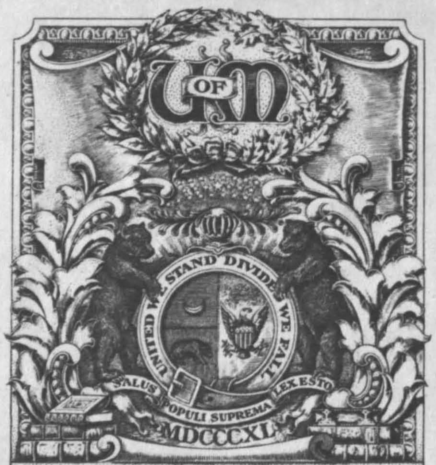
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THE COMPOSITION OF SOIL

AS AFFECTED BY

DIFFERENT CROPPING SYSTEMS

by

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THE COMPOSITION OF SOIL AS AFFECTED BY DIFFERENT CROPPING SYSTEMS.

Among the experiments in soil fertility which are being carried out by the University of Missouri College of Agriculture is a series of plot experiments which have been in progress since 1889. There are thirty-nine plots in the field and each has received a definite treatment during this time, the aim being to compare the effect of rotations with continuous single crops, both with and without fertilizer, and to compare the effect of commercial fertilizers with that of barnyard manure.

Some striking differences in yields have been obtained but no effort had been made to investigate the changes produced in the composition of the soil until 1909, when Dr. L. D. Haigh took samples from a series of the plots and determined the hygroscopic moisture, total nitrogen and acidity. The humus, total phosphoric acid and the phosphoric acid soluble in N/5 HCl, total ~~potash~~ potassium, calcium, magnesium and the lime requirement by the Veitch method have since been determined on these samples and ~~this~~ these data, as well as the determinations made by Dr. Haigh, ~~is~~ are presented in the following thesis.

HISTORICAL.

There seems to be a natural tendency for soils that are cropped continuously to become acid. Breazeale and LeCleric[1] state that the acidity in the soil is from

[1] Bull. 149, Bu. Chem.

two sources. First, organic acids are formed in the intermediate processes in the decay of organic matter and if decay is hindered by unfavorable conditions, such as poor aeration, drainage, etc., the soil will be acid, but if decay goes on to the end without hinderance, the reaction will again become alkaline or neutral. Examples of this form of acidity are bog and peat lands which are known to be distinctly acid.

The second cause of acidity as given by them is the decomposition of fertilizer salts like potassium sulphate, potassium chloride, and ammonium sulphate to form acids. Plants possess a selective power in absorbing fertilizers of this kind. Analyses of culture solutions in which wheat seedlings had been grown, to which potassium had been added in the form of potassium sulphate, showed that all the potassium had been absorbed, while 70 per cent of the sulphate radical remained in the solution. When potassium chloride was used, all the potassium was again removed and 50 per cent of the chlorin was left in the solution. This shows that plants absorb plant food as the element and not as the molecule. To explain this, the theory is advanced that the useful constituents like potassium, phosphorus, and nitrogen go into combination with the tissues of the plants. The osmotic pressure being thus relieved in the cells of the roots and root hairs, more of the elements can be absorbed. On the other hand, the constituents that are not useful to the plant do not go into combination with it and an equilibrium is soon formed which prevents the further absorption of these elements. The evidence seems to show that potassium sulphate, and especially ammonium sulphate, increases the acidity of the soil when used as fertilizers. A comparison of the acidity produced by different forms of nitrogenous fertilizers was made by Gardner and Brown[2] of the Pennsylvania Experiment Station.

[2] Pa. Expt. Sta. Rep. 1910-11.

The results were as follows:

Sodium Nitrate	433	pounds	CaO	per	acre.
Dried Blood	450	"	"	"	"
Ammonium Sulphate	1507	"	"	"	"

Plots receiving manure were equally as sour as the dried blood plots, but did not give consistant results as to the amounts applied.

Growth of Plants as Affected by Soil Acidity.

Numerous experiments have been made to determine the effect of varying amounts of acidity on the growth of plants. Gardner and Brown[3], in a pot test made with clover

[3] Pa. Expt. Sta. Rept. 1910-11.

in soil from the experimental plots, found a variation of from 2.6 grams of green material from a very sour soil to 61.75 grams grown on a good sweet one. Plots with a small lime requirement showed only a small increase in growth when lime was applied, but a marked increase in growth was obtained on the decidedly acid soils and this response increased in direct proportion to the acidity. It was found that acidity requiring 500 pounds of CaO for correction did not depress the growth of clover. But above that amount the depression increased with the acidity until the lime requirement of 1500 pounds per acre seven inches was reached, when clover practically refused to grow. It was noted above that the plots receiving ammonium sulphate had the highest lime requirement. When these plots were made alkaline with lime, they gave the largest yields of clover. A significant thing to be noted in these experiments is the fact that slaked lime or limestone, when applied in amounts indicated by the Veitch method, reduced the lime requirement only about 72 per cent when tested again by the same method. This would seem to show that about 50 per cent more lime than is indicated by the method should be added to meet the full acidity.

Brazeale and LeCleric[4] grew wheat seedlings in

[4] Bu. Chem. Bull. 149.

culture solutions with and without calcium carbonate. In every case the plants were more vigorous and healthy in the solutions receiving calcium carbonate. There was a considerable increase in the weight of the roots also though the weight of the tops showed no marked difference. This led them to infer that perhaps the roots are a better indication of the health of the plant than the tops.

Veitch[5] found that all the common field and garden

[5] Bu. Chem. Bull. 90.

crops gave higher yields on alkaline soils than on acid soils. When the soils were acid from an organic acid, a higher yield was obtained if it was fully neutralized. Of all the plots at the Maryland Experiment Station, with which the above bulletin deals, the alkaline plots gave higher yields than the acid plots.

TABLE I.

Effect of Acid and Alkaline Conditions on the Growth of Clover

Crops of Red Clover Grown on Acid and Alkaline Soil.

No. of plots.	Amount of CaO applied bushels per acre.	Reaction.	Dry weight of crop. grams.
1	10	acid	7
2	20	"	7
3	00	"	4
4	30	"	27
5	40	alkaline	28
7	50	"	69
8	60	"	72

It will be seen from Table I that the amount of the crop increases with the amount of lime applied. Other crops besides clover were benefitted by lime. The yield of oats increased 33 per cent, buckwheat 21 per cent and beans 41 per cent by an alkaline condition of the soil.

The increase in the crop is due most probably to the increased availability of the plant food elements in the soil. Veitch found that in alkaline soils there was an increase of 17 to 70 per cent of nitrogen, 12 to 99 per cent of the potash, and 40 to 356 per cent of phosphoric acid removed in excess of what was removed from acid soils proving a greated availability due to the lime.

