WHAT IS HAPPENING TO OUR SOIL FERTILITY

By C. C. Volkerding[1] and T. E. Stoa[2]

Farmers are becoming increasingly concerned about the fertility of their soil. Many of them have observed differences in the soil which have taken place over a period of years. Have the soils been changing under continuous cropping? Has their fertility declined? Should we use commercial fertilizers to maintain soil fertility and increase the productivity of the soil? These are just a few of the many questions progressive farmers are asking.

In order to answer some of these questions chemical studies have been made upon four series of plots, namely Fertility Series VI, VII, VIII and IX. Each series is divided into 9 plots. The several plots in each series are handled as indicated in the accompanying tables. The soil is the typical Fargo clay of the Red River Valley, a heavy black clay.

History of Soil Fertility Experiments

The soil fertility experiments on the Fargo clay at the North Dakota Agricultural Experiment Station reported upon in this article were designed and laid out by the late R. C. Doneghue, agronomist of the Station from 1908 to 1919. H.L. Walster was in charge of these experiments from 1919 to 1934. T. E. Stoa has assisted in the management of these experiments since 1920 and has been completely in charge of the field experiments since 1934.

The plan of the experiments reflects the philosophy of the late Dr. C. G. Hopkins of the University of Illinois about "Soil Fertility and Permanent Agriculture". Mr. Doneghue was a student under Dr. Hopkins. Hopkins held that the key to the maintenance and improvement of soil fertility and hence to permanent agriculture lay in the building up of the organic matter in the soil through the use of legumes, manure and crop residues, in relying upon the legumes to supply the necessary nitrogen and in adding phosphorus and potassium fertilizers to restore the phosphorus removed by crops and to increase the supply where a deficiency exists and finally to correct soil acidity through use of ground limestone.

He counted upon the use of limestone to provide suitable soil conditions for the maximum nitrogen restoring capacity of the legumes, upon the decay of organic matter to promote the release in soluble form of the phosphorus and potassium compounds. Whenever such decay did not supply enough he added phosphates to increase the stock of available phosphorus and potash salts to increase the supply of available potassium.

[1]Associate Director and Associate Soil Scientist.
[2]Agronomist.

The "Hopkins" philosophy as applied to the soils of North Dakota, especially of the Red River Valley and of the glaciated plains, fails to reckon with the fact that the intensity of acidity where such does exist is low, and that in general the immediate subsurface and deeper subsoil are amply supplied with natural ground limestone because our rainfall has not been sufficient to leach out the subsoil lime carbonate. Hopkins stressed the lack of sufficient phosphorus as a general limiting factor in American agriculture.

These experiments in the Red River Valley in North Dakota amply confirm that latter point of view. They also demonstrate that crop residues alone are not as effective as manure in maintaining yields and that supplementary phosphorus increases yields under both crop residue or cash crop farming, and livestock farming systems. (*H. L. W.*)

Soil samples had been taken in 1913 from each of the plots, dried, and stored in sealed glass jars. In the fall of 1946, samples were again taken from each of the same plots in Fertility Series VI, VII, VIII and IX. Chemical analyses have been made on the 1913 and 1946 soil samples to determine what changes, if any, had taken place during the 33 years of cropping. Has the fertility of this soil been maintained, or at what rate has its fertility been declining?

Two Farming Systems Tested

This soil fertility experiment is divided into two systems—a livestock farming system where manure is returned to the soil on certain plots, and a grain farming system where crop residues (the barley straw, the wheat straw, and the second growth of clover) are returned to the soil. The livestock system is operated as a four-year rotation of corn, wheat, clover, oats. Red clover was used up to and including 1931 since which time sweet clover has been substituted for red clover. The grain farming or cash crop system consisted of potatoes, wheat, clover and barley. The clovers used have been the same as in the livestock farming system. Because of the unsuitability of the heavy soil for potatoes, corn was substituted for potatoes in 1944 and since.

