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Soil Changes as Influenced by Cropping and Fertilizer Treatment

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Contents

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By Leo F. Puhr[1]

Yields of crops are dependent in a large measure on the supply of plant food in the soil. It has been recognized that the capacity of the soil to supply sufficient plant food for maximum crop production is reduced by continuous cropping, unless adequate measures are taken to restore the depleted fertility constituents. Although many of our soils, which were developed under grass vegetation and a subhumid climate, had a high virgin fertility, past soil management practices have not included adequate provisions for the return to the soil (in the form of crop residues, legumes, manures, or fertilizers) of a substantial portion of the plant food removed by crops. Associated with removal of plant food by cropping, is the loss of soil organic matter. Loss of this constituent, which exerts a controlling influence on certain biological, physical, and chemical properties of soils, also may affect crop production adversely. Specific knowledge concerning the rate of depletion of our soils with respect to soil organic matter, nitrogen and phosphorus is imperative to sound recommendations regarding crop rotations, fertilizer application and other soil-building practices.

This investigation is concerned with soil fertility changes which are the result of cropping practices and fertilizer treatment on plots at the Agronomy Farm of the South Dakota Agricultural Experiment Station.

Previous Investigations

The following review of literature is confined to experiments which were conducted under soil, climate, and cropping systems similar or related to those of this investigation.

Peevy, Smith and Brown (8)[2] studied the effects of rotational and manurial treatments on the organic matter, nitrogen and phosphorus content of soils. It was shown that losses of organic matter and nitrogen were less with 3- and 5-year crop rotations, which included a legume crop, than the two-year rotation of corn and oats. Decrease in organic matter and nitrogen where manure was applied was much less than instances when crop residues were returned. Losses of total phosphorus were generally insignficant. A partial explanation was that crops take up phosphorus from the subsoil, and that erosion has removed some surface soil which results in some soil originally below six inches, being incorporated with the plowed layer.

Smith, Brown and Peevy (9) determined the effect on soil of continuous cropping to corn. They reported considerable decreases in organic matter, nitrogen and phosphorus in all plots during a 20-year period, even when large applications of manure were made.

Muhr et al (7) found that at the end of a 16-year crop rotation the surface soil of the check plots had decreased signficantly in nitrogen. The plots which had manure treatments at the end of the same rotation had a significantly higher content of soil nitrogen than the untreated or check plots.

Metzger (6) studied the influence of cropping systems on soil nitrogen and organic carbon. The data indicate that corn caused a decrease in soil nitrogen and carbon, more than any other crops or cropping systems, and that applications of manure did not produce significant increase of nitrogen or carbon, which could be attributed directly to the manure and not to increased crop residues.

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[2]See "Literature Cited" on page 10.

DeTurk, Bauer and Smith (4) concluded from a study of the Morrow plots that cropping the land without soil treatment, reduced the total amounts of phosphorus, nitrogen and soil organic matter. Soil treatment consisting of manure, limestone, and phosphorus maintained the total nitrogen, phosphorus and organic matter at a higher level in the treated plots than that found in the untreated plots.

Blair and Prince (2) studied the effects of the application of manure, nitrogen, potassium, and phosphate fertilizers on the organic matter, nitrogen and phosphorus supply in soils. Organic matter and nitrogen was increased in the soil only on the plots which received manure in combination with mineral fertilizers. Total soil phosphorus was increased by application of phosphate fertilizers.

Purpose of Investigation

The purpose of this investigation was to determine the soil changes associated with long continued cropping and fertilizer treatment. This investigation is particularly concerned with the changes in the nitrogen, phosphorus, and organic matter contents of soils extending over a period of 31 years. Since these soil constituents are highly important from the standpoint of crop production, any change in their quantity or nature as the result of cropping practices or soil treatment is important.

Plan and Experimental Methods

History of Experimental Plots. The Soils plots, established in 1908 for the purpose of conducting complete fertility field tests, were studied from the standpoint of the effect of crop production and fertilizer treatment on the chemical composition or fertility of the soil. The results obtained by fertilizer treatment on the yield of crops on these plots has been previously reported in South Dakota Agricultural Experiment Station bulletins, No. 280 and No. 325.

The Soil. The soil type on the plots involved in this project is Barnes loam, and is a member of the Chernozem group. This soil has been derived from the weathering of glacial drift. The following is a brief profile description:

Horizon 1, 0-7 Inches. In texture, this layer is a loam, dark to black in color, with a decided granular texture. Horizon 2, 7-14 inches is a transitional layer, between the horizon of dark surface soil and the underlying lighter colored soil which is the zone of lime accumulation. This layer is slightly finer in texture than the layer above. Containing less organic matter than the first horizon, it ranges in color from dark to light brown. In Horizon 3, 14-40 inches at a depth of approximately 18 inches, a definite zone of calcium carbonate accumulation, consisting of a highly calcareous, grayish-yellow, silty clay loam occurs. Beneath this zone of lime accumulation is found the parent glacial drift from which the soil was derived.

Plan of the Plots. Fig. 1 illustrates the general plan of the complete fertility test plots and the explanation of the crop rotation practiced and the fertilizer treatment.

The five-year rotation is the same for each acre or block with respect to the corn crop and red clover crop which occurs on both acres the same year, but the others, wheat, oats, and barley never occur on both acres the same year.

Soil Treatment. Fertilizer was applied at the rates per acre as indicated in Fig. 1., each year in the five-year rotation except the years when the plots were in clover when no fertilizer was applied. From 1908 to 1939, there were 25 applications of fertilizer. All the crop residues including straw and corn stalks were removed each year, and only the remaining stubble residues were returned to the soil. The clover crop was not returned to the soil, but was harvested for hay and seed.