Gaither[6] of the Ohio Station, states that lime

[6] J.Ind.Eng.Chem. July 1910.

renders the insoluble phosphates in the soil available to plants by replacing the iron and aluminum which is in combination with the phosphorus. He states that lime breaks up certain silicates and makes them more soluble but that it does not have any effect on the insoluble potassium compounds in the soil. The other constituents such as magnesium, iron and aluminum compounds, etc., were made more soluble in proportion to the amount of lime added. Potassium alone was the only compound in the soil that did not seem to be affected.

Stoddart[7] found that acid soils did not have a

[7] "23 Report Wis. Expt. Sta., p. 171 and Wis. Research Bull. No. 2.

larger amount of iron and aluminum phosphates but a larger per cent of the total phosphorus in the acid soils was in that form. The ratio of iron and aluminum phosphates to calcium phosphate was 3 to 1 in the acid soils and 1½ to 1 in the non-acid soils. He found that most acid soils were low in phosphoric acid.

The Georgia Experiment Station[8] made experiments

[8] Ga. Expt. Sta. Bull. 81.

to determine the effect of carbonates on nitrification.in the soil, using pure cultures of Nitrosomonas and Nitrobactor. It was found that nitrification increased as the amount of carbonates in the soil increased. A comparison of potassium, magnesium and calcium carbonates showed that magnesium carbonate gave the highest amount of nitrification. Potassium carbonate was next in efficiency and calcium carbonate was the least efficient. The presence of an excess of carbon dioxide or the exclusion of it made no difference in the amount of nitrification showing that the nitrifying organisms in the soil did not depend on the carbon dioxide of the air for their carbon supply.

Lyon and Bizzell[9] of Cornell, found that the soil

[9] J. Ind. Eng. Chem. July 1910.

in which alfalfa had been grown possessed a greater nitrifying power than the same soil without legumes and they concluded that the growth of legumes favored the process of nitrification. It was found that alfalfa grown in acid soil contained a larger amount of protein when the soil was limed. This was evidently due to the lime making better conditions for nitrification. The increase amounted in some cases to 88 poundsa of crude protein per ton.

A. D. Hall[10] of the Rothamstead Station gives a

[10] J. Agri.Science I (1905) No. 2.

report of the effect of letting land run wild. A portion of the wheat and bean plots were allowed to run wild for twenty years. The space was taken by wild grass and herbage. The carbon content of this plot increased considerably as did the nitrogen. The increase was also apparent in the lower depths as well as in the surface soil.

It was found at the Rothamstead Experiment Station[11]

[11] Dyer U. S. Expt. Sta. Bull. 106.

that on their plots which had been under definite treatment for fifty years, the soil in continuous wheat receiving no manure contained 2572 pounds of nitrogen per acre nine inches, while the plot getting fourteen tons of manure per acre annually contained 5151 pounds. The second depth of nine inches contained 1950 pounds of nitrogen for the untreated soil and 2049 pounds for the manured soil showing that only a small amount of the organic nitrogen was carried into the lower depths or, if it ~~had~~ was, it had been leached away. Considerable loss had evidently taken place from some source, for it was estimated that in all 10,000 pounds of nitrogen had been supplied in the manure. Of this amount 1600 pounds had been removed in the increased crops yields and 2500 was fixed in the surface soil, leaving 6,000 pounds to be accounted for.

There was a considerable increase in the amount of organic carbon in the second depth of the manured soil over the untreated soil but this may have been caused by the plants on this plot rooting deeper and thus leaving more plant residues in the deeper layers of the soil. Plots manured with rape-seed cake were the next highest in the amount of organic nitrogen and this plot showed the highest carbon content in the lower layers of the soil, showing that some of the organic matter from the rape cake percolated deeper than that from the manure,

A complete mineral fertilizer without nitrogen consisting of potassium sulphate, sodium sulphate, magnesium sulphate and superphosphate gave slightly higher yields than the unmanured plot. The nitrogen and carbon content in the top nine inches was only slightly more than in the unmanured plot as will be seen in Table II

TABLE II.

Nitrogen and Carbon Content of Rothamstead Soils.

Treatment	Nitrogen Per Cent.	Carbon Per Cent
Unmanured	0.0992	0.888
Mineral Manures	0.1013	0.931
Ammonium Salts	0.1069	1.049
Sodium Nitrate	0.1094	1.008
Full Minerals & Ammonium Salts	0.1107	1.019
Phosphates, Sodium & Ammonium Salts	0.1194	1.123
Full Minerals & Ammonium Salts	0.1234	1.170
Full Minerals & Sodium Nitrate	0.1189	1.162

A comparison of mineral manures alone shows that better yields have resulted from sodium nitrate than from an equal amount of nitrogen applied as ammonium sulphate. This held true when they were applied both alone and with full mineral fertilizers. With few exceptions the nitrogen found in the soil increased in proportion to the yield and in most cases this held true for the organic carbon also. Dyer states that as a general rule, the greater the amount of the crop and therefore the greater the amount of it removed from the soil, the greater the quantity of nitrogen stored in the soil by accumulated crop residues and thus saved from loss in drainage.

When varying amounts of ammonium sulphate were added with a full supply of minerals, the yield increased in proportion to the amount of the ammonium salts added. The per cent of nitrogen found in the surface soil also increased with the amount of ammonium sulphate added until the equivalent of 129 pounds of nitrogen per acre had been added when there was a slight decrease of the nitrogen in the surface nine inches. This, however, was accounted for in the lower depths of the soil, which shows that above a certain amount there would be a wasteful loss of nitrogen through drainage.

When the same amount of ammonium salts were applied with varying mineral treatments, the crop increased as the completeness of the mineral fertilizer increased and under the influence of more complete feeding the nitrogen in the soil increased which shows again that increased soil nitrogen follows increased yields.

The nitrate nitrogen was found to be only little less in the second nine inches of the unmanured plot than in the first nine inches but on the heavily manured plot and on the plot receiving rape seed cake, the nitrate nitrogen was more in the second nine inches than in the first; although Dyer states that there is little nitrification taking place below the surface soil. More nitrate nitrogen was found in the soil fertilized with sodium nitrate than when an equal amount of nitrogen was supplied as ammonium sulphate. This is to be expected since sodium nitrate is already in the nitrate form while ammonium sulphate necessarily must go through the process of nitrification and there is a possibility of loss before this can take place.

