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BASE EXCHANGE PROPERTIES OF SOME TYPICAL TEXAS SOILS

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS
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Base exchange properties of soils are related to the retention of compounds of ammonia and potassium in the soil; the basicity, buffer capacity, and degree of acidity (pH) of the soil; and the physical condition of the soil as influenced by calcium and sodium salts in the soil or in irrigation waters. The ammonium acetate method for the determination of the total exchange capacity of soils is more accurate than the Puri method of titration or the Kappen method of titration. The total exchange capacity of about 360 representative Texas soils varied from 0.7 M.E. in dune sand to 70.7 M.E. per 100 grams in a Houston black clay. Variations are as large between different samples of the same soil type as variations between soils of the same physical character of different soil series. The exchange capacities of heavy soils are much greater than those of light soils. The bases found to be present in the exchange complex are principally calcium with small quantities of magnesium, potassium, and sodium, and also hydrogen in acid soils. There is a relation between the exchange capacities of soils and the alumina and iron oxides dissolved by strong acids. The nitrogen, phosphoric acid, potash, lime, and basicity on an average increased with the exchange capacity of the soil up to 20 M.E., after which there was little relation between these constituents and the exchange capacity.

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BASE-EXCHANGE PROPERTIES OF SOME TYPICAL TEXAS SOILS

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Soils have the power of taking some substances out of solution and replacing them with others. If a solution of ammonium sulphate is mixed with a soil, part of the ammonium goes out of solution, while calcium, magnesium, potassium, and sodium go into solution. This phenomenon, which has been known for over 75 years, was formerly termed "fixation," but is now termed "base-exchange." The bases in the soil which can be exchanged are combined with organic or inorganic acids of complex composition. As the exact composition of these acids is not known, they are termed the "base-exchange complex."

Base-exchange and the base-exchange complex are important in soils for a number of reasons. Soluble compounds of ammonia and potash, when introduced into the soils in commercial fertilizers or plant residues, by exchanging with other bases, chiefly calcium, are rendered less soluble in water. They are thereby prevented from washing out of the soil readily and are held for the use of plants. The potash held by the base-exchange complex is more available to plants than that in more stable silicates. When the bases in the base-exchange complex are replaced by hydrogen, an acid compound is formed so that the soil becomes acid. The greater the buffer capacity of the exchange complex of the soil, the greater the resistance of the soil to acidifying influences. If an acid soil is treated with a sufficient quantity of lime, the calcium of the lime replaces the hydrogen in the base-exchange complex, and the soil is made neutral or alkaline. The base-exchange complex consists of very fine particles, most of which are so fine as to be colloidal. When the complex is saturated chiefly with calcium, the particles attract one another so as to coagulate or flocculate, and this helps the soil to be porous and crumbly or to assume a condition of good tilth. When the complex contains sufficient amounts of potassium, sodium, or sometimes hydrogen, and when the soil contains only small amounts of soluble salts, the particles repel one another and become dispersed so as to deflocculate the soil. In this condition, the particles can readily become suspended in water, and may be washed down through the soil, or washed away on its surface suspended in water. Such soil may become heavy, sticky, and not easily penetrated by water. When a soil containing particles in the deflocculated condition dries out, it becomes hard and cloddy, and assumes a condition of poor tilth. In extreme cases the fine particles may fill the pores of the soil and the soil may become so hard and impervious that water and air can hardly penetrate it and plants cannot grow upon it. Irrigation waters containing sodium salts may cause the replacement by sodium of sufficient quantities of the calcium in the base-exchange complex to cause the dispersal of the fine particles and so bring about unfavorable changes in the physical character of the soil. This brief outline of some of the important relations of the base-exchange complex in soils will be expanded in some detail in the discussion which follows, and applied to Texas soils.

NATURE OF BASE-EXCHANGE IN SOILS

The portion of the soil capable of base-exchange is made up of complex inorganic and organic acids, combined with various bases, and is found in the colloidal portion of the soil. Since practically all of the soils of Texas are so low in organic matter that the organic acids can play only a very minor role in base-exchange in these soils, only the inorganic acids will be considered in the following discussion. Kelly and his coworkers (6, 10 to 15), Fraps and Fudge (7, 8), and Baver and Scarseth (4) claim that several acids occur in different exchange complexes. Such acids vary considerably in physicochemical properties, principally in the dissociation constant of the acid. Baver and Scarseth (4) state that soil material capable of base-exchange may originate in a number of ways, that the properties of the material will vary with the factors conditioning their development, and that the nature of the soil acids involved in base-exchange is solely a function of the kind and extent of weathering, and is independent of the parent material. Kelley, Dore, and Brown (15) found that the colloids from an old soil derived from granite and formed under conditions of intensive weathering had a total exchange capacity of 18.3 M.E. per 100 grams. Those from a soil likewise derived from granite in a semiarid region where weathering was limited had an exchange capacity of 57.2 M.E. The colloids of older and more weathered soils therefore had a much lower exchange capacity than those of younger soils which had been subject to less intensive weathering. Pierre and Scarseth (19) found that the soil acids formed under conditions of high weathering were weaker than those of soils less highly weathered. A number of investigators (4, 8, 15, 19) have shown a relation between the acids of the exchange complex and the ratio of alumina to silica in the soil colloids. In general, soils with colloids having a low ratio of alumina to silica, as compared with soils with a high ratio, tend to be more highly buffered, to have a higher total exchange capacity, and to contain acids which are stronger. Kerr (16, 17), Vanselow (22), and others claim that the acids of the base exchange complex are monobasic. The inorganic base-exchange complex is thus shown to be made up of a number of complex alumino-silicic acids, combined with different bases or with hydrogen, and differing in strength and composition, depending upon conditions of their development.

