EFFECT OF ALFALFA ON THE FERTILITY ELEMENTS OF THE SOIL IN COMPARISON WITH GRAIN CROPS¹

C. O. SWANSON AND W. L. LATSHAW

Kansas Agricultural Experiment Station

Received for publication July 7, 1919

INTRODUCTION

That continuous growing of grain crops decreases the fertility of the soil, and that the growing of legumes in a measure restores this fertility are facts well known to students of soil science. To what degree this takes place is not so well known.

Alfalfa is one of the important crops of Kansas, and was one of the first to be grown. Most of the work concerning the effect of legumes on soil nitrogen has been with red clover and legumes other than alfalfa. This is partly due to the fact that in those states and the countries where investigations have been conducted, alfalfa is not a common crop.

The main problem of the present investigation is this: When alfalfa has been grown continuously on a piece of land, and all the crop harvested as hay, how much nitrogen and organic matter has been added to the soil? Phosphorus and calcium were also included in the study.

There are in Kansas a large number of fields where alfalfa has been grown from 20 to 30 years and near by are others which are still in native sod and also some which have been cropped continuously to grain since the native sod was broken. It was thought that a study of the fertility of the cropped fields as compared with those still in native sod would give valuable information. It will be well to consider first the present status of knowledge on this subject.

HISTORICAL

That native legumes are important sources of nitrogen in the native soil has been shown by several investigators. Warren (10) in a study of the native vegetation of Kansas and Nebraska found that on the average there were 17 native legumes to the square yard. Most of them have enormous root systems. Warren attempted to ascertain the prevalence of nodules on different species and found large numbers on every one. Also he found that the native legumes were more abundant on the poorer soils. This appears

¹ This work was conducted in cooperation with the Department of Agronomy, and of Division of Extension who rendered valuable service in locating these fields.

to show that after the legumes have enriched the soil, other plants crowd them out. In pastures the legumes tend to disappear because they are so readily eaten by live stock.

Alway and Pinckney (2) found in four species of native legumes, an average nitrogen content of 2 per cent. They estimated that the natural growth of legumes could furnish 10 pounds of nitrogen per acre annually.

According to Russel, a plat on Broadbalk field, Rothamstead, which was not cropped after 1882, gained 91.7 pounds of nitrogen per acre per annum. This plot contained 3.32 per cent CaCO_3 . Another plat which contained only 0.16 per cent CaCO_3 , gained 60 pounds of nitrogen per acre per annum. These amounts are figured to the depth of 27 inches (5). On Doctor Gilbert's meadow which was laid down to grass in 1856, and mowed annually, the amount of nitrogen was doubled in the top 9 inches in a little over 50 years (5).

Russel (4) mentions the classic instance of the restoration of the nitrogen content of the soil of the Schultz-Lupitz estate in Germany as an example, of the power of legumes to restore nitrogen to worn-out soil. This estate was once a barren sand. Lime and fertilizers containing phosphorus and potassium were used but no nitrogenous manures. The land was cropped alternately to lupines and cereals, the former being either plowed under or fed. The barren sand after a time became a rich soil capable of producing a large variety of crops. As shown by Russel the enrichment in nitrogen of soils by legumes is dependent upon available phosphorus and potassium. Thus in experiments at the Rothamstead station there was a large increase in the nitrogen content of soils in which clover was grown in rotation with other crops and to which potash and superphosphates but no nitrogenous manures had been added. There was a loss in nitrogen with the same cropping when no potash or superphosphates were applied. As the experiments were conducted over twenty years the results are no doubt significant.

Shutt (6) found that after 22 years of cultivation a prairie soil of Western Canada had lost a total of 2190 pounds of nitrogen per acre in the top 8 inches. Of this only 700 pounds were contained in the crops removed from the soil. Snyder (7) determined the loss of nitrogen in the soil of a number of typical Minnesota farms in a 10-year period. "The loss from grain farms was from 3 to 5 times the amount removed by the crops. This loss was attributed to the rapid decay of humus and the liberation of nitrogen." The nitrogen content in all these soils was high. Whitson, Stoddart and McLeod (12) collected a number of samples of both cropped and virgin soil from Wisconsin farms. The average nitrogen content of the cropped soil was 0.107 per cent and of the virgin soil 0.170 per cent, showing a loss of over one-third the original stock of nitrogen. These authors also estimated the amount of nitrogen removed by crops and that added by manure and clover. The nitrogen not accounted for by crop removal after correcting for that added in the manure and the clover, was assumed to be lost by leaching and denitrification.

In 6 of the 21 cases, the difference in the amount of nitrogen in the virgin soil and in the cropped soil was not enough to account for the nitrogen which had been removed in the crop. It was suggested that this difference was accounted for by the fixation of nitrogen by soil bacteria. The average amount lost by leaching and denitrification amounted to only 22.3 per cent of that removed by the crops. In clay soils more than four-fifths of the total loss of nitrogen was removed by crops.

In continuing these studies, the authors (13) found that the largest losses of nitrogen occurred in those soils which have a rather large per cent of total nitrogen. In 16 of the 21 cases in which the virgin soil contained 0.2 per cent of nitrogen or over, the loss above that removed by crop exceeded 500 pounds per acre. In 21 of 26 cases where the per cent of nitrogen in the virgin soil was less than 0.2 per cent, the loss was less than 500 pounds per acre. The loss from manured soil was greater than where soils were not manured.

Alway (1) concluded that in the soils of Nebraska, the only constituents that have declined appreciably under cultivation are nitrogen and total organic matter. Whitson and Stoddart (11) found a decrease in the phosphorus content in virgin soil. They found that the average content of phosphoric acid, expressed as P_2O_5 was 0.185 per cent and in nine adjoining cropped soils it was 0.120 per cent, indicating a loss of one-third of the original stock of phosphorus.

It appears that cultivating the soil does not always cause a decrease of nitrogen. Stewart (8) analyzed a number of Utah soils and found an average of 2055 pounds of nitrogen per acre to a depth of 12 inches in soil that had been cropped to wheat, as compared with 2009 pounds in fields that had been cropped to alfalfa and 1984 pounds in virgin soil.

Stewart explains these results by a difference in the composition of the virgin soil, an increase in nitrogen in the cultivated soils due to azotobacter and to a rise of nitrogen from the subsoil by deep roots.

That crop production may be increased after the growth of alfalfa even if the stock of nitrogen has not been materially increased, is shown by an experiment reported by Lyon and Bizzell (3).

Alfalfa and timothy were grown for 6 years on adjoining plats. On plowing up they were planted to corn the first year and oats the second. The yield of corn on the alfalfa plat was 63 bushels per acre, and on the timothy plat 47 bushels per acre. The oats yielded 26 bushels on the alfalfa plat and 27 on the timothy plat. Analyses of the soils from the two plats showed that the alfalfa plat contained not to exceed 0.01 per cent more nitrogen than the soil from the timothy plat. This would amount to 250 pounds per acre if the soil to the depth of 8 inches is assumed to weigh 2,500,000 pounds.

Very little work has been done relating to the effect of legumes on the mineral elements of the soil. Certain work has shown that some elements, particularly phosphorus, have decreased. Other work fails to show any appreciable change. This is partly due to the inherent difficulties of the

TABLE 1
Analysis of soils in virgin sod, fields cropped to alfalfa and of fields cropped to grain in Kansas

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED	LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
				Nitrogen	Phosphorus	Calcium	Organic carbon	Inorganic carbon
Humid section								
inches								
<i>Leavenworth County</i> N. W. 10 of N. W. 40 of N. E. $\frac{1}{4}$ Sec. 35. T. 10 S. R. 22 E. of 6 p. m.	Alfalfa 8 years. Blue Grass 10 years before alfalfa. Brown silt loam.	Soil 0-7	1316.1	per cent 0.163	per cent 0.043	per cent 0.530	per cent 1.610	
		Subsurface 7-20	1316.2	0.094	0.046	0.480	0.920	
		Subsoil 20-40	1316.3	0.061	0.049	0.640	0.360	
		Subsoil 40-80	1316.4	0.040	0.035	0.610	0.190	0.050
N. E. 10 of S. W. 40 of S. E. $\frac{1}{4}$ sec. 26. Twp. 10 S. R. 22 E. of 6 p.m.	Cropped to wheat. Well farmed. Brown silt loam.	Soil 0-7	1317.1	0.174	0.048	0.520	1.870	
		Subsurface 7-20	1317.2	0.139	0.041	0.500	1.280	0.070
		Subsoil 20-40	1317.3	0.084	0.034	0.610	0.100	
		Subsoil 40-80	1317.4	0.052	0.044	0.680	0.070	0.040
S. W. 10 of N. E. 40 of N. E. $\frac{1}{4}$ sec. 15. Twp. 9 S. R. 21 E. of 6 p.m.	Alfalfa 14 years. Before that corn and wheat. Brown silt loam.	Soil 0-7	1318.1	0.222	0.052	0.580	2.500	
		Subsurface 7-20	1318.2	0.177	0.043	0.480	2.180	
		Subsoil 20-40	1318.3	0.121	0.074	0.590	1.640	
		Subsoil 40-80	1318.4	lost				
S. E. 10 of N. E. 40 of N. E. $\frac{1}{4}$ sec. 5. Twp. 9 S. R. 21 E. of 6 p.m.	Native meadow. Brown silt loam.	Subsoil 80-120	1318.5	0.059	0.042	0.420	0.120	
		Soil 0-7	1319.1	0.296	0.061	0.630	3.760	
		Subsurface 7-20	1319.2	0.225	0.057	0.600	2.540	
		Subsoil 20-40	1319.3	0.144	0.056	0.630	1.120	0.100
		Subsoil 40-80	1319.4	0.082	0.062	0.740	0.260	0.100
		Subsoil 80-100	1319.5	0.085	0.076	0.540	0.200	0.100

<i>Brown County</i>	N. E. 10 of N. W. 40 of S. E. $\frac{1}{4}$ sec. 34. Twp. 1 N. R. 15 E. of 6 p.m.	Soil	0-7	1768.1	0.211	0.063	0.770	2.280	0.770
		Subsurface	7-20	1768.2	0.142	0.055	0.680	1.540	0.680
		Subsoil	20-40	1768.3	0.062	0.059	0.760	0.400	0.760
		Subsoil	40-80	1768.4	0.031	0.066	0.810	0.060	0.810
	S. E. 10 of S. E. 40 of S. E. $\frac{1}{4}$ sec. 28. Twp. 1 N. R. 15 E. of 6 p.m.	Soil	0-7	1770.1	0.228	0.061	0.620	2.860	
		Subsurface	7-20	1770.2	0.133	0.051	0.610	1.450	
		Subsoil	20-40	1770.3	0.073	0.051	0.710	0.680	
		Subsoil	40-80	1770.4	0.047	0.049	0.710	0.310	
	S. W. 10 of S. E. 40 of N. W. $\frac{1}{4}$ sec. 34. Twp. 1. N. R. 15. E. of 6 p.m.	Soil	0-7	1769.1	0.160	0.048	0.610	1.940	
		Subsurface	7-20	1769.2	0.135	0.048	0.660	1.510	
		Subsoil	20-40	1769.3	0.066	0.053	0.710	0.610	
		Subsoil	40-80	1769.4	0.031	0.066	0.860	0.096	
<i>Nemaha County</i>	N. W. 10 of S. E. 40 of S. E. $\frac{1}{4}$ sec. 8. Twp. 5 S. R. 14. E. of 6 p.m.	Soil	0-7	1765.1	0.170	0.039	0.660	1.690	
		Subsurface	7-20	1765.2	0.080	0.031	0.700	0.900	
		Subsoil	20-40	1765.3	0.032	0.049	2.000	0.230	0.280
		Subsoil	40-80	1765.4	0.008	0.061	5.280	1.490	
	N. W. 10 of S. E. 40 of S. E. $\frac{1}{4}$ sec. 8. Twp. 5 S. R. 14. E. of 6 p.m.	Soil	0-7	1766.1	0.102	0.040	0.860	1.130	0.030
		Subsurface	7-20	1766.2	0.055	0.044	2.890	0.980	0.620
		Subsoil	20-40	1766.3	0.024	0.050	7.400	1.350	0.960
		Subsoil	40-80	1766.4	0.005	0.059	6.400	0.050	1.650
	S. E. 10 of N. E. 40 of N. E. $\frac{1}{4}$ sec. 17. Twp. 5 E. R. 14. E. of 6 p.m.	Soil	0-7	1767.1	0.181	0.038	0.840	1.970	0.050
		Subsurface	7-20	1767.2	0.085	0.042	1.860	0.900	0.240
		Subsoil	20-40	1767.3	0.028	0.049	7.000	0.460	1.940
		Subsoil	40-80	1767.4	0.008	0.058	6.810	0.280	1.680

