4-1912

Fertility Experiments in a Rotation of Cowpeas and Wheat

University of Tennessee Agricultural Experiment Station

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BULLETIN

OF THE

Agricultural Experiment Station

OF THE

UNIVERSITY OF TENNESSEE

NUMBER 96 APRIL, 1912

FERTILITY EXPERIMENTS IN A ROTATION OF COWPEAS AND WHEAT

PART II—THE EFFECT OF LIMING ON THE CROP PRODUCTION

By C. A. MOOERS

PART III—THE EFFECT OF LIMING AND OF GREEN MANURING ON THE SOIL CONTENT OF NITROGEN AND HUMUS

By C. A. MOOERS, H. H. HAMPTON, AND W. K. HUNTER

KNOXVILLE, TENNESSEE

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FERTILITY EXPERIMENTS IN A ROTATION OF COWPEAS AND WHEAT

PART II*—THE EFFECT OF LIMING ON THE CROP PRODUCTION

INTRODUCTION

Widespread interest has recently been aroused throughout the State in the subject of liming. In addition to the possibility of adding to the number of profitable crops that may be grown, two questions are of present importance in this connection. First, what increase in yield may be expected at the outset or in the course of the first three to five years after liming? Second, what effect has liming on the nitrogen and humus content of the soil? As regards the first question, the contents of this bulletin relate to only two of the common farm crops, neither of which is recognized as being especially responsive to liming; that is, both cowpeas and wheat will thrive on a soil so poor in lime as to be called "acid," or "sour." There are other crops, such as clover and alfalfa, which thrive only on a soil relatively well supplied with lime and for whose successful culture on the soils under investigation liming is a necessity. As to the second question, there are presented, in Part III, some analytical data which show the effect of a moderate application of burnt lime on the nitrogen and humus content of the soil at the Station farm at the end of both the second and the fifth year after its application.

THE FIELD DATA

The major part of the field data are recorded in detail in Part I (Bull. 90), but a summary of the most important results from Part I is given here, in Table I. The data for the other plots, which are shown in the diagrams of Part I but unrecorded there, are presented in detail in Table II.

In every series recently slaked burnt lime was applied once at the outset of the experiments and at the rate of nearly one ton per acre, and none thereafter.

THE NATURE OF THE SOILS UNDER INVESTIGATION

Each of the three experimental series which are here considered represents a distinct type of soil. The series at the Station farm has

*For Part I, see Bulletin No. 90.

Table I—*Average yields of cowpea hay and of wheat from each of three series of experiments (last 4 of the 5 years at the Station farm, 4 years at the Ford farm and 3 years at the Weaver farm)*

Series	Phosphate	Cowpea hay		Disposition of cowpea crop	Wheat			
		Unlimed	Limed		Unlimed		Limed	
					Grain	Straw	Grain	Straw
		Ton	Ton		Bu.	Ton	Bu.	Ton
Station farm	None	1.07	1.11	Turned under	23.3	1.51	26.1	1.69
Ford farm	"	0.78	0.84	"	16.0	1.08	19.5	1.35
Weaver farm	"	0.21	0.28	"	6.4	0.38	9.1	0.54
Average		0.69	0.74		15.2	0.99	18.2	1.19
Station farm	None	0.69	0.91	Removed	15.4	0.91	20.1	1.08
Ford farm	"	0.51	0.61	"	10.0	0.61	16.4	1.00
Weaver farm	"	0.21	0.28	"	5.3	0.31	9.2	0.53
Average		0.47	0.60		10.2	0.61	15.2	0.87
Station farm	Acid phosphate	0.98	1.19	Turned under	24.4	1.39	29.7	1.68
Ford farm	"	0.95	1.13	"	19.7	1.22	23.9	1.55
Weaver farm	"	0.47	0.72	"	17.0	0.95	19.8	1.11
Average		0.80	1.01		20.4	1.19	24.5	1.45
Station farm	Acid phosphate	0.82	1.12	Removed	17.6	1.02	22.7	1.30
Ford farm	"	0.98	1.16	"	16.9	0.97	23.3	1.28
Weaver farm	"	0.47	0.64	"	14.9	0.84	16.5	0.92
Average		0.76	0.97		16.5	0.94	20.8	1.17
Station farm	Phosphate rock	1.12	1.21	Turned under	26.7	1.76	28.7	1.83
Ford farm	"	0.85	0.89	"	20.3	1.17	21.6	1.31
Weaver farm	"	0.41	0.37	"	12.3	0.69	13.3	0.76
Average		0.79	0.82		19.8	1.21	21.5	1.30

TABLE I—*Average yields of cowpea hay and of wheat from each of three series of experiments (last 4 of the 5 years at the Station farm, 4 years at the Ford farm and 3 years at the Weaver farm)—Concluded*

Series	Phosphate	Cowpea hay		Disposition of cowpea crop	Wheat			
		Unlimed	Limed		Unlimed		Limed	
					Grain	Straw	Grain	Straw
		Ton	Ton		Bu.	Ton	Bu.	Ton
Station farm	Phosphate rock	0.99	1.04	Removed	17.7	1.01	18.9	1.00
Ford farm	"	1.01	0.92	"	17.9	1.13	17.9	1.14
Weaver farm	"	0.41	0.37	"	10.6	0.57	8.8	0.56
Average		0.80	0.78		15.4	0.90	15.2	0.90
Station farm	Bone meal	1.09	1.34	Turned under	26.0	1.69	29.4	1.94
Ford farm	"	1.02	1.21	"	23.8	1.48	26.1	1.84
Weaver farm	"	0.50	0.65	"	17.3	0.99	18.7	1.08
Average		0.87	1.07		22.4	1.39	24.7	1.62
Station farm*	Thomas slag meal	1.35	1.32	Turned under	30.1	2.01	30.4	2.07
Ford farm	"	1.26	1.32	"	23.6	1.64	25.8	1.73
Average		1.31	1.32		26.9	1.83	28.1	1.90

*From J6 where the heavy application was made.

TABLE II—*Yields of cowpea hay and of wheat from three series of experiments (results obtained in the same series with those published in Part I., Bull. 90)*

