35,400	11.89	97,643

1. Alfalfa, 4 years; corn, wheat, wheat for 12 years.
3. All green manure crops are cowpeas seeded after wheat harvest and plowed under in early fall.

TABLE IA.—Continued

CROPPING SYSTEM.	Plat.	Soil treatment.	Year sampled.	Pounds per acre of—		C / N	Total dry matter 1911-'34, inclusive.
				N.	C.		
16-year ¹ rotation: SERIES III.....	1	Superphosphate.....	1933	2,992	34,920	11.67	105,156
	2	Check.....		2,820	34,600	12.27	107,756
	3	Green manure, ² rock phosphate after second year wheat.....		2,924	34,400	11.76	114,894
	4	Superphosphate, K ₂ SO ₄		2,752	34,660	12.59	113,507
	5	Check.....		2,804	34,800	12.41	101,379
	6	Superphosphate, K ₂ SO ₄ , NaNO ₃		2,838	33,700	11.87	98,349
	7	Manure 5 tons on corn and third year alfalfa, superphosphate.....		2,770	33,800	12.20	120,321
	8	Check.....		2,752	33,800	12.28	95,306
	9	Manure 5 tons on corn and third year alfalfa.....		2,734	32,400	11.85	117,528
	10	Manure 5 tons on corn and third year alfalfa, lime.....		2,786	31,600	11.34	122,429
	11	Check.....		2,666	34,000	12.75	98,702
	12	Manure 5 tons on corn and third year sod, Brome grass.....		2,786	32,000	11.49	104,288
SERIES IV.....	1	Superphosphate.....	1932	2,856	35,760	12.52	113,139
	2	Check.....		2,872	36,280	12.63	108,762
	3	Green manure, ² rock phosphate after second year wheat.....		2,856	36,040	12.62	120,289
	4	Superphosphate, K ₂ SO ₄		2,942	36,240	12.32	121,959
	5	Check.....		2,786	34,060	12.22	98,668
	6	Superphosphate, K ₂ SO ₄ , NaNO ₃		2,890	34,840	12.06	121,744
	7	Manure 5 tons on corn and third year alfalfa, superphosphate.....		2,924	35,740	12.22	121,668
	8	Check.....		2,838	36,420	12.83	101,733
	9	Manure 5 tons on corn and third year alfalfa.....		3,062	39,780	12.99	121,867
	10	Manure 5 tons on corn and third year alfalfa, lime.....		3,200	40,500	12.66	133,299
	11	Check.....		2,872	35,920	12.51	108,299
	12	Manure 5 tons on corn and third year sod, Brome grass.....		2,906	36,280	12.48	75,242

CROPPING AND SOIL TREATMENT

TABLE IA.—Continued

CROPPING SYSTEM.	Plat.	Soil treatment.	Year sampled.	Pounds per acre of—		C / N	Total dry matter 1911-'34, inclusive.
				N.	C.		
3-year ² rotation: SERIES V.....	1	Superphosphate.....	1933	2,856	39,740	13.91	98,580
	2	Check.....		2,890	36,800	12.73	108,374
	3	Superphosphate, K ₂ SO ₄		3,028	40,420	13.35	110,889
	4	K ₂ SO ₄		3,010	37,060	12.31	101,843
	5	Check.....		2,976	36,200	12.16	99,996
	6	Superphosphate, K ₂ SO ₄ , NaNO ₃		3,010	38,400	12.76	111,525
	7	Manure, 2½ tons on corn, 2½ tons on wheat.....		2,958	34,240	11.58	102,984
	8	Check.....		2,992	34,000	11.36	91,240
	9	Manure 5 tons on corn.....		2,856	36,300	12.71	102,334
	10	Corn, corn, wheat (no legume).....		2,580	29,200	11.32	83,988
	11	Check.....		2,562	31,000	12.10	80,465
	12	Corn, corn, wheat; green manure after wheat.....		2,546	29,340	11.52	90,892
SERIES VI.....	1	Superphosphate.....	1935	2,840	37,000	13.03	102,378
	2	Check.....		2,820	36,200	12.84	100,183
	3	Superphosphate, K ₂ SO ₄		2,840	36,370	12.81	100,162
	4	K ₂ SO ₄		2,680	33,200	12.39	98,518
	5	Check.....		2,660	33,600	12.63	82,629
	6	Superphosphate, K ₂ SO ₄ , NaNO ₃		2,600	32,600	12.54	109,858
	7	Manure, 2½ tons on corn, 2½ tons on wheat.....		2,720	33,200	12.21	104,321
	8	Check.....		2,580	35,400	13.72	84,293
	9	Manure, 5 tons on corn.....		2,700	34,400	12.74	97,775
	10	Corn, corn, wheat (no legume).....		2,640	32,600	12.35	50,960
	11	Check.....		2,760	35,400	12.83	90,764
	12	Corn, corn, wheat; green manure after wheat.....		2,740	33,000	12.04	106,234