Dyer states that contrary to the general belief, sodium nitrate does not remove lime from the soil. On the other hand, more lime was removed in the drainage water from the plots receiving ammonium sulphate than from the plot treated with sodium nitrate. He advises therefore, the application of lime to the soil when ammonium salts are applied if the soil is poor in lime. This action of the ammonium salts may account for the increased acidity in the plots at the Pennsylvania Station caused by the application of ammonium sulphate.

The unfertilized plots contained only 0.121 per cent of total phosphoric acid and 0.0082 per cent soluble in 1 per cent acid.

TABLE III.

Average Per Cent of Phosphoric Acid in the Rothamstead Soils.

Treatment	Per Cent Solution in HCl.	Per Cent Solution in 15 Citric Acid.
No phosphates	0.121	0.0082
Superphosphate and ammonium salts.	0.200	0.0448
Superphosphates and alkaline salts.	0.219	0.0642
Manured.	0.215	0.0560

The plots receiving no phosphates suffered from phosphorus starvation and only yielded half as much as the plots receiving superphosphates and alkaline salts. The plots getting superphosphates without manure gave a slightly higher phosphate content than the plots getting superphosphates and ammonium salts though the crop yield was only half as much. The plots getting 14 tons of manure per acre annually gave the highest yield of any of the plots but had slightly less total phosphorus. The citric acid soluble phosphoric acid does not come in the same order as does the total. The plots treated with phosphates and alkaline salts gave the highest results as shown in the following table, while the manured plots were next highest showing that the total phosphorus does not indicate the amount that will be soluble.

TABLE IV.

Ratio of Phosphoric Acid in Treated and Untreated Soils to That Receiving No Phosphates.

Treatment	Total	Soluble in 1 Per Cent Citric Acid.
No phosphates	1.00 - 1	1.00 - 1
Phosphates and nitrogen	1.65 - 1	5.46 - 1
Phosphates and alkaline salts	1.81 - 1	7.83 - 1
Manure	1.78 - 1	6.83 - 1

Analysis of the drainage water indicates that the loss of phosphates in drainage is very small not over four pounds per acre annually. The general conclusions made by Dyer were that although a large part of the phosphorus applied to the soil is soluble, by far the greater part of it is fixed in the surface soil. In the case of the manured plots there has been a considerable descent of the phosphorus into the second and third nine inches. This is also true to some extent with the superphosphates applied with the alkaline mineral salts.

The application of alkaline mineral salts seems to keep the phosphorus in a less fixed and therefore, presumably more available form.

A continuous application of potash, both as minerals and in manure made a difference in the amount of potash extracted by hydrochloric acid but the difference was not enough to be remarkable.

TABLE V.

Ratio of the HCl Soluble Potash to That in the Non-potash Plots. (Top Nine Inches).

No potash	1.00 - 1
Potash dressings	1.20 - 1
Manured	1.27 - 1

It will be seen from the table that the manured plot contained the highest per cent of potash soluble in hydrochloric acid and the plots manured with minerals were the next highest. The greatest difference is noted in the potash soluble in 1 per cent citric acid

TABLE VI.

Ratio of Citric Acid Soluble Potash to That of the Non-potash Plots.

Treatment.	1st Nine Inches.	2nd Nine Inches.	3rd Nine Inches.
No potash	1.00 - 1	1.00 - 1	1.00 - 1
Potash dressings	6.75 - 1	3.63 - 1	1.74 - 1
Manure	9.17 - 1	3.65 - 1	2.09 - 1

It will be seen in Table VI that the manured plot contained ten times as much citric acid soluble potash as the unmanured plot and the plot treated with minerals contained almost seven times as much as the untreated plot. The same relation was noted in the lower depths of the soil but a much larger proportion was found in the lower depths of the manured plot than in any of the others.

The amount of potassium in the drainage water showed that the plots receiving manure and a full mineral dressing without ammonium salts had the heaviest loss. The addition of ammonium salts to the minerals reduced the loss to the minimum for the plots receiving potassium. In general the use of sodium and magnesium salts tends to make potash and phosphorus more available.

Closely connected with the nitrogen in the soil is the humus and organic matter. Rather, the amount of soil nitrogen seems to vary in proportion as the humus varies and the per cent of humus depends to a large extent on the length of time the soil has been cultivated and the kind of rotation that has been practiced as well as the fertilizer treatment. We saw in the case of the Rothamstead results that the nitrogen varied with the organic carbon, or total organic matter.

Snyder[12] analyzed several cultivated and native

[12] Minn. Expt. Sta. Bull. 30, 53, 70 and 94.

soils of Minnesota and found that continued grain cropping greatly depleted the organic matter in the soil. The loss of nitrogen from the soils from four grain farms in ten years amounted to from three to five times as much as was removed by the crop owing to the rapid decay of the humus. When stock was kept, rotation of crops practiced and clover grown, the nitrogen supply was kept about constant.

According to him, a large supply of humus and organic matter in the soil will help make the mineral matter available as in its decay, carbon dioxide is liberated which helps dissolve the mineral matter of the soil. Soils that are rich in humus contain a larger amount of available phosphates than those poor in humus.

The growth of sod crops in the rotation helps to keep up the supply and cultivated crops tend to decrease the supply of humus. Soils rich in humus retain more water than those poor in humus.

In a plot test it was found that plots cropped to grain steadily lost humus while those under rotation, including wheat, oats, clover and corn including manure, kept about constant.

TABLE VII.

Changes in the Amount of Humus in Four Years Due to Different Rotations.

Treatment.	Per Cent Humus.	Per Cent Volatile Matter.
At beginning all plots	3.30	7.68
1. Wheat	3.00	7.48
2. Rotated	3.80	8.05
3. Rotated	3.50	7.83
4. Corn	3.10	7.26
5. Oats	3.08	7.04
6. Barley	3.10	6.87

There has also been a larger loss of nitrogen from these plots as seen in Table VIII.

TABLE VIII.

Loss of Nitrogen Under Different Crops.

Crop	Per Cent Nitrogen at Beginning.	Per Cent Nitrogen After Eight Years.
Wheat	0.221	0.173
Rotated	0.221	0.198
Rotated	0.211	0.198
Oats	0.211	0.189
Corn	0.211	0.185
Barley	---	---

Snyder advises against summer fallowing. While it increases the crop the following year, the increase is at the expense of the humus and volatile matter in the soil. Nitrogen is set free and made available to crops by oxidation of the humus and organic matter and the more this is brought about in excess of the amount needed for crops, the greater will be the loss from leaching, dentrification, etc.

Snyder found the amount of humus in a virgin prairie soil to be 5.3 per cent, while in a cultivated field adjacent it was only 2.38 per cent. The composition of the humus as well as the amount in the soil was affected by cropping.

TABLE IX.

Composition of Humus From Virgin and Cultivated Soil.