SERIES I, ON EXPERIMENT STATION FARM

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay			Wheat					
				Un-limed	Limed	Aver-age	Unlimed		Limed		Average of limed and unlimed	
							Grain	Straw	Grain	Straw	Grain	Straw
				Ton	Ton	Ton	Bu.	Ton	Bu.	Ton	Bu.	Ton
F 6	1905	4 tons farmyard manure......	Removed......									
	1906	" "	"	......	......	1.24	......	......	......	......	35.7	2.11
	1907	Nothing......................	"	0.67	0.67	0.67	30.7	1.88	30.3	2.01	30.5	1.95
	1908	4 tons farmyard manure......	"	1.30	1.24	1.27	22.2	1.29	23.5	1.30	22.9	1.30
	1909	" "	"	1.62	1.80	1.71	23.3	1.44	24.0	1.48	23.7	1.46
		....	......	1.26	1.26	1.26	27.3	1.82	27.7	1.77	27.5	1.79
		Average..........	....	1.21	1.24	1.23	25.9	1.61	26.4	1.64	28.1	1.72
G 6	1905	{ 4 tons farmyard manure..... 200 lbs. acid phosphate ..... }	Removed......									
	1906	" "		......	......	1.45	......	......	......	......	38.8	1.89
	1907	200 lbs. acid phosphate	"	0.67	0.67	0.67	32.3	1.87	27.7	1.69	30.0	1.78
	1908	{ 4 tons farmyard manure..... 200 lbs. acid phosphate ..... }	"	1.43	1.57	1.50	21.5	1.16	24.5	1.30	23.0	1.23
	1909	" "	"	1.60	1.75	1.67	21.7	1.27	23.0	1.47	22.9	1.37
		....	"	1.4[illegible]	1.69	1.59	26.0	1.80	27.3	1.80	26.7	1.80
		Average..........	....	1.[illegible]	1.42	1.38	25.4	1.53	25.6	1.57	28.2	1.62
H 5	1905	{ 200 lbs. acid phosphate...... 50 " muriate of potash.... }	No cowpeas grown									
	1906	" "					......	......	......	......	34.6	1.38
	1907	" "					30.7	2.52	34.3	2.37	32.5	2.45
	1908	" "					24.5	1.31	25.9	1.38	25.2	1.35
	1909	" "					21.3	1.45	24.3	1.84	22.8	1.60
		....					15.0	1.23	19.7	1.17	17.4	1.20
		Average....					22.9	1.63	26.1	1.69	26.5	1.60

TABLE II—*Yields of cowpea hay and of wheat from three serires of experiments (results obtained in the same series with those published in Part I., Bull. 90)—Concluded*

Plot	Year	Fertilizer per acre	Disposition of cowpea crop	Cowpea hay: Un-limed	Cowpea hay: Limed	Cowpea hay: Aver-age	Wheat, Unlimed: Grain	Wheat, Unlimed: Starw	Wheat, Limed: Grain	Wheat, Limed: Straw	Wheat, Average of limed and unlimed: Grain	Wheat, Average of limed and unlimed: Straw
				Ton	Ton	Ton	Bu.	Ton	Bu.	Ton	Bu.	Ton
H 8	1905	200 lbs. acid phosphate ..... 50 ' muriate of potash	Turned under..	......	......	1.24	No wheat grown					
	1906	" "	"	0.58	0.58	0.58						
	1907	" "	"	1.13	1.16	1.15						
	1908	" "	"	1.98	1.77	1.88						
	1909	" "	"	1.45	1.51	1.48						
		Average....	....	1.29	1.26	1.27						
			SERIES II, ON FORD FARM									
1	1906	200 lbs. acid phosphate ..... 50 " muriate of potash	No cowpeas grown				13.3	0.76	18.7	1.04	16.0	0.90
	1907	" "					8.7	0.50	14.0	0.78	11.4	0.64
	1908	" "					18.7	0.90	24.0	1.14	21.4	1.02
	1909	" "					4.0	0.30	6.0	0.24	5.0	0.27
		Average....					11.2	0.62	15.7	0.80	13.5	0.71
			SERIES III, ON WEAVER FARM									
10	1907	None........................	No cowpeas grown				9.0	0.50	14.6	0.86	11.8	0.68
	1908	"					3.1	0.45	8.0	0.44	5.6	0.45
	1909	"					2.9	0.17	2.8	0.17	2.9	0.17
		Average....					5.0	0.37	8.5	0.49	6.8	0.43

been conducted for five years. The soil, which is a friable loam of a dark red color, such as is characteristic of the best limestone soils of East Tennessee, is relatively well supplied with the three important elements of plant food, phosphoric acid, nitrogen, and potash. The series on the Ford farm has run for four years. This soil is the rather heavy yellowish-red silt loam which results from the decomposition of the blue limestone of East Tennessee and responds readily to phosphatic fertilizers. The series on the Weaver farm has run for three years, and this soil, which is decidedly the poorest of the three in all plant-food elements, is a gray-colored silt loam, underlaid with a red-colored subsoil such as is characteristic of the Highland Rim of Middle Tennessee.

DISCUSSION OF THE RESULTS GIVEN IN TABLE I

As one-half of every plot in each series was limed, the effects of liming on the crops grown may be studied under a number of different conditions, such as with and without the addition of phosphate, with the cowpea crop turned under, and with it removed annually as hay.

Profit from liming

Although two of the three soils clearly stood in need of an additional supply of phosphate, the application of lime by itself was highly profitable in each series. Where the cowpea crop was turned under the average annual increase of wheat attributable to the lime was 3 bushels per acre. Allowing $5.00 per acre as the cost of one ton of burnt lime, including cost of application, the increase for two years would in each series more than repay this expenditure. Where the peas were removed for hay, the average annual increase of cowpea hay due to liming was 260 pounds per acre, and of wheat 5 bushels, or taken together they amount annually to somewhat more than enough to pay the cost of liming for the entire period.

Influence of various phosphates

The effect of liming in conjunction with the application of different phosphates was found to vary with the kind of phosphate.

Where acid phosphate was used the liming was even more profitable than where no phosphate was applied; the average annual increase per acre of the limed sections over the unlimed being 4.1 bushels of wheat where the cowpeas were turned under, and 420 pounds of hay and 4.3 bushels of wheat where the hay was removed. On the bone meal plots liming proved profitable in each series, but the average profit was a little less than on the unphosphated plots. Where Thomas slag meal was applied in large quantity the value of liming is questionable. According to the results obtained, it was unprofitable at the Station farm, but profitable at the Ford farm. Leaving out of consideration the possible inequality of fertility in the halves of the same plot, varying results would naturally be expected on different soils, depending on the need of lime. Also, for experimental purposes, 2,800 pounds per acre of the slag meal, which furnished about 1,000 pounds of lime capable of neutralizing acidity, were used on the Station plot, but only 1,690 pounds, containing some 600 pounds of lime, on the Ford plot. Apparently enough slag meal could be profitably used to take the place of liming on either soil. With regard to a light annual dressing of this material, such as would ordinarily be made in practice, plot I6 at the Station farm shows throughout the five-year period profitable returns from the liming.

Lime unfavorable to the utilization of phosphate rock

An entirely different proposition is presented by the results obtained on the phosphate rock plots. Where this material was used there was, at most, according to the experimental data, a narrow margin of probable profit from liming where the cowpea crop was turned under and a decided loss where the cowpea crop was removed; but the slight apparent effect from the liming as noted under the former condition can not be attributed, as in the case of the slag meal, to the lime in the phosphate. There is, it is true, a small amount of carbonate of lime in nearly all samples of phosphate rock—more in the low-grade rock than in the high-grade—but not sufficient to be of any special value in supplying lime to an "acid" soil. At least two of these soils, Ford's and the Weaver Brothers', were poor in phosphoric acid and the low yields obtained under liming on the phosphate rock plots can, in the writer's opinion, be attributed only to the insufficient supply of soluble phosphate furnished under this condition. It should be noted in this connection that the yields of wheat from the limed sections of the no-phosphate plots are very similar to those obtained on either the limed or the unlimed sections of the phosphate rock plots.