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED <i>inches</i>	LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
				Nitrogen	Phosphorus	Calcium	Organic carbon	Inorganic carbon
				<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
<i>Montgomery County</i> S. E. 10 of S. W. 40 of N. W. ¼ sec. 1. Twp. 33 S. R. 14 E. of 6 p.m.	Alfalfa 13 years. Oswego silt loam.	Soil 0-7	1294.1	0.131	0.036	0.429	2.070	
		Subsurface 7-20	1294.2	0.106	0.022	0.485	1.350	
		Subsoil a 20-40	1294.3	0.054	0.029	0.506	0.800	
		Subsoil b 40-80	1294.4	0.031	0.032	0.712	0.520	0.020
		Subsoil c 80-120	1294.5	0.045	0.051	0.774	0.400	0.030
N. E. 10 of N. W. 40 of S. E. ¼ sec. 1. Twp. 33 S. R. 1 E. of 6 p.m.	Native meadow. Oswego silt loam. To be compared with 1294. This land lies a little lower than 1294 and 1295.	Soil 0-7	1296.1	0.186	0.046	0.580	2.590	
		Subsurface 7-20	1296.2	0.114	0.032	0.630	1.640	
		Subsoil a 20-40	1296.3	0.067	0.037	0.530	0.910	
		Subsoil b 40-72	1296.4	0.024	0.056	0.130	0.350	0.160
S. E. 10 of S. W. 40 of N. W. ¼ sec. 1. Twp. 33 S. R. 14 E. of 6 p.m.	Kafir, corn, and grain for about 35 years. Oswego silt loam. To be compared with 1294.	Soil 0-7	1295.1	0.110	0.034	0.510	1.730	
		Subsurface 7-20	1295.2	0.094	0.028	0.570	1.250	
		Subsoil a 20-40	1295.3	0.050	0.025	0.640	0.710	0.010
		Subsoil b 40-80	1295.4	0.039	0.022	1.010	0.320	0.110
		Subsoil c 80-120	1295.5	0.049	0.055	0.750	0.260	0.030
S. E. 10 of N. E. 40 of S. E. ¼ sec. 13. Twp. 33 S. R. 16 E. of 6 p.m.	Alfalfa 10 years. Oswego silt loam.	Soil 0-7	1297.1	0.168	0.043	1.410	2.320	0.160
		Subsurface 7-20	1297.2	0.087	0.034	1.190	1.150	0.070
		Subsoil a 20-40	1297.3	0.038	0.023	2.170	0.700	0.430
		Subsoil b 40-72	1297.4	0.028	0.027	1.740	0.460	0.310
S. E. 10 of N. E. 40 of S. E. ¼ sec. 13. Twp. 33 S. R. 16 E. of 6 p.m.	General grain and corn farming. Oswego silt loam. To be compared with 1297.	Soil 0-7	1298.1	0.135	0.038	1.050	2.050	0.060
		Subsurface 7-20	1298.2	0.076	0.016	1.930	1.130	0.290
		Subsoil a 20-40	1298.3	0.043	0.026	2.460	0.700	0.500
		Subsoil b 40-72	1298.4	0.026	0.028	1.330	0.410	0.170

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED <i>inches</i>	LABORATORY NUMBER	PLANT-FOOD ELEMENT				
				Nitrogen <i>per cent</i>	Phosphorus <i>per cent</i>	Calcium <i>per cent</i>	Organic carbon <i>per cent</i>	Inorganic carbon <i>per cent</i>
<i>Harvey County</i> S. E. 10 of N. E. 40 of N. W. $\frac{1}{4}$ sec. 23. Twp. 24 S. R. 2 W. of 6 p.m.	Wheat and corn about 14 years then alfalfa 11 years. Dark gray fine sandy loam.	Soil 0-7	1890.1	0.161	0.041	0.570	1.910	
		Subsurface 7-20	1890.2	0.087	0.032	0.450	0.720	
		Subsoil a 20-40	1890.3	0.045	0.023	0.400	0.410	0.050
		Subsoil b 40-80	1890.4	0.036	0.055	0.300	0.160	
S. E. 10 of N. E. 40 of N. W. $\frac{1}{4}$ sec. 23. Twp. 24 S. R. 2. W. of 6 p.m.	Native bluestem pasture. Fine sandy loam. To be compared with 1890.	Soil 0-7	1891.1	0.189	0.056	0.470	2.280	
		Subsurface 7-20	1891.2	0.101	0.033	0.350	1.010	
		Subsoil a 20-40	1891.3	0.049	0.026	0.460	0.400	
		Subsoil b 40-80	1891.4	0.029	0.026	0.400	0.060	
S. W. 10 of N. W. 40 of N. W. $\frac{1}{4}$ sec. 23. Twp. 24 S. R. 2. W. of 6 p.m.	Wheat and corn 25 years. Fine sandy loam. To be compared with 1890.	Soil 0-7	1892.1	0.140	0.053	0.600	1.120	
		Subsurface 7-20	1892.2	0.107	0.045	0.670	0.980	
		Subsoil a 20-40	1892.3	0.072	0.043	0.560	0.490	
		Subsoil b 40-80	1892.4	0.056	0.032	0.560	0.410	
S. W. 10 of S. E. 40 of S. E. $\frac{1}{4}$ sec. 2. Twp. 22 S. R. 2. W. of 6 p.m.	Corn and wheat 30 years, then alfalfa 14 years. Heavy silt loam.	Soil 0-7	1893.1	0.200	0.043	0.530	2.310	
		Subsurface 7-20	1893.2	0.097	0.034	0.720	1.630	
		Subsoil 20-36	1893.3	0.075	0.029	1.300	0.800	0.060
N. W. 10 of S. E. 40 of S. E. $\frac{1}{4}$ sec. 2. Twp. 22 S. R. 2. W. of 6 p.m.	Native pasture. Heavy silt loam.	Soil 0-7	1894.1	0.222	0.045	0.620	2.660	
		Subsurface 7-20	1894.2	0.122	0.047	0.740	1.370	
		Subsoil 20-40	1894.3	0.057	0.046	1.030	0.790	0.030
S. E. 10 of the N. W. 40 of S. E. $\frac{1}{4}$ sec. 2. Twp. 22 S. R. 2. W. of 6 p.m.	Farmed to corn and wheat. Heavy silt loam.	Soil 0-7	1895.1	0.124	0.036	0.570	1.230	
		Subsurface 7-20	1895.2	0.099	0.036	0.680	0.980	
		Subsoil 20-40	1895.3	0.062	0.048	0.990	0.500	0.070

<i>Dickinson County</i> S. E. 10 of S. E. 40 of N. W. ¼ sec. 30. Twp. 12 S. R. 4. E. of 6 p.m.	Alfalfa 15 to 20 years. Os- age silt loam.	Soil 0-7 Subsurface 7-20 Subsoil a 20-40 Subsoil b 40-80	1874.1	0.168	0.048	0.730	1.820	0.0090
			1874.2	0.117	0.045	0.780	1.200	
			1874.3	0.084	0.047	0.980	0.854	0.0059
			1874.4	0.051	0.050	1.960	0.350	0.2000
N. E. 10 of S. E. 40 of S. E. ¼ sec. 19. Twp. 12 S. R. 4. E. of 6 p.m.	Native bluestem. Osage loam. To be compared with 1874.	Soil 0-7 Subsurface 7-20 Subsoil a 20-40 Subsoil b 40-80	1876.1	0.204	0.048	0.940	2.460	
			1876.2	0.134	0.042	0.760	1.610	0.0059
			1876.3	0.109	0.041	0.880	1.120	
			1876.4	0.062	0.042	1.020	0.360	
S. W. 10 of S. W. 40 of N. W. ¼ sec. 29. Twp. 12 S. R. 4. E. of 6 p.m.	Farmed to grains, mostly corn for 33 years. Osage silt loam. To be com- pared with 1874.	Soil 0-7 Subsurface 7-20 Subsoil a 20-40 Subsoil b 40-80	1875.1	0.140	0.057	1.060	1.820	0.0200
			1875.2	0.101	0.047	1.070	1.070	0.0046
			1875.3	0.084	0.062	1.570	0.960	0.0600
			1875.4	0.062	0.063	2.000	0.940	0.2600
N. E. 10 of N. W. 40 of N. E. ¼ sec. 8. Twp. 12 S. R. 4. E. of 6 p.m.	Alfalfa 15-20 years. Brown silt loam.	Soil 0-7 Subsurface 7-20 Subsoil a 20-40 Subsoil b 40-80	1877.1	0.179	0.044	0.880	2.000	
			1877.2	0.134	0.037	0.980	1.260	
			1877.3	0.077	0.040	0.940	0.795	0.0046
			1877.4	0.060	0.044	1.060	0.320	0.0400
N. W. 10 of N. E. 40 of N. E. ¼ sec. 8. Twp. 12 S. R. 4. E. of 6 p.m.	Native pasture. Dark brown silt loam. To be compared with 1877.	Soil 0-7 Subsurface 7-20 Subsoil 20-40 Subsoil 40-80	1879.1	0.204	0.061	0.890	2.630	
			1879.2	0.131	0.043	0.890	1.430	
			1879.3	0.080	0.040	1.040	0.750	0.0400
			1879.4	0.066	0.046	0.930	0.680	
S. E. 10 of N. W. 40 of N. E. ¼ sec. 8. Twp. 12 S. R. 4. E. of 6 p.m.	Corn, wheat, oats for 40 years. Brown silt loam. To be compared with 1877.	Soil 0-7 Subsurface 7-20 Subsoil a 20-40 Subsoil b 40-80	1878.1	0.163	0.048	0.970	2.006	0.0036
			1878.2	0.120	0.046	1.010	1.185	0.0046
			1878.3	0.070	0.041	1.220	0.640	0.0400
			1878.4	0.069	0.041	0.910	0.380	0.0068

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED	LABORATORY NUMBER	PLANT-FOOD ELEMENTS			
				Nitrogen per cent	Phosphorus per cent	Calcium per cent	Inorganic carbon per cent
<i>Dickinson County—Continued</i> S. E. 10 of S. E. 40 of S. E. ¼ sec. Twp. 14 S. R. 3. E. of 6 p.m.	Alfalfa 25 years. Broken 3 years. Reseeded to alfalfa. Dark gray silty clay loam. This was at times pastured by hogs.	inches Soil 0-7 Subsurface 7-20 Subsoil a 20-40 Subsoil b 40-80	1880.1 1880.2 1880.3 1880.4	0.201	0.091	0.890	2.510
				0.130	0.043	0.970	1.470
				0.083	0.037	1.220	0.770
				0.066	0.041	1.170	0.637
N. E. 10 of N. E. 40 of N. E. ¼ sec. 24. Twp. 14 S. R. 3. E. of 6 p.m.	Native bluestem pasture. Dark gray, silty clay loam. To be compared with 1880.	inches Soil 0-7 Subsurface 7-20 Subsoil 20-40 Subsoil 40-80	1881.1 1881.2 1881.3 1881.4	0.209	0.087	0.920	3.030
				0.136	0.042	0.990	1.490
				0.081	0.038	1.040	0.830
				0.050	0.045	1.220	0.260
S. W. 10 of S. W. 40 of N. W. ¼ sec. 18. Twp. 14 S. R. 4. E. of 6 p.m.	Farmed mostly to wheat, some corn and kafir, for 35 years. Dark gray silty clay loam. To be compared with 1880.	inches Soil 0-7 Subsurface 7-20 Subsoil a 20-40 Subsoil b 40-80	1883.1 1883.2 1883.3 1883.4	0.155	0.045	0.890	2.060
				0.123	0.038	0.860	1.590
				0.082	0.040	0.920	0.840
				0.061	0.037	0.920	0.500
S. E. 10 of S. E. 40 of N. E. ¼ sec. 13. Twp. 14 S. R. 3. E. of 6 p.m.	Alfalfa about 5 years. Dark gray, probably Summit silty clay loam.	inches Soil 0-7 Subsurface 7-20 Subsoil 20-40	1882.1 1882.2 1882.3	0.157	0.052	0.840	2.270
				0.113	0.051	0.920	1.400
				0.081	0.048	1.040	0.840