Soil Treatments—Livestock System

Manure applications: Fresh barnyard manure, recently taken from the barns or feeding yards has been applied to the manured plots going into corn at a rate varying from 7 to 10 tons per acre in the fall before plowing. The fertilizers are applied in the corn rows by means of a fertilizer attachment on the corn planter. The ground limestone is applied with a broadcast spreader before planting and is disked in. The corn therefore receives the direct effect of the manure and fertilizer; the wheat which follows, the first residual effect—that is, an effect due to the application one year previous to the seeding of wheat; similarly the clover receives an effect due to the application two years previous to the year of harvesting the clover; and the oats receives the effect due to the application three years previous to the seeding of oats. Each rotation is manured only once every four years. Fertility Series VIII which was corn in 1946 was fertilized in 1946, 1942, 1938, 1934, 1930, 1926, 1922, 1918, and 1914; manure was applied to the grain stubble in the preceding autumn in each case. Fertility Series VI which was in wheat in 1946 was fertilized for corn in 1945, 1941, 1937, 1933, 1929, 1925, 1921, 1917, and 1913, manure being applied in the previous autumn in each case.

Rates of application, once each four years.

Phosphorus plots:	140 pounds of 43 percent superphosphate, or 300 pounds of 20 percent acid phosphate. The 43 percent goods have been used since 1921. In general the amount of available phosphate used has been kept at the same level.
Lime plots:	1000 pounds per acre of ground limestone, a finely ground dolomitic limestone.
Potash plots:	120 pounds per acre of sulphate of potash.

Soil Treatments—Grain Farming System

Straw application: During the year a series is in barley, the barley straw is returned to the barley stubble of that year, as is also an equivalent amount of wheat straw produced in this series during the year cropped to wheat, both lots of straw being applied on the barley stubble in the autumn previous to plowing for the succeeding inter-tilled crop of potatoes (corn since 1944).

Legume residues: The second growth of clover, following the removal of a first cutting for hay is left on all plots except the "no treatment" or "check" plots where the crop is removed.

Fertilizer and limestone: Applied in the same amounts, at the same time, and in the same way as in the livestock farming system. Fertility Series IX, in the Grain Farming System, which was in corn in 1946 was fertilized in the same years as Fertility Series VIII in the Livestock Farming System. Fertility Series VII, in the Grain Farming System, which was in wheat in 1946 was fertilized in the same years as Fertility Series VI in the Livestock Farming System.

The results of the chemical analysis of the soil after the various treatments are shown in tables I, II, III, and IV. In several cases, the 1913 soil samples were not available for analysis. In calculating changes which have taken place between the 1913 and 1946 samples, the average analysis for the 1913 available samples was used. The results presented in this discussion are from only those plots which were in corn and wheat in 1946. The plots in sweet clover and oats or barley in 1946 were not sampled and thus are not included in the study, although they should give similar results.

Table I shows the nitrogen content of the 1913 and 1946 surface soil samples in the livestock and grain farming systems. The change in nitrogen in the soil has been calculated from the average nitrogen content of the 1913 soil samples.

Table I.—Changes in Total Nitrogen—1913 to 1946

Surface Soil 0 to 7 inches

Livestock Farming System

Plot Numbers	Treatments	Percent of Nitrogen F. S. VIII (after corn) 1913	1946	Change[1]	F. S. VI (after wheat) 1913	1946	Change[2]
1	Manure	.350	.291	-16%	.369	.328	-12%
2	No treatment—check	.353	.263	-24%	.367	.269	-28%
3	Manure & Phosphate	.347	.286	-18%	.378	.300	-20%
4	Manure, Phosphate & Limestone	......	.263	-24%	.350	.311	-17%
5	Manure	.319	.269	-23%	.389	.302	-19%
6	Manure & Phosphate	.342	.277	-20%	.354	.288	-23%
7	Manure, Phosphate & Limestone	......	.274	-21%	......	.305	-18%
8	No treatment—check	.370	.277	-20%	......	.300	-20%
9	Manure, Phosphate, Limestone and Potash	.345	.303	-13%	......	.325	-13%
	Average	.347	.278	-20%	.368	.303	-19%