	Virgin Soil.	Old Soil.
Carbon	44.12	50.10
Hydrogen	6.00	4.80
Oxygen	36.16	33.66
Nitrogen	8.12	6.50
Ash	6.60	4.90

The material from which humus is formed also affects its composition. Snyder found that humus formed from green clover, manure or meat scraps gave a higher per cent of nitrogen than did that formed from straw sawdust or sugar. Snyder also compared the humus, nitrogen, the water holding capacity and the phosphoric acid combined in humus.

TABLE X.

Variation of Humus, Nitrogen, Phosphorus and Water Capacity.

	Humus. Per Cent.	Nitrogen. Per Cent.	Humus P_2O_5 in Soil. Per Cent.	H_2O Capacity of Soil. Per Cent.
Rotated productive	3.32	0.30	0.04	48.00
Grain. Low Productiveness.	1.80	0.16	0.01	39.00
Rotated. Productive.	3.46	0.26	0.03	59.00
Same as above not rotated or manured.	2.45	0.21	0.03	57.00

Humus and nitrogen were the highest in the most productive soils and the phosphoric acid and the water holding capacity increased as the humus increased.

Schreiner and Skinner[13] have published some inter-

[13] Bu. Soils, Bull. 77, 83, 87 and 90.

esting work recently on the organic compounds in the soil, their isolation and effect on plant growth. A large number of definite organic compounds have been isolated from the so-called humus solution thus proving that humus as determined by our present methods is a mixture of a large number of compounds and not a compound in itself as at first supposed. Some of the compounds isolated are detrimental to plant growth, a few are beneficial and a larger number seem to have little effect either way. The nitrogenous compounds, nucleic acid, hypoxanthine, xanthine, guanine, creatinine, creatine, histidine, arginine and chlorine are all beneficial to plant growth. Their effect is less marked when nitrates are present but it was found that less nitrates were absorbed by the plant when the organic nitrogenous compound was present with nitrates than when nitrates were present alone. The theory is presented that plants absorb these nitrogenous compounds as such and are able to build them directly into protein without the necessity of having them broken down to simpler compounds.

Guanidine, picoline carboxylic acid, cumarin, dihydroxa stearic acid, vanillin and quinone were found too toxic to the growth of plants. The identification and determination of the amounts of these compounds in the soil would often doubtless tell more of the real crop producing power of a soil than many of the determinations of the mineral matter in the soil.

Stewart[14] of the Utah Experiment Station found

[14] J. Ind. Eng. Chem. (1910) VII No. 9.

that the continuous cropping to wheat under dry-farming conditions does not decrease the nitrogen and humus content in the surface foot of soil.

TABLE XI.

Effect of Different Crops on Nitrogen and Humus.

Crop.	Per Cent Total Nitrogen.	Per Cent Nitrates.	Per Cent Humus.
Wheat	0.2055	0.80	2.67
Virgin soil	0.1984	1.04	2.45
Alfalfa	0.2009	1.74	2.27

This, he thought to be caused by the fact that deep rooting is induced by dry-farming methods and heading the grain is practiced which leawes most of the straw on the ground. The second foot of cultivated soil contained less humus and nitrogen than does the second foot of the virgin land. The cropping of land to alfalfa causes a decrease in the per cent of humus and in most cases in the nitrogen also.

Bradley[15] of the Washington Experiment Station

[15] J. Ind. Eng. Chem. II (1910) No. 4.

found that continuous cropping to wheat where the soil was kept fallow when the crop was not growing did not materially lower the nitrogen content below that of the virgin soil, but there was a loss of from 21 to 24 per cent of the organic carbon originally in the soil. This is without doubt due to the extra cultivation given to conserve moisture and the fact that little organic matter is returned to the soil.

Alway[16] of the Nebraska Experiment Station found

16 Nebraska Expt. Sta. Bull. III.

little difference in the virgin prairies and long cultivated fields in the amount of potash, phosphorus and lime, but there was a large loss of nitrogen, humus and organic matter from the long cultivated fields.

Whitson, Stoddard and McLeod[17] give the nitrogen

17 Wis. Expt. Sta. Report for 1906 - 1907.

content of 51 cultivated soils and the adjacent virgin soil. In most cases, the cultivated soils have been in cultivation for many years and in many cases with little or no manure. The excess of nitrogen in the virgin soil over the cultivated soil runs from 220 pounds per acre as the lowest limit to 3,200 pounds per acre as the highest limit. In 36 cases, the excess was over 1,000 per acre and in 14 cases, it was over 2,000 per acre.

Whitson and Stoddard[18] found that in nine exhausted

18 Wis. Expt. Sta. Research No. 2.

soils there was 0.102 per cent of total phosphoric acid as against 0.185 per cent in adjacent virgin soil. In sixteen soils which had been heavily manured, the phosphorus remained practically constant. The most interesting thing about the results is that the crops removed from the exhausted soil account on the average for 80 per cent of the loss in phosphoric acid, leaving only 301 pounds per acre to be accounted for by leaching. On the manured soils, however, the crops removed accounted for only 19 per cent of the loss, leaving a loss of 3,340 pounds to be accounted for by leaching, showing a great difference in the solubility of the phosphoric acid.

EXPERIMENTAL PART.

Treatment of the Plots.

Eleven plots from the experimental field and the uncultivated soil were selected for this study. The plots are one thirteenth of an acre in size and each has been receiving the given treatment for twenty-one years previous to the time the samples were taken. One plot has been continuously in wheat and has received chemical fertilizers. On four others, two systems of rotation have been carried out with and without manure. On the remaining six, single crops -- corn, oats and timothy -- have been grown with and without manure.

TABLE XII.

Treatment of the Plots.

Plot No.	Lab. No.	Kind of sample.	Rotation.	Annual fertilizer per plot.
2	994	Soil	Continuous wheat	Minerals for 40 bushels
	995	Subsoil		
12	996	Soil	Corn, wheat, oats clover, timothy, timothy*	1200# Manure
	997	Subsoil		
13	998	Soil	Corn, wheat, oats clover, ** timothy, timothy	No treatment
	999	Subsoil		
15	9910	Soil	Continuous oats	1200# Manure
	9911	Subsoil		
16	9912	Soil	Continuous oats	No treatment
	9913	Subsoil		
17	9914	Soil	Continuous corn	No treatment
	9915	Subsoil		
18	9916	Soil	Continuous corn	1200# Manure
	9917	Subsoil		
22	9918	Soil	Continuous timothy	1200# Manure
	9919	Subsoil		
23	9920	Soil	Continuous timothy	No treatment
	9921	Subsoil		
26	9922	Soil	Corn, wheat, clover ***	1200# Manure
	9923	Subsoil		
27	9924	Soil	Corn, wheat, clover ****	No treatment
	9925	Subsoil		
Virgin	1142	Soil		
	1143	Subsoil		

* In corn when sampled.
** In timothy when sampled
*** In corn when sampled.
**** In cowpeas when sampled.