COMMENTS ON THE RESULTS GIVEN IN TABLE II

Table II gives some important data not only with regard to the effect of lime on both of the crops when manured and on wheat where no cowpeas were grown, but also as an important aid in the explanation of the increased yields of both cowpeas and wheat under the various conditions noted.

Liming may not be effective on cowpeas when removed

At the Station farm the two plots F6 and G6, which received light annual applications of farmyard manure, agree in showing little if any effect from the application of lime. Also a similar result was obtained on plot H8, where only cowpeas were grown and were turned under each year. On the other hand, where no cowpeas were grown (plot H5) there was a decidedly profitable increase in the yield of wheat, and this was true in each of the other two series. The question now arises, why did the lime where farmyard manure was used and where only cowpeas were grown (but turned under) fail to give the increased yields which resulted under other conditions?

A possible explanation of the results obtained

Although liming undoubtedly produces a number of different effects in the soil, in these experiments the explanation of its action appears to be this, that it increased, probably indirectly, through the action of bacteria, the supply of available soil nitrogen, so that whether it were the non-legume wheat or the legume cowpea the result was increased growth. In the case of plots F6 and G6 the manure furnished sufficient additional nitrogen to produce, so far as that element was concerned on this particular soil, maximum crops. In the case of plot H8 the annual turning under of the only crop grown, cowpeas, was sufficient to furnish an abundance of nitrogen where no lime was applied. If the correction of soil "acidity" were the cause of the increased yields following liming on plots F4 and F5, for example, then liming might be expected to produce on F6, G6 and H8 a similar result, which was not the case.

The increased crop production on the limed sections can not be attributed to any direct demand for calcium as an element of plant food because of the ample supply of soluble calcium, which is always found in acid phosphate combined both with the "available" phosphoric acid and with sulphuric acid, on the acid phosphate plots, those heavily treated in particular. One of the best proofs that the increased yields from the liming were due to soluble soil nitrogen is furnished by the data of Part III of this bulletin, which shows a marked decrease at the end both of two and of five years in total nitrogen on the limed side of nearly every plot. The additional point was brought out by the examination of the roots of the cowpea plants from various plots that the nodules were appreciably smaller and less numerous on the limed than on the unlimed sections. This finding is of interest in view of the fact that sparse and small-sized nodules are the rule on cowpea roots growing in a soil rich in nitrogen.

Percentage of nitrogen in cowpea crop increased by liming

Also it is of interest to note that chemical analyses, which were made of the 1907 crop of cowpea hay from 11 of the plots, showed that in addition to the increased production the per cent of nitrogen in the hay from the limed areas was appreciably greater than from the unlimed, the average per cent found in the hay from the limed sides of the 11 plots being 2.44, and from the unlimed 2.17. The per cent of nitrogen in the wheat crop (grain and straw) was very little affected by the liming, although the per cent in the grain of the 1907, 1908 and 1909 crops was slightly higher when grown on the limed than on the unlimed areas.

SUMMARY OF RESULTS.

1. Burnt lime applied at the rate of one ton per acre gave a profitable increase in the yields of both cowpea hay and wheat under most of the experimental conditions of all three series.

2. The effect of the liming was appreciably modified by the kind of phosphate used, with results as follows:

a. In each of the three series liming was most profitable on the acid phosphate plots.

b. In two out of the three series the second most profitable results were gotten on the no-phosphate plots.

c. In two out of three series the third place was taken by the bone meal plots.

d. Where very heavy applications of Thomas slag were made, as in two of the series, the value of liming proved questionable, but on the plot receiving the light application of slag liming was profitable.

e. Where phosphate rock was used liming proved of little value and in at least one series was unprofitable.

3. The excellent yields on the unlimed section of the plots receiving the heavy application of Thomas slag meal may well be due in part to the lime in the slag, and the comparatively low yields on the limed side of the phosphate-rock plots are attributed to the unfavorable effect of the lime on the phosphate rock in rendering it less soluble.

4. As an exception to the general result stated in summary 1, the yields both of cowpea hay and of wheat were not increased by liming where light annual applications of manure (4 tons per acre) were made; also it did not increase the growth of cowpeas on the plot where only cowpeas were grown each year and turned under.

5. In these experiments the increased yields obtained from liming are attributed to an increase in available nitrogen, which was utilized by both the cowpeas and the wheat.

PART III—THE EFFECT OF LIMING AND OF GREEN MANURING ON THE SOIL CONTENT OF NITROGEN AND HUMUS

INTRODUCTION

That the final result of liming without the return to the soil of adequate quantities of vegetable matter, either through applications of farmyard manure or by the turning under of green crops, or the like, may be decreased productiveness, is well known and has given rise to various adages, such as the following:

"Lime and marl without manure
Make both farm and farmer poor."

With a view to cutting down the possible waste of soil nitrogen and humus, the common recommendation in recent years has been to make light and frequent applications of lime rather than heavy and infrequent ones. Also at the present time the use of ground limestone is being urged by many writers in preference to burnt lime, both because of its relatively slow action in the soil and because of its comparative cheapness. Accurate data, however, with regard to the quantitative effect of either form on the nitrogen and humus supplies of the soil are far from abundant. In fact, extensive investigation is needed, under various conditions of cropping, rates of liming and fertilizing, and on various types of soil, and under different climatic conditions, in order to get the information desired. This publication is intended as a contribution to our knowledge in this direction.

Attention may be called to the following results which were gotten in this country, and which are of present interest:

Experiments at the Rhode Island Station

In a series of pot experiments at the Rhode Island Station* 4 tons of air-slaked lime per acre were found at the end of two years to have materially decreased the percentage of humus and to have very slightly decreased the percentage of humus nitrogen, when calculated on the dry-soil basis. For the average of the three sets of these Rhode Island experiments, which are comparable on the 4-ton basis, we have calculated that at the close of the period the percentage of humus was 3.87 in the case of the unlimed soil but only 3.52 for the limed; and that the percentage of total nitrogen was 0.1333 for the unlimed and 0.1327 for the limed.

*R. I. Exp. Sta. Rep., 1899, pp. 152-162, by Wheeler, Sargent, and Hartwell.

Experiments at the Pennsylvania Station

At the Pennsylvania Station,* in a series of field experiments with a four-year crop rotation, which had run for 28 years, the calculation was made that without manure the plots which received lime at the rate of two tons per acre once every four years had yielded products worth every four years of the rotation $4.21 less than the untreated plots. With 6 tons of manure per acre, however, the burnt lime gave a profit amounting to $2.59 per acre for each set of four years. In connection with these field experiments rather extensive laboratory investigations have been made for several years, and among other determinations are those of total nitrogen and carbon on both unlimed and limed plots. As these data are unpublished, we are indebted to Director Hunt and Mr. McIntire of the Pennsylvania Station for permission to use the following results:

The nitrogen and carbon contents of certain rotation plots at the Agricultural Experiment Station, State College, Pa., at the end of 30 years —analyses by W. H. McIntire.