Grain Farming System

Plot Numbers	Treatments	Percent of Nitrogen F. S. IX (after corn) 1913	1946	Change[1]	F. S. VII (after wheat) 1913	1946	Change[2]
1	Crop Residues	.341	.322	- 7%	......	.303	-19%
2	No treatment—check	.344	.268	-23%	......	.263	-29%
3	Crop Residues and Phosphate	.333	.286	-18%	.374	.280	-25%
4	Crop Residues, Phosphate and Limestone	.341	.277	-20%	......	.280	-25%
5	Crop Residue	.347	.283	-19%	......	.275	-26%
6	Crop Residues and Phosphate	.353	.288	-17%	.368	.280	-25%
7	Crop Residues, Phosphate and Limestone	.333	.286	-18%	......	.300	-20%
8	No treatment—check	.358	.283	-19%	.392	.294	-21%
9	Crop Residues, Phosphate, Limestone and Potash	.372	.316	- 9%	.378	.325	-13%
	Average	.347	.290	-17%	.378	.289	-22%

[1]Based on 1913 average of .347.
[2]Based on 1913 average of .373.
Phosphate=140 lbs. of 43% superphosphate/acre (60 lbs. P_2O_5).
Limestone=½ ton limestone per acre.
Potash=120 lbs. Sulfate of potash/acre (60 lbs. K_2O).

Nitrogen Losses

It is evident from the above table that a loss of nitrogen has taken place in the soil even under a good crop rotation including a legume and supplemented with the use of manure and fertilizers.

It must be realized that a considerable portion of the nitrogen supplied by manure and crop residues is readily utilized by the crops grown. The addition of phosphates and other fertilizers may also create a greater withdrawal of nitrogen from the soil to sustain the larger yields. The addition of nitrogen in manure and crop residues may thereby be reflected in higher yields rather than in the maintenance of a high soil nitrogen level. Little difference in nitrogen losses can be seen from treatment except possibly a smaller loss where potash was included in the fertilizer treatment.

There has been approximately a 20% decrease in the nitrogen content of the soil during the 33 years of the rotation. How does this loss in nitrogen affect the soil and subsequent crop growth? First, there is a lower supply of nitrogen available for crop production. Of the total nitrogen in a soil only a small fraction is available for plant growth at any one time, but as the supply is used, more becomes available. With a lower supply, the rate of availability and the level of available nitrogen is going to be lower; consequently, deficiencies may occur, especially in the spring and during periods of rapid growth. Second, nitrogen, besides being an essential element for plant growth, is also a constituent of organic matter. A loss of nitrogen means a loss of soil organic matter.

Organic matter is necessary for good soil structure, good soil tilth and rapid intake of water, especially on heavy clay soils. High organic matter content helps prevent compaction, puddling, and makes a heavy soil workable and easy to cultivate. Consequently, the loss of organic matter and nitrogen which has taken place should also be reflected in the workability or ease of handling of the soil. How low we can let the nitrogen and organic matter of this soil go without affecting yields and workability is not known. The level of available nitrogen necessary for maximum crop production will depend on the crop, the growing season, the soil, and climatic factors.

Table II shows the "available" phosphorus in the 1913 and 1946 soil samples in the livestock and grain farming systems. The available phosphorus was determined colorimetrically with a photoelectric colorimeter. An acetic acid-sodium acetate solution at pH 3.55 containing normal acetic acid and 10 grams of sodium acetate per liter was used to extract the so-called "available" phosphorus out of the soil. The change in "available" phosphorus has been calculated for the soil samples from the 1946 wheat plots and those 1946 corn plots which have not received superphosphate fertilizer. The 1946 corn plots which received superphosphate fertilizer in the spring showed a very high phosphate availability in the row. Since this high availability exists only in the row due to localized row application of the fertilizer, it does not represent the true level of phosphorus in the entire plot. For this reason the change in "available" phosphorus for the corn plots receiving superphosphate has not been calculated.