The mechanism of base exchange is simple, and is a special case of a general phenomenon in chemistry known as metathesis, in which two different acids, combined with different bases and in contact with each other, exchange part of their bases. The reaction in the case of soils may be represented by the equation

$$CaX_2 + 2NH_4C_2H_3O_2 \rightleftarrows Ca(C_2H_3O_2)_2 + 2NH_4X.$$

The base exchange complex (represented by X) combined with calcium reacts partly with ammonium acetate to form calcium acetate and an ammonium salt of the base exchange complex. The reaction is reversible, and the direction in which it tends is determined by the relative quantities of each of the compounds present. In the equation given, the direction is to the right, since calcium complex and ammonium acetate were assumed to be the only compounds present at the start of the reaction. If the quantity of the compounds on the right side of the equation are increased, the reaction is forced to the left. At equilibrium, all four compounds are present and the reaction never goes to completion in either direction if the products of the reaction are not removed from the soil. Other salts react with the soil in the same manner as the ammonium acetate discussed above.

METHODS FOR THE ESTIMATION OF TOTAL EXCHANGE CAPACITY

The total exchange capacity of a soil may be considered as the sum of all of the bases, and also hydrogen if any, which are combined with the exchange complex of the soil. In order to express the sum as a chemical unit, the bases are usually calculated to their equivalent in combining power of hydrogen. The unit usually used is 1 milligram of hydrogen, termed 1 milliequivalent or M.E. In base-exchange work, the M.E. referred to is usually in 100 grams of soil.

A number of methods have been proposed for determining the total base exchange capacities of soils. Most of them depend upon the replacement of all the bases, including hydrogen, by ammonia, and the estimation of the ammonia in the soil complex. Kelley and Brown (14) used barium hydroxide to neutralize the hydrogen, followed by ammonium chloride to replace the bases with ammonia. Pierre and Scarseth (19) used barium acetate followed by ammonium chloride, securing somewhat lower results than by the method of Kelley and Brown. Schollenberger and Dreibelbis (21) proposed the use of ammonium acetate, and it has been used by other workers. Since the excess of ammonium acetate is easily removed, the method is convenient. The ammonium acetate method was used in the work here reported.

The Ammonium Acetate Method

The method finally used for the determination of total exchange capacity is essentially the same as that described by Schollenberger and Dreibelbis (21) and Chapman and Kelley (6). The details of the method are as follows: Ten grams of soil in a Gooch crucible provided with a disc of filter paper were leached with 250 cc of neutral, normal ammonium acetate solution. Suction was applied to expedite the leaching, care being taken that it was not too rapid to allow complete reaction. After the ammonium acetate solution had leached through, the excess was washed out with 95 per cent ethyl alcohol. Tests for ammonia in the washings were made with Nessler's solution. After complete removal of the excess ammonia, the soil was transferred to 800 cc Kjeldahl flasks, water and light magnesium oxide were added, and the liberated ammonia was distilled into standard hydrochloric acid. The excess acid was then titrated with standard ammonium hydroxide. In the case of calcareous soils, the calcium carbonate was destroyed by preliminary treatment with a slight excess of hydrochloric acid. Fraps and Fudge (7) have shown that such treatment did not destroy the exchange complex.

Method of Titration—Puri

Two methods have been proposed for estimating the total exchange capacity from the determination of the quantity of acid consumed or neutralized by the soil. These methods are much more rapid than either the ammonium acetate or the ammonium chloride method. In the Puri method (20), the carbonates in the soil are first estimated by titrating the soil with 0.5 N sulfuric acid in the presence of aluminum chloride and calcium sulfate, with bromcresol green and bromthymol blue as inside indicators. Next, to estimate total exchange capacity, hydrochloric acid equivalent to the carbonate content is added to 10 grams of soil in a 500 cc reagent bottle. Then 100 cc of 0.1 N hydrochloric acid is added and the mixture shaken. The solution is filtered and the soil washed several times with 0.05 N hydrochloric acid and then with water. The filtrate is made up to volume and an aliquot titrated with standard sodium hydroxide, with phenolphthalein as an indicator.