Preparation of the Sample.

In gathering the sample, sixteen borings were made on each plot with a soil auger. The borings were made in four rows four borings in each row. The position of each boring was shifted so as to alternate with the boring in the next row. A level spot was selected between the rows of the crop, trash removed if present, and the boring made to the depth of eight inches for the soil sample and continued to the depth of twenty-four inches for the subsoil sample. The collections of soil and subsoil were taken to the laboratory, spread out on large sheets of paper and allowed to become perfectly air dry. Large particles were broken up, but not ground, until the entire sample, exclusive of trash and stones, would pass through an eighth of an inch sieve. The sample was then mixed very thoroughly and quartered down to about 2,000 grams. This portion was pulverized with a rubber pestle until it would pass through a one millimeter sieve. After again being thoroughly mixed, this sample was stored in screw-topped jars for analysis. Samples of virgin uncultivated soil and subsoil from sod adjacent to the plots were taken and prepared in the same way.

Analytical Methods.

Lime Requirement.

Lime requirement was determined by the Veitch method as follows: A ten gram sample was placed in a 200 cc. Erlenmeyer flask with 50 cc. of distilled water and evaporated to dryness on the water bath. It was then taken up by shaking with 100 cc. of distilled water, stoppered and allowed to settle over night. Fifty cc. of the clear solution was then drawn off, placed in a small flask with a few drops of phenolphthalein and evaporated on the hot plate to a volume of 5 cc, or until a pink color was obtained. If a pink color developed, the sample was considered as alkaline and the lime requirement recorded as 0, but if no color was produced, the operation was repeated with the addition of varying amounts of standard lime water, (approximately 1 milligram of CaO per cc.) until a color was developed. The lime requirement was calculated as pounds of CaO per acre foot (3,000,000 pounds).

The original directions call for the evaporation of several portions of the same sample at once in porcelain dishes using varying amounts (10, 20 and 30 cc.) of lime water and the transferring of the dried soil to the flasks with 100 cc. of water. It was found, however, that the work of transferring could be eliminated by weighing the samples directly into the flasks.

Determination of Total Nitrogen.

Total nitrogen was determined by the official Kjeldahl method, modified to include nitrates, as follows: A ten gram sample of the soil was placed in a 500 cc. Kjeldahl flask. Thirty cc. of sulphuric acid containing two grams of salicylic acid was added and the mixture allowed to stand twelve hours or longer. Two grams of zinc dust were then added and the flask heated gently on the nitrogen frame until danger of frothing was past, when approximately 0.7 gram of mercury was added and the digestion continued until the contents of the flask was almost colorless. The oxidation was then completed by the addition of a few crystals of potassium permanganate while the flask was still hot.

After cooling, the liquid portion of the flask was transferred by decantation to an 800 cc. Kjeldahl flask and the residue washed by decantation with several portions of distilled water amounting in all to not over 400 cc. A few pieces of zinc and a small piece of parafin were then added to the flask and 85 cc. of alkali sulphide solution were carefully poured down the neck of the flask to form a layer in the bottom of the flask. It was then placed on the nitrogen distilling apparatus and the nitrogen distilled over into standard HCl and titrated with standard ammonia solution.

Determination of Humus.

A ten gram sample was weighed onto an 11 centimeter filter which had previously been fitted in a two and one-half inch long-stem funnel. It was washed with 1 per cent HCl until free from calcium and then with distilled water until free from chlorides. The sample and the filter was then transferred to a liter Erlenmeyer flask and 500 cc. of 4 per cent ammonia was added. This was allowed to stand with frequent shaking for 24 hours when it was shaken thoroughly and poured on a 24 - 30 centimeter folded filter.[19]

[19] O. C. Smith, J.Ind. Eng. Chem., Jan. 1913 .

The turbid filtrate was poured back onto the filter until the filtrate came through clear when a clean flask was placed under the funnel and the filtration continued until 200 - 250 cc. of the clear liquid was obtained. To prevent evaporation while filtering, the funnels were placed directly in Erlenmeyre flasks and were covered with watch glasses. One hundred cc. of the clear filtrate were evaporated to dryness at 100° C and weighed, then ignited in the muffle, cooled and weighed. The difference in the two weights is considered to be humus. The results by this method compare very closely to the Rather, or ammonium carbonate method.[20]

[20] J. Ind. Eng. Chem V. III No. 9, p. 660.

Total Potassium.

Five-tenths of a gram of the soil was mixed with an equal amount of ammonium chloride by stirring in an agate mortar. After it was well mixed, about four grams of calcium carbonate were added and the mixture was transferred to a tall platinum crucible. The mortar was cleaned out by stirring about four grams more calcium carbonate in it and this was placed on the top of the charge.

The charge was warmed gently at first and later the lower three-quarters of the crucible was kept at a bright red heat until the charge was turned to a cinder. The fused mixture was then pulverized and transferred to a casserole, boiled with water and filtered. Ammonium carbonate was added, and the solution was boiled and filtered. The filtrate was evaporated to about 20 cc. and ammonium oxalate was added to precipitate the last traces of calcium. After filtering out the calcium oxalate formed, the filtrate was placed in large platinum dishes and evaporated to dryness on the steam bath. A few drops of sulphuric acid was added and the ammonium salts driven off by ignition. The residue was taken up with hot water and filtered if any dark specks were left undissolved. The solution was returned to the platinum dishes and about 1 cc. of hydrochloric acid (1-1) was added and enough platinic chloride to precipitate the potassium. The solution was evaporated to a pasty consistancy, but not allowed to go dry, and the precipitate was washed onto a tared Gooch crucible with about 25 cc. of 80 per cent alcohol. It was then washed with about 50 cc. of ammonium chloride solution saturated with potassium platinic chloride and then again in 80 per cent alcohol. Then heated in the oven at 110° C and weighed.

Determination of Total Phosphorus.