Plot (Avg. 4 tiers)	Treatment	Total nitrogen	Total organic carbon
	Per acre	Per cent	Per cent
16	6 tons manure every two years...	0.1523	1.961
22	2 tons burnt lime and 6 tons manure every two years....	0.1589	1.869
28	2 tons burnt lime every two years	0.1199	1.467
24	Nothing	0.1122	1.482
34	4 tons ground limestone every four years.........................	0.1222	1.693

The fact that these analyses, while showing, with the exception of plot 34, a decrease in total carbon, show an increase in total nitrogen on all the limed plots as compared with the unlimed is interesting in connection with the data from the cowpea-wheat plots, which, resembling the Rhode Island results, show a decrease in both total nitrogen and humus on the limed sections as compared with the unlimed.

Possible causes of variance in experimental data

The question naturally arises as to the cause of such different results, but the number of factors involved is so great, including, as they do, differences in system of cropping, physical and chemical differences in soil, and different degrees of alkalinity and acidity of soil, that no definite conclusion can safely be drawn.

*Pa. Sta. Bull. 90, p. 26, by T. F. Hunt.

Experiments at the Iowa Station

A recent publication by Brown* brings out clearly the most important effect of liming on the bacterial activities of the soil and suggests reasons for some of the diverse results. Liming increased the total number of soil bacteria, the ammonifying power, and the nitrate production, and, to a marked extent, the fixation of nitrogen from the air, and this especially where the largest amounts of lime (ground limestone) were present.

SOIL STUDY OF THE COWPEA-WHEAT PLOTS† AT THE TENNESSEE EXPERIMENT STATION FARM

SOME PRELIMINARY CONSIDERATIONS

The soil acidity

The actual amount of burnt lime applied per acre in the cowpea-wheat experiments at the Station farm was 1,800 pounds. Two years after liming, four plots showed an average acidity by the Veitch Method of 0.076 per cent for the unlimed sections. Of the limed sections, two showed an acidity of 0.01 per cent, one was neutral, and one was slightly alkaline. We would conclude, therefore, that the liming was not heavy enough to make the soil distinctly alkaline. At the same time, this rate proved to be sufficient to produce strong, healthy growths of both alsike clover and alfalfa on adjacent plots where without lime both crops were practically failures even when rather heavily manured.

The soil samples

At the outset of the experiments and before any fertilizer or lime was applied, soil samples were carefully taken from each plot. Two years later (1907) and again in three years (1910) samples were taken from both the limed and unlimed sides of each plot. The samples in every instance were taken at the same time of the year—shortly after wheat harvest—and in a uniform and methodical manner, as follows: The depth of sampling was 8 inches, as determined by a mark on the sampling instrument, which was a steel tube 2¼ inches in diameter. The method of using the tube was found to be of consequence, for if it were driven at once to the required depth, the soil was apt to clog in the tube, which was then driven down without cutting, and like a solid bar, so that the sample obtained represented only the upper 3 to 5 inches, as the case might be. To avoid this difficulty the tube was driven down about 2 inches, the sample of soil removed by means of a plunger, and the process repeated until the required depth was reached. In this manner 10 samples from each

*Iowa Exp. Sta., Research Bull. 2, 1911, p. 100, by P. E. Brown.

†For diagram of plots and chemical analyses of the soil see Part I, Bull. 90.

half plot were taken in two rows about 5 feet apart, as indicated in Diagram 1.

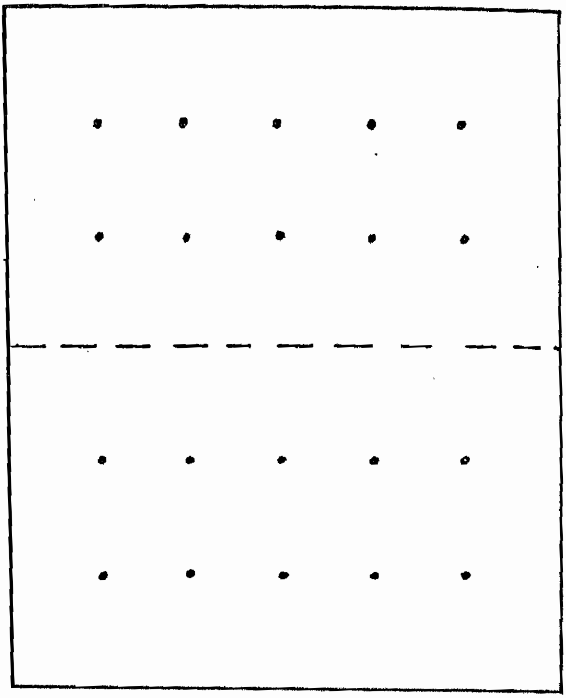

DIAGRAM 1—SHOWING THE NUMBER AND DISTRIBUTION OF SOIL SAMPLES TAKEN FROM EACH HALF OF EVERY PLOT IN 1907 AND AGAIN IN 1910.

The lots from each half plot were mixed together and about 2 pounds taken to the laboratory for analytical purposes.

Since comparable results from plot experiments can be expected only where there is great uniformity of soil conditions, the uniformity of depth, as well as of composition of the surface, or humified portion, of the soil, in which the major portion of the plant roots develop, is of great importance to the understanding and interpretation of the results obtained.

The soil profile

There is given, therefore, in Diagram 2 the soil profile of each plot in the range in which it is found. The profiles show that the dark-colored surface soil extends below the depth of sampling and of plowing in 18 out of the 20 plots.