The Puri method was compared with the ammonium acetate method on a number of soils, with the results given in Table 1. The results by the Puri method are in most cases appreciably higher than those by the ammonium acetate method. This is probably due to the extraction by the acid of bases from other soil compounds in addition to those from the exchange complex. The method may be used for rapid approximate results but we do not consider it to be accurate.

The Puri method is not adapted to the estimation of the base exchange capacity of acid soils, since only the bases and not the hydrogen would neutralize the acid. With such soils, the results would be too low.

The amounts of calcium carbonate estimated by the Puri method were compared with amounts estimated by liberating the carbon dioxide with hot dilute acetic acid, absorbing it in standard barium hydroxide, and titrating the barium hydroxide with standard hydrochloric acid (7, p. 11). A comparison of the results is given in Table 1. In general, the agreement is fairly close, although there are notable exceptions. The method of Puri does not measure very small quantities of carbonates. In the four soils of highest carbonate content, it did not show nearly as much carbonate as was actually present. Since the method for total exchange capacity is corrected by results of the carbonate estimation, any error in the latter will cause a corresponding error in the former. The Puri method for carbonates may be considered to be a rapid approximate method.

Method of Titration—Kappen

In the Kappen method (9) for the estimation of total exchange capacity, 50 grams of soil is stirred or shaken with 250 cc of 0.1 N hydrochloric

Table 1. Comparison of three methods for estimating total exchange capacity

Laboratory number	Soil type	Carbonates in soil: By absorption of CO_2 M.E.	Carbonates in soil: By direct titration (Puri) M.E.	Total exchange capacity: Ammonium acetate method M.E.	Total exchange capacity: Acid method of Puri M.E.	Total exchange capacity: Acid method of Keppen M.E.
26103	Crockett fine sandy loam	0.26	0	4.93	9.00	3.29
29450	Amarillo fine sandy loam	2.40	0	6.80	14.30	4.20
31888	Webb fine sandy loam	0.12	0	8.58	12.00	5.24
31820	Amarillo fine sandy loam	0.98	0	9.15	10.70	7.25
31802	Yahola fine sandy loam	61.10	60.62	10.90	31.70	....
25883	Willacy fine sandy loam	7.92	5.64	11.61	21.80	12.27
25865	Lomalto clay loam	20.14	18.24	13.40	28.90	14.44
31884	Hidalgo clay loam	254.80	236.00	17.59	44.00	....
25891	Raymondville fine sandy loam	26.80	27.76	19.12	66.90	17.42
31905	Victoria clay loam	11.00	11.26	19.22	29.20	18.30
29436	Wilson clay	1.04	1.14	20.40	25.70	17.48
31321	Amarillo silty clay loam	2.88	2.88	20.62	30.90	....
25905	Laredo silt loam	317.60	301.88	20.68	28.30	....
29434	Wilson clay	1.34	0.88	21.00	33.10	18.64
31833	Spur fine sandy loam	14.20	7.00	21.46	42.40	13.85
29426	Crockett clay loam	0.99	0	23.36	22.20	....
29438	Lufkin fine sandy loam	0.05	1.26	23.90	32.10	....
29425	Crockett clay loam	0.79	0	25.90	23.50	....
29365	Amarillo fine sandy loam	0.11	0	30.10	8.50	24.41
26089	Catalpa clay	118.00	115.92	35.08	43.40	....
25967	Houston clay	2.10	2.38	35.78	40.00	24.93
25959	Irving clay	2.00	1.88	38.22	38.10	25.82
25869	Point Isabel fine sandy loam	91.20	68.74	38.60	52.70	....
26823	Lake Charles clay	8.80	10.62	45.10	49.80	....

acid for one hour. The suspension is then allowed to stand overnight. The clear, supernatant liquid is decanted the next morning, and 125 cc is titrated with standard sodium hydroxide, phenolphthalein being used as the indicator. In this method, the products of the reaction are not removed by leaching with acid, so that the acid consumed represents a state of equilibrium between soil and acid, rather than the total capacity of the soil to neutralize acid. Fraps and Fudge (7) have shown that on the average under these conditions about 13 per cent of the exchange complex does not react with the acid. In the Kappen method, no attempt is made to correct for the portion of the acid which is used by the carbonates of the soil, nor for the portion used by soil materials other than carbonates and bases in the exchange complex. This method is therefore unsuitable for soils containing appreciable amounts of calcium carbonate. It is also unsuitable for acid soils, since only the bases will react with the acid.

Results by the Kappen method on a number of soils are compared in Table 1 with the results by the ammonium acetate method. As could be expected, the results are too low. They are decidedly lower than those secured by the Puri method. We consider the Puri method better than the Kappen method, but neither method is as accurate as the ammonium acetate method.

