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THE LOESS SOILS OF THE NEBRASKA PORTION OF THE TRANSITION REGION :

III. POTASH, SODA, AND PHOSPHORIC ACID.¹

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INTRODUCTION.

In Nebraska the loess extends westward for about 300 miles from the eastern boundary on the Missouri River. Throughout this distance the temperature conditions are quite uniform, but there is a gradual decrease in the humidity of the climate, the normal annual precipitation, which exceeds 30 inches at the eastern boundary, steadily falling until it is less than 20 inches in the extreme western portion, while the rate of evaporation increases considerably. The climate of this region has been considered in detail in a previous paper (3).

The soil samples, upon which this article is based, were collected from 30 virgin prairie fields, 5 near each of six stations of the United States Weather Bureau shown in figure 1—Wauneta, McCook, Holdrege, Hastings, Lincoln, and Weeping Water. In each field, at intervals of 30 feet, ten borings were made to a depth of 6 feet and composite samples prepared of each foot-section, thus giving 6 samples from each field, the so-called "field samples." From these we prepared the "area samples," by mixing equal weights of the corresponding five "field samples." Thus each of the "area samples" is a composite from 50 individual borings. The details of the methods of sampling are given in the article referred to above.

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² The work reported in this paper was carried out during the summers of 1911 and 1912 at the Nebraska Agricultural Experiment Station, where the authors were Chemist and Assistant in Chemistry, respectively. Mr. J. W. Tobiska assisted during the latter summer.

The data reported in Table I were included in a previous article by one of the authors (1). Later, in checking over the analyses, it was found that an error had been made in introducing corrections for the soda and the potash contained in the reagents, the correction for the former having been deducted from the found percentage of the latter and vice versa. Accordingly the data in the article referred to are .07 or .08 per cent too low for potash and too high for soda. In the case of a few of the samples new determinations have been made.

TABLE I.

TOTAL POTASH AND SODA IN THE FOOT-SECTIONS FROM THE SIX AREAS.

POTASH (K_2O).

Depth Foot	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	2.63	2.51	2.40	2.49	2.46	2.46	2.49
2	2.68	2.49	2.46	2.45	2.47	2.38	2.49
3	2.70	2.50	2.56	2.51	2.51	2.42	2.53
4	2.65	2.55	2.67	2.56	2.54	2.37	2.56
5	2.67	2.63	2.64	2.67	2.52	2.45	2.60
6	2.75	2.60	2.66	2.65	2.53	2.42	2.60
Average	2.68	2.55	2.56	2.55	2.50	2.42	2.54

SODA (Na_2O).

1	1.41	1.50	1.50	1.48	0.96	1.05	1.32
2	1.43	1.49	1.38	1.36	0.94	0.99	1.27
3	1.34	1.40	1.40	1.36	1.06	1.04	1.27
4	1.42	1.36	1.44	1.59	1.14	1.29	1.37
5	1.45	1.51	1.57	1.47	1.21	1.27	1.41
6	1.48	1.50	1.49	1.54	1.18	1.37	1.43
Average	1.42	1.46	1.46	1.47	1.08	1.17	1.34

In the surface foot the potash varies only little from field to field in the same area (Table II), but is slightly higher in the fields near Wauneta than in those of the more easterly areas.

TABLE II.

TOTAL POTASH IN THE SURFACE FOOT OF THE DIFFERENT FIELDS OF EACH OF THE SIX AREAS.

Field No.	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %
I	2.62	2.52	2.46	2.57	2.42	2.46
II	2.59	2.46	2.53	2.43	2.44	2.47
III	2.59	2.54	2.52	2.49	2.40	2.43
IV	2.59	2.53	2.48	2.51	2.45	2.43
V	2.60	2.56	2.47	2.61	2.44	2.43
Average	2.60	2.52	2.49	2.52	2.43	2.44

The total phosphoric acid, while showing a greater variation than the potash, is also quite evenly distributed (Table III). In the first foot and in the second it seems much the same throughout, but in the deeper sections it shows a higher content in the two eastern areas. In the surface foot-samples from the thirty fields (Table IV) it shows almost as great a uniformity as the potash except that it is somewhat lower in all the fields of the Hastings area. The data on the amounts in the first and second feet, compared with those in the lower levels of the Lincoln area, as reported in Table V, indicate that the subsoil in this area is uniformly richer in phosphoric acid than the surface soil.

TABLE III.

TOTAL PHOSPHORIC ACID IN THE FOOT-SECTIONS FROM THE SIX AREAS.