Table II.—Changes in "Available" Phosphorus—1913 to 1946
Surface Soil 0 To 7 Inches
Livestock Farming System

Plot Numbers	Treatments	F. S. VIII (after corn) 1913	1946	Change[1]	F. S. VI (after wheat) 1913	1946	Change[2]
		Percent "Available" Phosphorus					
1	Manure	.0030	.0022	-35%	.0029	.0014	-55%
2	No treatment—check	.0029	.0015	-56%	.0031	.0012	-61%
3	Manure and Phosphate	.0035	.0163	*	.0027	.0031	0%
4	Manure, Phosphate and Limestone	....	.0111	*	.0028	.0034	+10%
5	Manure	.0031	.0030	-12%	.0033	.0020	-36%
6	Manure and Phosphate	.0030	.0104	*	.0028	.0031	0%
7	Manure, Phosphate and Limestone	.0034	.0096	*	....	.0061	+97%
8	No treatment—check	.0036	.0017	-50%	....	.0015	-52%
9	Manure, Phosphate, Limestone and Potash	.0033	.0162	*	....	.0044	+42%
	Average	.0032			.0029		

Grain Farming System

Plot Numbers	Treatments	F. S. IX (after corn) 1913	1946	Change[1]	F. S. VII (after wheat) 1913	1946	Change[2]
		Percent "Available" Phosphorus					
1	Crop Residues	.0036	.0019	-44%	....	.0017	-45%
2	No treatment—check	.0031	.0017	-50%	....	.0018	-42%
3	Crop Residues and Phosphate	.0032	.0081	*	.0032	.0035	+13%
4	Crop Residues, Phosphate and Limestone	.0040	.0180	*	....	.0039	+26%
5	Crop Residues	.0033	.0021	-38%	....	.0022	-29%
6	Crop Residues and Phosphate	.0044	.0108	*	.0030	.0032	+ 3%
7	Crop Residues, Phosphate and Limestone	.0033	.0110	*	....	.0036	+16%
8	No treatment—check	.0042	.0024	-29%	.0034	.0018	-42%
9	Crop Residues, Phosphate, Limestone and Potash	.0037	.0160	*	.0032	.0040	+29%
	Average	.0036			.0033		

[1]Based on 1913 average of .0034.
[2]Based on 1913 average of .0031.

*Change not calculated because high localized "availability" existed in the row due to phosphate application in the row at seeding time. Soil samples were taken in the corn row and great variation with high results would be expected because of the method of phosphate application.

Changes in the amount of "available" phosphorus in the soil indicate a definite decrease since 1913 where no commercial phosphate fertilizer has been applied. The average decrease in "available" phosphorus on the 16 plots which did not receive superphosphate is 42%. (This 42% is the average of plots 1, 2, 5, 8 respectively in each of Fertility Series VIII, VI, IX, and VII.)

On the plots which have received superphosphate once every four years the level of available phosphorus has not changed appreciably or it is higher than the level which existed in 1913. On the corn plots, which were fertilized with superphosphate in the row at the time of planting, much greater phosphorus availability existed in the row as a result of the fertilization. This is a localized effect and would not be expected between the rows or after a period of time. This localized row effect is reduced and evened out on the wheat plots, which are two crop years (corn and wheat) removed from the superphosphate application. The addition of 140 pounds of a 43% superphosphate (60 pounds of P_2O_5) once every four years maintained the availability of the phosphorus at its 1913 level or above.

Table III which follows reports the average losses from duplicate plots. The reader will note that Plot 9, carrying the potash treatment, occurs only once in each series.

Table III.—Average percentage reduction or increase in total nitrogen and "available" phosphorus in 33 years of rotation farming (Surface 0-7 inches of soil) in Fertility Series VI (Livestock Farming System) and in Fertility Series VII (Grain Farming System)*

Livestock Farming System (F. S. VI)

Plot Numbers	Treatments	Nitrogen change	Phosphorus change
2 and 8	No treatment—check	-23%	-55%
1 and 5	Manure	-17%	-34%
3 and 6	Manure and Phosphate	-20%	0%*
4 and 7	Manure, Phosphate and Lime	-20%	+53%*
9	Manure, Phosphate, Lime and Potash	-13%	+42%*

Grain Farming System (F. S. VII)

Plot Numbers	Treatments	Nitrogen change	Phosphorus change
2 and 8	No treatment—check	-23%	-40%
1 and 5	Crop residues	-18%	-39%
3 and 6	Crop residues and Phosphate	-21%	+ 8%*
4 and 7	Crop residues, Phosphate and Lime	-21%	+21%*
9	Crop residues, Phosphate, Lime and Potash	-11%	+29%*

*These percentages include only the analysis from the 1946 wheat plots which were two crop years, corn and wheat, removed from the phosphate application. The variation in the results on phosphated plots can be attributed to the row placement of the fertilizer and difficulty in obtaining uniform sampling.