Sub-humid section								
Mitchell County								
S. W. 10 of the N. E. 40 of N. W. $\frac{1}{4}$ Sec. 20, Twp. 7 S. R. 6. W. of 6 P.M.	Alfalfa 24 years, very dark gray silty, clay loam; bottom land.	Soil 0-7	1771.1	0.204	0.075	3.180	2.420	0.470
		Subsurface 7-20	1771.2	0.098	0.068	3.910	1.170	0.660
		Subsoil a 20-40	1771.3	0.034	0.050	5.580	0.810	0.980
		Subsoil b 40-80	1771.4	0.020	0.053	4.680	1.190	0.096
S. E. 10 of the N. W. 40 of N. E. $\frac{1}{4}$ sec. 20, Twp. 7 S. R. 6. W. of 6 P.M.	Corn and wheat mostly corn for 30 years, very dark gray, silty clay loam, bottom land.	Soil 0-7	1772.1	0.180	0.072	2.290	2.180	0.270
		Subsurface 7-20	1772.2	0.093	0.055	4.320	1.010	0.910
		Subsoil a 20-40	1772.3	0.033	0.063	5.680	0.500	1.270
		Subsoil b 40-80	1772.4	0.017	0.054	5.170	0.200	1.140
S. W. 10 of the S. E. 40 of N. E. $\frac{1}{4}$ Sec. 20, Twp. 7 S. R. 6. W. of 6 P.M.	Native pasture, gray on dark yellow; a loam soil; upland.	Soil 0-7	1773.1	0.238	0.063	1.400	3.140	0.048
		Subsurface 7-20	1773.2	0.140	0.062	1.750	1.590	0.140
		Subsoil a 20-40	1773.3	0.067	0.056	4.350	0.790	0.930
		Subsoil b 40-80	1773.4	0.062	0.045	2.300	0.390	0.340
S. E. 10 of the S. W. 40 of N. E. $\frac{1}{4}$ Sec. 20, Twp. 7, S. R. 6. W. of 6 P.M.	Alfalfa 26 years, gray on dark yellow; a loam soil; upland.	Soil 0-7	1774.1	0.269	0.069	2.380	3.230	0.310
		Subsurface 7-20	1774.2	0.101	0.059	5.930	1.390	1.530
		Subsoil a 20-40	1774.3	0.090	0.059	4.150	1.290	0.850
		Subsoil b 40-80	1774.4	0.045	0.057	3.550	0.440	0.750
In center of 10 of the N. E. 40 of N. W. $\frac{1}{4}$ Sec. 21, Twp. 7 S. R. 6. W. of 6 P.M.	Native pasture, gray on yellow, silt loam; upland. Compare with 1775.	Soil 0-7	1776.1	0.290	0.105	3.370	2.890	0.380
		Subsurface 7-20	1776.2	0.119	0.083	4.900	1.420	1.110
In center of N. E. 40 of N. W. $\frac{1}{4}$ Sec. 21, Twp. 7 S. R. 6 W. of 6 P.M.	Corn and wheat 23 years, gray on yellow, a silt loam; upland.	Soil 0-7	1775.1	0.186	0.096	4.000	2.090	0.790
		Subsurface 7-20	1775.2	0.084	0.071	4.090	1.060	0.920

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED inches	LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
				Nitrogen per cent	Phosphorus per cent	Calcium per cent	Organic carbon per cent	Inorganic carbon per cent
<i>Mitchell County—Continued</i> N. E. 10 of the N. W. 40 of S. E. ¼ Sec. 6, Twp. 6 S. R. 10. W. of 6 P.M.	Alfalfa 23 years, gray, Lincoln silt loam, bottom land.	Soil 0-7	1779.1	0.160	0.079	1.300	1.260	0.070
		Subsurface 7-20	1779.2	0.068	0.059	3.260	0.830	0.590
		Subsoil a 20-40	1779.3	0.062	0.058	2.610	0.730	0.400
		Subsoil b 40-72	1779.4	0.048	0.066	1.200	0.630	0.080
S. E. 10 of the N. W. 40 of N. W. ¼ Sec. 6, Twp. 6 S. R. 10. W. of 6 P.M.	Native pasture, gray Lincoln silt loam; bottom land. Compare with 1779.	Soil 0-7	1778.1	0.180	0.068	1.030	1.870	0.040
		Subsurface 7-20	1778.2	0.069	0.056	2.180	0.750	0.380
		Subsoil a 20-40	1778.3	0.048	0.066	1.650	0.390	0.130
		Subsoil b 40-80	1778.4	0.026	0.065	2.710	0.260	0.120
S. E. 10 of the N. W. 40 of N. W. ¼ Sec. 6, Twp. 6 S. R. 10. W. of 6 P.M.	Corn and wheat 30 years gray Lincoln silt loam, bottom land. Compare with 1778.	Soil 0-7	1777.1	0.129	0.065	1.500	1.420	0.120
		Subsurface 7-20	1777.2	0.058	0.060	3.130	0.670	0.670
		Subsoil a 20-40	1777.3	0.069	0.064	2.830	0.360	0.490
		Subsoil b 40-80	1777.4	0.064	0.064	1.800	0.950	0.150
S. W. 10 of N. W. 40 of N. W. ¼ Sec. 6, Twp. 6 S. R. 10. W. of 6 P.M.	Wheat and corn 30 years, gray on yellow, silt loam, upland.	Soil 0-7	1781.1	0.115	0.057	0.950	1.340	
		Subsurface 7-20	1781.2	0.046	0.071	2.690	1.230	
N. E. 10 of N. E. 40 of S. E. ¼ Sec. 1, Twp. 6 S. R. 11. W. of 6 P.M.	Native pasture yellow on gray, silt loam, upland.	Soil 0-7	1780.1	0.153	0.055	0.950	1.780	
		Subsurface 7-20	1780.2	0.082	0.058	0.950	0.920	

<i>Osborne County</i>		Soil	1783.1 1783.2 1783.3 1783.4	0.184 0.101 0.062 0.039	0.060 0.059 0.060 0.060	1.100 1.400 1.300 1.400	2.300 1.350 0.660 0.360	0.080 0.060 0.090
N. W. 40 of the S. W. $\frac{1}{4}$ Sec. 1, Twp. 8 S. R. 13. W. of 6 P.M.	Alfalfa 20 years, dark gray Lincoln silt loam. The soil had been plowed the spring before sampling.	Soil	0-7					
		Subsurface	7-20					
		Subsoil a	20-40					
		Subsoil b	40-80					
S. E. 40 of the S. W. $\frac{1}{4}$ Sec. 1, Twp. 8 S. R. 13. W. of 6 P.M.	Native pasture, dark gray Lincoln silt loam.	Soil	0-7	0.250	0.068	1.100	3.220	0.090
		Subsurface	7-20	0.120	0.063	1.250	1.610	0.560
		Subsoil a	20-40	0.066	0.066	3.030	0.780	0.560
		Subsoil b	40-80	0.038	0.076	2.950	0.510	0.560
N. W. 40 of the N. W. $\frac{1}{4}$ Sec. 12, Twp. 8 S. R. 13. W. of 6 P.M.	Farmed to corn and wheat 40 years, dark gray Lincoln silt loam.	Soil	0-7	0.134	0.067	1.050	1.660	0.120
		Subsurface	7-20	0.096	0.066	1.500	1.250	0.840
		Subsoil a	20-40	0.050	0.068	3.910	0.530	0.760
		Subsoil b	40-80	0.033	0.067	3.810	0.540	0.070
N. E. 40 of the N. E. $\frac{1}{4}$ Sec. 12, Twp. 8 S. R. 13. W. of 6 P.M.	Native pasture and meadow, type same as 1785.	Soil	0-7	0.232	0.106	1.200	3.710	0.058
		Subsurface	7-20	0.120	0.071	1.200	1.440	
		Soil	0-7	0.211	0.103	1.350	2.650	0.050
		Subsurface	7-20	0.149	0.080	1.150	1.730	0.050
N. W. 40 of S. W. $\frac{1}{4}$ Sec. 9, Twp. 6 S. R. 13. W. of 6 P.M.	Alfalfa 33 years dark gray Lincoln silt loam.	Soil	0-7	0.196	0.070	2.200	2.220	0.320
		Subsurface	7-20	0.095	0.085	3.510	1.330	0.650
		Subsoil	20-40	0.084	0.077	2.100	1.180	0.280
		Soil	0-7	0.220	0.100	2.030	3.110	0.240
N. W. 40 of the S. W. $\frac{1}{4}$ Sec. 9, Twp. 6 S. R. 13. W. of 6 P.M.	Native timber, otherwise the same as 1787.	Subsurface	7-20	0.115	0.098	2.780	1.340	0.520
		Subsoil	20-36	0.092	0.087	3.830	1.090	0.890
		Soil	0-7	0.143	0.090	2.330	1.770	0.350
		Subsurface	7-20	0.078	0.084	3.580	1.020	0.680
N. E. 40 of S. W. $\frac{1}{4}$ Sec. 9, Twp. 6 S. R. 13. W. of 6 P.M.	Corn and wheat for 35 years, otherwise same as 1787.	Subsoil	20-40	0.046	0.090	4.290	0.650	0.930

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED <i>inches</i>	LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
				Nitrogen <i>per cent</i>	Phosphorus <i>per cent</i>	Calcium <i>per cent</i>	Organic carbon <i>per cent</i>	Inorganic carbon <i>per cent</i>
<i>Barton County</i> N. E. 10 of S. W. 40 of N. E. ¼ Sec. 17, Twp. 20 S. R. 13 W. of 6 P. M.	Alfalfa 15 years before that wheat and corn 15 years, dark gray Greensburg sandy loam.	Soil 0-7	1884.1	0.159	0.054	0.580	1.910	
		Subsurface 7-20	1884.2	0.058	0.054	0.730	0.570	
		Subsoil a 20-40	1884.3	0.037	0.051	1.340	0.480	0.170
		Subsoil b 40-80	1884.4	0.029	0.048	5.900	0.760	1.470
N. E. 10 of S. W. 40 of N. E. ¼ Sec. 17, Twp. 20 S. R. 13 W. of 6 P. M.	Buffalo grass pasture, dark Greensburg sandy loam.	Soil 0-7	1885.1	0.106	0.052	0.720	1.280	
		Subsurface 7-20	1885.2	0.050	0.033	0.940	0.390	0.040
		Subsoil a 20-40	1885.3	0.028	0.057	0.950	0.200	0.070
		Subsoil b 40-80	1885.4	0.021	0.041	5.580	0.130	1.370
S. E. 10 of S. W. 40 of N. E. ¼ Sec. 17, Twp. 20 S. R. 13 W. of 6 P. M.	Wheat and corn 30 years, dark gray Greensburg sandy loam.	Soil 0-7	1886.1	0.137	0.047	1.030	1.680	0.030
		Subsurface 7-20	1886.2	0.076	0.052	1.040	0.940	0.030
		Subsoil a 20-40	1886.3	0.038	0.050	4.230	0.660	1.020
		Subsoil b 40-80	1886.4	0.022	0.042	21.500	0.750	5.930
<i>Pawnee County</i> S. E. 10 of N. W. 40 of N. W. ¼ Sec. 7, Twp. 22 S. R. 16 W. of 6 P. M.	Alfalfa 28 years, dark gray Arkansas fine sandy loam.	Soil 0-7	1887.1	0.221	0.053	1.200	2.560	0.070
		Subsurface 7-20	1887.2	0.122	0.052	1.640	1.610	0.150
		Subsoil a 20-40	1887.3	0.059	0.059	4.37	1.150	0.990
		Subsoil b 40-80	1887.4	0.017	0.058	3.860	0.420	0.870