Depth Foot	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	.124	.135	.140	.107	.132	.126	.127
2	.129	.122	.113	.107	.139	.115	.121
3	.116	.115	.131	.116	.160	.125	.127
4	.151	.117	.151	.108	.166	.160	.142
5	.149	.128	.130	.135	.187	.182	.152
6	.137	.129	.108	.147	.171	.171	.144
Average	.134	.124	.129	.120	.159	.146	.135

TABLE IV.

TOTAL PHOSPHORIC ACID IN THE SURFACE FOOT OF THE DIFFERENT FIELDS OF EACH OF THE SIX AREAS.

Field No.	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %
I	.139	.132	.139	.111	.130	.130
II	.131	.132	.139	.104	.146	.120
III	.125	.132	.139	.105	.140	.126
IV	.125	.126	.132	.105	.146	.126
V	.145	.139	.145	.119	.132	.132
Average	.133	.132	.139	.109	.139	.127

TABLE V.

TOTAL PHOSPHORIC ACID AT DIFFERENT DEPTHS IN THE FIVE FIELDS OF THE LINCOLN AREA.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.130	.146	.140	.146	.132	.139
2	.146	.147	.146	.138	.117	.139
3 & 4	.168	.160	.161	.163	.171	.165
5 & 6	.184	.175	.165	.178	.160	.172

HYDROCHLORIC ACID SOLUBLE PORTIONS.

Both potash and soda were determined by Hilgard's method of acid extraction, digesting with hydrochloric acid of 1.115 sp. gr. for 5 days over the steam bath (7, p. 18). In the same extract the phosphoric acid was determined, but it should be pointed out that this is not the method of analysis for phosphoric acid employed by Hilgard, who ignites the sample and then digests it with strong nitric acid for 2 days. The data reported on these hydrochloric acid soluble fractions (Table VI) are from single analyses, while for the total constituents we use the average of concordant duplicate determinations. In some cases the acid-soluble portion is clearly out of place, even exceeding the total. The exceptional values referred to, however, do not materially affect the results as a whole. In order to determine finer differences it would be necessary both to make duplicate determinations and to use a weight of soil greater than we employed, viz., 2 to 4 gm.

TABLE VI.

POTASH, SODA AND PHOSPHORIC ACID, IN FOOT-SECTIONS FROM THE SIX AREAS, DISSOLVED BY 5-DAY DIGESTION WITH HYDROCHLORIC ACID OF SP. GR. 1.115.

POTASH.

Depth Foot	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	.96	1.15	1.13	1.15	1.09	1.25	1.12
2	1.17	1.23	1.35	1.42	1.14	1.42	1.29
3	1.06	1.27	1.33	1.46	1.16	1.43	1.28
4	1.14	1.22	1.36	1.36	1.26	1.37	1.28
5	1.16	1.21	1.32	1.38	1.29	1.38	1.29
6	1.16	1.22	1.32	1.35	1.27	1.37	1.28
Average	1.11	1.22	1.30	1.35	1.20	1.37	1.26

SODA.

1	.32	.47	.32	.48	.39	.23	.37
2	.37	.41	.42	.45	.45	.26	.39
3	.43	.49	.50	.46	.43	.33	.44
4	.33	.45	.50	.54	.51	.29	.44
5	.53	.41	.45	.46	.48	.37	.45
6	.43	.38	.47	.42	.46	.33	.41
Average	.40	.43	.44	.47	.45	.30	.42

PHOSPHORIC ACID.

1	.121	.121	.115	.104	.115	.105	.114
2	.119	.108	.105	.111	.119	.104	.111
3	.100	.110	.127	.118	.115	.111	.114
4	.133	.105	.137	.105	.145	.159	.131
5	.130	.105	.130	.133	.135	.159	.132
6	.124	.108	.092	.127	.140	.166	.126
Average	.121	.110	.118	.116	.128	.134	.121

The acid-soluble potash is lowest in the two western areas, reaching a minimum at Wauneta, where the total potash is highest, but where also there is the highest proportion of very fine sand. In each area the proportion soluble in acid is somewhat the lowest in the surface foot. The proportion of the total soda soluble in acid is lower, varying from 22 to 36 per cent, shows no distinct dependence upon the depth, and does not differ between the humid and the semi-arid areas. The proportion of the total phosphoric acid dissolved averages over 90 per cent, the lowest found being 82, and shows no dependence upon the depth.

COMPOSITION OF THE SOIL SEPARATES.