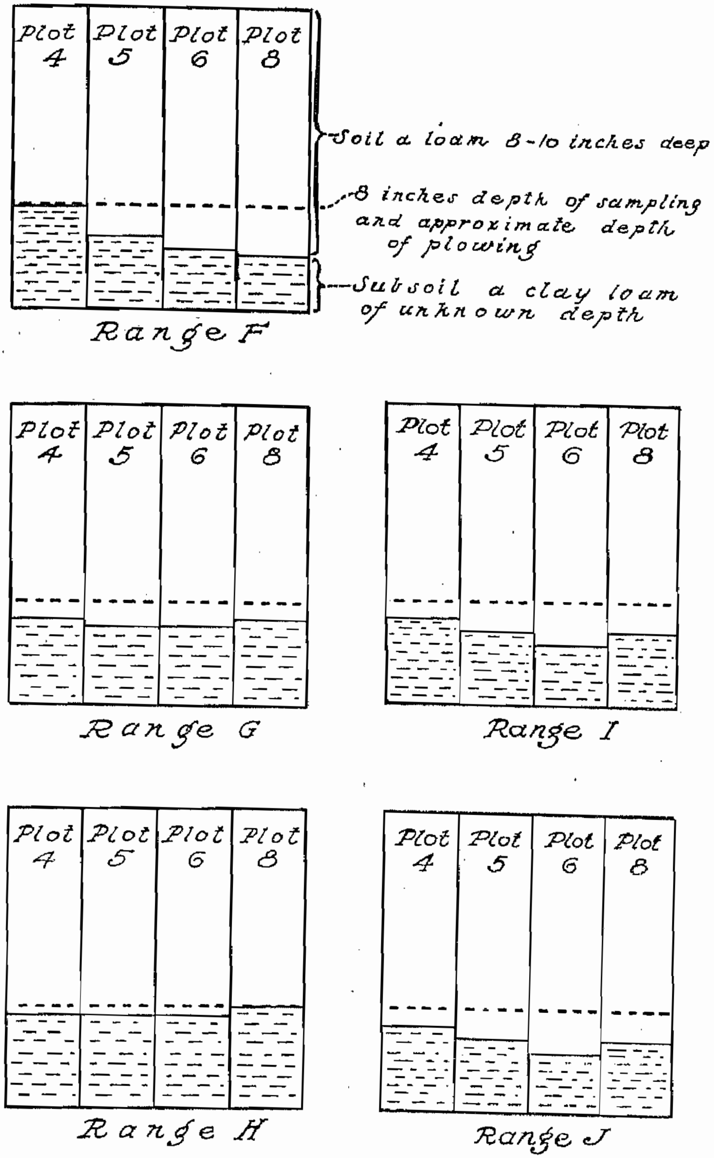

DIAGRAM 2—SHOWING RELATIVE DEPTH OF SURFACE SOIL FOR EACH PLOT; ALSO 8-INCH DEPTH OF SAMPLING, AND APPROXIMATE DEPTH OF PLOWING.

Soil depth and uniformity

The extreme depths are found in range F, with the minimum of 8 inches for plot 4, and the maximum of 9¾ inches for plot 8. The average depth for the 20 plots was found to be 8.9 inches. The differences in depth of soil over the experimental area are therefore appreciable, but are considered to be as little as can be expected on this type of soil. In fact, this field was chosen at the outset because of its apparent uniformity. The depth of the subsoil to the underlying rock (dolomite) is not known, but is probably 20 or more feet.

Derivation of soil

This soil appears to be derived in part from dolomite and in part from an ancient alluvial deposit from the Tennessee River; the experimental field being the third bench above the river.

Mechanical soil analysis

In Table III are given the results of a mechanical analysis, made according to the method of the Bureau of Soils of the U. S. Department of Agriculture, of a composite sample from each of the five ranges. They show marked uniformity throughout.

THE ANALYTICAL RESULTS, ETC.

Table IV gives the analytical data obtained from the plots at the Experiment Station farm. In Table V is a summary of the most

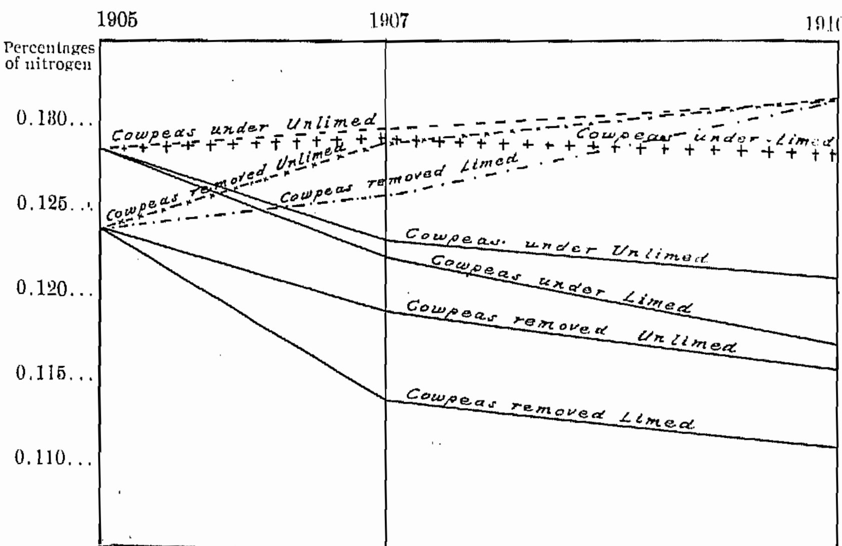

DIAGRAM 3—SOLID LINES INDICATE THE CHANGE IN PER CENT OF SOIL NITROGEN UNDER FOUR CONDITIONS. BROKEN LINES INDICATE THE SUM OBTAINED BY ADDING THE NITROGEN REMOVED BY THE CROPS TO THE NITROGEN FOUND IN THE SOIL.

TABLE III—*Mechanical analyses of the soil from each of the five ranges (by method of Bureau of Soils)*

Class	Size of particles in mm.	Range F	Range G	Range H	Range I	Range J
		Per cent	Per cent	Per cent	Per cent	Per cent
1. Fine gravel	2–1	1.51	1.14	1.62	1.14	1.05
2. Coarse sand	1–.5	2.66	2.43	3.16	2.60	2.58
3. Medium sand	.5–.25	3.27	3.17	3.63	3.32	3.56
4. Fine sand	.25–.1	9.16	8.92	8.62	9.10	9.04
5. Very fine sand	.1–.05	18.01	17.96	16.89	17.23	16.25
6. Silt	.05–.005	47.74	47.91	47.52	47.14	48.36
7. Clay	.005–0	17.65	18.47	18.56	19.47	19.16
Total		100.00	100.00	100.00	100.00	100.00

important averages derived from Table IV. Table VI furnishes some calculations, in pounds per acre of nitrogen, of interest in connection with the other tables.

SOURCES OF ERROR

As there are always possible sources of error in connection with this kind of investigation, an understanding of the possibilities in this direction is necessary in order to form a true opinion of its worth.

Soil sampling a source of error

Probably the most serious chance of error comes from some uncertainty as to whether the soil samples represent exactly the same quantity of surface soil in every year's sampling. That is, did the samples taken in 1910, for example, represent the same weight of soil as those taken in 1905? The depth of sampling was the same each year, but might not the soil have been more compact in one year than in another, and hence, on the assumption that the nitrogen-content decreases with the depth, introduce an error?

Depth of plowing, etc.

As to the 1905 samples, the first plowing was fully 8 inches deep, and the furrow slices were not completely inverted, but tipped to an angle of about 45°, so that the after-preparation must have given a thorough mixture, which could hardly have failed to make the 8-inch samples representative to the full depth of plowing. Separate samples were, however, not taken from each half plot, and this probably accounts for some lack of uniformity in the analyses from certain plots, so that special stress can be placed only on averages from a number of plots. To get evidence in regard to the possible error in later samplings, samples were taken in January, 1912, from both the unlimed and limed sides of each plot, of the soil stratum which lies immediately under the 8-inch depth, but above the usually well-defined subsoil line, as referred to under the soil profile.

Soil and subsoil samples taken below depth of plowing

At the same time there were taken samples representing the first two inches of subsoil lying immediately beneath the soil. Four composite samples were then made up, two of soil, one each from the unlimed and limed sides, and similarly two of subsoil. The analyses are given in Table VII, and show for the soil stratum only 3.7 per cent less nitrogen on the unlimed and 3.5 per cent less on the limed sections than were obtained from the 8-inch samples taken in 1910.

Falling off of nitrogen and humus in subsoil

The subsoils show, as would be expected from their relatively light color, a marked falling off in both nitrogen and humus, amounting, as compared with the 1910 soil samples, to 37 per cent on the unlimed and 36 per cent on the limed sides.