S. E. 10 of N. W. 40 of N. W. 1/4 Sec. 7, Twp. 22 S. R. 16 W. of 6 P. M.	Soil	0-7	1888.1	0.214	0.059	1.000	2.530	
	Subsurface	7-20	1888.2	0.106	0.046	0.910	0.940	
	Subsoil a	20-40	1888.3	0.053	0.053	2.570	0.570	0.280
	Subsoil b	40-80	1888.4	0.014	0.054	2.820	0.280	0.700
S. E. 10 of S. W. 40 of S. W. 1/4 Sec. 6, Twp. 22 S. R. 16 W. of 6 P. M.	Soil	0-7	1889.1	0.201	0.093	0.950	2.110	0.005
	Subsurface	7-20	1889.2	0.113	0.058	0.980	1.390	0.051
	Subsoil a	20-40	1889.3	0.072	0.055	3.800	0.540	1.020
	Subsoil b	40-80	1889.4	0.060	0.058	4.640	1.010	1.020
Semi-arid section								
Ford County -10 of the S. E. 40 of S. W. 1/4 Sec. 27, Twp. 26 S. R. 25 W. of 6 P. M.	Soil	0-7	1310.1	0.210	0.082	1.710	2.080	0.260
	Subsurface	7-20	1310.2	0.085	0.058	2.660	0.610	0.550
	Subsoil a	20-40	1310.3	0.069	0.058	2.710	0.330	0.680
	Subsoil b	40-80	1310.4	0.075	0.044	1.970	0.600	0.290
-10 of the S. E. 40 of S. W. 1/4 Sec. 27, Twp. 26 S. R. 25 W. of 6 P. M.	Subsoil c	80-120	1310.5	0.046	0.055	2.080	0.290	0.370
	Soil	0-7	1311.1	0.171	0.079	1.580	3.600	0.160
	Subsurface	7-20	1311.2	0.108	0.033	1.930	0.970	0.300
	Subsoil a	20-40	1311.2	0.061	0.043	2.300	0.540	0.500
-10 of the S. E. 40 of S. W. 1/4 Sec. 27, Twp. 26 S. R. 25 W. of 6 P. M.	Subsoil b	40-80	1311.4	0.073	0.058	1.780	0.770	0.120
	Subsoil c	80-120	1311.5	0.039	0.040	2.440	0.250	0.430
	Soil	0-7	1312.1	0.136	0.075	1.980	1.820	0.280
	Subsurface	7-20	1312.2	0.079	0.056	2.870	0.910	0.560
Cultivated 30 years, principally forage crops. Compare with 1310.	Subsoil a	20-40	1312.3	0.057	0.064	2.450	0.860	0.420
	Subsoil b	40-80	1312.4	0.055	0.055	2.410	0.620	0.500
	Subsoil c	80-120	1312.5	0.051	0.052	1.920	0.480	0.340

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED	LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
				Nitrogen	Phosphorus	Calcium	Organic carbon	Inorganic carbon
		inches		per cent	per cent	per cent	per cent	per cent
<i>Ford County—Continued</i>								
N. W. 10 of the N. E. 40 of N. E. ¼ Sec. 36, Twp. 25 S. R. 25 W. of 6 P. M.	Alfalfa 10 years. Richland silt loam.	Soil	1313.1	0.156	0.082	0.970	1.660	
		Subsurface	1313.2	0.051	0.030	2.150	0.990	0.400
S. W. 10 of S. E. 40 of S. E. ¼ Sec. 25, S. R. 25 W. of 6 P. M.	Native pasture, dark gray. Compare with 1313.	Soil	1315.1	0.152			1.740	
		Subsurface	1315.2	0.089	0.043	0.930	0.690	0.060
N. W. 10 of the N. E. 40 of N. E. ¼ Sec. 36, Twp. 25 S. R. 25 W. of 6 P. M.	Cultivated 30 years. Compare with 1313.	Soil	1314.1	0.118	0.063	0.890	1.480	0.080
		Subsurface	1314.2	0.085	0.057	1.710	0.650	0.280
<i>Finney County</i>								
N. E. 10 of the N. E. 40 of S. E. ¼ Sec. 9, Twp. 22, S. R. 33 W. of 6 P. M.	Alfalfa, 20 years. Richland silt loam.	Soil	1299.1	0.168	0.076	0.930	1.610	
		Subsurface	1299.2	0.085	0.066	1.340	0.698	0.142
		Subsoil a	1299.3	0.047	0.054	6.030	0.498	1.282
		Subsoil b	1299.4	0.040	0.062	4.150	0.707	0.913
N. W. 10 of the N. W. 40 of S. W. ¼ Sec. 10, Twp. 22, S. R. 33 W. of 6 P. M.	Native range, Richland silt loam. Compare with 1299.	Soil	1300.1	0.137	0.077	0.920	1.940	
		Subsurface	1300.2	0.084	0.063	1.990	0.460	0.380
		Subsoil a	1300.3	0.038	0.056	5.670	0.300	0.980
		Subsoil b	1300.4	0.048	0.076	3.660	0.610	0.720
S. W. 10 of the S. W. 40 of S. W. ¼ Sec. 26, Twp. 23 S. R. 33 W. of 6 P. M.	Farmed to wheat, sorghum and kafir, 20 years. Richland silt loam. Compare with 1303.	Soil	1301.1	0.134	0.070	1.500	1.760	0.160
		Subsurface	1301.2	0.101	0.073	3.600	0.750	0.830
		Subsoil a	1301.3	0.058	0.064	5.350	0.540	1.200
		Subsoil b	1301.4	0.033	0.089	3.500	0.370	0.840
		Subsoil c	1301.5	0.028	0.076	2.730	0.430	0.530

	Soil	1303.1	1303.2	1303.3	1303.4	1303.5	0.200	0.085	3.030	1.930	0.680
N. E. 10 of the S. W. 40 of S. W. $\frac{1}{4}$ Sec. 26, Twp. 23, R. 33, W. of 6 P. M.	Alfalfa 27 years. Rich- land silt loam.	0-7	7-20	20-40	40-80	80-120	0.113	0.062	1.680	1.030	0.250
		Subsurface					0.067	0.067	5.500	0.790	0.970
		Subsoil a					0.035	0.061	4.280	0.490	0.920
		Subsoil b					0.015	0.065	3.000	0.160	0.560
		Subsoil c									
N. W. 10 of the N. W. 40 of N. W. $\frac{1}{4}$ Sec. 36, Twp. 23 S. R. 33 W. of 6 P. M.	Native Buffalo grass. Richland silt loam. Com- pare with 1303.	0-7	7-20	20-40	40-80	80-120	0.135	0.082	0.990	1.680	0.048
		Subsurface					0.086	0.061	2.090	0.670	0.340
		Subsoil a					0.050	0.055	2.900	0.470	0.600
		Subsoil b					0.034	0.084	1.630	0.130	0.160
		Subsoil c					0.028	0.063	1.200	0.050	0.050
N. W. 10 of the N. E. 40 of N. W. $\frac{1}{4}$ Sec. 11, Twp. 24 S. R. 33 W. of 6 P. M.	Alfalfa 27 years, Laurel sandy loam.	0-7	7-20	20-40	40-80		0.178	0.064	1.070	1.720	
		Subsurface					0.080	0.052	2.930	0.760	0.300
		Subsoil a					0.048	0.036	5.880	0.790	1.240
		Subsoil b					0.020	0.041	2.140	0.540	0.420
S. E. 10 of the S. W. 40 of S. W. $\frac{1}{4}$ Sec. 12, Twp. 24 S. R. 33 W. of 6 P. M.	Farmed about 27 years. Laurel sandy loam. Compare with 1304.	0-7	7-20	20-40	40-80		0.079	0.053	1.290	1.040	0.710
		Subsurface					0.057	0.048	1.400	0.690	0.200
		Subsoil a					0.039	0.043	3.540	0.750	0.690
		Subsoil b					0.012	0.040	1.750	0.390	0.380
N. W. 10 of the N. W. 40 of S. E. $\frac{1}{4}$ Sec. 7, Twp. 24 S. R. 32, W. of 6 P. M.	Alfalfa for 30 years, Finney sandy loam.	0-7	7-20	20-40	40-72		0.192	0.078	3.170	2.040	0.680
		Subsurface					0.082	0.041	1.520	0.830	0.230
		Subsoil a					0.040	0.060	3.480	0.670	0.630
		Subsoil b					0.010	0.043	1.350	0.100	0.290
N. W. 10 of the S. E. 40 of S. E. $\frac{1}{4}$ Sec. 7, Twp. 24, R. 32 W. of 6 P. M.	Native Buffalo grass pas- ture, laurel loam. Com- pare with 1306.	0-7	7-20	20-40	40-60		0.099	0.068	0.980	0.890	0.070
		Subsurface					0.052	0.052	2.810	0.300	0.620
		Subsoil a					0.048	0.058	5.180	0.370	1.200
		Subsoil b					0.028	0.039	5.400	0.230	1.510
N. W. 10 of the N. W. 40 of S. E. $\frac{1}{4}$ Sec. 7, Twp. 24 S. R. 32 W. of 6 P. M.	Sorghum, kafir and small grain for 30 years. Fin- ney sandy loam. Com- pare with 1306.	0-7	7-20	20-40	40-72		0.097	0.062	1.310	0.980	0.100
		Subsurface					0.066	0.050	3.280	0.680	0.730
		Subsoil a					0.036	0.063	5.780	0.920	1.320
		Subsoil b					0.010	0.044	0.740	0.020	0.120

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED <i>inches</i>	LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
				Nitrogen <i>per cent</i>	Phosphorus <i>per cent</i>	Calcium <i>per cent</i>	Organic carbon <i>per cent</i>	Inorganic carbon <i>per cent</i>
<i>Finney County—Continued</i> S. E. 10 of the N. E. 40 of the S. E. $\frac{1}{4}$ Sec. 15, Twp. 24 S. R. 33. W. of 6 P.M.	Alfalfa for 15 years, dark brown, very shallow, Laurel sandy loam.	Soil 0-7	1309.1	0.166	0.075	2.350	1.600	0.450
		Subsurface 7-20	1309.2	0.066	0.049	2.480	0.540	0.670
		Subsoil 20-36	1309.3	0.028	0.045	2.450	0.120	0.580
<i>Gore County</i> N. E. $\frac{1}{4}$ Sec. 29. Twp. 11, R. 26	Native pasture, Grama and Buffalo grass, Colby silt loam.	Soil 0-7	1797.1	0.154	0.084	1.080	1.840	
		Subsurface 7-20	1797.2	0.077	0.094	1.050	0.750	
N. E. $\frac{1}{4}$ Sec. 29. Twp. 11, R. 26.	Farmed 30 years, mostly wheat, Colby silt loam. Compare with 1797.	Soil 0-7	1796.1	0.128	0.105	1.000	1.350	
		Subsurface 7-20	1796.2	0.070	0.082	1.300	0.670	
N. W. 10 of the S. E. 40 of N. E. $\frac{1}{4}$ Sec. 12, Twp. 13 S. R. 28 W. of 6 P.M.	Buffalo grass, then alfalfa 15 years, loam bottom land.	Soil 0-7	1798.1	0.210	0.100	1.830	2.230	0.100
		Subsurface 7-20	1798.2	0.086	0.078	2.200	0.900	0.300
		Subsoil a 20-40	1798.3	0.039	0.082	3.560	0.400	0.830
		Subsoil b 40-72	1798.4	0.021	0.097	3.810	0.130	0.860
S. W. 10 of the S. E. 40 of N. E. $\frac{1}{4}$ Sec. 12, Twp. 13, S. R. 28, W. of 6 P.M.	Native grass, loam bottom land. Compare with 1798. This land was burned over occasionally.	Soil 0-7	1799.1	0.188	0.086	2.000	2.160	0.200
		Subsurface 7-20	1799.2	0.056	0.084	3.110	0.650	0.550
		Subsoil a 20-40	1799.3	0.036	0.077	3.110	0.300	0.670
		Subsoil b 40-72	1799.4	0.015	0.069	3.980	0.330	0.890
N. W. 10 of N. W. 40 of S. E. $\frac{1}{4}$ Sec. 13. Twp. 3 S. R. 28, W. of 6 P.M.	Grain 15 years, loam bottom land. Compare with 1798.	Soil 0-7	1801.1	0.121	0.090	1.750	1.210	0.120
		Subsurface 7-20	1801.2	0.063	0.086	3.780	0.590	0.800
		Subsoil a 20-40	1801.3	0.030	0.086	4.210	0.180	0.970
		Subsoil b 40-72	1801.4	0.020	0.084	3.060	0.090	0.590