To determine whether the separates—clay, silt, etc.—from the humid eastern areas differ chemically from the corresponding ones from the western semi-arid portion, two subsoil composites were prepared and subjected to mechanical analysis. For the former we used a composite of equal weights of the third, fourth, fifth and sixth foot area samples from Lincoln, and for the latter a similar composite from Wauneta.

TABLE VII.
COMPOSITION OF SOIL SEPARATES FROM A HUMID (A) AND A SEMI-ARID SUBSOIL (B).

	Mec'l Analyses		Potash		Soda		Phos. Acid	
	A %	B %	A %	B %	A %	B %	A %	B %
Coarse to fine sand (— to 0.1 mm.)	1.94	3.25	1.46	2.83	1.25	1.67		0.057
Very fine sand (0.1 to 0.05 mm.)	5.02	54.98	2.25	2.65	1.81	1.94	0.096	0.051
Silt (0.05 to 0.005 mm.).....	56.83	22.41	2.56	2.64	1.73	1.40	0.096	0.057
Clay (0.005 to —).....	32.24	14.24	2.19	2.42	0.33	0.37	0.126	0.120
Material soluble in HCl.....	11.72	15.25	2.21	2.76	6.22	1.24	5.820	1.850
Original material	100.00	100.00	2.53	2.70	1.24	1.42	0.171	0.138
Portion of material dissolved by the 1% HCl	11.72	15.25	0.038	0.145	0.107	0.065	0.102	0.097

¹ By difference.

In order to disintegrate thoroughly the floccules in which the soil particles were cemented together by carbonates, the soil was washed on the filter with hydrochloric acid until the washings gave no test for lime or magnesia. It was then washed free of acid and separated into clay, silt, very fine sand and a coarser fraction, which included the fine, medium and coarse sands. In each case the medium sand constituted about one-fourth of this fraction, while coarse sand was practically absent. The leachings and wash waters were collected, evaporated, and analyzed for potash, soda and phosphoric acid. In the four soil separates the total potash, soda and phosphoric acid were determined by the methods described above. Table VII shows both the proportions of the different separates and the chemical composition of these.

In the humid subsoil the potash is somewhat higher in the silt, and very much lower in the coarsest fraction, than in either the clay or the very fine sand, while in the semi-arid sample it is similar in the silt and the very fine sand and higher than in the clay but lower than in the coarsest fraction. Thus the silt and the very fine sand from the western area are alike and only slightly richer in potash than the silt from the eastern area. These two fractions together have been found to constitute from 77 to 95 per cent¹ of the weight of each of the area composites, the silt predominating in all except the Wauneta samples, and the proportion of very fine sand being lowest in the eastern two areas. The coarsest fraction forms such a very small proportion of any of the loess samples that it may be ignored. In the three other groups of separates the variation in potash is comparatively slight, the clay, which contains the least, having about nine-tenths as much as the silt, which contains the most. The comparatively slight variation in the distribution of the potash over the region is in accord with the variations in mechanical composition, together with the found composition of the separates.

In both subsoils the soda was highest in the very fine sand and much the lowest in the clay, it being in the latter but slightly more than one-fourth as high as in the original material and less than one-fifth as high as in the very fine sand. These variations are extreme, compared with those found for the potash. Accordingly we should expect to find a greater variation in the distribution of soda, as is actually the case.

In the case of both subsoils the acid used to remove the carbonates dissolved out over half of the total phosphoric acid, but only a small part of the potash and soda. From the semi-arid subsoil there was dissolved about four times as much potash but only about half as much soda as from the humid subsoil. This in comparison with the data in Table VI indicates that the relative solubility of these constituents is not the same in a cold dilute, as in a hot, concentrated, mineral acid.

It should be pointed out that the composition of these separates—especially of the clay—is not to be expected to be similar to that of those obtained by the method commonly used in this country, namely, deflocculation by means of prolonged violent shaking with a very dilute ammonia solution, followed by repeated decantations of the "clay-water" and the evaporation of this along with the clay. Also, the proportions of the various separates are different from those found by the common method, the effect of the hydrochloric acid treatment being to increase the finest separate, the so-called "clay."

¹ According to analyses by Mr. C. O. Rost, by the method described in Bureau of Soils Bulletin 84 (1912). These will be reported in the next paper in the series which will appear in *Soil Science*, Vol. I, No. 5, May, 1916.

CITRIC ACID SOLUBLE PORTIONS.