TABLE IV—*Analytical results—the percentages of nitrogen and humus found in the soil of the cowpea-wheat plots at the Station farm (all results calculated to water-free basis)*

Plot	Fertilizer per acre (annual applications except as noted)	Disposition of cowpea crop	Year sampled	Unlimed		Limed	
				Nitrogen	Humus	Nitrogen	Humus
				Per cent	Per cent	Per cent	Per cent
F 4	193 lbs. acid phosphate	Turned under	1905	.1293	1.32	.1293	1.32
			1907	.1202	1.31	.1212	1.25
			1910	.1165	1.32	.1179	1.27
F 5	193 lbs. acid phosphate 50 lbs. muriate of potash	"	1905	.1329	1.39	.1329	1.39
			1907	.1313	1.44	.1226	1.29
			1910	.1290	1.45	.1223	1.33
F 6	4 tons farmyard manure	Removed	1905	.1428	1.45	.1428	1.45
			1907	.1384	1.47	.1327	1.46
			1910	.1362	1.54	.1307	1.47
F 8	295 lbs. phosphate rock 50 lbs. muriate of potash	Turned under	1905	.1321	1.39	.1321	1.39
			1907	.1273	1.40	.1280	1.39
			1910	.1317	1.48	.1209	1.39
G 4	193 lbs. acid phosphate	Removed	1905	.1314	1.34	.1314	1.34
			1907	.1198	1.33	.1254	1.34
			1910	.1191	1.35	.1191	1.33
G 5	193 lbs. acid phosphate 50 lbs. muriate of potash	"	1905	.1300	1.38	.1300	1.38
			1907	.1269	1.36	.1172	1.29
			1910	.1209	1.39	.1153	1.31
G 6	4 tons farmyard manure 193 lbs. acid phosphate	"	1905	.1302	1.32	.1302	1.32
			1907	.1320	1.40	.1285	1.39
			1910	.1256	1.49	.1190	1.32

TABLE IV—*Analytical results—the percentages of nitrogen and humus found in the soil of the cowpea-wheat plots at the Station farm (all results calculated to water-free basis)—Continued*

Plot	Fertilizer per acre (annual applications except as noted)	Disposition of cowpea crop	Year sampled	Unlimed		Limed	
				Nitrogen	Humus	Nitrogen	Humus
				Per cent	Per cent	Per cent	Per cent
G 8	295 lbs. phosphate rock; 50 lbs. muriate of potash	Removed	1905	.1101	1.09	.1101	1.09
			1907	.1098	1.08	.1019	1.04
			1910	.1052	1.08	.1027	1.01
H 4	None	Turned under	1905	.1284	1.33	.1284	1.33
			1907	.1235	1.34	.1171	1.24
			1910	.1158	1.35	.1113	1.23
H 5	193 lbs. acid phosphate; 50 lbs. muriate of potash	None grown	1905	.1334	1.41	.1334	1.41
			1907	.1197	1.31	.1226	1.41
			1910	.1097	1.31	.1129	1.34
H 6	140 lbs. steamed bone meal; 50 lbs. muriate of potash	Turned under	1905	.1178	1.28	.1178	1.28
			1907	.1204	1.29	.1198	1.25
			1910	.1166	1.36	.1136	1.26
H 8	193 lbs. acid phosphate; 50 lbs. muriate of potash	"	1905	.1037	0.92	.1037	0.92
			1907	.1027	0.94	.0977	0.92
			1910	.1006	1.19	.0946	1.01
I 4	None	Removed	1905	.1236	1.24	.1236	1.24
			1907	.1202	1.37	.1111	1.17
			1910	.1175	1.33	.1080	1.23
I 5	2900 lbs. acid phosphate*; 50 lbs. muriate of potash	Turned under	1905	.1330	1.40	.1330	1.40
			1907	.1255	1.39	.1280	1.42
			1910	.1261	1.44	.1219	1.44

TABLE IV—*Analytical results—the pertentages of nitrogen and humus found in the soil of the cowpea-wheat plots at the Station farm (all results calculated to water-free basis)—Concluded*

Plot	Fertilizer per acre (annual applications except as noted)	Disposition of cowpea crop	Year sampled	Unlimed		Limed	
				Nitrogen	Humus	Nitrogen	Humus
				Per cent	Per cent	Per cent	Per cent
I 6	188 lbs. Thomas slag meal; 50 lbs. muriate of potash	Turned under	1905	.1290	1.36	.1290	1.36
			1907	.1177	1.20	.1232	1.34
			1910	.1202	1.33	.1197	1.29
I 8	590 lbs. phosphate rock; 50 lbs. muriate of potash	"	1905	.1082	1.05	.1082	1.05
			1907	.1069	1.10	.1098	1.10
			1910	.1092	1.18	.1027	1.18
J 4	2100 lbs. steamed bone meal*; 50 lbs. muriate of potash	"	1905	.1321	1.35	.1321	1.35
			1907	.1329	1.38	.1219	1.29
			1910	.1250	1.50	.1149	1.29
J 5	1475 lbs. phosphate rock*; 50 lbs. muriate of potash	"	1905	.1346	1.34	.1346	1.34
			1907	.1291	1.33	.1310	1.36
			1910	.1250	1.44	.1241	1.52
J 6	2816 lbs. Thomas slag meal*; 50 lbs. muriate of potash	"	1905	.1422	1.40	.1422	1.40
			1907	.1269	1.34	.1278	1.35
			1910	.1241	1.37	.1236	1.47
J 8	50 lbs. muriate of potash	"	1905	.1219	1.26	.1219	1.26
			1907	.1183	1.24	.1170	1.20
			1910	1148	1.19	.1163	1.20

*Only one application of phosphate.

TABLE V—*Various averages obtained from Table IV; also per cent of loss or gain calculated for both nitrogen and humus*

No. of plots in average	Average of—	Year sampled	Unlimed		Limed		Calculated losses (—) or gains (+) of nitrogen and humus since 1905			
							Unlimed		Lim d	
			Nitrogen	Humus	Nitrogen	Humus	Nitrogen	Humus	Nitrogen	Humus
			Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
20	All plots	1905	.1273	1.30	.1273	1.30	....	....	....	....
		1907	.1225	1.30	.1204	1.28	—3.77	0.00	—5.42	—1.54
		1910	.1194	1.35	.1156	1.29	—6.21	+3.85	—9.19	—0.77
12	Plots where cowpeas were turned under	1905	.1285	1.32	.1285	1.32	....	....	....	....
		1907	.1233	1.31	.1223	1.29	—4.05	—0.76	—4.83	—2.27
		1910	.1212	1.37	.1174	1.32	—5.68	+3.79	—8.64	0.00
4	Plots where cowpeas were removed and no manure applied	1905	.1238	1.26	.1238	1.26	....	....	....	....
		1907	.1192	1.29	.1139	1.21	—3.72	+2.38	—8.00	—3.97
		1910	.1157	1.29	.1113	1.22	—6.54	+2.38	—10.10	—3.17
8	Acid phosphate plots	1905	.1280	1.31	.1280	1.31	....	....	....	....
		1907	.1223	1.31	.1204	1.29	—4.45	0.00	—5.94	—1.53
		1910	.1184	1.37	.1154	1.29	—7.50	+4.58	—9 84	—1.53
8	No-phosphate and phosphate rock plots	1905	.1252	1.27	.1252	1.27	....	....	....	....
		1907	.1217	1.29	.1186	1.25	—2.80	+1.58	—5.28	—1.58
		1910	.1194	1.32	.1146	1.28	—4.63	+3.94	—8.48	+0.79