Table IV shows the soil reaction of the surface soil in 1913 and 1946 and the change in soil reaction which has taken place under the livestock and grain farming systems. The soil reaction is expressed as pH with the standards for interpreting pH given just below Table IV.

All plots are slightly less acid than they were in 1913. The small change in soil acidity could be due to (1) cultivation and plowing, resulting in some mixing of the lower, less acid soil with the surface soil; (2) the growing of sweet clover with its deep root system and translocation of lime from the subsoil to the surface soil when the roots decompose; (3) small deposits of high lime soil from the surrounding region blowing in during the winter months; (4) lower content of organic matter in the soils which gives rise to organic acids and lower pH. The plots which received one-half ton of lime every four years are considerably lower in acidity (nearly neutral in reaction) than the non-limed plots. Treatments other than the addition of limestone have not affected the soil reaction.

Table IV.—Soil Reaction Changes—1913 to 1946

Surface Soil 0 to 7 Inches

Livestock Farming System—Soil Reaction (expressed as pH)

Plot Number	Treatments	pH of 1946 corn plots Fertility Series VIII 1913	1946	Change	pH of 1946 wheat plots Fertility Series VI 1913	1946	Change
1	Manure	5.5	6.0	+ .5	5.5	6.1	+ .6
2	No treatment—check	5.6	6.0	+ .4	5.7	6.2	+ .5
3	Manure and Phosphate	5.7	6.0	+ .3	5.6	6.2	+ .6
4	Manure, Phosphate and Limestone	....	6.9	+1.2*	6.0	6.9	+ .9
5	Manure	5.9	6.2	+ .3	5.8	6.3	+ .5
6	Manure and Phosphate	5.6	6.0	+ .4	5.8	6.4	+ .6
7	Manure, Phosphate and Limestone	5.5	6.6	+1.1	....	6.8	+1.1*
8	No treatment—check	5.7	6.0	+ .3	....	6.3	+ .6*
9	Manure, Phosphate, Limestone and Potash	5.7	6.5	+ .8	....	6.8	+1.1*
	Average	5.7			5.7		

Grain Farming System—Soil Reaction (expressed as pH)

Plot Number	Treatments	pH of 1946 corn plots Fertility Series IX 1913	1946	Change	pH of 1946 wheat plots Fertility Series VII 1913	1946	Change
1	Crop residues	6.0	6.2	+ .2	....	5.8	+ .1*
2	No treatment—check	5.8	6.4	+ .6	....	5.8	+ .1*
3	Crop Residues and Phosphate	6.0	6.3	+ .3	5.5	5.8	+ .3
4	Crop Residues, Phosphate and Limestone	6.2	7.1	+ .9	....	6.3	+ .6*
5	Crop Residues	6.2	6.3	+ .1	....	5.9	+ .2*
6	Crop Residues and Phosphate	6.4	6.3	- .1	5.7	6.0	+ .3
7	Crop Residues, Phosphate and Limestone	6.2	7.1	+ .9	....	6.3	+ .6*
8	No treatment—check	5.8	6.3	+ .5	5.5	6.0	+ .3
9	Crop Residues, Phosphate, Limestone and Potash	6.1	6.9	+ .8	5.7	6.5	+ .7
	Average	6.1			5.6		

*Change based on average of samples in 1913=pH 5.7

Standards for classifying soil reaction (pH).

pH 5.1 to 5.5	strongly acid.
pH 5.6 to 6.0	medium acid.
pH 6.1 to 6.5	slightly acid.
pH 6.6 to 7.3	neutral.

Influence of Treatments on Crop Yields

Table V shows the average yields of corn or potatoes and wheat which have been obtained following the treatments under the livestock and grain farming systems. The yields of sweet clover hay and the oats or barley in the rotation are not included. Small fairly consistent benefits to these crops have, however, been obtained from the manure, crop residue and fertilizer treatments.