The uniformity in the distribution of the total potash, and to a lesser degree also that of the total phosphoric acid, in these Nebraska loess soils is such that there seems to be little promise of results of interest in further such analyses. Almost the same may be said of the portions soluble in strong hydrochloric acid. The situation, however, seems entirely different when we consider only the portions soluble in weak solvents. Attention has already been called to the much greater solubility of the potash of the western subsoil, when cold 1 per cent hydrochloric acid is used. A study of the solubility in 1 per cent citric acid solution has given unexpected results. The data reported in Tables VIII, IX and X were secured by shaking 200 gm. of soil with 2,000 c.c. of 1 per cent citric acid solution at frequent intervals through 7 days (6, p. 159). The potash and the phosphoric acid were determined in 500 c.c. aliquot portions, corresponding to 50 gm. of soil. A difference of .001 per cent of P_2O_5 or K_2O would be indicated by .008 gm. magnesium pyrophosphate or .0026 gm. potassium platinochloride, thus giving some actual significance to figures in the third decimal place. The duplicate digestions usually give a difference of less than .001 per cent, and none was accepted when this exceeded .002 per cent P_2O_5 or K_2O . The irregular intervals which characterize shaking by hand seem to exert no distinct effect upon the amount dissolved, the duplicate digestions giving as concordant results when made at intervals of several weeks as when carried on side by side; also the results obtained by two analysts, the one working a year after the other, were strictly concordant. In the later work the tedious shaking by hand was replaced by the use of a machine. Seven days' shaking by hand gave the same results as five hours in the machine; eight hours with the latter gave no higher result than five, but three gave lower. The data reported in Table XIII and part of those in XI were obtained by using the five-hour agitation.

The citric acid soluble phosphoric acid and potash in the different foot sections are reported in Table VIII. The potash increases from east to west, being lowest in the two eastern areas and highest in the extreme western. In the former it decreases somewhat in passing from the first to the sixth foot, while in the latter it distinctly increases. The intervening three areas show an intermediate behavior. The distribution of the citric acid soluble potash agrees with neither that of the total amount nor with that of the part soluble in hot strong hydrochloric acid. The increase in the solubility from east to west, and, in the western areas, from the surface downward, accompanies an increase in the carbonate content which must serve to neutralize a portion of the acid and so to lessen its solvent action. Thus in the Wauneta area the carbon dioxide content of the six area-composites, ranged in order from the first to the

sixth foot, are: 0.09, 0.07, 0.59, 1.67, 1.78 and 1.68 per cent. The carbonate contained in 200 gm. of the sixth foot sample would be sufficient to neutralize just about half of the citric acid contained in 2,000 c.c. of the solution used.

TABLE VIII.
POTASH AND PHOSPHORIC ACID SOLUBLE IN 1 PER CENT CITRIC ACID SOLUTION.

POTASH (K_2O).

Depth Foot	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	.047	.044	.048	.044	.032	.036	.042
2	.058	.055	.049	.042	.025	.032	.043
3	.073	.062	.057	.046	.021	.025	.047
4	.083	.066	.061	.049	.020	.023	.050
5	.084	.068	.064	.051	.019	.016	.050
6	.083	.067	.067	.053	.020	.016	.051
Average	.071	.060	.058	.047	.023	.025	.047

PHOSPHORIC ACID (P_2O_5).

1	.043	.040	.038	.021	.012	.010	.027
2	.045	.030	.044	.025	.016	.009	.028
3	.032	.029	.060	.047	.036	.025	.038
4	.029	.027	.050	.056	.046	.045	.042
5	.026	.026	.044	.057	.050	.057	.043
6	.026	.029	.041	.055	.055	.064	.045
Average	.033	.030	.046	.043	.036	.035	.037

To ascertain whether all the fields of the eastern areas are characterized by a greater amount of soluble potash in the upper layers of the soil, and those of the western areas by the reverse, determinations were made for the first and sixth foot samples from all the fields of the two extreme areas—Weeping Water and Wauneta (Table IX). In the former all the fields show an excess of potash in the first foot, it being about twice as great as in the sixth, while in the latter all show less in the first foot, in which it is, in general, about two-thirds as high as in the sixth.

TABLE IX.
CITRIC ACID SOLUBLE POTASH IN THE DIFFERENT FIELDS OF THE OUTER AREAS.

Field	Weeping Water			Wauneta		
	First Foot	Sixth Foot	Ratio ¹	First Foot	Sixth Foot	Ratio ¹
No.	%	%	%	%	%	%
I	.031	.017	55	.057	.080	140
II	.034	.015	44	.051	.082	161
III	.039	.016	41	.043	.091	212
IV	.029	.016	55	.052	.078	150
V	.035	.015	43	.050	.077	154
Average	.034	.016	48	.051	.082	163

¹ The percentage in the first foot = 100.