Soil Sampling. Samples were taken from each soil fertility plot in the years, 1915, 1922, 1929, and 1939. In order to secure representative soil samples, each plot was divided into 12 sections, and one boring was made in each section. The soil was sampled at two depths 0 to 7 inches and 7 to 14 inches. The 12 borings from each plot and each depth were thoroughly

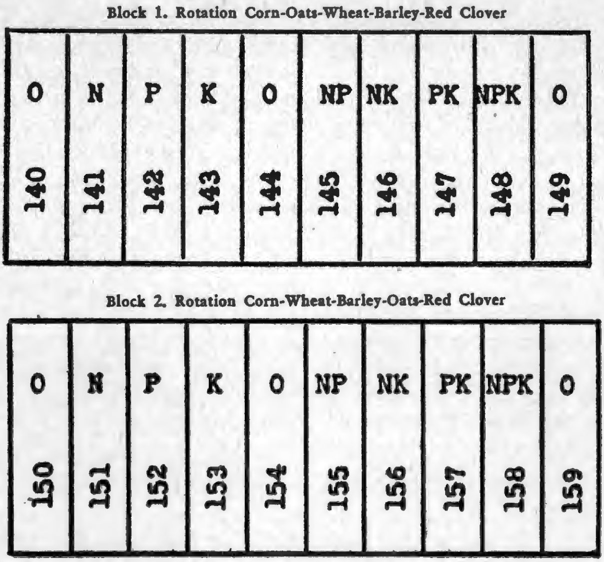

Fig. 1. Plan of the Complete Fertility Plots at Brookings, South Dakota

O—Check or unfertilized

N—Nitrogen, as nitrate of soda, 350 pounds per acre

P—Phosphorus, as superphosphate, 200 pounds per acre

K—Potassium, as potassium chloride, 200 pounds per acre

mixed in preparing a composite sample. From the composite sample a sub-sample was withdrawn for analysis. In 1908, a single soil sample of surface soil was taken from each plot. In this manner, a soil sample was secured which was representative of all plots, rather than of an individual plot.

Methods of Analysis. Nitrogen was determined by the Gunning-Hibbard method (1). Total carbon was determined by the method of Winters and Smith (11). Organic carbon was converted to organic matter by use of the factor 1.724. Total phosphorus was determined by the colorimetric method as described by Dickman and Bray (3), on aliquots from sodium carbonate fusion. For determination of available phosphorus, the Truog method was used (10).

Experimental Results

Nitrogen Changes in Surface Soil. The data presented in Table 1 and Fig. 2 reveal the changes in the nitrogen content of the surface soil of all the plots from 1915 to 1939. The part most worthy of note is the highly significant (Table 4) decline in total nitrogen of all plots irrespective of fertilizer treatment.

Plots which received no fertilizer and the plots which received nitrogen and phosphorus alone, and those with a complete fertilizer NPK had the highest average residual nitrogen content after 24 years of cropping and fertilizer treatment. Although all plots exhibited a downward trend in nitrogen content, this change in the treated plots did not differ significantly from the check or no-treatment plots. The N x P x K interaction was however significant. All other fertilizer treatments had no significant effect on nitrogen changes. The average surface soil nitrogen content of the NP and NPK plots was somewhat higher than the other plots at the beginning of the experiment. This variation in nitrogen content between plots was not significant as indicated by analysis of variance.

The average reduction in surface soil nitrogen from 1915 to 1939 was 786 pounds per acre for the untreated or check plots and 1,044 pounds for all the fertilizer-treated plots.

Plots receiving nitrogen alone and nitrogen in combination with K or P had an average loss of 1,078 pounds of soil nitrogen per acre for the same period. The potassium- and phosphorus-fertilized plots lost 1,034 and 918 pounds of nitrogen from the surface soil respectively per acre.

Nitrogen Changes in Subsurface Soil. Results of the analysis for nitrogen in the subsurface soil for all plots are presented in Table 2 and Fig. 3. While the decrease in nitrogen in the subsurface soil is not large enough to be significant, it does show that the general trend is downward. The fertilizer applications had no significant effect on the changes in the nitrogen composition of the subsurface soil.

Factors Contributing to Nitrogen Losses. In order to compare the actual loss of soil nitrogen as revealed by chemical analysis of the soil with the removal by crops, the total yield of crops for all plots from 1915 to 1939 were calculated. The amounts of nitrogen removed from the soil from 1915 to 1939 by the harvested grain, straws and stalks, based on the average nitrogen composition of the recorded yields, are presented in Table 3.

As the amount of nitrogen removed by crops is directly proportional to the yield, plots receiving fertilizer removed the most nitrogen. The largest nitrogen removal in crops was from the plots receiving phosphorus alone and the least nitrogen from the check or unferti-