Five grams of soil were mixed in a nickel crucible with ten grams of sodium peroxide and ignited by first applying the flame of a Fletcher burner to the top and sides of the crucible, to start the reaction and then beneath, keeping the charge at low red heat for fifteen minutes, avoiding fusion. The ignited charge was then transferred to a casserole, dissolved in hot water, and acidified with hydrochloric acid. The solution was then boiled and the silica dehydrated on the steam bath. The residue was taken up with hydrochloric acid, filtered and washed free from acid and the dehydration repeated. Great care must be used in washing the silica from the first dehydration or some of the phosphorus will be retained. After the second dehydration, the iron, aluminum and phosphorus were precipitated with ammonium hydroxide, filtered and washed with hot water. The precipitate was dissolved in dilute hydrochloric acid and reprecipitated with ammonia in order to avoid the occlusion of calcium and magnesium. The filtrate and washings were retained for calcium and magnesium. After being dissolved the second time in hydrochloric acid, the solution was made alkaline with ammonium hydroxide and again cleared up with nitric acid. Fifteen grams of ammonium nitrate was then added and the beaker heated on the water bath to 65° C after which 100 cc. of ammonium molybdate were added and the solution kept at 65° for one hour, the precipitate filtered and washed with 10 per cent ammonium nitrate solution. It was then dissolved in hot two and one-half per cent ammonium hydroxide solution. This solution was nearly neutralized with hydrochloric acid and the phosphorus precipitated as magnesium ammonium phosphate with magnesia mixture, filtered, ignited and weighed.

Phosphorus Soluble in N/5 Hydrochloric Acid.

A preliminary digestion was made with ten grams of soil tp determine the amount of the acid which carbonates in the soil would neutralize. Then 100 grams of the sample was placed in a 2000 cc. flask and 1000 cc., plus the amount neutralized by the soil carbonates, of fifth normal hydrochloric acid was added. The flask was kept at a temperature of 40 degrees C for exactly five hours, shaking thoroughly every half hour. The contents of the flask was then shaken thoroughly and filtered immediately. Five hundred cc. of the filtrate was evaporated to dryness in a casserole and a few cc. of nitric acid added to oxidize the organic matter. The residue was taken up with hydrochloric acid and hot water and filtered. The insoluble portion was washed with hot water until free from acid. Phosphorus was determined in the filtrate as for total phosphorus.

Determination of Calcium.

Calcium was determined in the filtrate and washings from the precipitate of iron, aluminum and phosphorus above. The solution was made slightly alkaline with ammonium hydroxide and heated almost to boiling. Ammonium oxalate was added in slight excess and the solution brought to boiling. The precipitate was allowed to stand in the solution over night after which it was filtered on an ashless filter, washed with hot water, ignited and weighed as CaO.

Determination of Magnesium.

The filtrate from the calcium determination was acidified with hydrochloric acid and a large excess (four grams) of sodium acid phosphate added. Foulk.[21]

[21] Foulk, Quantitative Analysis, p. 151.

The solution was then made alkaline, drop by drop, with ammonium hydroxide and allowed to stand for twelve hours. The precipitate was then filtered out, washed with two and one-half per cent ammonium hydroxide, dissolved on the filter in dilute hydrochloric acid and reprecipitated. The precipitate was finally filtered on an ashless filter, washed with dilute ammonium hydroxide, ignited and weighed as magnesium pyrophosphate.

DISCUSSION OF RESULTS.

In all cases the results are calculated to the dry basis and with the exception of humus and lime requirement, the results are given in per cent of the element in question instead of its compound. For example, phosphorus, potassium, etc., instead of phosphoric acid or potash.

TABLE XIII.

Nitrogen Content Arranged in Order of the Highest Per Cent in the Surface Soil.

Plot	Treatment.	Per Cent Nitrogen in Soil.	Per Cent Nitrogen in Subsoil.
15	Oats, manure	0.1705	0.0767
12	6 year rotation, manure	0.1674	0.0787
Virgin		0.1560	0.0910
22	Timothy, manure	0.1522	0.0812
26	3 year rotation, manure	0.1494	0.0716
18	Corn, manure	0.1371	0.0731
23	Timothy, no treatment	0.1344	0.0749
13	6 year rotation, no treatment	0.1224	0.0708
16	Oats, no treatment	0.1175	0.0716
27	3 year rotation, no treatment	0.1123	0.0813
2	Wheat, chemicals	0.1017	0.0732
17	Corn, no treatment	0.0852	0.0682

As would be expected, the plots receiving barnyard manure have, with the exception of the virgin soil, the highest per cent total nitrogen owing to the organic matter that has been stored in the soil. The virgin soil comes third in nitrogen, probably because, while there has been no additions of fertility in the form of fertilizers, neither has there been any crop removed and therefore no draft made on the nitrogen in the soil, as is the case when a grain crop is grown. The plot receiving the chemical fertilizer fell very low in nitrogen, even lower than most of the unmanured plots. Although, theoretically, enough fertilizer was applied for a yield of 40 bushels annually, the yield has actually averaged 19.4 bushels. The excess of nitrogen not used by the crop has not been stored in the soil, but on the other hand, it has been losing nitrogen almost as fast as the poorest untreated plot. Although the same amount of nitrogen has not been added to the chemical plot as has been added to the manured plots, it would seem fair to expect that the chemically manured plot should be at least as well supplied with nitrogen as the best untreated plot since the needs of the crop was supposedly more than fully supplied.

Sod crops and oats seem to be fairly light in their demands on the soil's supply of nitrogen. In the manured series, the continuous oat plot has the highest per cent of nitrogen and the six year rotation which includes two years in timothy follows very closely and these are followed by the virgin soil and the continuous timothy plot with almost identical per cents of nitrogen. On the plots getting no manure treatment, the same three plots head the list, but in a slightly different order, the timothy plot leading, followed by the six year rotation and the oats plot, all very close together in per cent of nitrogen. On the other hand, corn seems to be a very heavy feeder on nitrogen. The plots in corn stand at the bottom of the list both in the manured and the untreated series, while the three year rotation consisting of corn, wheat and clover did not greatly exceed it.

The nitrogen content of the subsoils was practically the same for all of the plots and for that reason have not been taken into consideration in the discussion. This fact would indicate that the various cropping systems have affected the subsoil very little as far as the nitrogen is concerned.

The relation found between the nitrogen and the humus will be discussed with the humus.

TABLE XIV.

Humus Content Arranged in Order of the Highest Per Cent in the Surface Soil.

Plot	Treatment.	Per Cent Humus in Soil.	Per Cent Humus in Subsoil.
26	Three year rotation, manure	2.375	1.340
15	Oats, manure	2.230	1.255
22	Timothy, manure	2.058	1.234
23	Timothy, no treatment	1.975	1.343
12	Six year rotation, manure	1.925	1.185
18	Corn, manure	1.668	1.303
16	Oats, no treatment	1.638	1.130
13	Six year rotation, no treatment	1.603	1.200
27	Three year rotation, no treatment	1.538	1.383
Virgin		1.498	0.895
17	Corn, no treatment	1.335	1.118
2	Wheat, chemicals	1.245	0.993

The manured plots stand the highest in humus with one exception, the continuous timothy plot unmanured, which exceeds the manured plots in corn and under the six year rotation, though only very slightly. Corn fell to the bottom of the list in the manured plots due to the excessive amount of cultivation which must be given this crop. In the unmanured plots, timothy and oats lead with almost identical per cents of humus while the chemically manured plots fall below all the unmanured plots because no organic matter from which humus can be made is added and when the store that is in the soil is exhausted, there is nothing to replace it.