In contrast with the potash the citric acid soluble phosphoric acid, considering the amount in the whole six-foot layer, does not increase from east to west, but is similar in the extreme areas, with the maximum in the intermediate. In the surface two feet it increases from east to west, while in the fifth and sixth it decreases. In the more easterly areas it shows an increase from the surface downward, while in the most westerly area it decreases markedly. The data for the first and the sixth foot sections from the fields of the outer areas (Table X) indicate that this difference is an area characteristic.

TABLE X.
CITRIC ACID SOLUBLE PHOSPHORIC ACID IN DIFFERENT FIELDS OF THE
OUTER AREAS.

Field No.	Weeping Water			Wauneta		
	First Foot %	Sixth Foot %	Ratio ¹ %	First Foot %	Sixth Foot %	Ratio ¹ %
I	.009	.049	544	.030	.026	87
II	.008	.050	625	.036	.031	87
III	.013	.053	408	.046	.028	61
IV	.013		...	.036	.028	77
V	.011		...	.034	.025	74
Average	.011		...	.036	.028	77

¹The percentage in the first foot = 100.

Thus we find that the citric acid soluble potash and phosphoric acid show very marked differences according to the depth of the soil layer, in the most easterly areas the former decreasing and the latter increasing, while in the most westerly area the conditions are reversed (fig. 2).

It was evident that the decrease in the amount of citric acid soluble phosphoric acid in the western areas might be due to the greater amount of carbonates in the lower sections. Hilgard (8, p. 339) has suggested that in using the citric acid extraction one make "allowance for such neutralization as may occur in the soil," but Hall (6, p. 160) considers that in attempting to establish the amount of immediately available plant food "no attempt should be made to add an extra amount of citric acid to combine with the carbonate; secondary solvent actions are set up both by the carbon dioxide evolved and by the calcium citrate formed; moreover, the real comparative basis of the method of analysis is destroyed."

A bulk sample of loess subsoil taken at a depth of from 4 to 7 feet from the Experiment Station farm was subjected to eight successive extractions. After each extraction 1,000 c.c. of solution was removed for analysis and the remainder of the clear liquid decanted. In order to remove the citric acid solution remaining mixed with the soil the bottles were filled with water, shaken vigorously, and allowed to stand until the liquid became clear, when it was decanted, this operation being repeated

four or five times. Then there was added 20 gm. of citric acid and enough water to bring the liquid up to the mark at which it had first stood after adding the 2,000 c.c. citric acid solution to the 200 gm. of soil. The successive extractions removed gradually decreasing amounts

Ft.

Wauneta. McCook. Holdrege. Hastings. Lincoln. W. Water.

Fig. 2—Diagram showing relative amounts of citric acid soluble potash and phosphoric acid at different depths.

of phosphoric acid, this decreasing rapidly with the first three and slowly with the later ones, as shown in Table XI.

The depressing effect of the presence of calcium carbonate is shown by lines 5 and 6 in the above table. Some of the subsoil was in the one case mixed with 2 per cent and in the other with 6 per cent of calcium carbonate. Both of these were extracted at the same time as the untreated subsoil. Only .036 and .017 per cent, respectively, were dissolved from the first and second, while the last gave .061 per cent.

The first and the sixth foot samples from the fields of the outer areas, reported in Table X, were extracted a second time with citric acid, according to the method described above. As shown in Table XII, considerably less phosphoric acid was removed in the second extraction than in the first, except in the case of the calcareous subsoils of the Wauneta

area. In the latter area the two extractions together removed an average of 0.051 per cent from the first foot and 0.056 from the sixth, evidence that the decrease in solubility with increasing depth is to be attributed to the increase in the carbonate content and that such a decrease would not

TABLE XI.
AMOUNTS OF PHOSPHORIC ACID DISSOLVED BY 1 PER CENT CITRIC ACID SOLUTION, UNDER DIFFERENT CONDITIONS, FROM A SUBSOIL (4 TO 7 FEET) FROM THE LINCOLN AREA.

	Phosphoric Acid %
1. Shaken by hand 7 days	.061
2. Shaken in machine 3 hours	.056
3. Shaken in machine 5 hours	.060
4. Shaken in machine 8 hours	.061
5. After addition of 2% CaCO_3 , shaken by hand 7 days	.036
6. After addition of 6% CaCO_3 , shaken by hand 7 days	.017
7. Repeatedly extracted with fresh solution, the mixture being shaken 3 hours in the machine each time after the first extraction.	
1st extraction	.061
2nd extraction	.036
3rd extraction	.014
4th extraction	.008
5th extraction	.004
6th extraction	.004
7th extraction	.003
8th extraction	.002
Total removed by the 8 extractions	.132

have been found had we acted upon Hilgard's suggestion to allow for the neutralizing action of the carbonates.