-10 of N. E. 40 of S. W. ¼ Sec. 10. Twp. 12 S. R. 30, W. of 6 P.M.	Alfalfa 15 years, loam bot- tom land.	Soil 0-7 Subsurface 7-20 Subsoil a 20-40 Subsoil b 40-72	1802.1 1802.2 1802.3 1802.4	0.133 0.067 0.045 0.039	0.098 0.095 0.090 0.078	2.080 2.150 2.730 4.810	1.440 0.570 0.300 0.280	0.240 0.290 0.700 1.170
-10 of the N. E. 40 of S. W. ¼ Sec. 10. Twp. 12 S. R. 30 W. of 6 P.M.	Native meadow loam bot- tom land. Compare with 1802.	Soil 0-7 Subsurface 7-20 Subsoil a 20-40 Subsoil b 40-72	1803.1 1803.2 1803.3 1803.4	0.116 0.050 0.043 0.033	0.080 0.090 0.088 0.085	2.130 2.450 2.730 3.830	1.270 0.540 0.410 0.270	0.290 0.430 0.560 0.830
S. W. 10 of the S. W. 40 of N. W. ¼ Sec. Twp. 11 S. R. 28 W. of 6 P.M.	Farmed 30 years, mostly wheat, Colby silt loam. Compare with 1805.	Soil 0-7 Subsurface 7-20	1804.1 1804.2	0.118 0.075	0.099 0.079	1.050 1.030	1.310 0.810	0.160
S. E. 10 of the S. E. 40 of N. E. ¼ Sec. 7. Twp. 11 S. R. 28, W. of 6 P.M.	Native Buffalo grass, Colby silt loam.	Soil 0-7 Subsurface 7-20	1805.1 1805.2	0.170 0.080	0.079 0.084	1.200 1.180	2.060 0.600	
S. E. 10 of the N. W. 40 of N. W. ¼ Sec. 18, Twp. 12 S. R. 27, W. of 6 P.M.	Alfalfa 20 years, then cane 3 years, loam bottom land.	Soil 0-7 Subsurface 7-20	1800.1 1800.2	0.184 0.079	0.093 0.084	3.180 4.210	1.900 0.920	0.610 0.870
<i>Sheridan County</i>								
S. E. 10 of the S. E. 40 of the N. W. ¼ Sec. 28, Twp. 10 S. R. 28 W. of 6 P.M.	Alfalfa 20 years, loam bot- tom land.	Soil 0-7 Subsurface 7-20 Subsoil a 20-40 Subsoil b 40-80	1806.1 1806.2 1806.3 1806.4	0.187 0.107 0.057 0.043	0.093 0.090 0.082 0.082	1.350 1.450 2.150 4.880	1.830 1.220 0.380 0.360	0.030 0.030 1.230
S. W. 10 of the S. W. 40 of N. W. ¼ Sec. 28. Twp. 10 S. R. 28 W. of 6 P.M.	Native meadow, loam bot- tom land. Compare with 1806.	Soil 0-7 Subsurface 7-20 Subsoil a 20-40 Subsoil b 40-72	1807.1 1807.2 1807.3 1807.4	0.182 0.115 0.064 0.033	0.064 0.087 0.097 0.087	1.200 1.200 2.300 3.660	2.270 1.200 0.700 0.320	0.310 0.900

TABLE 1—Continued

LOCATION, COUNTY AND LAND SURVEY	DESCRIPTION, TREATMENT, CHARACTER AND TYPE OF SOIL	STRATUM SAMPLED <i>inches</i>	LABORATORY NUMBER	PLANT-FOOD ELEMENTS				
				Nitrogen <i>per cent</i>	Phosphorus <i>per cent</i>	Calcium <i>per cent</i>	Organic carbon <i>per cent</i>	Inorganic carbon <i>per cent</i>
<i>Sheridan County—Continued</i> N. W. 10 of the N. W. 40 of N. W. ¼ Sec. 30. Twp. 10 S. R. 28, W. of 6 P. M.	Cultivated 20 years, creek bottom land. Compare with 1806.	Soil 0-7	1808.1	0.118	0.082	1.330	1.140	0.030
		Subsurface 7-20	1808.2	0.058	0.069	2.400	0.460	0.360
		Subsoil a 20-40	1808.3	0.034	0.085	3.530	0.160	0.720
		Subsoil b 40-72	1808.4	0.022	0.079	3.180	0.130	0.680
N. E. ¼ Sec. 6. Twp. 9 S. R. 28, W. of 6 P. M.	Alfalfa 20 years, Colby silt loam.	Soil 0-7	1809.1	0.153	0.084	1.680	1.630	0.110
		Subsurface 7-20	1809.2	0.066	0.084	4.060	0.660	1.260
		Subsoil a 20-40	1809.3	0.040	0.077	3.880	0.340	0.890
		Subsoil b 40-72	1809.4	0.026	0.082	3.430	0.160	0.720
N. E. ¼ Sec. 6. Twp. 9 S. R. 28 W. of 6 P. M.	Native meadow, Colby silt loam. Compare with 1809.	Soil 0-7	1810.1	0.157	0.098	1.200	1.820	
		Subsurface 7-20	1810.2	0.072	0.084	3.180	0.620	0.540
		Subsoil a 20-40	1810.3	0.038	0.086	3.180	0.170	0.610
		Subsoil b 40-72	1810.4	0.035	0.076	5.050	0.080	1.250
<i>Wallace County</i> Sec. 35 Twp. 13 S. R. 39, W. of 6 P. M.	Alfalfa 25 years, bottom land.	Soil 0-7	1811.1	0.182	0.099	2.470	1.760	0.280
		Subsurface 7-20	1811.2	0.039	0.063	3.970	0.660	0.400
		Subsoil 20-40	1811.3	0.101	0.073	2.800	0.390	0.840
Sec. 35. Twp. 13 S. R. 39 W of 6 P. M.	Native pasture, loam bot- tom land. Compare with 1811.	Soil 0-7	1812.1	0.151	0.080	2.750	1.890	0.400
		Subsurface 7-20	1812.2	0.088	0.070	3.000	1.110	0.210
		Subsoil 20-40	1812.3	0.052	0.055	3.130	0.470	0.600

<i>Trego County</i> S. W. 10 of the S. W. 40 of S. W. ¼ Sec. 20. Twp. 12 S. R. 23 W. of 6 P.M.	Alfalfa over 20 years, creek bottom silt loam.	Soil	0-7	1794.1	0.131	0.072	1.180	1.060	0.053
		Subsurface	7-20	1794.2	0.052	0.095	2.430	0.660	0.340
		Subsoil a	20-40	1794.3	0.019	0.085	2.560	0.210	0.470
		Subsoil b	40-72	1794.4	0.017	0.084	2.200	0.290	0.230
	Wheat prevailing crop, creek bottom land near higher ground, loam or silt loam. Compare with 1794.	Soil	0-7	1795.1	0.160	0.073	1.050	1.840	
		Subsurface	7-20	1795.2	0.076	0.073	1.200	0.800	
		Subsoil a	20-40	1795.3	0.040	0.088	1.100	0.450	
		Subsoil b	40-72	1795.4	0.022	0.099	1.900	0.430	
N. E. 10 of the S. W. 40 of S. W. ¼ Sec. 20. Twp. 12 S. R. 23 W. of 6 P.M.									

problem. A ton of average alfalfa hay contains about 5 pounds of phosphorus. If a soil analyzes 0.05 per cent of phosphorus, the amount to the depth of 40 inches is 6,000 pounds per acre. Calculating an average yield of 4 tons per year, the amount of phosphorus removed from the soil in 20 years is 400 pounds or a little over 6 per cent of this total. This is quite likely no greater than the difference in the composition of adjoining fields when they were in virgin sod.

The foregoing review shows that when land is in a wild or virgin state, the supply of nitrogen is kept constant or increases; but as soon as the land is cultivated there is a tendency for the nitrogen content to decrease, and that not all of this decrease can be attributed to the removal of nitrogen by the crop. It is also shown that legumes tend to increase the nitrogen content of the soil.

EXPERIMENTAL

The general plan of the experiment reported in this paper was to sample old alfalfa fields, old cultivated fields near by, and virgin sod wherever they could be found adjoining or in close proximity separated by a fence or road. The samples were generally taken in four different strata, namely 0 to 7 inches, 7 to 20 inches, 20 to 40 inches and 40 to 80 inches in depth. These are called surface, subsurface and first and second subsoil, respectively. For the upper three strata a soil augur was generally used. For the lowest it was found best to use a soil tube, particularly in Western Kansas. Borings were made in a number of places in each field. In Western Kansas most of the fields were on bottom land.

The soil samples were put in bags and shipped to the laboratory. When thoroughly air-dry, the whole sample was put in a ball mill and given a preliminary grinding. This served to mix the sample thoroughly. A small subsample was then ground in an ore sample grinder to pass a 100-mesh sieve.

The samples were analyzed for nitrogen, organic carbon, inorganic carbon, phosphorus and calcium. The results of the analyses are given in table 1. The location of the field as given in the first column is by county and by legal description. The location is also indicated in figure 1. In a few cases one field was compared with another across the road and in another county. In such cases the location does not exactly correspond to the county under which it is classed.

There is given in the table a brief description of the soil and its treatment as far as known. For purposes of comparative study, the samples have been divided into three classes according to the location in the state and the amount of rainfall. The samples taken from locations where rainfall is 30 inches or more are classed as from the humid section; those taken where the annual rainfall is between 22 and 30 inches as from the sub-humid, and those where the rainfall is less than 22, as from the semi-arid portions of the state.