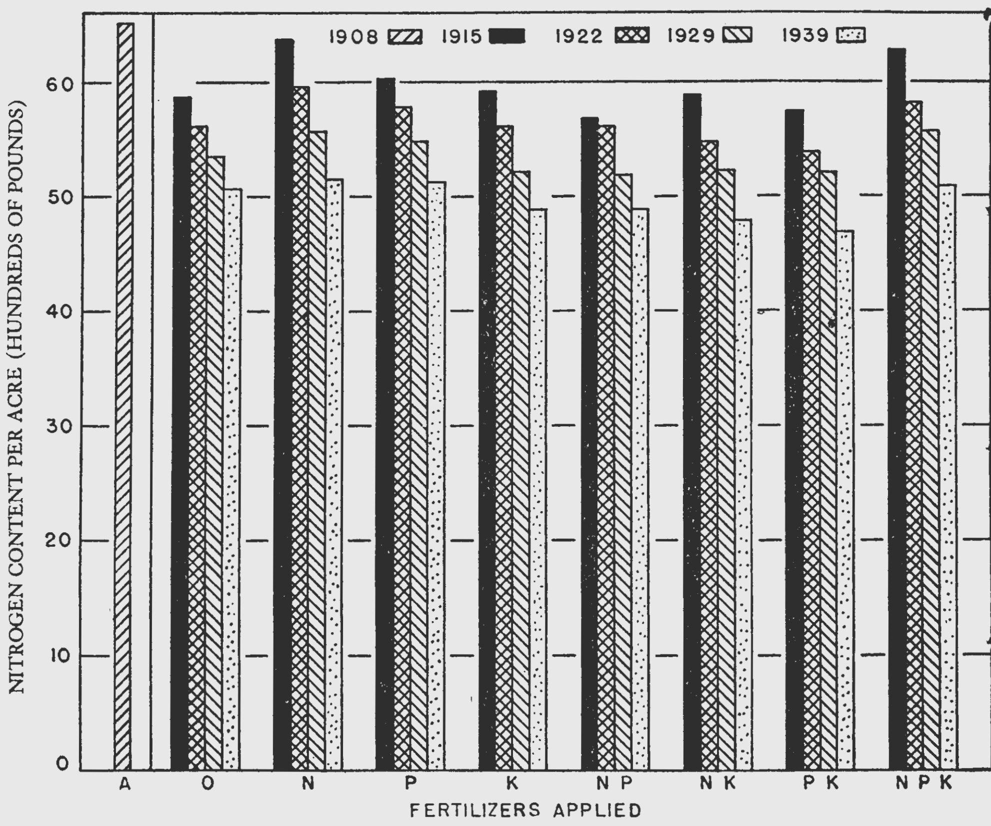

Fig. 2. Changes in the nitrogen content of the surface soil under different fertilizer treatments from 1915 to 1939.

Note: A—represents the average nitrogen content of all plots in 1908 before fertilizer was applied.

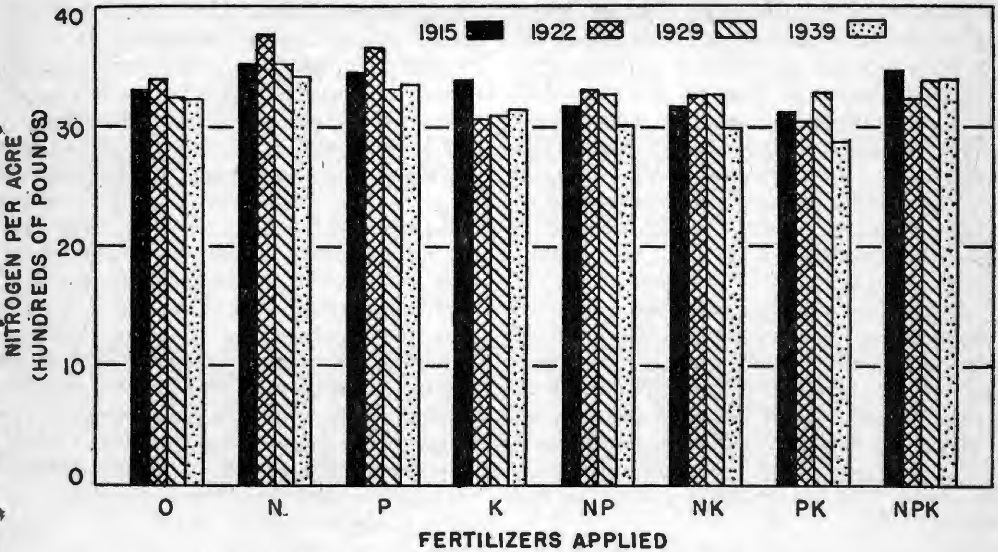

Fig. 3. Changes in the nitrogen content of the subsurface soil under different fertilizer treatments from 1915 to 1939.

lized plots. (Table 3) Plots receiving phosphorus alone produced the highest yield of all crops and the untreated plots the lowest yield. In every case the loss of soil nitrogen as revealed by chemical analysis was higher than the calculated amounts removed in crops. The loss of soil nitrogen from the check or unfertilized plots may be largely accounted for by removal in crops. The loss not accounted for by crop removal may be attributed to erosion or volatilization of the soil nitrogen. Losses of soil nitrates by leaching under subhumid conditions should be small in quantity.

Loss of soil nitrogen from the plots receiving nitrogen fertilizer seems to be somewhat higher than the check plots in proportion to the crop yield. These plots also had a loss of nitrogen from the applied nitrogen fertilizer. Reduction in soil nitrogen on the nitrate fertilized plots may likewise be attributed largely to crop removal. Additional loss of nitrogen in the applied nitrate fertilizer may be due to increased uptake of nitrate nitrogen by plants or possibly volatilization of the nitrogen in the nitrate fertilizer.

It appears that the application of sodium nitrate fertilizer did not maintain the soil nitrogen level, or that any accumulation of soil nitrogen resulted from synthesis of nitrates by soil microorganisms into organic nitrogen.

Phosphorus Changes in the Soil. The analysis of the soil for total phosphorus from plots under different treatment from 1915 to 1939 are given in Tables 5 and 6 and Fig. 4 and 5. These findings show a decline in the total phosphorus content of all plots where no phosphorus fertilizer was applied. The average decline for all plots receiving no phosphorus fertilizer in terms of pounds per acre is 86 pounds for the surface soil 0 to 7 inches deep and 74 pounds for the subsurface soil 7 to 14 inches deep. Although this decline in total phosphorus appears to be small in quantity, nevertheless, it does show that cropping reduces the total quantity of phosphorus in the soil. The phosphorus which has been removed by cropping probably represents that portion of the total phosphorus which is the most readily available to plants. On a percentage basis, the surface soil of the plots receiving no phosphorus fertilizer had an average loss of 6.2 percent phosphorus and the subsurface soil had an average loss of 6.5 percent phosphorus. These percentages are based on the phosphorus content of the soil in 1915.