TABLE XII.
RELATION OF THE AMOUNT OF PHOSPHORIC ACID REMOVED BY THE SECOND EXTRACTION WITH CITRIC ACID TO THAT REMOVED BY THE FIRST. WEEPING WATER.

Field No.	First Foot			Sixth Foot		
	1st Ext. %	2nd Ext. %	Ratio ¹ %	1st. Ext. %	2nd Ext. %	Ratio ¹ %
I	.009	.008	90	.049	.036	73
II	.008		..	.050	.034	68
III	.013	.006	46	.053	.038	72
IV	.013	.006	46			..
V	.011	.006	55			..

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I	.030	.021	70	.026	.020	77
II	.036	.012	33	.031	.039	126
III	.046	.016	35	.028	.032	114
IV	.036	.011	31	.028	.030	107
V	.034	.017	50	.025	.019	76
Average	.036	.015	44	.028	.028	100

¹ The percentage in the first extraction = 100.

In the case of Fields I and III of the Weeping Water area, the only ones for which the data are complete, the first extraction removed 4.6 times as much phosphoric acid from the sixth as from the first foot, and the two extractions together 4.9 times as much. Thus the greater solubility of the phosphoric acid in the lower levels of the eastern area does not become any the less striking when a second extraction is employed.

It has been pointed out that in the case of the eastern areas the citric acid soluble phosphoric acid increases rapidly as we pass from the first to the sixth foot. To ascertain whether this increase is continued below the latter depth determinations were made of several deep samples which had been collected in connection with soil moisture studies (Table XIII). All, except Nos. 12 to 19, were from fields either on the Nebraska Experiment Station farm or not more than a mile distant, the loess on all varying from 15 to 25 feet in depth and overlying Kansan till. Nos. 12 to 18 are from a farm near Elgin, Nebraska, Nos. 17 and 18 being from an alfalfa field in which the loess deposit was found to have a thickness of 35 feet and in which the roots of the alfalfa plants had developed so freely to 30 feet that the subsoil to this depth had been practically exhausted of its available water (2, p. 118). No 19 is from a deep railway cut near Blair, Nebraska, where 25 feet of loess was removed over twenty years ago. The exposed loess subsoil has since been cropped. We do not know the depth of the loess at this place, but the deposit probably extends to at least 25 feet below the present surface, or 50 feet below the original. In general the high content of citric acid soluble phosphoric acid found in the sixth foot is continued into the deeper portions of the loess but without any marked increase. The low percentages in Nos. 11, 16, 17 and 18 seem directly connected with the presence of comparatively large amounts of carbonates.

Cameron (4, p. 77) estimates that the potash and phosphoric acid annually brought to the surface soil by capillary water is more than sufficient to replace the amounts that would be removed by "one ton per acre of dry crop containing 1 per cent potash and 0.6 per cent phosphoric acid." Where, as is the case with the soils of this study, no crop had been removed since the loess was laid down, we should expect to find a concentration of these nutrients in a readily soluble form in the surface soil. However, in the humid eastern areas we actually find a great exhaustion of phosphoric acid accompanying a distinct concentration of potash, while in the most arid areas of the west there is less readily soluble potash in the surface soil than in the lower levels, and the apparent concentration of phosphoric acid in the former is due to the neutralizing action of the carbonates in the latter.

In connection with the analytical data reported above it may be of interest to mention that, as the result of field observations and pot experiments on the loess soils of this region, we have concluded that alfalfa thrives almost as well upon the exposed loess subsoils of Eastern Nebraska as upon the surface soils. The former contain from 0.04 to 0.05 per cent nitrogen as compared with 0.20 to 0.30 in the latter. The "rawness" commonly attributed to humid subsoils must be entirely wanting, at least in so far as phosphoric acid and potash are concerned.

TABLE XIII.

CITRIC ACID SOLUBLE PHOSPHORIC ACID IN THE LOESS AT DEPTHS
GREATER THAN SIX FEET.