TABLE 2
Effect of cropping on the nitrogen content of the surface 7 inches of soil

COUNTY	NITROGEN: POUNDS PER ACRE			DIFFERENCE					
	Native	Alfalfa	Cropped	Alfalfa vs. native		Cropped vs. native		Alfalfa vs. cropped	
Humid section									
Leavenworth.....		3260	3480	lbs.	per cent	lbs.	per cent	lbs.	per cent
Leavenworth.....	5920	4440		-1480	25.00			-220	6.75
Brown.....	4560	4220	3200	+340	7.46	1360	29.83	+1020	24.17
Nemaha.....	3620	3400	2040	-220	6.07	-1580	43.64	+1360	40.00
Montgomery.....	3720	2620	2200	-1100	29.56	1520	40.70	+400	16.04
Montgomery.....		3360	2700					+660	19.64
Butler.....	3920	3220	2780	-700	17.85	-1140	29.10	+440	13.66
Chase.....	3840	4020	2660	+180	4.68	-1180	30.73	+1360	33.83
Harvey.....	3780	3220	2800	-560	14.81	-980	25.92	+420	13.03
Harvey.....	4440	4000	2480	-440	9.90	-1960	44.14	+1520	38.00
Dickinson.....	4080	3360	2800	-720	17.64	-1280	31.37	+560	16.66
Dickinson.....	4080	3580	3260	-500	12.25	-820	20.09	+320	8.94
Dickinson.....	4180	4020	3100	-160	3.81	-1080	25.83	+920	22.88
Average.....	4195	3592	2793	-549	13.55	-1290	32.13	+827	22.31
Sub-humid section									
Mitchell.....		4080	3600					+480	11.76
Mitchell.....	4760	5380		+620	13.02				
Mitchell.....	5800		3720			-2080	35.86		
Mitchell.....	3600	3200	2580	-400	11.11	-1020	28.33	+620	19.37
Mitchell.....	3060		2300			-760	24.83		
Osborne.....	5000	3680	2680	-1320	26.40	-2320	46.40	+1000	27.19
Osborne.....	4640		4220			-420	9.05		
Osborne.....	4400	3920	2860	-480	10.90	-1540	35.00	+1060	27.04
Barton.....	2120	3180	2740	+1060	50.00	+620	29.44	+440	13.83
Pawnee.....	4280	4420	4020	+140	3.27	-260	6.07	+400	9.05
Average.....	4184	3980	3191	-204	4.87	-993	23.75	+789	18.04
Semi-arid section									
Ford.....	3420	4200	2720	+780	22.80	-700	20.49	+1480	35.23
Ford.....	3040	3120	2360	+80	2.63	-680	22.36	+760	24.35
Finney.....	2740	3360		+620	22.62				
Finney.....	2700	4000	2680	+1300	48.14	-20	0.74	+1320	33.00
Finney.....		3560	1580					+1980	55.62
Finney.....	1980	3840	1940	+1860	93.93	-40	2.02	+1900	49.47
Trego.....		2620	3200					-580	22.13
Gove.....	3080		2560			-520	16.88		
Gove.....	3760	4200	2420	+440	11.70	-1340	35.63	+1780	42.38
Gove.....	2320	2600		+340	14.67				
Gove.....	3400		2360			-1040	30.58		
Sheridan.....	3640	3740	2360	+100	2.74	-1280	34.06	+1380	36.89
Sheridan.....	3140	3060		-80	2.55				
Wallace.....	3020	3640		+620	20.54				
Average.....	3020	3495	2418	+606	24.23	-702	20.48	+1077	37.38

THE EFFECT OF CROPPING ON THE NITROGEN CONTENT OF THE SOIL

The number of pounds of nitrogen per acre in 7 inches of the surface soil has been presented in table 2. The differences for virgin soils and for soils cropped in different ways are also given. Soil in native sod is compared with soil cropped to alfalfa, and also with soil which has grown crops other than legumes. A comparison is also made between soil cropped to alfalfa and soils that have grown crops other than legumes. In the first case the native sod is used as the basis of comparison and the second case the soil that had been cropped to alfalfa. The comparison is made both in pounds per acre and on a percentage basis. In calculating the number of pounds per acre, the following weights of soil are assumed:

	<i>pounds</i>
Surface, 0-7 inches.....	2,000,000
Subsurface, 7-20 inches.....	4,000,000
First subsoil, 20-40 inches.....	6,000,000
Second subsoil, 40-80 inches.....	12,000,000

The results are summarized in table 3.

TABLE 3
Effect of cropping on the nitrogen content of surface soil: Summary

	POUNDS OF NITROGEN PER ACRE		
	Native	Alfalfa	Cropped
Humid.....	4195	3592	2793
Sub-humid.....	4184	3980	3191
Semi-arid.....	3020	3495	2418

In the humid section the cropped soils contained on the average 1402 pounds less nitrogen per acre than the native soils. This means a loss of nearly one-third of the original amount of nitrogen. The soils which had been in alfalfa contained 799 pounds more nitrogen than soils which had grown other crops than legumes, but 603 pounds less than the native soils. This is a loss of 14.3 per cent as compared with the native soils but an increase of 21.6 per cent as compared with the cropped soil.

In the sub-humid section the cropped soils contained 993 pounds less nitrogen than the soils in native sod. This is a loss of nearly one-fourth. The soils in alfalfa contained 789 pounds more nitrogen than the cropped soils, but 204 pounds less than the soils in native sod, a loss in this case of only 5 per cent as compared with the native sod and a gain of 20 per cent as compared with the cropped soil.

In the semi-arid section the cropped soils contained 602 pounds less nitrogen than the soils in native sod, or a loss of one-fifth of the original nitrogen. The alfalfa soils contained 475 pounds of nitrogen more than the native soils, and 1077 pounds more than the cropped soils.

All the fields in alfalfa but one have more nitrogen than those in native sod. In every cropped field but one, the nitrogen content was less than in the native sod. In other words, the fields in alfalfa have over 30 per cent more nitrogen than the cropped soils, and 15.7 per cent more than the soils in native sod. This represents an unmistakable gain of nitrogen through the growing of alfalfa. It should be borne in mind that the average age of the alfalfa fields in the sub-humid and semi-arid section was much greater than that of the fields in the humid section.

It is probable that the decrease in nitrogen of the fields in alfalfa in the humid and sub-humid sections took place before the alfalfa was seeded. The increase in nitrogen, if any, since the alfalfa was seeded has not been sufficient to restore the original amount. For reasons to be presented later, it is probable that in some fields at least, the growth of alfalfa has simply prevented a further decrease.

Perhaps more accurate conclusions can be drawn from the data presented in table 4 in which only those fields are included which were close enough together to permit direct comparisons. The figures in the first three columns are the same as those in table 2. In the next two columns are given the number of years of continuous alfalfa or grain production in the respective fields. By subtracting the number of pounds of nitrogen in the continuously cropped field from that in native sod, the loss of nitrogen by cropping is obtained. These figures are given in the sixth column. The average yearly loss obtained by dividing the total by the number of years in cultivation is given in the seventh column.

The average yearly loss multiplied by the number of years the land was in grain crops gives the total loss sustained before seeding to alfalfa. The figures so obtained are given in the eighth column. Subtracting this from the amount present in the native sod gives the amount presumably present in the soil when the alfalfa was seeded. These figures are given in the ninth column. By comparing this amount with that present when the sample was taken the gain or loss through the continuous growing of alfalfa can be calculated. The results of this calculation are given in the last column of table 4.

It will be seen that in both the humid and the sub-humid sections, the gains are practically balanced by the losses. The growing of alfalfa has simply prevented further losses or has secured enough from the air to take the place of that removed by the crop. In the semi-arid section there is an unmistakable gain. This corroborates the statements made on the basis of the figures presented in table 2.

If continuous growing of alfalfa simply maintains a balance in the nitrogen content of the soil, it seems that the amount of nitrogen in the hay crop is about equal to that obtained from the air, while that in the roots and stubble is about equal to that obtained from the soil.

Another factor however, must be considered, viz; the loss of leaves in curing and stacking. The loss is probably greater in the semi-arid section than in the more humid sections. The intense sunshine causes the leaves to fall very easily if the period of drying is prolonged even a few hours. It has been calculated that from 7 to 25 per cent of the leaves are lost in curing and stacking, and from 3 to 14 per cent of the entire crop (9).

TABLE 4
Gain or loss of nitrogen as a result of cropping to alfalfa

COUNTY	POUNDS OF NITROGEN PER ACRE			YEARS IN ALFALFA	YEARS IN A GRAIN CROP	LOSS OF NITROGEN			NITRO- GEN PER ACRE WHEN SEEDED	GAIN OR LOSS WHILE IN ALFALFA
	Alfalfa	Native	Cropped			Total loss by crop- ping to grains	Average yearly loss	Loss before seeding to alfalfa		
Humid section										
Brown.....	4220	4560	3200	28	45	1380	31	527	4050	+170
Nemaha.....	3420	3620	2040	21	45	1580	35	840	2760	+649
Montgomery.....	2620	3720	2200	12	35	1520	43	989	2730	-110
Butler.....	3220	3920	2780	12	32	140	4	80	3840	+620
Chase.....	4020	3840	2660	25	40	1180	29	435	3405	+615
Harvey.....	3220	3780	2800	11	25	980	39	546	3234	-14
Harvey.....	4000	4440	2480	14	44	1960	44	1320	3120	+880
Dickinson.....	3360	4080	2800	20	35	1280	37	555	3530	-170
Dickinson.....	3580	4080	3260	20	40	820	20	400	3680	-100
Dickinson.....	4020	4180	3100	25	35	1080	31	310	3870	+150
Sub-humid section										
Mitchell.....	3200	3600	2580	23	30	1020	34	238	3370	-170
Osborne.....	3680	5000	2680	20	40	2320	58	1160	3840	-160
Osborne.....	3920	4400	2860	33	35	1540	44	88	4310	-390
Pawnee.....	4420	4280	4020	28	20	260	13	0	4280	+140
Semi-arid section										
Ford.....	4200	3420	2720	30	30	700	23	0	3420	+780
Ford.....	3120	3040	2360	10	30	680	22	220	2580	+540
Finney.....	4000	2700	2680	27	20	20	0	0	2700	+1300
Finney.....	3840	1980	1940	30	30	40	0	0	1980	+1860
Gove.....	4200	3760	2420	15	15	1340	89	0	3760	+440
Sheridan.....	3740	3640	2360	20	20	1280	64	0	3640	+1000

We may assume that on the average, 20 per cent of the leaves, or about 10 per cent of the crop, is lost. When bad weather prevails during harvesting, as much as half the crop may be lost. This no doubt is a factor in increasing the nitrogen content of the soil. Assuming an annual yield of hay of 5000 pounds per acre, half of which is leaves, the nitrogen added to the soil in

Semi-arid section									
Ford.....	72,000	41,600	36,400	-30,400	42.22	-35,600	49.44	+5,200	12.50
Ford.....	34,800	33,200	29,600	-1,600	4.59	-5,200	14.94	+3,600	10.84
Finney.....	33,600	38,600	35,200	+5,000	14.88	+1,600	4.76	+3,400	8.80
Finney.....	38,800	32,200	19,600	-6,600	17.01	+1,800	10.11	+21,200	51.96
Finney.....	17,800	40,800	20,800	+23,000	29.21			+13,600	39.54
Finney.....		34,400	36,800					-15,600	73.58
Trego.....		21,200	24,200	+1,400	3.24	-19,000	43.98	+20,400	45.74
Gove.....	43,200	44,600	24,200	+1,400	3.24				
Gove.....	25,400	28,800		+3,400	13.38				
Gove.....	36,800		27,000			-9,800	26.63		
Gove.....	41,200		26,200			-15,000	36.40		
Sheridan.....	45,400	36,600	22,800	-8,800	19.38	-22,600	49.78	+13,800	37.70
Sheridan.....	36,400	32,600		-3,800	10.43				
Wallace.....	37,800	35,200		-2,600	6.87				
Average.....	38,600	34,983	27,860	-3,846	9.96	-10,740	27.83	+8,200	+23.50

this way would amount to 17.5 pounds annually or a total of 350 pounds in 20 years. There may be two reasons for no apparent gain in the humid and sub-humid sections: (1) The leaves remain on the surface of the soil and the nature of the decay is such that a portion of the nitrogen is lost. (2) Alfalfa uses the nitrogen liberated by decay and nitrification of organic matter. When the nitrogen is abundant more nitrogen is used. In this way the addition of nitrogen through the loss of leaves may create such a condition that less is taken from the air.

The fact must not be lost sight of that alfalfa takes large amounts of nitrogen from the air which is not accounted for in this investigation, because no data on the amount removed in the crops are available. For every ton of hay harvested, it appears that 50 pounds of nitrogen has been taken from the air. With the best methods of farming the greater part of this can be returned to the soil.