TOTAL EXCHANGE CAPACITY OF TYPICAL TEXAS SOILS

The total base-exchange capacity of about 360 Texas soils was determined by the ammonium acetate method already described. The type

Table 2. Total exchange capacity of typical Texas soils

Laboratory number of surface soil	Type Name	County	Surface soil			Subsoil		
			Depth inches	Basicity per cent	Total Exchange capacity M.E.	Depth inches	Basicity per cent	Total Exchange capacity M.E.
20196	Abilene clay loam	Coleman	0–8	1.84	29.60	8–30	......	24.82
9297	Amarillo fine sandy loam	Lubbock	0–18	0.69	11.11	......	......	......
31331	Amarillo fine sandy loam	Potter	0–7	0.52	8.33	7–19	0.53	9.54
31820	Amarillo fine sandy loam	Potter	0–7	0.57	9.15	7–12	0.25	9.20
9382	Amarillo clay loam	Lubbock	0–12	0.74	14.91	12–24	0.93	18.90
12655	Bastrop sand	Brazos	......	0.24	3.50	......	0.08	2.55
12653	Bastrop fine sandy loam	Brazos	......	1.70	11.54	......	0.45	8.80
12657	Bell clay	Brazos	......	2.03	24.29	......	1.43	26.36
21222	Bell clay	Henderson	0.10	2.20	44.37	10–36	4.95	44.28
26079	Bell clay	Navarro	0–7	2.61	46.36	7–19	3.59	44.08
29523	Bowie fine sandy loam	Van Zandt	0–7	0.26	2.51	7–19	0.24	4.74
18538	Bowie very fine sandy loam	Red River	0–10	0.43	4.05	16–36	0.89	12.69
31896	Brennan fine sandy loam	Frio	0–7	0.16	6.31	7–19	0.10	4.11
12590	Caddo fine sandy loam	Camp	......	0.45	5.48	......	0.35	4.21
9161	Caddo fine sandy loam	Harrison	0–8–10	0.25	3.23	10–16	0.20	5.21
21809	Cahaba fine sandy loam	Henderson	0–6	0.45	5.00	6–20	0.05	2.39
26089	Catalpa clay	Navarro	0–7	7.12	35.08	7–19	7.41	37.96
12572	Crawford clay loam	Ellis	......	3.18	44.21	......	3.88	43.52
21771	Crockett fine sandy loam	Henderson	0–10	0.28	6.66	10–26	0.78	4.95
23954	Crockett fine sandy loam	Milam	0–7	0.70	12.44	7–19	1.05	24.73
25969	Crockett fine sandy loam	Navarro	0–7	0.30	7.12	7–19	0.56	16.22
26103	Crockett fine sandy loam	Navarro	0–7	0.25	4.92	7–19	0.65	14.69
12512	Crockett fine sandy loam	Washington	0–5	0.75	15.10	5–	1.08	24.37
29533	Crockett very fine sandy loam	Van Zandt	0–7	0.35	12.24	7–18	0.30	9.08
12667	Crockett loam	Brazos	......	0.40	9.96	......	0.48	12.25
12518	Crockett loam	Washington	......	0.94	13.71	......	1.00	18.49
29427	Crockett clay loam	Brazos	0–7	1.22	28.85	7–19	1.92	34.78
26099	Crockett clay loam	Navarro	0–7	1.47	31.54	7–19	1.14	22.24
18234	Denton clay	Tarrant	0–8	1.23	31.80	8–36	8.93	31.02
25871	Dune sand	Willacy	0–7	0.41	.69	7–19	0.42	1.16
12576	Durant (Now Wilson) fine sandy loam	Ellis	0–12	2.33	20.27	12–	......	25.50