Series No.	Location	Depth Foot	Composite from	Phosph'c Acid %
1	Lincoln	7-12	From excavation	0.073
2	Experiment Station Farm	7-10	From 2 borings	0.066
3	Near above farm	6-11	From 1 boring	0.067
4	Same boring as No. 3	12-15	From 1 boring	0.044
5	Same field as No. 3	6-11	From 1 boring	0.069
6	Same boring as No. 5	12-15	From 1 boring	0.066
7	University Place	7-12	From 1 boring	0.067
8	Same boring as No. 7	13-15	From 1 boring	0.075
9	Same field as No. 7	7-12	From 1 boring	0.057
10	Same boring as No. 9	13-15	From 1 boring	0.070
11	University Place	7-18	From 2 borings	0.038
12	Elgin	1- 3	From 3 borings	0.015
13	Same boring as No. 12	4- 6	From 3 borings	0.044
14	Same boring as No. 12	7- 9	From 3 borings	0.040
15	Same farm as No. 12	7- 9	From 3 borings	0.047
16	Same boring as No. 15	10-12	From 3 borings	0.024
17	Same farm as No. 12	15-20	From new well	0.027
18	Same well as No. 17	21	From bottom of same well.	0.022
19	Blair	25	Exposed subsoil	0.057

Alfalfa probably makes a heavier draft upon the phosphoric acid than any other crop grown upon these soils. On one of the fields of this Experiment Station farm, which had been under cultivation a little over 40 years, alfalfa was grown from 1895 to 1907, all of it being removed as hay, giving an average yield of about 4 tons to the acre. No phosphate fertilizers, and little, if any, manure had been applied to the field. In 1912 composite samples were taken from each of the first six feet, 15 borings being used, and the citric acid soluble phosphoric acid was determined. The following percentages were found: 1st, 0.024; 2nd, 0.021; 3rd, 0.037; 4th, 0.041; 5th, 0.048; 6th, 0.075; average, 0.041. The first foot and the second show a considerably higher proportion than the average for the first and second foot of the five prairie fields of the Lincoln area, while for the other four feet the differences are not marked. In the alfalfa hay there was probably removed about 680 pounds of phosphoric acid and in the other crops about 450 pounds. The total, 1,130 pounds, would correspond to 0.037 per cent of the weight of an acre foot

of soil, assuming the latter to be 3,000,000 pounds, or more than the total amount of citric acid soluble phosphoric acid found in the first and second feet of the prairie fields. This affords a certain amount of support to the assumption that the plants have freely drawn for their supply upon the lower levels of the subsoil whenever their root distribution and the moisture conditions have permitted.

COMPARISON WITH CHERNOZEM AND ARID SOILS.

The Chernozem soils (10, p. 326) show a content of about 2.00 per cent total potash with small variations in both directions, while from 0.4 to 1.0 per cent is dissolved by 10 hours' digestion with 10 per cent hydrochloric acid on the water bath. The total soda is about 1.00 per cent, approximately half that of the potash, but a much smaller proportion of it is soluble in hydrochloric acid.

In the Nebraska loess soils the total potash and soda are somewhat higher, averaging 2.54 and 1.36 per cent, respectively, but bear about the same relation to one another. Digestion with hydrochloric acid of specific gravity 1.115 for 120 hours dissolved an average of 1.26 per cent potash and .42 per cent soda, the latter being here also the less soluble. The data on the acid soluble portions are not directly comparable, as the digestion of the Chernozem soils was made with a weaker acid and for a much shorter period.

The total phosphoric acid content of the Chernozem soils (10, p. 327) varies from .05 to occasionally more than .30 per cent, but usually the amounts lie between .15 and .30 per cent, the acid soluble portion constituting about four-fifths. This is appreciably higher than in the Nebraska loess soils, which show an average of .127 for the surface foot and of .135 for the first six feet, with a variation, in the case of very composite samples, between .104 to .184 per cent. In the Chernozem soils the phosphoric acid of the immediate surface (4 to 8 inches) is somewhat higher than in the underlying layers. The same has been found to be true for the Nebraska loess soils when different sections of the first foot are compared.¹

The transition soils, while in general somewhat richer in total potash and slightly poorer in phosphoric acid, may on the whole be considered as very similar to the Russian Chernozem in potash, soda and phosphoric acid.

The data on the zeolithic (acid soluble) portions are directly comparable with those reported by Hilgard (9, p. 424), in a comparison of arid and humid soils. He finds the acid-soluble potash and soda to be much higher in arid than in humid soils, while the phosphoric acid in the one is similar to that of the other. The comparison is shown in Table XIV,

¹ Unpublished data of Alway, F. J., and Rost, C. O.

where the data for the surface foot samples from the Nebraska loess are reported. The soils from all the areas resemble arid soils, those from the most easterly as much as those from the western, semi-arid areas.

TABLE XIV.