TABLE VI—*Some calculations on the nitrogen account (weight of dry, fine earth—less than ½ mm. in diam.—per 8-in. acre of this soil—determined to be 2,318,000 lbs.)*

No. of plots in average	Average of—	Nitrogen per 8-in. acre in 1905	Nitrogen per 8-in. acre in 1907		Nitrogen removed by crops during first 2 years		Nitrogen unaccounted for in 1907		Nitrogen per 8-in. acre in 1910		Nitrogen removed by crops in 5 years		Nitrogen unaccounted for in 1910	
			Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
			Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
12	Plots where cowpeas were turned under	2979	2858	2835	151	163	+30	+19	2809	2721	237	258	+67	0
4	Plots where cowpeas were removed and no manure applied	2870	2763	2640	228	278	+121	+48	2682	2580	369	467	+181	+177

Small probable error in sampling Provided, therefore, that the subsoil were not penetrated, an inch difference in depth of sampling does not appear seriously to affect the results. For example, if the stratum analyzing 0.1150 per cent nitrogen were included by error in the sampling of the unlimed areas, the percentage of nitrogen found would be changed from 0.1194 per cent to 0.1189, or a difference of only 0.4 of 1 per cent.

Analytical errors Much of the analytical work was duplicated by two or more analysts, and the same methods were followed throughout. Of the two estimations, however, that of nitrogen is recognized as much more exact than that of humus*, and is, indeed, one of the most reliable of analytical methods.

Of course the various chances of error would be expected to affect in particular the comparison between the nitrogen and humus contents of the soil for the different years, but to have little influence on the comparison between the limed and the unlimed areas.

THE NITROGEN DATA

The nitrogen data of Tables IV and V show that a marked decrease in the soil content of nitrogen took place under all of the experimental conditions, but especially where lime was applied. The average per cent of nitrogen found in the surface 8 inches of soil of

TABLE VII—*Percentages of total nitrogen and humus in composite samples taken below the 8-in. depth of plowing, etc. (results calculated to water-free basis)*

Lab. No.	Description of sample	Nitrogen	Humus
1979	Soil from unlimed sides, but below 8-in. depth................................ (Average thickness of stratum about 1 in.)	0.1150	1.21
1978	Soil from limed sides, but below 8-in. depth .... (Average thickness of stratum about 1 in.	0.1116	1.17
1981	First 2 in. of subsoil immediately underlying 1979................................	0.0751	0.68
1980	First 2 in. of subsoil immediately underlying 1978................................	0.0740	0.61

*For the estimation of nitrogen, the Official Method, with 10g. of soil, and with blanks run on the reagents, was followed throughout. In the estimation of humus the Official Method was used except that special pains were taken to get rid of the clay by repeated evaporation, etc., of the humus matter. Also, in order to make the results as comparable as possible, a correction of 14 per cent for loss of water from the insoluble residue left after the humus was burnt off was made. The amount of this insoluble residue was usually in the neighborhood of one-half of one per cent of the original soil, but the variation was sufficient to make the correction advisable.

the 20 plots at the outset of the experiments was 0.1273, or 2,951 pounds per acre. At the end of the first two years the same plots gave an average of 0.1225 per cent for the unlimed and 0.1204 per cent for the limed sections, or 2,840 pounds and 2,791 pounds per acre, respectively. At the end of five years the unlimed sections showed an average content of 0.1194 per cent and the limed of only 0.1156 per cent, or 2,768 pounds and 2,680 pounds per acre, respectively.

Amounts of nitrogen removed by the crops

As determined by crop analyses, which were made annually for a number of plots, a close approximation to the nitrogen removed by the wheat crops* in five years from the four typical plots, H4, F4, F5, and F8, is 237 pounds per acre for the unlimed and 260 pounds for the limed sections, but 170 and 258 pounds are the losses from the soil as calculated from the estimations of nitrogen for the average of the 12 plots where the cowpeas were turned under, and where, consequently, an appreciable quantity of nitrogen must have been added to the soil through the action of the nitrogen-gathering bacteria, which were abundantly present in the roots of the cowpea plants. This leaves for the unlimed sections 67 pounds of nitrogen per acre derived from sources outside of the surface 8 inches of soil, but for the limed only 2 pounds. From plots I4, G4, G5, and G8, which were fertilized exactly as the other four, but from which the cowpea hay was removed, the approximate quantities of nitrogen removed by the two crops, cowpeas and wheat, in five years amounted to 369 pounds per acre for the unlimed and 467 pounds for the limed halves, and the calculated soil losses were 188 pounds and 290 pounds, respectively. This leaves in each case nearly 180 pounds of nitrogen per acre to be derived from sources outside of the surface 8 inches of soil, and probably in large part from the atmosphere. Table VI and Diagram 3 show that more nitrogen was removed by crops in every case save one than appears to have been lost from the surface 8 inches of the soil.

Acid phosphate may cause loss of nitrogen and humus

The comparison between the plots which received acid phosphate and those which were either unphosphated or received applications of phosphate rock, was made in Table V because of the popular impression that commercial fertilizers consisting chiefly of acid phosphate "burn up" the soil; that is, are destructive to the vegetable matter of the soil, which then becomes less productive and more difficultly managed than formerly. The results of the analytical data give some foundation for this opinion, but further evidence is needed in order to establish it as a fact.

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*Approximately 1.73 pound of nitrogen was removed, on the average, by the grain and straw of a bushel of wheat.

Fertilizers wrongly blamed

The commercial fertilizer mixtures in common use furnish little nitrogen (2 to 3 pounds per 100) and a relatively large amount (8 to 12 pounds per 100) of phosphoric acid, so that their use is practically limited to soils poor in phosphate. Such soils at first may respond well to the usual light applications of 100 or 200 pounds of the fertilizer per acre, and are therefore put oftener than before into grain crops, which draw heavily on the soil supply of nitrogen, and through whose culture humus is lost rather than gained. The fertilizer can therefore be blamed only indirectly for the soil deterioration, which should be attributed first of all to the system of cropping.