Another effect of growing alfalfa is an improved physical condition of the soil, as a result of the large, deeply penetrating roots. Alfalfa roots are large and contain a large amount of organic matter; they decay easily and rapidly making available an abundance of the mineral elements, phosphorus, and potassium contained in the alfalfa roots. The process of decay also liberates more of these elements from the insoluble compounds found in the soil.

Finally it should be remembered that the fields studied were comparatively well stocked with nitrogen when alfalfa was seeded. If the investigation had been made on fields which had lost more nitrogen before the alfalfa was seeded, the results probably would be different.

THE EFFECT OF CROPPING ON THE ORGANIC CARBON CONTENT OF THE SOIL

The organic carbon content of surface soil of fields in native sod, alfalfa and those cropped to grain is given in table 5. The differences are also given in pounds and percentage, the comparisons being made as in table 2. The results are summarized in table 6.

In the humid section the fields cropped to grain contain on the average 18,863 pounds less of organic carbon than those in native sod, an average loss of nearly 36 per cent. The fields in alfalfa contain an average of 7667 pounds more than those in grain crops, but 11,196 pounds less than those in native sod. This is a loss of 21.26 per cent as compared with the native sod and a gain of 18.48 per cent as compared with the cropped fields. All the soils in native sod have more organic carbon than the fields in alfalfa or those cropped to grains. All but two of the fields in alfalfa have more organic carbon than the fields cropped to grains.

In the sub-humid section the fields cropped to grains contain an average of 14,733 pounds less of organic carbon than the native sod. This is a loss of nearly 28 per cent. The fields in alfalfa contained an average of 7873 pounds of organic carbon more than those in grains, but 6860 pounds less

than the fields in native sod. This is a loss of a little over 13 per cent as compared with the native sod and a gain of over 18 per cent as compared with the cropped land.

In the semi-arid section the fields cropped to grain contained 10,740 pounds less organic carbon than those in native sod. This is a loss of nearly 30 per cent. Those in alfalfa contained on the average 7123 pounds more organic carbon than those cropped to grains, but 3817 pounds less than those in native sod, a loss of about 10 per cent as compared with the native sod, and a gain of over 25 per cent as compared with the fields cropped to grains. All but four of the fields in native sod contained more organic carbon than those cropped to alfalfa or grain.

These results show that the growing of alfalfa has not fully restored the organic carbon. There is no doubt as to the possibility of increasing the organic carbon content of the soil by growing alfalfa, but in the majority of cases studied, such cropping has resulted in a further decrease.

We must recognize the possibility of error in the determinations, since we do not know the exact carbon content of these fields, at the time the alfalfa

TABLE 6

Effect of cropping on the organic carbonic content of the surface soil: Summary

	POUNDS PER ACRE		
	Native	Alfalfa	Cropped
Humid.....	52,673	41,477	33,810
Sub-humid.....	50,638	45,429	37,536
Semi-arid.....	38,433	34,983	26,720

was seeded. The approximate amounts can be calculated however, by the same method employed in studying the loss of nitrogen. Data secured by this method are presented in table 7.

The data corroborate those presented in table 5 and the statements made in relation to them. Unlike the effect on the nitrogen there has not been an increase in the carbon content of these soils as a result of cropping to alfalfa. This is true for all the three sections.

THE EFFECT OF CROPPING ON THE NITROGEN AND ORGANIC CARBON CONTENT OF THE SUBSOIL

An attempt has been made to compare the nitrogen and organic carbon content of the different strata. The results are presented in tables 8 and 9. In interpreting these results it should be remembered that the experimental errors of determination are rather large. There are two reasons for this. Most of these samples are from bottom land. While the fields compared appeared to be very uniform, the subsoils were often found to differ considerably. Also the weight of the subsoil from 20 to 40 inches deep was assumed

TABLE 7
Gain or loss of organic carbon as a result of cropping to alfalfa

COUNTY	POUNDS OF ORGANIC CARBON PER ACRE			YEARS IN ALFALFA CROP	LOSS OF ORGANIC CARBON			POUNDS OF ORGANIC CARBON PER ACRE WHEN SEEDING	GAIN OR LOSS WHILE IN ALFALFA
	Alfalfa	Native	Cropped		Total loss by cropping to grain	Average yearly loss	Loss before seeding to alfalfa		
Humid section									
Brown.....	45,600	57,200	38,800	28	18,400	409	6,953	50,247	lbs. -4,647
Nemaha.....	33,800	39,400	22,600	21	16,800	373	8,952	30,448	+3,352
Montgomery.....	41,400	51,800	34,600	12	17,200	491	11,293	40,507	+893
Butler.....	34,200	47,000	30,800	12	16,200	506	10,120	36,880	-2,680
Chase.....	44,600	47,600	36,000	25	11,600	290	4,350	43,250	+1,350
Harvey.....	38,200	45,600	22,400	11	23,200	928	12,992	32,608	+5,592
Harvey.....	46,200	53,200	24,600	14	28,600	650	19,500	33,700	+12,500
Dickinson.....	36,400	49,200	36,400	20	12,800	365	5,475	43,725	-7,325
Dickinson.....	40,000	52,600	40,120	20	12,480	312	6,240	46,360	-6,360
Dickinson.....	50,200	60,600	41,200	25	19,400	554	5,540	55,060	-4,860
Sub-humid section									
Mitchell.....	25,200	37,400	28,400	23	9,000	300	2,100	35,300	-10,100
Osborne.....	46,000	64,400	33,200	20	31,200	780	15,600	48,800	-1,800
Osborne.....	44,400	62,200	35,400	33	26,800	765	1,530	60,670	-16,270
Pawnee.....	51,200	50,600	42,200	28	8,400	420	0	50,600	+600
Semi-arid section									
Ford.....	41,600	72,000	36,400	30	35,600	1,186	0	72,000	-30,400
Ford.....	33,200	34,800	29,600	10	5,200	173	3,460	31,340	+1,860
Finney.....	38,600	33,600	35,200	27	-1,600*	-80	0	33,600	+5,000
Finney.....	40,800	17,800	19,600	30	-1,800*	-60	0	17,800	+23,000
Gove.....	44,600	43,200	24,200	15	19,000	1,260	0	43,200	+1,400
Sheridan.....	36,600	45,400	22,800	20	22,600	1,130	0	45,400	-8,800

* Gain.

to be 6,000,000 pounds per acre, and the subsoil from 40 to 80 inches 12,000,000 pounds per acre. When these sums are multiplied by the significant errors in the determinations, the differences between duplicate determination is often greater than the differences due to the cropping.

It will be seen that the method of cropping has not influenced materially the nitrogen content of the subsoil below a depth of 20 inches, except possibly

TABLE 8
Average nitrogen content of the soil of different strata

SECTION	KIND OF SOIL	0-7 INCHES	7-20 INCHES	20-40 INCHES	40-80 INCHES
		<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Humid.....	Native	0.200	0.121	0.069	0.045
	Alfalfa	0.175	0.111	0.062	0.043
	Cropped	0.136	0.105	0.068	0.046
Sub-humid.....	Native	0.209	0.101	0.059	0.032
	Alfalfa	0.200	0.092	0.061	0.033
	Cropped	0.159	0.088	0.051	0.036
Semi-arid.....	Native	0.151	0.079	0.048	0.037
	Alfalfa	0.173	0.077	0.051	0.035
	Cropped	0.121	0.073	0.042	0.025

TABLE 9
Average carbon content of the soil of different strata

SECTION	KIND OF SOIL	0-7 INCHES	7-20 INCHES	20-40 INCHES	40-80 INCHES
		<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Humid.....	Native	2.52	1.39	0.77	0.44
	Alfalfa	2.09	1.27	0.72	0.48
	Cropped	1.67	1.23	0.81	0.43
Sub-humid.....	Native	2.72	1.16	0.67	0.31
	Alfalfa	2.27	1.14	0.90	0.63
	Cropped	1.88	1.11	0.54	0.69
Semi-arid.....	Native	1.93	0.71	0.41	0.34
	Alfalfa	1.63	0.74	0.46	0.37
	Cropped	1.39	0.70	0.55	0.29

in the semi-arid section. In the subsurface (7 to 20 inches), the nitrogen content of the fields in native sod is slightly higher than the others, the difference being greatest when the comparison is made with the fields cropped to grain. It is sometimes thought that plants secure nitrogen from the subsoil and deposit it in the surface soil. The facts here presented do not support this theory.

TABLE 10
Effect of cropping on the phosphorus content of the surface 7 inches of soil

COUNTY AND SECTION	POUNDS OF PHOSPHORUS PER ACRE			DIFFERENCES					
	Native	Alfalfa	Cropped	Alfalfa vs. native		Cropped vs. native		Alfalfa vs. cropped	
Humid									
Leavenworth.....	1220	1040		lbs.	per cent	lbs.	per cent	lbs.	per cent
Leavenworth.....		860	960	-180	14.75			-100	9.61
Brown.....	1220	1260	960	+40	3.27	-260	21.31	+300	23.80
Nemaha.....	760	780	800	+20	2.63	+40	5.26	-20	2.56
Montgomery.....	920	720	680	-200	21.73	-240	26.08	+40	5.55
Montgomery.....		860	760					+100	11.62
Butler.....	700	760	540	+60	8.57	-160	22.85	+220	28.94
Chase.....	1000	780	840	-220	22.00	-160	16.00	-60	7.69
Harvey.....	1120	820	1060	-300	26.78	-60	5.35	-240	29.26
Harvey.....	900	860	720	-40	4.44	-180	20.00	+140	16.27
Dickinson.....	960	960	1140	0	0	+180	18.75	-180	18.75
Dickinson.....	1220	880	960	-340	27.86	-260	21.31	-80	9.09
Dickinson.....	1740	1820	900	+80	4.59	-840	48.27	+920	50.54
Average.....	1069	954	860	-115	10.76	-209	19.55	+94	9.85
Sub-humid									
Mitchell.....	1260	1380		+120	9.52				
Mitchell.....	1360	1580	1300	+220	16.17	-60	4.41	+280	17.72
Mitchell.....	1100		1140			+40	3.63		
Mitchell.....	2100		1920	-720	34.29	-180	8.57	-540	39.13
Mitchell.....		1500	1440	+240	19.05	+180	14.28	+60	4.00
Osborne.....	2000	1400	1800	-600	30.00	-200	10.00	-400	28.57
Osborne.....	1360	1200	1340	-160	11.76	-20	1.47	-140	11.66
Osborne.....	2120		2060			-60	2.83		
Barton.....	1040	1080	940	+40	3.84	-100	9.61	+140	12.96
Pawnee.....	1180	1060	1860	-120	10.17	+680	57.71		75.47
Average.....	1502	1314	1533	-123	16.85	+31	2.06	-219	16.67
Semi-arid									
Ford.....	1580	1640	1500	+60	3.79	-80	5.06	+140	8.53
Ford.....	860	1640	1260	+780	90.61	+400	46.51	+380	23.17
Finney.....	1540	1520		-20	1.29				
Finney.....	1640	1700	1400	+60	3.65	-240	14.63	+300	17.64
Finney.....	1360	1560	1240	+200	14.70	-120	8.82	+320	20.51
Finney.....		1280	1060					+220	17.18
Trego.....		1440	1460					-20	1.38
Gove.....	1720	2000	1800	+280	16.27	+80	46.51	+200	10.00
Gove.....	1600	1960		+360	22.50			-600	40.00
Gove.....	1680	1500	2100	-180	10.71	+420	25.00		
Gove.....	1580		1980			+400	25.31		
Sheridan.....	1280	1860	1640	+580	45.31	+360	28.10	+220	11.82
Sheridan.....	1960	1680		-280	14.28				
Wallace.....	1600	1980		+380	23.75				
Average.....	1533	1674	1544	+141	9.19	+152	10.00	+130	8.48

The organic carbon content of the subsoil below 20 inches appears not to be materially affected by the method of cropping. In two cases the carbon content of the fields cropped to grain is the highest of any. This suggests that the differences are less than the error of determination. There appears to be a significant though slight difference in the subsurface (7 to 20 inches) in favor of the fields in native sod. Also, those in alfalfa appear to be slightly higher in carbon than those cropped to grain. As previously pointed out there are rather large differences in the carbon content of the surface soil (0 to 7 inches).