It will be noticed that the virgin soil is exceeded by all of the manured plots and several of the untreated plots. This is probably due to less organic matter being accumulated from root residues than in the other plots and of course the manured plots would accumulate humus from the manure added.

The subsoils varied so little as to be practically the same, however, it may be worth noting that the virgin subsoil has the lowest per cent of humus of any of the subsoils. This is most likely due to the fact that the bluegrass sod growing on it is comparatively shallow rooted and since it is not cultivated there is no way for organic matter to become incorporated in the lower layers of the soil.

To see what relation existed between the nitrogen and humus, Table XV, showing the nitrogen and humus in the surface soil, was prepared. The numbers in parentheses indicate the order in which these soils come in total nitrogen as shown in Table XIII.

TABLE XV.

Humus and Total Nitrogen in the Surface Soil Arranged in the Order of the Highest Per Cent of Humus.

Plot.	Treatment	Per Cent Humus.	Per Cent Total Nitrogen.
26	3 year rotation, manure	2.375	0.1494 (5) *
15	Oats, manure	2.230	0.1701 (1)
22	Timothy, manured	2.058	0.1522 (4)
23	Timothy, no treatment	1.975	0.1344 (7)
12	6 year rotation, manured	1.925	0.1674 (2)
18	Corn, manured	1.668	0.1371 (6)
16	Oats, no treatment	1.638	0.1175 (9)
13	6 year rotation, no treatment	1.603	0.1224 (8)
27	3 year rotation, no treatment	1.538	0.1123 (10)
Virgin		1.498	0.1560 (3)
17	Corn, no treatment	1.335	0.0852 (12)
2	Wheat, chemicals	1.245	0.1017 (11)

* The numbers in parentheses indicate the order in which the soils come in nitrogen content as indicated in Table XIII.

In general the amount of total nitrogen increased directly with the amount of humus. The most marked exception to this is in the case of the virgin soil which was third in per cent of nitrogen though tenth in per cent of humus.

In general all the plots have a high lime requirement. Table XVI shows the lime requirement of the soil and subsoil and the total for both the soil and subsoil arranged in the order of the highest total lime requirement.

TABLE XVI.

Lime Requirement Arranged in Order of Highest Total Lime Requirement. Pounds CaO Per Acre.

Plot.	Treatment.	Soil.	Subsoil.	Total.
17	Corn, no treatment	7935	7935	15870
27	3 year rotation, no treatment	3795	12075	15870
13	6 year rotation, no treatment	7245	7935	15180
2	Wheat, chemicals	7935	7245	15180
18	Corn, manure	2415	12075	14490
Virgin		10695	3105	13800
15	Oats, manure	12075	0	12075
16	Oats, no manure	7935	2415	10350
23	Timothy, no treatment	7245	2415	9660
26	3 year rotation,manure	2415	7245	9660
22	Timothy, manured	2415	6555	8970
12	6 year rotation,manure	2415	2415	4830

The manured plots have a lower lime requirement than the unmanured plots. The average for the five plots receiving barnyard manure amounts to 10,000 pounds per acre, while the plots with the same crops unmanured required an average of 13,386 pounds per acre.

The corn plot and the three year rotation both unmanured, are the most acid of all the plots having a total lime requirement of 15,870 pounds per acre and in the manured series, corn again has the highest lime requirement. The six year rotation and the plot with chemicals had the next highest acidity. In the unmanured series, however, the six year rotation had the lowest lime requirement. The manured oats plot was more acid than the untreated plot, being the only exception to the rule that the untreated plots were more acid than the manured ones. The timothy plot was the least acid of the unmanured series. The virgin soil was a little higher than the average of the unmanured plots, having a lime requirement of 13,800 pounds per acre. This is over 3,000 pounds per acre higher than the average of the manured plots.

In some cases the soil has been much more acid than the subsoil while in others, the opposite has been the case and in a few cases they have been about equal. The most surprising difference between the soil and subsoil is in the case of the manured oats plot which has a lime requirement of 12,075 pounds per acre in the soil, while the subsoil was found to be alkaline. The oat plot without manure also had a comparatively acid soil while the subsoil was among the lowest.

Evidently the acids in the oat plots are very insoluble and are not carried into the subsoil.

Dr. Haigh determined the acidity by the potassium nitrate method which consists of shaking a portion of the soil with normal potassium nitrate and titrating the solution. (Bulletin 107 Revised of the Bureau of Chemistry).

It is interesting to compare these results with those of the Veitch Method.

TABLE XVII.

Comparison of Lime Requirement by the Veitch and the Potassium Nitrate Method.

Plot.	Treatment.	Veitch Method. pounds Per Acre. Soil.	Potassium Nitrate Pounds Per Acre. Soil.
15	Oats, manured	12075	136
17	Corn, no treatment	7935	1102
16	Oats, no treatment	7935	188
2	Wheat, chemicals	7935	558
13	6 year rotation, no treatment	7245	274
23	Timothy, no treatment	7245	162
27	3 year rotation, no treatment	3795	670
18	Corn, manured	2415	168
26	3 year rotation, manure	2415	136
22	Timothy, manured	2415	172
12	6 year rotation, manure	2415	190

The Veitch, or lime water method gives much higher results, but in general the relative acidity, with the exception of the oat plots is about the same by both methods.

It will be noticed that the oats plots both treated and untreated are both very acid by the Veitch method but among the lowest by the potassium nitrate method which would again indicate that the acids of the oat plots are very insoluble. Evidently much of the acid is not dissolved by the potassium nitrate and therefore the results by that method are too low.

TABLE XVIII.

Total Phosphorus in Soil and Subsoil Arranged in Order of the Highest Per Cent in the Surface Soil.

Plot.	Treatment.	Soil.	Subsoil.	Pound Per Acre in Surface Soil*
18	Corn, manure	0.0680	0.0463	1360
12	6 year rotation,manure	0.0594	0.0503	1188
15	Oats, manure	0.0591	0.0345	1182
26	3 year rotation,manure	0.0558	0.0485	1116
13	6 year rotation, no treatment	0.0549	0.0443	1098
22	Timothy, manure	0.0485	0.0468	970
17	Corn,no treatment	0.0466	0.0641	932
23	Timothy,no treatment	0.0460	0.0507	920
2	Wheat, chemicals	0.0421	0.0390	842
Virgin		0.0382	0.0444	764
27	3 year rotation, no treatment	0.0371	0.0449	742
16	Oats, no treatment	0.0357	0.0368	714

* The weight of the surface eight inches was considered to be two million pounds per acre.