REMARKS ON THE LOSSES OF NITROGEN

The question arises as to the reason for the rather excessive losses of nitrogen which took place in the brief period of five years and even where the conditions of the experiment were favorable to the maintenance of fertility. Previous to the experiments the land had been in grass for some ten or more years, and had accumulated, for a Tennessee soil, a comparatively large supply of vegetable matter. Since 1905 the land has been plowed twice each year and thoroughly harrowed, rolled, and the like, in preparation for seeding. These manipulations greatly expose the soil to the air, so that the oxidation processes causing loss of organic matter would be increased. Some loss can be attributed to erosion. The surface of the experimental field was slightly sloping, ample to permit of surface drainage, and, as is common for soils throughout the State, there was a perceptible loss of soil during heavy rains; but this must have been less than that which takes place under usual field conditions, both because of the lay of the land and because it was covered almost throughout the year by a growing crop, which protected and helped to hold the soil in place. The fact, therefore, that the soil content of nitrogen was not even maintained where a leguminous green crop equal to more than a ton per acre of thoroughly cured hay, on the average, not to mention the fallen leaves, stubble and roots, was turned under each year is almost startling and shows the necessity of a superior system of management if anything like high fertility of the soil is to be maintained without recourse to outside supplies of nitrogen, such as would be furnished by nitrogenous fertilizers and commercial feeding stuffs. Certainly there is little in the findings to encourage the claim that cowpeas when removed as hay are of permanent benefit to the land or are at all comparable to clover in this respect.*

*The authors recognize, however, the fact that cowpeas, even when removed, have a decided effect on the mechanical condition of a heavy soil, which is made looser and more friable than it was before the peas were grown, and that this effect might be followed by an increased yield of the succeeding crop. Also a very poor soil might, even when the pea crop is removed, be appreciably better supplied with available nitrogen than if none had been grown.

HUMUS

The humus results indicate gains on the unlimed sections, but losses are the rule on the limed. Naturally the greatest gains at the end of the five-year period are where the cowpea crops were turned under and no lime was used, the average gain for 12 plots being 3.79 per cent over that found at the outset; but on the corresponding limed sections, although the cowpea crop was increased, the humus supply was on the average only maintained. For these 12 plots the average difference in humus between the limed and unlimed sections amounted at the end of five years to 1,159 pounds per 8-inch acre in favor of the latter. Even where the cowpea crop was removed there appears to be a gain of 2.38 per cent of humus in the unlimed sections, but on the limed there is a loss of 3.17 per cent, or a difference between the limed and unlimed sections amounting to 1,623 pounds per 8-inch acre in favor of the latter.

Table VI is of interest not only because of its bearing on the possible error in sampling, but also as showing that the effects of liming extended plainly below the depth of plowing, both the soil and subsoil samples from the unlimed sections giving a slightly higher per cent of both nitrogen and humus than the limed.

THE CHANGES IN SOIL CONTENT OF NITROGEN AND HUMUS FOR THE FIRST TWO YEARS AFTER LIMING (1905-1907) AS COMPARED WITH THOSE OF THE LAST THREE YEARS (1907-1910)

Table IV gives a summary of the changes in soil content of nitrogen and humus under various conditions, both at the end of two and of five years. According to the average results from all 20 plots, there was a considerably greater annual decrease in nitrogen under both limed and unlimed conditions the first two years than the subsequent three years. This annual decrease for the first two years amounted to 1.89 per cent of the total content at the outset for the unlimed sections but was increased under liming to 2.71 per cent. During the next three years the annual decrease was only 0.81 per cent on the unlimed sections and 1.26 per cent on the limed. In the case of the humus there appears at the end of the first two years to have been neither gain nor loss on the average for the unlimed sections, but an average annual loss of 0.77 per cent for the limed, while for the three-year period there appears to have been a gain of 3.85 per cent of humus on the unlimed sections and an annual loss of 0.39 per cent from the limed.

These results indicate, therefore, that the losses due to the various operations of tillage were much greater during the first two years than those during the following three years. In fact, even the turning under of the cowpea crops where no lime was applied did not result in a gain of humus at the end of the first two years. The loss of soil nitrogen due to liming shows an appreciably slower change in rate for the last three than for the first two years; the average annual loss directly attributable to the liming being 0.52 per cent of the total soil content for the last three years and 0.83 per cent for the first two years. Of course not all, by any means, of this loss from the soil was an actual waste, as is proved by the increased crop yields on the limed sections. There does appear, however, from the calculations given on page 38, to have been an actual waste of nitrogen due to liming, amounting, in the course of the five years, as the average of the twelve plots where the cowpeas were turned under, to at least 65 pounds per acre.

SOME PRACTICAL CONSIDERATIONS FROM THE FIELD AND ANALYTICAL DATA

The data of Part II of this bulletin show that liming was highly profitable on all three of the soils in question, but Part III shows that it causes an appreciable loss of both nitrogen and humus from the soil. In view of these facts, the practical question may arise, under what conditions is liming justified? No complete answer is attempted here, but the foregoing, together with well-known facts, allow, in the opinion of the writers, the following conclusions:

1. Liming, to the extent of that practiced in the experiments reported, is justified—

a. In order to get crops which can not otherwise be obtained; in particular, such crops as clover and alfalfa.

b. In case of a poor soil which needs stimulating in order to produce profitable crops, especially if the purpose be to increase the fertility of the soil by fertilizing, manuring, and a judicious rotation of crops.

2. Liming is not apt to be justified—

a. When the soil is able to produce without it (though some manure or commercial fertilizer be required) healthy and vigorous crops of clover and alfalfa.

b. When used for the sake of the immediate returns without regard to the future condition of the soil; that is, without applications of farmyard manure, green crops turned under, or a suitable rotation of crops.

3. In view of the excellent results obtained both by this Station in trials on numerous soils throughout the State, and by others, ground limestone can be recommended as a desirable source of lime. Two tons of this material, the usual application for one acre, contains about as much calcium oxide as one ton of burnt lime, but its comparatively coarse mechanical condition prevents its ready solution in the soil, and its effect on the nitrogen and humus must, therefore, be much more gradual than that from one ton of the burnt lime when properly slaked and distributed. Fortunately, the two-ton applica-

tion of the rock appears to be sufficient, so far as lime is concerned, to produce excellent crops of either clover or alfalfa on almost any Tennessee soil.

SUMMARY OF GENERAL CONCLUSIONS

1. Land in sod for a number of years suffered in five years, under cultivation in a double-crop rotation of cowpeas and wheat, a serious loss of nitrogen. Loss took place under all of the experimental conditions, including the turning under annually of a cowpea crop, which amounted to more than a ton of hay per acre, not including the fallen leaves, stubble, and roots.

2. The loss of nitrogen was appreciably greater on the limed than on the unlimed areas, and extended below the depth of plowing.

3. The average annual loss of nitrogen directly attributable to liming was calculated to be 0.83 per cent of the total soil content for the first two years and 0.52 per cent for the last three years.

4. A slightly greater loss of nitrogen took place from the acid phosphate plots than from the no-phosphate and phosphate-rock plots.

5. By taking the nitrogen removed by the crops into consideration, there was found to be, at the end of five years, (1) where the cowpea crop was turned under, a gain per acre on the unlimed sections of 67 pounds, to be accounted for in sources outside of the 8-inch depth of plowing, but on the limed sections none; (2) where the cowpea crop was removed, a gain per acre of 181 pounds on the unlimed and 177 pounds on the limed, to be accounted for as before.

6. Where the cowpea crop was turned under each year for five years there was found at the end of that time, on the unlimed sections, an increase of 3.79 per cent of humus as the average of 12 plots, but neither gain nor loss on the corresponding limed sections.

7. Where the cowpea crop was removed for the five years there was an apparent gain of 2.38 per cent on the unlimed sections as the average of four plots,* but an apparent loss of 3.17 per cent on the corresponding limed sections.

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*Three of the four plots, however, showed no appreciable gain, whereas all of the corresponding limed sections showed appreciable loss.