12531	Durant (Now Wilson) very fine sandy loam	Ellis	......	3.63	19.23	......	5.88	20.44
12584	Durant (Now Wilson) loam	Ellis	......	1.67	29.80	......	1.59	31.34
12574	Durant (Now Houston) clay	Ellis	......	2.98	5.93	......	2.57	36.97
31880	Duval fine sandy loam	Frio	0–7	0.23	7.31	7–19	0.40	8.00
31892	Duval fine sandy loam	Frio	0–7	0.21	5.31	7–19	0.30	9.16
26083	Ellis clay	Navarro	0–7	1.56	32.58	7–19	2.27	35.70
12582	Elis clay	Ellis	......	10.9	32.52	......	12.3	36.08
31804	Fritch fine sandy loam	Potter	0–7	0.75	11.56	7–19	0.75	12.92
18210	Frio fine sandy loam	Erath	0–15	0.88	5.50	15–36	0.63	8.78
29331	Frio silt loam	Midland	0–7	8.95	11.76	7–19	13.3	11.38
7223	Frio silty clay loam	Edwards	0–12	......	25.30	12–	37.26	23.96
23950	Frio clay	Milam	0–7	26.3	31.46	7–19	31.7	30.96
26817	Guadalupe silty clay loam	Victoria	0–7	18.9	19.24	7–15	19.1	16.40
20724	Hockley fine sandy loam	Harris	0–7	0.23	4.13	7–19	0.10	3.00
26819	Hockley fine sandy loam	Victoria	0–7	0.14	2.70	7–19	0.45	5.96
12500	Houston loam	Washington	......	0.55	8.64	......	0.40	16.42
12498	Houston clay loam	Washington	......	1.13	27.38	......	1.21	......
12568	Houston clay	Ellis	0–12	6.96	47.79	12–	7.00	50.08
23952	Houston clay	Milam	0–7	11.7	34.68	7–19	15.00	33.23
25967	Houston clay	Navarro	0–7	1.72	35.78	7–19	1.49	16.15
26085	Houston clay	Navarro	0–7	3.71	39.98	7–19	3.17	41.76
21073	Houston clay	Rockwall	0–7	19.7	34.54	7–19	33.5	43.14
12502	Houston black clay	Ellis	......	7.43	41.82	......	8.41	44.53
12535	Houston black clay	Ellis	......	8.99	43.38	......	......	43.67
23956	Houston black clay	Milam	0–7	5.28	53.06	......	6.95	53.28
26095	Houston black clay	Navarro	0–7	4.17	51.44	7–19	4.35	51.42
25961	Houston black clay	Navarro	0–7	5.11	43.88	7–19	6.43	60.64
18546	Houston black clay	Red River	0–14	6.39	38.10	14–36	6.83	37.87
9313	Houston black clay	Lamar	0–6	0.26	36.62	......	2.00	36.56
21069	Houston black clay	Rockwall	0–7	6.93	70.66	7–19	7.94	......
18226	Houston black clay	Tarrant	0–10	5.69	47.12	10–36	17.83	39.74
12570	Houston stony clay	Ellis	......	21.38	48.44	......	23.08	44.13
25959	Irving clay	Navarro	0–7	1.15	38.22	7–19	1.25	35.22
26075	Irving clay	Navarro	0–7	1.76	36.86	7–19	1.82	37.97
20722	Katy fine sandy loam	Harris	0–7	0.35	3.48	7–19	0.08	2.32
21215	Kirvin fine sandy loam	Henderson	0–6	0.20	2.76	6–26	0.45	9.68
24007	Kirvin fine sandy loam	Nacogdoches	0–7	0.59	6.03	7–19	0.54	7.05
23964	Kirvin fine sandy loam	Milam	0–7	0.53	10.88	7–19	1.05	26.89
18230	Kirvin fine sandy loam	**Tarrant**	0–7	0.38	4.98	7–36	0.28	16.57