Table V.—Effect of Farm Manure or Crop Residue on Yields of Corn and Potatoes and Carry-Over Effect on Wheat When Supplemented with Superphosphate or Other Fertilizers

(Percent increase is increase over the "check" for the years included in the averages)

Livestock Farming System		Yield per acre—bushels					
		Corn			Wheat		
Plot Numbers	Treatments	Average 1946	Average 1912-45[a]	Percent Increase 1912-45 Average	Average 1946	Average 1913-45[b]	Percent Increase 1913-45 Average
2 and 8	No treatment—check	40.4	31.4	....	30.1	24.5	....
1 and 5	Manure	42.8	33.6	7	34.9	27.8	**14**
3 and 6	Manure and Phosphate	44.6	35.8	**14**	33.6	29.0	**18**
4 and 7	Manure, Phosphate and Limestone	49.0	36.4	**16**	34.1	29.0	**18**
9	Manure, Phosphate, Limestone and Potash	49.7	34.8	**11**	37.9	29.1	**19**

Grain Farming System		Yield per acre—bushels					
		Corn	Potatoes*		Wheat		
Plot Numbers	Treatments	Average 1946	Average 1912-40	Percent Increase 1912-40 Average	Average 1946	Average 1913-45[b]	Percent Increase 1913-45 Average
2 and 8	No treatment—check	39.2	91.9	....	27.3	24.5	....
1 and 5	Crop Residues	42.5	97.7	6	30.4	25.1	2
3 and 6	Crop Residues and Phosphate	41.0	109.1	**19**	30.1	26.9	**10**
4 and 7	Crop Residues, Phosphate, and Limestone	40.5	109.8	**20**	29.7	27.0	**10**
9	Crop Residues, Phosphate, Limestone and Potash	44.9	111.5	**21**	33.1	28.1	**15**

*Corn substituted for potatoes in the rotation in 1944. Plots damaged from excessive rains or stands otherwise unsatisfactory in 1915, 1916, 1925, 1941, 1942, 1943, omitted from averages.

[a]The 1913-15, 1917-18, 1926 and 1943 corn crops failed to mature or stands unsatisfactory so yields not reliable thus omitted from the average.

[b]Wheat plots not harvested in 1944 due to excessive field moisture. Yields omitted from the average.

The treated plots in the livestock system generally have been more productive than the plots under the grain farming system. In the livestock series where manure alone was added, corn yields have shown an average increase of 7 percent. When the manure was supplemented with superphosphate the increase yield over the check plot averaged 14 percent.

Wheat yields following corn in the livestock series benefited to a larger extent from the treatments than did corn. Wheat yields on the plots treated with manure alone averaged 14 percent over the non-treated check plot. Where superphosphate was added to the manure the increase in the yield of wheat averaged 18 percent over the check.

In the crop residue series, the wheat yields following the cultivated crop, potatoes or corn, show only a 2 percent increase for the residue treated plots. However, where the residues were supplemented with superphosphate the increase in yield has averaged 10 percent over the non-treated plot.

Lime in the form of ground limestone has not shown any increase over "no lime" in the fertility trial. Although the surface soil is slightly acid, the subsoil is neutral to alkaline in reaction. The acidity present in the surface soil is apparently not detrimental to crop production.

Summary

1. A decrease of approximately 20 percent of the total nitrogen in the surface soil has taken place in the fertility plots under a four year rotation of corn (or potatoes)-wheat-clover-oats or barley from 1913 to 1946. Additions of manure, crop residues, and commercial phosphate fertilizer have not retarded this loss.

2. An average decrease of 42 percent in the amount of "available" phosphorus has taken place on the plots not receiving additions of superphosphate during this period, (1913 to 1946). Plots receiving superphosphate at the rate of 60 pounds of P_2O_5 (phosphoric acid) once every 4 years have maintained or increased their supply of readily "available" phosphate.

3. Soil reaction changes have not been great except on plots which received one-half ton of limestone every 4 years. There has been a general small decrease in soil acidity on all plots.

4. Larger yields have been obtained on plots treated with manure, crop residues, and fertilizers than on those plots receiving no amendments.