COMPARISON OF THE TRANSITION SOILS WITH ARID AND WITH HUMID SOILS IN REGARD TO ACID-SOLUBLE POTASH, SODA AND PHOSPHORIC ACID.

	Potash %	Soda %	Phos. Acid %
Arid soils. Average of 313 soils (Hilgard)	.73	.26	.12
Humid soils. Average of 466 soils (Hilgard)	.22	.09	.11
Western two areas (from 10 fields)	1.05	.40	.12
Intermediate two areas (from 10 fields)	1.14	.40	.10
Eastern two areas (from 10 fields)	1.17	.31	.11

SUMMARY.

The soils studied represent the first six foot-sections from five virgin prairie fields in each of six so-called "areas" in Nebraska, located between the Missouri River and the western limit of the loess, a distance of more than 300 miles, in which, while the temperature conditions, wind velocity and relative humidity are quite uniform, there is a great range in aridity, the annual precipitation decreasing from more than 30 inches in the east to less than 20 in the west, while the relative aridity exhibits a still greater range on account of the increase in the rate of evaporation which accompanies the decrease in precipitation.

The total potash is very uniform in distribution both from east to west and from the first to the sixth foot. While, on the whole, it is slightly lower in the eastern areas and in the higher levels, the variations are small and irregular. The proportion soluble in hot, strong hydrochloric acid seems largely dependent upon the amount of silt present, it being lowest in the most westerly area, in which, while the total potash is highest, the proportion of very fine sand also reaches its maximum.

The total soda shows somewhat more variation. In the western four areas it is quite uniformly distributed, both from area to area and from the surface downward, amounting, in general, to a little more than half as much as the total potash. In the two eastern areas it is distinctly lower; less is found in the upper than in the lower three feet, and in general it amounts to a little less than half as much as the total potash. The proportion of soda soluble in strong hydrochloric acid is lower than in the case of potash and is quite uniform.

The total phosphoric acid is still less evenly distributed. In the first two feet it seems much the same from east to west, while in the two eastern areas it is higher in amount in the lower than in the upper sec-

tions. Most of it is soluble in strong hydrochloric acid, neither location nor depth seeming to influence the proportion.

The loess consists chiefly of silt and very fine sand, with less than 5 per cent coarser than the latter. Determinations were made of the total potash, soda and phosphoric acid, as well as of the portions of these soluble in cold 1 per cent hydrochloric acid, in four separates—clay, silt, very fine sand, and coarser particles—from typical humid and semi-arid subsoils. In the very fine sand from the humid subsoil the amount of potash was found to be about the same as in the clay, but distinctly lower than in the silt. In the semi-arid subsoil it was similar in the silt and very fine sand, in both of which it was only very slightly higher than in the silt from the humid area, but was somewhat lower in the clay. In both subsoils the amount of soda was highest in the very fine sand and much the lowest in the clay. The dilute acid dissolved about four times as much potash, but only about half as much soda, from the semi-arid as from the humid subsoil, but the soluble portions of both form only a small proportion of the total amounts present. On the other hand, the dilute acid removed from both more than half the total phosphoric acid, the proportion dissolved being higher in the semi-arid subsoil. In the separates much more phosphoric acid was found in the clay than in the coarser fractions, the silt and the very fine sand, in which it was alike.

The most noteworthy differences were shown by treatment with citric acid solution. The potash soluble in this reagent was found to increase with the aridity; in the most humid areas it decreases from the surface downward, while in the least humid it increases, notwithstanding an accompanying increase in the carbonate content, which lessens the solvent action of the acid. In contrast with this, the citric acid soluble phosphoric acid was found not to increase with the aridity, when we consider the whole six-foot section; in the first two feet it increases, but in the lower four it decreases from east to west. In the most humid areas it increases rapidly from the surface to a depth of 6 feet, while in the most westerly areas it decreases. However, in the latter the difference is to be attributed to the increase in carbonate content, because when this is neutralized the sixth foot yields as much to the acid as does the first. The high content of citric acid soluble phosphoric acid is not confined to the lower portion of the six-foot sections, but continues to more than twice this depth. This high proportion of available phosphoric acid in the deep subsoil suggests a possible basis for a crop rotation in which deep-rooted legumes would provide both for the fixation of atmospheric nitrogen and for a transfer of phosphoric acid from the deep subsoil, through the medium of the plant parts, to the upper soil layers, in which the available portion is low and upon which the roots of annual and most perennial crop plants are dependent for their mineral nutrients.

In content of potash, soda and phosphoric acid the soils from all the areas resemble the Chernozem soils of Russia and the arid soils of California.

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