The loss of phosphorus revealed by chemical analysis in pounds per acre is approximately that which was calculated to be removed by the crops during the same period. The calculated amounts of phosphorus contained in crops based on the recorded yields and average phosphorus composition are found in Table 7.

The surface soil of all plots receiving phosphorus fertilizer showed a significant gain in total phosphorus (Table 10). The average gain in phosphorus for all phosphorus-fertilized plots was 57 pounds per acre. The subsurface soil of the phosphorus fertilized plots had an average loss of 35 pounds per acre in comparison to an average loss of 74 pounds per acre in the subsurface soil of the plots receiving no phosphorus fertilizer. For some unexplained reason plot number 141 had an unusually high loss which may partially account for the difference.

Analysis of variance data (Table 10) for the effect of soil treatment on soil phosphorus changes in subsurface soil indicates that the nitrogen-treated plots had a highly signficant greater rate of loss of phosphorus than the other treated plots. The rate of phosphorus depletion in subsurface soil was signficantly less where phosphorus was applied and where P and K were applied together the rate of loss was slower than for K alone or for P without K.

Results for available phosphorus in surface soil are presented in Table 8. The data in this table indicate that the trend of the available phosphorus is downward on the untreated plots and on those plots receiving fertilizer which did not include phosphorus. The phosphorus-treated plots show a definite upward trend in available phosphorus content.

Analysis of the subsurface soil for available phosphorus is found in Table 9. Although the available phosphorus content of the subsurface soil is somewhat variable, the data seem to indicate a downward trend.

Organic Matter Changes. The data on changes in the organic matter content of the

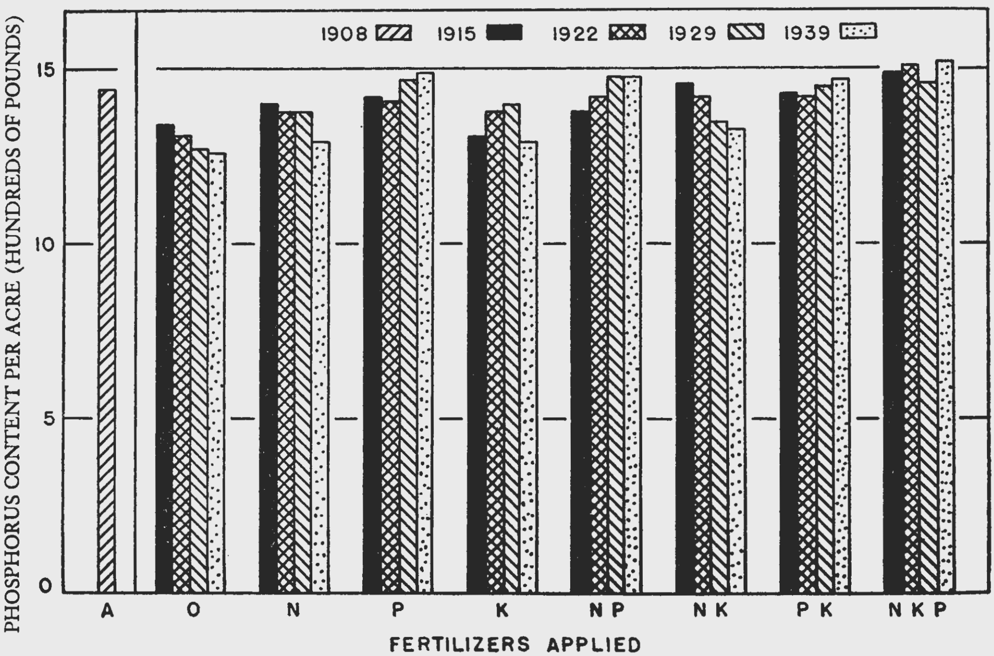

Fig. 4. Changes in the phosphorus content of the surface soil under different fertilizer treatment from 1915 to 1939.

Note: A—represents the average phosphorus content of all plots in 1908 before fertilizer was applied.