2. Corn, soybeans, wheat.

TABLE IA.—Continued

CROPPING SYSTEM.	Plat.	Soil treatment.	Year sampled.	Pounds per acre of—		C / N	Total dry matter 1911-'34, inclusive.
				N.	C.		
3-year ² rotation: SERIES VII.	1	Superphosphate.....	1935	2,840	32,400	11.41	110,671
	2	Check.....		2,880	32,800	11.39	106,834
	3	Superphosphate, K ₂ SO ₄		2,910	32,580	11.19	99,145
	4	K ₂ SO ₄		2,510	29,840	11.89	92,748
	5	Check.....		2,580	30,000	11.63	83,990
	6	Superphosphate, K ₂ SO ₄ , NaNO ₃		2,720	29,720	10.93	100,620
	7	Manure, 2½ tons on corn, 2½ tons on wheat.....		2,580	31,120	12.06	92,389
	8	Check.....		2,350	28,400	12.08	72,241
	9	Manure, 5 tons on corn.....		2,630	29,840	11.35	94,946
	10	Corn, corn, wheat (no legume).....		2,410	29,400	12.20	88,325
	11	Check.....		2,630	30,400	11.56	92,967
	12	Corn, corn, wheat; green manure after wheat.....		2,740	31,800	11.61	96,535
	13	Corn, corn, wheat; green manure and 1000 lbs. R. phosphate after wheat.....		2,780	34,400	12.37	113,660
	14	Check. (Corn, soybeans, wheat).....		2,750	34,000	12.36	89,970
	15	Corn, corn, wheat; green manure and 500 lbs. R. phosphate after wheat.....		2,800	34,000	12.14	107,058
Continuous wheat: SERIES VIII.	1	Superphosphate.....	1932	2,734	38,000	13.90	95,198
	2	Check.....		2,648	38,600	14.58	88,474
	3	Superphosphate, K ₂ SO ₄		2,528	36,400	14.40	87,906
	4	K ₂ SO ₄		2,374	31,600	13.31	72,565
	5	Check.....		2,340	31,700	13.55	66,095
	6	Superphosphate, K ₂ SO ₄ , NaNO ₃		2,304	31,460	13.65	87,904
	7	Superphosphate, K ₂ SO ₄ , green manure once in 3 years.....		2,340	31,000	13.25	78,173
	8	Check.....		2,168	30,000	13.84	56,231
	9	Green manure once in 3 years.....		2,598	31,800	12.24	57,327
	10	Manure, 2½ tons annually.....		2,374	32,840	13.83	88,893
	11	Check.....		2,460	32,100	13.05	62,594
	12	Green manure and rock phosphate once in 3 years.....		2,562	32,880	12.83	83,038

CROPPING AND SOIL TREATMENT

TABLE IA.—*Concluded*

CROPPING SYSTEM.	Plat.	Soil treatment.	Year sampled.	Pounds per acre of—		C / N	Total dry matter 1911-'34, inclusive.
				N.	C.		
Continuous alfalfa: SERIES X.....	1	Superphosphate.....	1934	3,320	45,460	13.69	109,917
	2	Check.....		3,200	37,800	11.81	78,311
	3	Superphosphate, K ₂ SO ₄		3,120	40,000	12.82	91,378
	4	K ₂ SO ₄		2,960	33,900	11.45	62,205
	5	Check.....		2,780	33,100	11.91	56,020
	6	Superphosphate, K ₂ SO ₄ , NaNO ₃		2,720	34,740	12.77	81,501
	7	Manure 2½ tons and rock phosphate annually.....		3,100	41,660	13.44	109,816
	8	Check.....		2,800	31,700	11.32	57,280
	9	Manure, 2½ tons annually.....		3,000	35,200	11.73	98,842
	10	Manure, 5 tons annually.....		3,240	41,200	12.72	127,645
	11	Check.....		2,860	36,500	12.76	59,110
	12	Manure, 2½ tons annually, lime.....		3,180	38,800	12.20	107,522

TABLE IIA. NITRATES IN THE SOIL OF PLATS PREVIOUSLY CROPPED TO ALFALFA, AND OF CONTINUOUS WHEAT PLATS, AT WHEAT SEEDING TIME AND THE RATIOS OF THESE VALUES
 (NO₃ to a depth of three feet, pounds per acre)