Table 2. Total exchange capacity of typical Texas soils (Continued)

Laboratory number of surface soil	Type Name	County	Surface soil			Subsoil		
			Depth inches	Basicity per cent	Total Exchange capacity M.E.	Depth inches	Basicity per cent	Total Exchange capacity M.E.
21807	Kirvin gravelly fine sandy loam	Henderson	0–10	0.33	4.15	10–36	0.33	10.03
24005	Kirvin clay loam	Nacogdoches	0–7	1.15	16.20	7–19	1.35	15.28
9347	Lake Charles clay loam	Harris	0–9	0.99	18.13	9–18	1.18	18.31
20720	Lake Charles clay loam	Harris	0–7	0.80	18.20	7–19	1.33	21.28
20728	Lake Charles clay	Harris	0–7	1.35	30.48	7–19	1.25	35.90
26823	Lake Charles clay	Victoria	......	2.52	45.23	7–19	2.39	22.46
25905	Laredo silt loam	Willacy	0–7	15.30	14.98	7–19	12.5	11.45
21773	Laredo silty clay loam	Cameron	0–15	8.09	23.00	15–30	23.14	16.74
21775	Laredo clay loam	Cameron	0–12	14.6	29.98	12–36	20.1	27.88
21812	Leaf fine sandy loam	Henderson	0–10	0.23	5.41	10–36	0.80	24.38
25873	Lomalto fine sandy loam	Willacy	0–7	0.46	3.54	7–19	0.59	3.24
25865	Lomalto clay loam	Willacy	0–7	2.07	13.40	7–19	3.52	16.88
21803	Lufkin fine sand	Henderson	0–6	0	1.66	6–36	0.20	.75
12674	Lufkin fine sandy loam	Brazos	12–20	0.57	9.67	20–	0.27	5.81
29438	Lufkin fine sandy loam	Brazos	0–7	1.14	23.90	7–19	1.36	35.74
29440	Lufkin fine sandy loam	Brazos	0–7	0.33	9.48	7–19	1.10	31.45
8836	Lufkin fine sandy loam	Franklin	0–11	0.20	8.95	11–23	0.55	21.38
21217	Lufkin fine sandy loam	Henderson	0–6	0.25	5.99	1–36	0.75	21.86
12520	Lufkin fine sandy loam	Washington	......	0.94	19.44	......	1.30	27.60
18540	Lufkin sandy clay loam	Red River	0–6	0.49	15.78	6–36	0.98	20.06
12677	Lufkin clay loam	Brazos	......	1.31	27.35	6–18	1.29	29.42
31890	Miguel fine sandy loam	Frio	0–7	0.36	8.28	7–19	1.00	19.43
20544	Miles fine sandy loam	Coleman	0–15	0.35	7.21	15–36	1.10	27.67
12647	Miller fine sandy loam	Brazos	......	0.79	6.44	......	0.74	11.12
29431	Miller fine sandy loam	Brazos	0–7	0.71	2.88	7–19	0.30	2.15
12514	Miller fine sandy loam	Washington	......	6.78	8.29	......	8.40	22.57
22234	Miller silty clay loam	Wichita	0–7	4.38	16.76	7–19	6.89	21.34
12649	Miller clay	Brazos	......	0.47	15.56	......	1.49	26.52
29429	Miller clay	Brazos	0–7	7.62	20.30	7–19	5.57	23.10
23946	Miller clay	Milam	0–7	10.9	35.96	7–19	11.8	36.74
12516	Miller clay	Washington	......	10.3	28.89	......	11.88	28.29
21224	Norfolk sand	Henderson	0–6	0.10	.64	6–36	0.10	.91
21783	Norfolk fine sand	Cameron	0–10	0.10	1.73	10–36	0.09	1.04
12594	Norfolk fine sand	Camp	0–6	0.28	1.56	......	0.22	1.48
23962	Norfolk fine sand	Milam	0–7	0.23	1.24	7–19	0.18	1.06
9139	Norfolk sandy loam	Tyler	0–6	0.07	1.59	......	0.05	2.64
21785	Norfolk fine sandy loam	Henderson	0–8	0.07	3.16	8–36	0.28	5.75
12592	Norfolk fine sandy loam	Camp	0–12	0.27	2.63	12–24	0.23	3.03
21814	Norfolk fine sandy loam	Henderson	0–12	0.13	2.91	12–36	0.29	8.08
25783	Nueces fine sand	Willacy	0–7	0.04	2.80	7–19	0.05	2.70
12676	Ochlockonee fine sandy loam	Brazos	......	0.05	3.70	......	......	......
21805	Ochlockonee very fine sandy loam	Henderson	0–8	0.50	9.25	8–36	0.65	10.55
22121	Orangeburg silt loam	Nacogdoches	......	0.10	......	......	0.30	9.61
31914	Orelia fine sandy loam	Frio	0–7	0.60	12.34	7–19	0.74	14.24
31904	Orelia clay loam	Frio	0–7	......	......	7–19	3.51	31.60
12645	Pledger clay	Brazos	......	3.01	46.30	15–70	3.53	42.89
25869	Point Isabel fine sandy loam	Willacy	0–7	5.78	8.73	7–19	6.24	10.87
25877	Point Isabel clay	Willacy	0–7	13.6	17.04	7–19	17.5	19.48
31329	Potter clay loam	Potter	0–7	6.33	18.65	7–19	26.8	27.78
31321	Pullman silty clay loam	Potter	0–7	1.10	20.16	7–19	1.53	22.96
31323	Pullman silty clay loam	Potter	0–7	1.23	20.66	7–19	1.52	16.16
31325	Pullman silty clay loam	Potter	0–7	0.89	18.75	7–19	1.48	26.67
29317	Randall clay	Midland	0–7	1.43	30.08	7–19	1.35	28.02
31327	Randall clay	Potter	0–7	1.48	27.60	7–19	1.52	28.63
25891	Raymondville fine sandy clay loam	Willacy	0–7	2.51	19.12	7–19	4.83	19.35
25893	Raymondville clay loam	Willacy	0–7	4.53	23.82	7–19	2.40	21.14
29333	Reagan fine sandy loam	Midland	0–7	3.54	10.60	7–19	6.30	11.63
29335	Richfield fine sandy loam	Midland	0–7	0.62	9.12	7–19	2.26	10.42
21777	Rio Grande silty clay loam	Cameron	0–15	19.3	22.74	15–36	17.7	13.18
21219	Ruston fine sandy loam	Henderson	0–8	0.10	1.71	8–24	0.10	1.47
24009	Ruston fine sandy loam	Nacogdoches	0–7	0.40	1.88	7–19	0.33	5.52
7147	San Antonio silty clay loam	Kendall	0–10	4.72	44.04	......	8.66	38.26
18232	San Saba clay	Tarrant	0–12	3.42	35.38	12–30	3.22	38.52
29311	Springer fine sand	Midland	0–7	0.01	1.72	7–19	0.08	2.00
29315	Springer fine sandy loam	Midland	0–7	0.41	5.48	7–19	0.47	9.65
29364	Springer fine sandy loam	Midland	0–7	0.20	4.14	7–19	0.30	30.10
29449	Springer fine sandy loam	Midland	0–7	0.45	5.20	7–19	0.46	6.80
31833	Spur fine sandy loam	Potter	0–7	1.02	14.20	7–19	5.19	19.75
31806	Spur clay loam	Potter	0–7	2.21	18.16	7–19	4.55	20.26