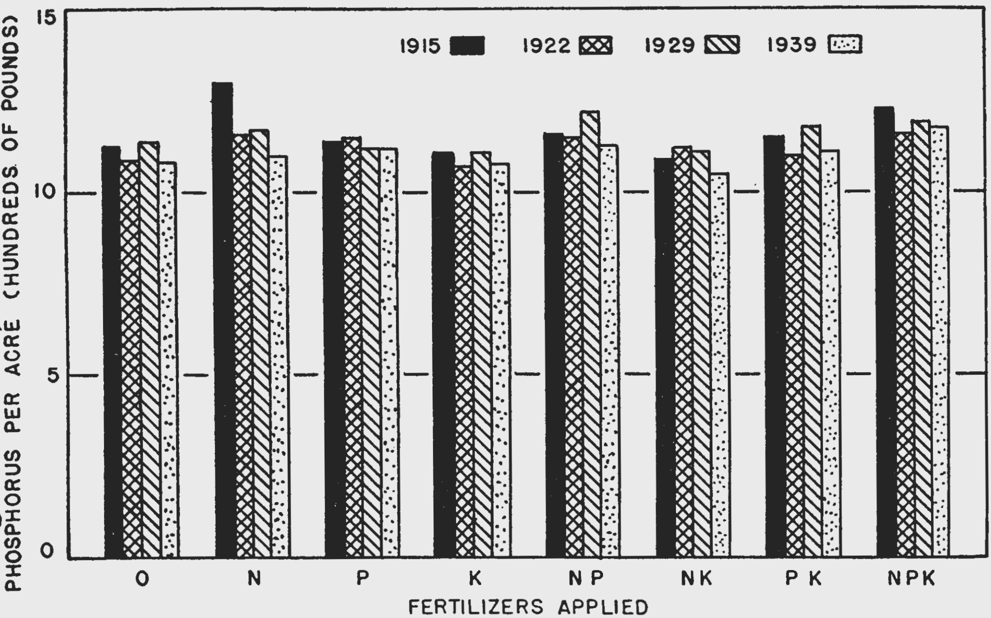

Fig. 5. Changes in the phosphorus content of the subsurface soil under different fertilizer treatments from 1915 to 1939.

surface soil of the variously treated plots are presented in Table 11 and Fig. 6.

A study of the tables and figures pertaining to the changes in the organic matter content of surface soil reveals that all plots had significant losses in organic matter ranging from an average of 14.09 percent for the check plots to 16.79 percent for the NPK plots. In terms of tons per acre, this would be equal to 8.36 and 10.54 tons, respectively, for the soil stratum to a depth of 7 inches. Average loss for all the variously treated plots was 14.99 percent, or 8.9 tons per acre, for the period from 1915 to 1939. This is equivalent to an annual loss of approximately 750 pounds of organic matter per acre. Fertilizer treatments had no significant effect on organic matter changes except for the interaction N x P x K. This interaction was significant.

The organic matter losses from the surface soil are closely related in relative quantity or percentage to the nitrogen changes, because most of the soil nitrogen exists in the organic form.

It appears from the analytical data on the surface soil that the application of mineral fertilizers alone without the return of additional organic matter other than the remaining stubble residues is not sufficient to retard the losses of organic matter which has occurred on these plots from 1915 to 1939. The consistent downward trend in the soil organic matter for each of the three sampling periods after 1915 indicates that the use of a crop rotation consisting of corn, wheat, barley, oats and a legume with or without fertilizer has not stabilized the organic matter content of the soil at any definite point or level. This would indicate that further losses of organic matter from the soil would take place. The same statement would also apply to the soil nitrogen in these plots.

Data obtained on the changes of the organic matter in subsurface soil from the plots are presented in Table 12 and Fig. 7. Most of these plots show slight gains in organic matter ranging from the average of .37 percent to 4.47, with the exception of the plots receiving NK, KP, and NPK fertilizer which showed very

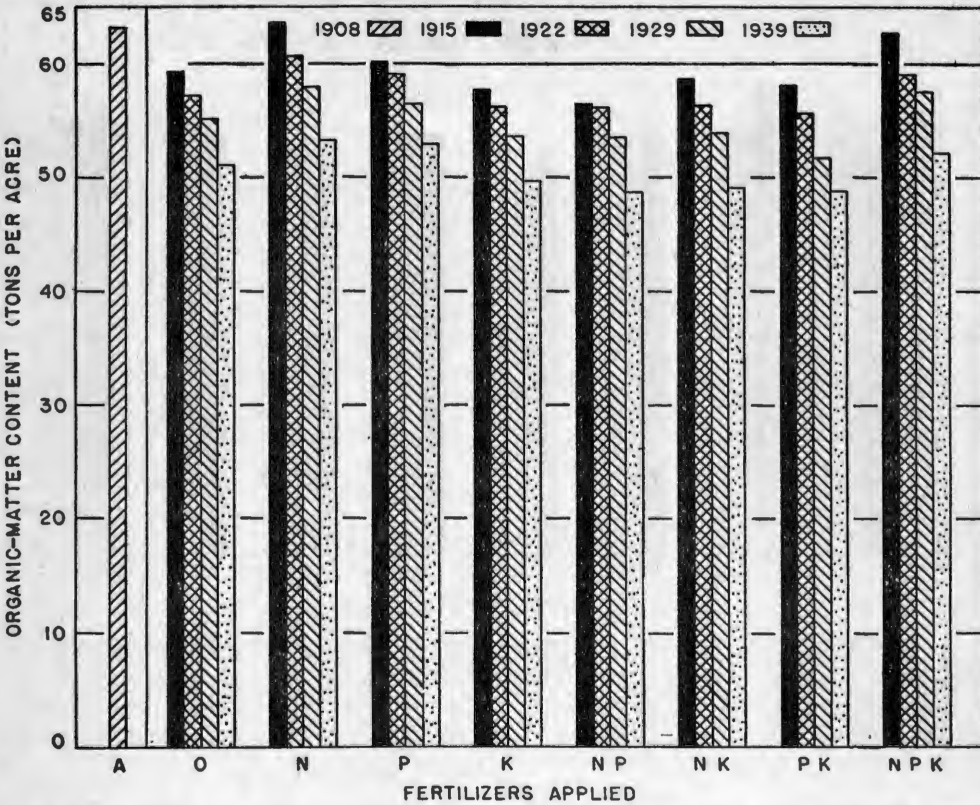

Fig. 6. Changes in the organic matter content of the surface soil under different fertilizer treatments from 1915 to 1939.

Note: A—represents the average organic matter content of all plots before fertilizer was applied.

slight losses. Changes in the organic matter content of subsurface soil from 1915 to 1939 are not signficant and the effect of fertilizer treatment on organic matter (Table 13) also is not significant. These data indicate that the organic matter in the subsurface soil is not subject to pronounced changes in quantity as the result of cultivation and crop production. The stability of the organic matter in the subsurface soil may be in part due to a reduced rate of bacterial decomposition, because this stratum is not disturbed by tillage operation.