	Number of years after alfalfa sod was broken.												
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1 year alfalfa	428	368	268	160	214	266	296	338	273	304	413	1,122	131
Check	288	266	174	131	154	485	302	208	272	227	321	1,158	176
Ratio	1.49	1.38	1.54	1.22	1.39	0.55	0.98	1.63	1.00	1.34	1.29	0.97	0.74
2 years alfalfa	339	430	317	313	469	402	283	532	290	355	1,539	165	251
Check	266	174	131	154	485	302	208	272	227	321	1,158	176	180
Ratio	1.27	2.47	1.42	2.03	0.97	1.33	1.36	1.96	1.28	1.10	1.33	0.94	1.39
3 years alfalfa	323	616	309	647	460	363	382	367	362	901	161	244	.....
Check	218	252	181	264	239	273	432	311	393	903	433	257	.....
Ratio	1.48	2.44	1.71	2.45	1.92	1.33	0.88	1.18	0.92	0.94	0.37	0.94	.....
4 years alfalfa	468	422	650	706	402	652	428	396	1,629	255	337	.....	.....
Check	252	181	264	239	273	432	311	393	963	433	257	.....	.....
Ratio	1.86	2.33	2.46	2.95	1.47	1.51	1.38	1.01	1.69	0.59	1.30	.....	.....
5 years alfalfa	435	497	429	407	726	398	367	2,132	164	342	.....	.....	.....
Check	179	233	250	272	207	271	305	1,131	750	275	.....	.....	.....
Ratio	2.43	2.13	1.72	1.50	3.51	1.47	1.20	1.88	0.22	1.24	.....	.....	.....
6 years alfalfa	379	434	388	504	411	569	411	368	342	.....	.....	.....	.....
Check	233	250	272	207	271	305	1,131	750	275	.....	.....	.....	.....
Ratio	1.63	1.74	1.43	2.43	1.52	1.86	2.04	0.49	1.24	.....	.....	.....	.....
7 years alfalfa	255	577	375	403	594	1,616	335	509	.....	.....	.....	.....	.....
Check	203	264	403	243	295	1,977	195	343	.....	.....	.....	.....	.....
Ratio	1.25	2.18	0.93	1.67	2.01	0.82	1.72	1.48	.....	.....	.....	.....	.....
8 years alfalfa	781	786	491	532	3,106	239	532	.....	.....	.....	.....	.....	.....
Check	264	403	243	295	1,977	195	343	.....	.....	.....	.....	.....	.....
Ratio	2.96	1.95	2.02	1.80	1.57	1.22	1.55	.....	.....	.....	.....	.....	.....
9 years alfalfa	1,201	488	695	4,711	317	473	.....	.....	.....	.....	.....	.....	.....
Check	399	360	282	1,601	248	296	.....	.....	.....	.....	.....	.....	.....
Ratio	3.01	1.36	2.46	2.94	1.28	1.59	.....	.....	.....	.....	.....	.....	.....

CROPPING AND SOIL TREATMENT

TABLE IIA.—*Concluded*

	Number of years after alfalfa sod was broken.												
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
2 years alfalfa*	360	324	628	299	354	294	317	438	424	249	1,259	150	414
Check	221	225	200	194	220	217	233	399	360	282	1,601	248	296
Ratio	1.67	1.44	3.14	1.54	1.61	1.35	1.36	1.10	1.18	0.88	0.79	0.60	1.39
3 years alfalfa	512	877	348	406	291	297	457	442	318	1,512	186	343	
Check	355	232	164	297	334	240	389	476	342	1,064	150	418	
Ratio	1.44	3.78	2.12	1.37	0.87	1.24	1.17	0.93	0.93	1.42	1.24	0.83	
4 years alfalfa	250	331	450	407	399	417	501	373	1,469	219	418		
Check	232	164	297	334	240	389	476	342	1,064	150	418		
Ratio	1.08	2.02	1.51	1.22	1.66	1.07	1.05	1.09	1.38	1.46	1.00		
5 years alfalfa	313	599	395	430	456	466	387	1,983	202	400			
Check	162	332	195	264	492	320	387	1,510	204	347			
Ratio	1.93	1.80	2.02	1.63	0.93	1.46	1.00	1.31	0.99	1.15			
6 years alfalfa	517	288	409	592	491	836	3,711	204	385				
Check	332	195	264	492	320	387	1,510	204	347				
Ratio	1.56	1.48	1.55	1.20	1.53	2.16	2.46	1.00	1.11				
7 years alfalfa	209	571	477	521	523	1,975	226	371					
Check	243	279	409	309	289	1,684	204	331					
Ratio	0.86	2.05	1.17	1.69	1.81	1.17	1.11	1.12					
8 years alfalfa	584	618	593	500	4,031	198	557						
Check	279	409	309	289	1,684	204	331						
Ratio	2.09	1.51	1.92	1.73	2.39	0.97	1.68						
9 years alfalfa	513	521	614	2,969	303	514							
Check	298	408	342	1,487	301	396							
Ratio	1.72	1.28	1.79	2.00	1.01	1.29							

* All alfalfa cropping periods are duplicated except the one-year period.