Table 2. Total exchange capacity of typical Texas soils (Continued)

Laboratory number of surface soil	Type Name	County	Surface soil			Subsoil		
			Depth inches	Basicity per cent	Total Exchange capacity M.E.	Depth inches	Basicity per cent	Total Exchange capacity M.E.
12671	Susquehanna fine sandy loam	Brazos	......	0.37	8.28	......	0.85	25.51
12586	Susquehanna fine sandy loam	Camp	......	0.25	4.04	......	0.19	10.28
12596	Susquehanna fine sandy loam	Camp	......	0.29	5.95	......	0.25	3.08
12578	Susquehanna (now Leaf) fine sandy loam	Ellis	......	0.69	6.98	......	0.65	10.90
18544	Susquehanna very fine sandy loam	Red River	0–12	0.43	3.70	12–36	0.78	24.73
12598	Susquehanna gravelly loam	Camp	......	0.51	2.32	......	0.25	1.99
12588	Susquehanna stony loam	Camp	......	0.19	4.64	......	0.20	7.46
12661	Tabor fine sandy loam	Brazos	......	0.30	4.46	......	0.75	16.13
12641	Trinity fine sandy loam	Brazos	0–12	0.74	6.58	12–24	0.89	18.71
12643	Trinity clay	Brazos	......	2.33	39.56	......	1.94	......
12580	Trinity clay	Ellis	......	14.0	29.60	......	13.3	27.60
21769	Trinity clay	Henderson	0–8	7.55	52.72	8–36	6.09	51.88
23972	Trinity clay	Milam	0–7	22.4	47.29	7–19	21.4	43.42
25965	Trinity clay	Navarro	0–7	5.13	55.62	7–19	3.30	52.45
26091	Trinity clay	Navarro	0–7	6.34	51.94	7–19	3.76	50.00
26093	Trinity clay	Navarro	0–7	7.75	53.82	7–19	7.21	51.52
21067	Trinity clay	Rockwall	0–7	25.9	45.81	7–19	29.4	43.98
12504	Trinity clay	Washington	......	2.76	19.28	......	3.56	25.28
22226	Vernon fine sandy loam	Wichita	0–7	0.45	6.16	7–19	0.67	......
25781	Victoria fine sandy loam	Willacy	0–7	1.38	15.88	7–19	1.28	15.67
17698	Victoria fine sandy loam	Brooks	......	0.21	7.24	......	4.80	7.04
25903	Victoria fine sandy loam	Willacy	0–7	0.96	4.72	7–19	1.01	16.51
25895	Victoria fine sandy clay loam	Willacy	0–7	1.71	21.14	7–19	1.28	23.18
25885	Victoria fine sandy clay loam	Willacy	0–7	0.71	14.37	7–19	0.94	20.25
31905	Victoria clay loam	Frio	0–7	1.70	19.22	......	......	23.34
25887	Victoria clay loam	Willacy	0–7	1.55	19.31	7–19	2.11	19.14
9298	Victoria clay	Willacy	0–12	7.22	72.2	......	......	......
25881	Victoria clay	Willacy	0–7	1.95	24.27	7–19	2.82	24.29
31888	Webb fine sandy loam	Frio	0–7	0.26	8.58	7–19	0.95	18.98
25883	Willacy fine sandy loam	Willacy	0–7	1.06	11.61	7–19	0.59	10.22
25785	Willacy fine sandy loam	Willacy	0–7	0.93	12.92	7–19	0.81	16.07
12679	Wilson fine sandy loam	Brazos	......	0.53	9.17	10–20	0.65	15.31
25963	Wilson fine sandy loam	Navarro	0–7	0.23	7.52	7–19	0.36	9.66
26097	Wilson fine sandy loam	Navarro	0–7	0.31	6.40	7–19	0.34	9.04
29525	Wilson very fine sandy loam	Van Zandt	......	0.44	14.01	......	0.90	18.09
12533	Wilson loam	Ellis	......	14.6	37.24	......	9.95	35.89
12659	Wilson clay loam	Brazos	......	0.90	23.43	......	0.90	22.40
23958	Wilson clay loam	Milam	0–7	1.13	19.20	7–19	1.18	23.54
25971	Wilson clay loam	Navarro	0–7	0.76	18.00	7–19	1.31	29.70
21071	Wilson clay loam	Rockwall	0–7	1.30	26.38	7–19	1.60	38.80
12639	Wilson clay	Brazos	......	0.34	28.97	12–24	1.39	30.45
29436	Wilson clay	Brazos	0–7	1.16	20.40	7–19	1.01	26.56
29434	Wilson clay	Brazos	0–7	1.31	27.16	7–19	1.41	29.03
26115	Wilson clay	Brazos	0–7	1.20	26.06	7–19	1.05	22.92
18542	Wilson clay	Red River	0–10	1.85	46.76	10–36	7.52	48.18
18548	Wilson clay	Red River	0–12	1.84	48.07	......	1.23	49.28
21077	Wilson clay	Rockwall	0–7	2.27	53.66	7–19	1.31	......
18205	Windthorst fine sandy loam	Erath	0–8	0.17	6.40	8–16	0.88	6.22
18208	Windthorst fine sandy loam	Erath	0–8	0.35	2.73	8–36	0.88	20.32
31802	Yahola fine sandy loam	Potter	0–7	4.50	10.90	7–19	7.04	11.85
12651	Yahola silt loam	Brazos	......	10.94	16.08	......	8.40	11.30