The fact that the principal loss of carbon is in the surface soil suggests that it is practically all due to the oxidation of organic matter, to soil blowing or to erosion. These factors also affect the nitrogen content.

THE EFFECT OF CROPPING ON THE PHOSPHORUS CONTENT OF THE SOIL

The phosphorus content of the soil is indicated in table 10. The data are arranged in the same way as for the nitrogen and for the organic carbon content presented above. In general, the differences are so small that no definite conclusions can be reached.

A ton of alfalfa hay contains about 5 pounds of phosphorus. At this rate 20 average crops would remove only about 500 pounds. If all of it came from the surface soil the removal of this amount no doubt would be noticeable, but a deep-rooted crop like alfalfa secures phosphorus from considerable depth. The smallest difference which can possibly be significant in a phosphorus determination is 0.005 per cent. This amounts to 600 pounds of phosphorus per acre to a depth of 40 inches assuming the weight of the soil to be 12,000,000 pounds. Accordingly, the amount of phosphorus removed by 20 average crops of alfalfa could not be determined with any degree of certainty. Also, there is no certainty that all fields had the same phosphorus content to begin with.

Considering the possibilities of error it is not probable that the differences in the phosphorus content of the fields cropped in different ways are significant. The rather high phosphorus content of the surface soil of the fields cropped to alfalfa in the semi-arid section is perhaps explained by the loss of leaves in curing.

The phosphorus content of the different strata is presented in table 11. Excepting only the cropped soils in the humid section, the surface averages higher in phosphorus than the subsoils. This accords with what would be expected. The phosphorus in the native vegetation becomes incorporated with the surface soil when the former decays or is burned off.

The fact that the cropped soils in the humid section do not contain more phosphorus than the lower strata may be taken to mean that so much of the phosphorus of the surface soil has been used that the average has been reduced to that found in the lower depths. In the sub-humid and semi-arid sections the soils have not been cultivated for so long a time, therefore this condition has apparently not yet been reached.

THE EFFECT OF CROPPING ON THE CALCIUM CONTENT OF THE SOIL

The principal object in analyzing the soils for calcium was to determine the calcium content of soils where alfalfa grows successfully. The amount of calcium in crops is small in comparison with the amount present in the soil, and with the amounts removed from the soil by leaching. A ton of alfalfa hay contains from 20 to 25 pounds of calcium. The amount in grain crops is much smaller. On the other hand, it is estimated that the equivalent of 500 pounds per acre of CaCO_3 is removed by leaching every year in a humid climate. The amount of calcium in these soils varies more than that of any other element.

As a rule the calcium content increases from the surface downward. This is especially true for soils with a high calcium content and for the sub-humid and semi-arid sections. By reference to table 1 it will be seen that most

TABLE 11
Phosphorus, average percentages in different strata

SECTION	KIND OF SOIL	0-7 INCHES	7-20 INCHES	20-40 INCHES	40-80 INCHES
		<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Humid section.....	Native	0.053	0.041	0.039	0.039
	Alfalfa	0.046	0.039	0.037	0.044
	Cropped	0.042	0.041	0.042	0.042
Sub-humid.....	Native	0.075	0.063	0.064	0.056
	Alfalfa	0.066	0.062	0.059	0.057
	Cropped	0.075	0.066	0.065	0.057
Semi-arid.....	Native	0.079	0.070	0.064	0.072
	Alfalfa	0.084	0.067	0.067	0.067
	Cropped	0.077	0.068	0.070	0.070

soils in the humid section contain from 0.5 to 1.0 per cent calcium in the surface soil. Of those devoted to alfalfa growing, few contained less than 0.5 per cent of calcium. In the sub-humid and semi-arid sections the percentage of calcium in practically all soils studied is 1 per cent and above. In none of the soils of these two sections can there be said to be a calcium deficiency. It is very probable that those soils which contain 0.5 per cent or less calcium are very near the border-line of calcium deficiency, and especially so when there is no material increase in calcium in the lower strata.

THE EFFECT OF CROPPING ON THE INORGANIC CARBON CONTENT OF THE SOIL

In the humid section only 6 out of 38 soils contained inorganic carbon in the surface or subsurface (table 1). In the subsoil, the occurrence of inorganic carbon was more frequent. This means that in this section calcium carbonate is absent from all but a very few soils and that the carbonate has disap-

peared from the surface and subsurface to a larger extent than from the subsoil. This shows that these soils are rapidly approaching a calcium deficiency. The calcium in forms other than the carbonate are relatively unavailable. In the sub-humid and semi-arid sections, only 11 soils out of 60 have no inorganic carbon in the surface soil, and of these 11, only 5 have no inorganic carbon in the subsoil. This means that practically all soils in the sub-humid and semi-arid sections have not only an abundance of calcium but that a large amount of it is in the carbonate form which is the most available.

SUMMARY AND CONCLUSIONS

1. It is generally assumed that alfalfa helps maintain the fertility of the soil by securing nitrogen from the air and by preventing the oxidation of the humus and organic matter which takes place rapidly when cultivated crops are grown; no exact figures seem to have been secured, however. It is very important that such data be available because when the alfalfa crop is removed it is quite possible that the field is left no richer in nitrogen than if no alfalfa had been grown, and because alfalfa removes a relatively large amount of other plant-food elements.

2. Kansas produces more alfalfa than any other state, and has some of the oldest alfalfa fields in the country, some of which have been continuously in alfalfa for 30 years or more. This offers unusual opportunities for a study of this kind.

3. The general plan of the experiment was to sample these old alfalfa fields and other fields nearby which were of the same type of soil but had been continuously in cultivation or in native sod. Preference was given to those locations where all these three fields were close enough together for direct comparison. The soil was generally sampled in four depths: 0 to 7 inches, 7 to 20 inches, 20 to 40 inches, and 40 to 80 inches. The samples were analyzed for nitrogen, organic carbon, inorganic carbon, phosphorus and calcium.

4. For purposes of comparisons, the state was divided into three sections; humid, sub-humid and semi-arid. The basis of division was the average annual rainfall. All samples taken from localities where the rainfall is 30 inches or more, were classed as from the humid section; those from localities where the rainfall is between 30 and 22 inches as from the sub-humid section; and those from localities where the rainfall is less than 22 inches as from the semi-arid section.

5. It was found that in the humid section the surface of the cropped soil had lost one-third of the nitrogen as compared with the surface soil of the native sod. The fields in alfalfa contained 14.3 per cent less nitrogen than the native sod, and 21.6 per cent more than those fields which had been cropped to grain. In the subsurface 7 to 20 inches, the changes due to cropping were much less than in the surface, and in the subsoils there were no changes that could be attributed to the methods of cropping.

6. In the sub-humid section the fields cropped to grain lost one-fourth of the nitrogen as compared with the surface soil of the native sod. The alfalfa fields contain 5 per cent less nitrogen than the native sod, but 20 per cent more than the fields in grain. In this section the changes due to cropping are also confined to the surface and subsurface.

7. In the semi-arid section the cropped soil has lost one-fifth of the nitrogen as compared with the native sod. Alfalfa fields contained 15.7 per cent more nitrogen than the soils in native sod, and 30 per cent more than the soils continuously cropped. In this section the significant changes are confined to the surface soil.

8. This comparison shows that there is an unmistakable gain in nitrogen of the soils in the semi-arid section. This may be attributed in part at least to a greater loss of leaves in curing alfalfa in the arid section.

9. It may be concluded that the continuous growing of alfalfa, may not increase the nitrogen content of the soil. The increased crop production which is usually obtained on alfalfa fields when they are plowed up is probably due to the large amount of available nitrogen they contain.

10. In the humid section, the cropped soils have lost 36 per cent of the organic carbon present in the virgin sod and those in alfalfa over 21 per cent. The fields in alfalfa contain 18 per cent more than those continuously cropped to grain.

11. In all sections the changes in the organic carbon content are confined to the surface soil. There is just one exception to this statement. In the humid section, the subsurface of the native sod has a significantly higher carbon content than the alfalfa or cropped soil.

12. In the sub-humid section the cropped soils have lost 28 per cent of the original carbon content and the alfalfa soils 13 per cent.

13. In the semi-arid section, the cropped soils contain 30 per cent less carbon than the virgin soils and the alfalfa soils 10 per cent less. In this section the changes in carbon content differ fundamentally from the changes in nitrogen which, as previously pointed out, show a gain.

14. The phosphorus content of the cropped soil is lower than that of the alfalfa soil, or soil in native sod. Alfalfa removes more phosphorus from the soil than grain crops. The fact that the alfalfa fields do not show a lower phosphorus content than the soils in native sod, may be taken to mean that there has been a transference of phosphorus from the subsoil to the surface. This transference has probably taken place because of falling of leaves. Because of the small per cent of phosphorus and the limits of determinations, this conclusion is not so well substantiated as those in regard to nitrogen and carbon.

15. In the humid section, the surface of the cropped soil contains the same amount of phosphorus as the subsoils. In all other cases, the phosphorus content of the surface soil is higher than that of the subsoils. This would point to a definite lowering of the phosphorus content of the cropped soil in the humid section.

16. In the sub-humid and semi-arid sections, most of the soils contain 1 per cent and more of calcium and nearly all have some calcium in the carbonate form. In the humid section, alfalfa was found growing on four soils successfully in which the calcium content was less than 0.5 per cent. The calcium content in most soils varies from 0.50 to 1 per cent, and in the majority the carbonate form of the calcium is absent.

REFERENCES

- (1) ALWAY, F. J. 1909 Changes in the Loess soils of Nebraska caused by cultivation. Neb. Agr. Exp. Sta. Bul. 111.
- (2) ALWAY, F. J., AND PINCKNEY, R. M. 1909 On the relation of native legumes to the soil nitrogen of the Nebraska prairies. *In* Jour. Indus. Engin. Chem., v. 1, p. 771.
- (3) LYON, T. L., AND BIZZELL, J. A. 1913 Experiments concerning the top-dressing of alfalfa. N. Y. (Cornell) Agri. Exp. Sta. Bul. 339.
- (4) RUSSEL, E. J. 1908 The nitrogen problem in crop production. *In* Jour. Roy. Agr. Soc., v. 69, p. 109.
- (5) RUSSEL, E. J. 1912 Soil Conditions and Plant Growth, p. 86. London.
- (6) SHUTT, F. T. 1910 Some characteristics of the prairie soils in Canada. *In* Jour. Agr. Sci., v. 4, p. 335-357.
- (7) SNYDER, HARRY 1906 The loss of nitrogen from soils. *In* Minn. Agr. Exp. Sta. Bul. 194, p. 188-194.
- (8) STEWART, ROBERT 1910 The nitrogen and humus problem in dry farming. Utah Agr. Exp. Sta. Bul. 109.
- (9) SWANSON, C. O., AND LATSHAW, W. L. 1916 Chemical composition of alfalfa as affected by stage maturity, mechanical losses and conditions of drying. *In* Jour. Indus. Engin. Chem., v. 8, no. 8, p. 726.
- (10) WARREN, JOSEPH A. 1909 Notes on "The number and distribution of native legumes in Nebraska and Kansas. U. S. Dept. Agr. Bur. Plant Indus. Circ. 31.
- (11) WHITSON, A. R., AND STODDART, C. W. 1908 Factors influencing the phosphate content of soils. Wis. Agr. Exp. Sta. Res. Bul. 2.
- (12) WHITSON, A. R., STODDART, C. W., AND MCLEOD, A. F. 1906 The nitrogen content of soils as affected by cropping. *In* Wis. Agr. Exp. Sta. 23rd Ann. Rpt. p. 160-170.
- (13) WHITSON, A. R., STODDART, C. W., AND MCLEOD, A. F. 1907 Nitrogen content of soils as affected by methods of farming. *In* Wis. Agr. Exp. Sta. 24th Ann. Rpt. p. 254.