Summary and Conclusions

An investigation was made of the nitrogen, phosphorus and organic matter changes from 1915 to 1939 in the surface and subsurface soil of the soil fertility plots located on the Agronomy Farm of the South Dakota Agricultural Experiment Station. The effect of fertilizer treatment and cropping on the progressive changes of these constituents was the principal object of this study. Composite samples of soil were taken from these plots in 1915, 1922, 1929 and 1939. These samples were analyzed for nitrogen, phosphorus and organic matter. The results were treated statistically by the analysis of variance in order to aid in the interpretation of the findings. The results may be summarized as follows:

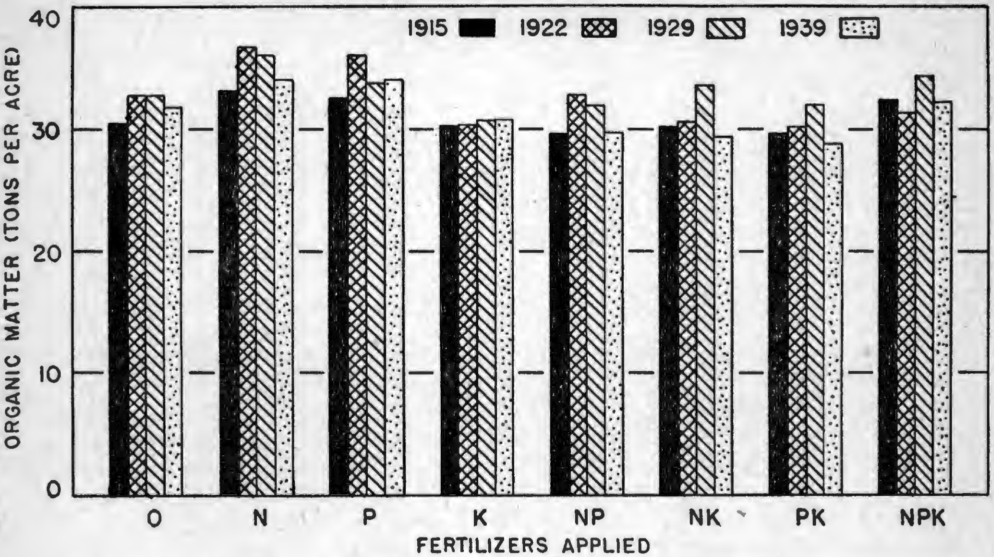

Fig. 7. Changes in the organic matter content of the subsurface soil under different fertilizer treatments from 1915 to 1939.

1. The loss of nitrogen in surface soil from 1915 to 1939 was highly significant. The average loss of nitrogen from all plots was 16.9 percent. Nitrogen changes in subsurface soil were small and statistically not signficant for the same period. Application of mineral fertilizers including nitrogen did not help in the maintenance of the soil nitrogen level in the surface soil nor have a pronounced effect on the rate of nitrogen depletion.

2. The surface soil of all plots which received no phosphorus fertilizer decreased in total phosphorus. Although the loss of total phosphorus from the plots which did not receive phosphorus fertilizer was small and statistically not signficant, it does show that the trend is downward. Plots which received phosphorus fertilizer showed signficant gains in total phosphorus in the surface soil. Subsurface soils showed decreases in total phosphorus. Decreases were less in the subsurface soil where phosphorus fertilizer was applied. Surface soil of the plots receiving phosphorus fertilizer were distinctly higher in available phosphorus.

3. The organic matter content of the surface soil of all the plots decreased significantly from 1915 to 1939. The average loss from the surface soil for all plots was 14.92 percent for the period. In general, fertilizer treatment had no significant effect on the changes in the organic matter content of the surface soil. Changes in the organic matter content of the subsurface soil were small and statistically not significant.

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Tables

Table 1. Changes in Nitrogen Content of Surface Soil 0 to 7 Inches Deep in Variously Treated Plots from 1915 to 1939.

Plot and Treatment	% Nitrogen			
Block 1	1915	1922	1929	1939
140 O	.289	.271	.256	.255
141 N	.311	.282	.258	.237
142 P	.283	.273	.257	.231
143 K	.282	.270	.246	.221
144 O	.272	.250	.241	.219
145 NP	.264	.255	.238	.229
146 NK	.295	.266	.249	.230
147 PK	.285	.260	.250	.229
148 NPK	.312	.282	.273	.256
149 O	.301	.284	.281	.255
Block 2				
150 O	.301	.301	.273	.279
151 N	.325	.314	.298	.278
152 P	.320	.305	.292	.281
153 K	.310	.291	.275	.268
154 O	.293	.286	.273	.253
155 NP	.304	.304	.280	.259
156 NK	.293	.281	.273	.249
157 PK	.288	.277	.269	.240
158 NPK	.316	.299	.281	.253
159 O	.302	.292	.279	.264

Table 2. Changes in Nitrogen Content of Subsurface Soil 7 to 14 Inches Deep in Variously Treated Plots from 1915 to 1939.

Plot and Treatment	% Nitrogen			
Block 1	1915	1922	1929	1939
140 O	.159	.151	.133	.141
141 N	.161	.164	.160	.155
142 P	.155	.158	.136	.143
143 K	.159	.138	.129	.130
144 O	.142	.151	.137	.130
145 NP	.148	.150	.149	.136
146 NK	.148	.163	.153	.144
147 PK	.143	.143	.156	.133
148 NPK	.169	.165	.165	.155
149 O	.166	.190	.169	.178
Block 2				
150 O	.181	.185	.188	.178
151 N	.193	.213	.192	.188
152 P	.190	.204	.194	.192
153 K	.179	.168	.180	.185
154 O	.162	.167	.165	.163
155 NP	.169	.181	.177	.165
156 NK	.168	.163	.174	.155
157 PK	.170	.161	.172	.155
158 NPK	.178	.158	.173	.185
159 O	.181	.174	.179	.179

Table 3. A Comparison of Nitrogen Removed by Crops and Loss of Soil Nitrogen and Fertilizer Nitrogen from Variously Treated Plots from 1915 to 1939 Expressed in Pounds per Acre.