The manured plots in general have the highest per cent of total phosphorus. The average for the manured plots is 1163 pounds per acre in the surface soil while the average for the unmanured plots is 881 pounds. Corn seems to draw the least on the phosphorus in the soil as the corn plot not only stands at the head of the list in the manured plots but is high in the unmanured plots as well. The two rotated plots and the oats plot follow closely in the manured series. The six year rotation unmanured exceeds all the other unmanured plots as well as the lowest manured plot, timothy. In the unmanured plots, following the six year rotation, stands corn and timothy. The wheat plot with chemicals is slightly lower than the average of the unmanured plots while the virgin soil has 100 pounds less per acre than the average of the unmanured plots.

The phosphorus soluble in N/5 hydrochloric acid averages twice as high in the manured soils as in the unmanured soils. The average for the former being 140 pounds per acre and for the latter, only 70 pounds per acre. This corresponds with the results of the Rothamstead Station where it was found that the phosphorus from the manured plots was more soluble in 1 per cent citric acid than that from the chemically manured and untreated plots.

TABLE XIX.

Phosphorus Soluble in N/5 Hydrochloric Acid. Arranged in Order of the Highest Per Cent in the Surface Soil.

Plot.	Treatment.	Per Cent in Soil.	Per Cent in Subsoil.	Pounds PerAcre in Surface*
18	Corn, manure	0.00904	0.00293	180.8
15	Oats, manured	0.00778	0.00357	154.6
2	Wheat, chemicals	0.00699	0.00363	139.8
22	Timothy, manured	0.00635	0.00494	137.0
12	6 year rotation, manured	0.00624	0.00298	124.8
26	3 year rotation, manured	0.00528	0.00332	105.6
23	Timothy, no treatment	0.00502	0.00496	100.4
Virgin		0.00493	0.00346	98.6
16	Oats, no treatment	0.00443	0.00387	88.6
27	3 year rotation, no treatment	0.00407	0.00292	81.4
17	Corn, no treatment	0.00393	0.00380	78.6
13	6 year rotation, no treatment	0.00125	0.00390	25.0

* The weight of the surface eight inches was considered as being two million pounds per acre.

The soluble phosphorus also corresponds in a general way to the total phosphorus though this is probably because both total and soluble phosphorus are higher in the manured plots. It does not necessarily follow that the soluble phosphorus is greater in the soils having the greatest amount of total phosphorus

The chemically manured plot stands third in the amount of soluble phosphorus while the virgin soil contains more than the average of the unmanured plots. The rotated plots stand low in both the manured and unmanured series.

Several investigators have found that acid soils lack readily soluble phosphorus. However, all the plots under consideration are so strongly acid that it would hardly seem probable that the difference in acidity would account for the difference in soluble phosphorus. However, the manured plots were in general the least acid also. It is impossible to say, then, whether the increase in the solubility of the phosphorus is due to there being more total phosphorus present, to the lower acidity, or to the influence of the manure, but it is most probably the last. The results for the potassium and magnesium show that there is very little difference in the various plots. Evidently none of them are suffering from a lack of these elements. In most cases, there was a slightly higher per cent of both in the subsoil than in the soil.

Calcium also varied only slightly and evidently there is enough present for the needs of plant nutrition.

TABLE XX.

Total Potassium Arranged in Order on the Highest Per Cent in the Surface Soil.

Plot.	Treatment.	Per Cent Potassium in Soil.	Per Cent Potassium in Subsoil.
26	3 year rotation, manure	1.341	1.354
23	Timothy,no treatment	1.302	1.373
27	3 year rotation, no treatment	1.278	1.343
18	Corn, manured	1.266	1.332
15	Oats, manured	1.260	1.221
22	Timothy, manured	1.259	1.295
16	Oats, no treatment	1.242	1.279
Virgin		1.170	0.971
17	Corn, no treatment	1.155	1.255
13	6 year rotation, no treatment	1.092	1.125
2	Wheat, chemicals	1.027	0.933
12	6 year rotation, manure	0.939	1.206

TABLE XXI.

Per Cent of Total Calcium in Soil and Subsoil Arranged in Order of the Highest Per Cent in the Surface Soil.

Plot.	Treatment.	Per Cent Calcium in Soil.	Per Cent Calcium in Subsoil.
22.	Timothy, manured	0.574	0.415
27	3 year rotation, no treatment	0.558	0.444
15	Oats, manure	0.544	0.446
17	Corn, no treatment	0.537	0.450
16	Oats, no treatment	0.491	0.452
13	6 year rotation, no treatment	0.485	0.539
23	Timothy, no treatment	0.474	0.414
18	Corn, manured	0.469	0.560
2	Wheat, chemicals	0.459	0.481
26	3 year rotation, manured	0.444	0.391
Virgin		0.426	0.490
12	6 year rotation, manured	0.419	0.321

TABLE XXII.

Total Magnesium in Soil and Subsoil Arranged in Order of Highest Per Cent in the Surface Soil.

Plot.	Treatment.	Per Cent Magnesium in Soil.	Per Cent Magnesium in Subsoil.
Virgin		0.396	0.564
18	Corn, manured	0.367	0.479
23	Timothy, no treatment	0.327	0.386
27	3 year rotation, no treatment	0.321	0. 381
22	Timothy, manured	0.291	0.396
26	3 year rotation, manured	0.279	0.275
17	Corn, no treatment	0.265	0.272
12	6 year rotation, manured	0.269	0.265
13	6 year rotation, no treatment	0.235	0.375
15	Oats, manured	0.228	0.260
2	Wheat, chemicals	0.218	0.185
16	Oats, no treatment	0.216	0.363

SUMMARY.

1. In general, barnyard manure has increased the per cent of nitrogen, humus and phosphorus in the soil over that of the virgin and untreated soils.

2. The lime requirement tended to be lower in the manured soils than in the untreated and chemically fertilized soils.

3. The phosphorus in the manured plots was much more soluble in the manured plots than in the untreated plots.

4. There appears to be a relation between the manured plots, the acidity and the total and soluble phosphorus. The acidity was lower and the total and soluble phosphorus higher in the manured plots.

5. The soluble phosphorus in the chemically fertilized plot was well up with that of the manured plots though the total phosphorus in this plot was low.

6. In general, barnyard manure is much more efficient than chemical fertilizer in maintaining nitrogen and humus.

7. Sod crops and oats seem to help maintain the nitrogen and humus while corn does not.

8. Potassium, calcium and magnesium did not vary materially.