Treatment	Nitrogen removed by crops	Soil nitrogen lost from surface soil	Soil nitrogen lost from subsurface soil	Total soil nitrogen loss	Loss from applied fertilizer
O	654	786	78	864	
N	727	1224	114	1338	1176
P	820	918	100	1018	
K	665	1034	238	1272	
NP	754	802	166	968	1176
NK	700	1092	178	1270	1176
PK	758	1046	254	1300	
NPK	773	1194	78	1272	1176

Table 4. Analysis of Variance of Soil Nitrogen Changes[1]

Source of variation	Degrees of freedom	Mean square for surface soil	Mean square for subsurface soil
Rep.	1	937,024	1,150,256
Years	3	747,950†	22,540
Reps. x years error (a)	3	9,737	9,846
N	1	37,055	25,840
P	1	3,047	3,751
K	1	62,374	118,852
N x P	1	367	12,826
N x K	1	30,626	16,706
P x K	1	55,820	29,156
N x P x K	1	281,428*	162,207
Treatment x rep. error (b)	7	33,121	34,083
Treatment x years	21	3,156	7,091
Error (c)	21	3,510	4,896

†Highly significant

*Significant

[1]The plots were not laid out in randomized order, but it is believed that the soil samples are representative of treatment rather than position. The average of the three check or no treatment plots were used in the analysis of variance.

Table 5. Changes in Phosphorus Content of Surface Soil 0 to 7 Inches Deep in Variously Treated Plots from 1915 to 1939.

Plot and Treatment	% Phosphorus 1915	1922	1929	1939
Block 1				
140 O	.0667	.0667	.0645	.0620
141 N	.0690	.0685	.0690	.0625
142 P	.0695	.0685	.0715	.0700
143 K	.0680	.0720	.0740	.0645
144 O	.0675	.0625	.0620	.0610
145 NP	.0685	.0685	.0747	.0720
146 NK	.0760	.0760	.0700	.0695
147 PK	.0735	.0712	.0725	.0735
148 NPK	.0795	.0795	.0760	.0802
149 O	.0695	.0685	.0667	.0635
Block 2				
150 O	.0660	.0660	.0625	.0635
151 N	.0710	.0690	.0690	.0667
152 P	.0725	.0725	.0750	.0785
153 K	.0635	.0660	.0660	.0645
154 O	.0685	.0667	.0645	.0670
155 NP	.0697	.0737	.0735	.0755
156 NK	.0695	.0660	.0650	.0637
157 PK	.0697	.0710	.0725	.0735
158 NPK	.0695	.0710	.0695	.0720
159 O	.0650	.0622	.0620	.0600

Table 6. Changes in Phosphorus Content of Subsurface Soil 7 to 14 Inches Deep in Variously Treated Plots from 1915 to 1939.

Plot and Treatment	% Phosphorus 1915	1922	1929	1939
Block 1				
140 O	.0552	.0530	.0540	.0520
141 N	.0710	.0552	.0560	.0537
142 P	.0580	.0555	.0530	.0530
143 K	.0545	.0532	.0540	.0520
144 O	.0532	.0525	.0545	.0532
145 NP	.0595	.0575	.0602	.0565
164 NK	.0570	.0565	.0537	.0520
147 PK	.0580	.0570	.0990	.0550
148 NPK	.0625	.0575	.0590	.0582
149 O	.0565	.0595	.0595	.0565
Block 2				
150 O	.0602	.0570	.0590	.0550
151 N	.0587	.0610	.0605	.0560
152 P	.0555	.0592	.0590	.0587
153 K	.0560	.0535	.0565	.0560
154 O	.0587	.0530	.0590	.0530
155 NP	.0565	.0570	.0620	.0560
156 NK	.0515	.0552	.0570	.0530
157 PK	.0570	.0530	.0590	.0555
158 NPK	.0602	.0587	.0602	.0600
159 O	.0552	.0530	.0570	.0552

Table 7. A Comparison of the Calculated Amount of Phosphorus Removed by Crops With the Average Gain or Loss of Soil Phosphorus as Found by Chemical Analysis of Variously Treated Plots from 1915 to 1939, Expressed in Pounds per Acre.

Soil treatment	Phosphorus removed by crops	Gain or loss from surface soil	Gain or loss from subsurface soil	Total gain or loss from soil
O	119.4	–88	–46	–134
N	130.0	–108	–200	–308
P	155.7	+66	–18	+48
K	118.0	–24	–14	–38
NP	133.4	+94	–34	+60
NK	119.2	–124	–36	–160
PK	139.9	+38	–44	–6
NPK	134.0	+32	–46	–12

Table 8. Changes in Available Phosphorus Content of Surface Soil 0 to 7 Inches Deep in Variously Treated Plots from 1922 to 1939.

Plot and Treatment	Available phosphorus in parts per million		
Block 1	1922	1929	1939
140 O	32.4	36.0	27.0
141 N	35.2	45.6	25.6
142 P	50.0	76.8	58.6
143 K	39.2	67.6	28.0
144 O	33.6	37.6	28.6
145 NP	50.4	87.2	70.4
146 NK	31.6	43.0	33.0
147 KP	44.8	65.8	69.0
148 NPK	56.8	64.4	76.0
149 O	32.6	41.6	*
Block 2			
150 O	36.8	25.2	30.8
151 N	38.0	41.6	31.4
152 P	52.0	68.6	64.8
153 K	47.6	39.6	32.4
154 O	34.4	36.8	30.2
155 NP	*	*	*
156 NK	65.6	58.8	72.8
157 KP	33.6	32.6	38.4
158 NPK	54.4	76.8	64.8
159 O	68.0	58.0	59.6

*Sample not available

Table 9. Changes in Available Phosphorus Content of Subsurface Soil 7 to 14 Inches Deep in Variously Treated Plots from 1922 to 1939.

Plot and Treatment	Available phosphorus in parts per million		
Block 1	1922	1929	1939
140 O	24.0	32.4	23.6
141 N	22.8	38.0	21.0
142 P	30.8	35.6	26.5
143 K	30.0	38.0	24.5
144 O	22.8	38.4	23.3
145 NP	27.6	42.4	29.7
146 NK	25.2	33.0	29.5
147 KP	26.0	26.6	30.0
148 NPK	29.2	28.4	30.0
149 O	26.8	29.2	22.0
Block 2			
150 O	20.0	33.6	22.5
151 N	30.0	32.6	20.5
152 P	34.4	39.2	30.7
153 K	31.6	34.8	30.0
154 O	31.0	60.8	24.7
155 NP	*	*	*
156 NK	24.0	37.6	30.0
157 NP	23.6	26.0	22.0
158 NPK	33.0	28.0	32.0
159 O	29.6	34.8	33.5

*Sample not available

Table 10. Analysis of Variance of Total Soil Phosphorus Changes.

Source of variation	Degrees of freedom	Mean square for surface soil	Mean square for subsurface soil
Rep.	1	4,067	582
Years	3	239	2,767
Yrs. x reps. error (a)	3	751	2,324
N	1	4,508	6,301†
P	1	44,448*	5,311*
K	1	2,775	1,671
N x P	1	2,418	118
N x K	1	1,646	478
P x K	1	1,574	5,274*
N x P x K	1	70	2,082
Treat. x reps. error (b)	7	4,435	446
Treat. x yrs.	21	955†	66
Error (c)	21	244	986

*Significant
†Highly significant

Table 11. Changes in Organic Matter Content of Surface Soil 0 to 7 Inches Deep in Variously Treated Plots from 1915 to 1939.

Plot and Treatment	% Organic Matter			
Block 1	1915	1922	1929	1939
140 O	5.82	5.57	5.28	4.87
141 N	6.21	5.78	5.45	4.96
142 P	5.55	5.48	5.15	4.70
143 K	5.65	5.47	5.09	4.49
144 O	5.54	5.17	4.89	4.39
145 NP	5.35	5.17	5.77	4.41
146 NK	5.78	5.45	5.08	4.65
147 KP	5.73	5.30	4.74	4.66
148 NPK	6.36	5.84	5.83	5.27
149 O	6.18	5.82	5.74	5.16
Block 2				
150 O	6.16	6.12	5.94	5.58
151 N	6.52	6.37	6.14	5.70
152 P	6.48	6.35	6.13	5.89
153 K	5.90	5.79	5.64	5.43
154 O	5.92	5.74	5.52	5.16
155 NP	5.96	6.09	4.94	5.34
156 NK	5.96	5.82	5.71	5.16
157 KP	5.91	5.84	5.60	5.10
158 NPK	6.21	5.98	5.68	5.19
159 O	6.03	5.92	5.79	5.46

Table 12. Changes in Organic Matter Content of Subsurface Soil 7 to 14 Inches Deep in Variously Treated Plots from 1915 to 1939.

Plot and Treatment	% Organic Matter			
Block 1	1915	1922	1929	1939
140 O	3.01	2.95	2.79	2.59
141 N	3.10	3.15	3.14	2.91
142 P	2.89	3.09	2.71	2.78
143 K	2.81	2.93	2.52	2.44
144 O	2.63	2.86	2.73	2.48
145 NP	2.80	2.93	2.87	2.62
146 NK	2.94	3.06	3.14	2.77
147 KP	2.87	2.99	2.04	2.70
148 NPK	3.10	3.19	3.26	2.91
149 O	3.08	3.68	3.44	3.65
Block 2				
150 O	3.29	3.58	3.64	3.67
151 N	3.53	4.17	4.08	3.90
152 P	3.62	4.11	4.02	4.02
153 K	3.24	3.14	3.61	3.70
154 O	3.15	3.09	3.21	3.18
155 NP	3.11	3.63	3.52	3.31
156 NK	3.09	3.06	3.56	3.09
157 KP	3.04	3.03	3.34	3.00
158 NPK	3.36	3.08	3.58	3.53
159 O	3.13	3.25	3.75	3.49

Table 13. Analysis of Variance of Soil Organic Matter Changes.

Source of Variation	Degrees of freedom	Mean square for surface soil	Mean square for subsurface soil
Reps.	1	113,894,251	157,884,735
Years	3	79,342,444*	5,212,888
Years x reps. error (a)	3	3,400,201	5,734,868
N	1	5,057,438	3,076,078
P	1	710,441	119,284
K	1	10,918,897	21,030,249
N x P	1	1,332,578	5,824,378
N x K	1	9,024,765	2,611,860
P x K	1	15,851,340	2,790,153
N x P x K	1	36,070,541*	23,256,239
Treat. x reps. error (b)	7	5,733,293	6,876,817
Treat. x yrs.	21	1,665,345*	730,436
Error C	21	738,030	699,788

*Significant