name, basicity, and total exchange capacity of the surface and subsoils are given in Table 2. The results are expressed as milligram equivalents (M.E.) per 100 grams of soil. One M.E. in 100 grams is equivalent to 500 parts per million of calcium carbonate, or 280 parts per million of calcium oxide. The soils are arranged in alphabetical order according to the name of the series, and the list is believed to be representative of the various kinds of soil found in Texas.

The exchange capacities of the soils studied varied from 0.69 M.E. in dune sand to 70.7 M.E. in a sample of Houston black clay. In general, the sands had a low exchange capacity, the sandy loams a little higher one, the loams a still higher, and the clays the highest. The exchange complex is associated with the clay particles, so that as a rule the greater the quantity of clay particles, the higher the exchange capacity. Subsoils as a general rule had higher exchange capacities than surface soils, but this was not always the case. Some examples to the contrary to be found in Table 2 are Pullman silty clay loam, No. 31323; Abilene clay loam, No. 20196; Bastrop sand; Bell clay, No. 26079; Caddo fine sandy loam, No. 12590; Crockett fine sandy loam, No. 21771; and others.

Variations in Exchange Capacity Between Different Samples of the Same Type

It is a matter of some significance to know whether there is as much variation between the exchange capacities of samples of the same soil type, taken in different localities, as there is between samples of different soil series. The variation in exchange capacity for surface soils and subsoils of samples of the same type taken from different localities is given in Table 3. Six of the types are named as fine sandy loams and four as clays. The surface soils of the Norfolk fine sandy loam had the lowest average exchange capacity and also showed the least variation. Three of the series of fine sandy loams averaged very nearly the same in exchange capacity. The difference between the highest and the average was about 5 M.E., about equal to the average exchange capacity. The Crockett fine sandy loam and the Lufkin fine sandy loam had high exchange capacities and the difference in M.E. between the average and the highest exchange capacity was not large, although the percentage difference was about the same as for the other soils. The Wilson clay had a lower average exchange capacity than the other three clays and was also more variable. The maximum deviation of the exchange capacity of surface soils of the last three clays was about 9 to 11 M.E. from the average, while that of the Wilson clay was about 21 M.E. from the average.

The subsoils of the fine sandy loams had higher average exchange capacities than the surface soils but varied approximately to the same extent. The subsoils of the clays averaged about the same as the surface soils and varied approximately to the same extent.

The exchange capacities of soils of the same physical character apparently resemble one another closely, even though the soils are of different series; variations in samples of the same series having the same physical character are generally as large as between samples of different series. It would require averages of many more samples than were here used to ascertain if the average exchange capacity can be used as a definite characteristic of a particular series, but it is certainly not an outstanding characteristic.

Table 3. Variations in total exchange capacity within soil types

Type	Number of samples	Total exchange capacity (M.E.)							
		Surface soils				Subsoils			
		Lowest	Highest	Average	Range	Lowest	Highest	Average	Range
Norfolk fine sandy loam.......	4	2.63	3.16	2.88	.53	2.64	8.08	4.89	5.44
Kirvin fine sandy loam.......	5	2.76	10.88	5.76	8.12	7.05	26.89	14.04	19.84
Susquehanna fine sandy loam..	4	4.04	8.28	6.31	4.24	3.08	25.51	12.44	22.43
Crockett fine sandy loam......	5	4.92	15.10	9.25	10.18	14.69	24.73	16.99	10.04
Lufkin fine sandy loam.......	6	5.99	23.90	12.90	17.91	5.81	31.45	23.97	25.64
Wilson clay.................	6	20.40	53.66	32.90	33.26	22.92	49.28	34.40	26.36
Houston clay................	5	34.54	47.79	38.55	13.25	16.15	50.08	36.87	33.93
Houston black clay..........	8	36.62	53.06	44.51	16.44	36.56	60.64	49.59	24.08
Trinity clay................	8	19.28	55.62	44.51	36.34	25.28	52.45	43.27	27.17
Average of fine sandy loams				7.42	8.18	.....	......	14.46	16.68
Average of clays...........	....	......	......	40.12	24.82	.....	......	41.03	27.88

Relation Between Exchange Capacity and Soil Texture

The exchange capacity, as pointed out in the previous section, is more closely related to the texture than to the soil series. The classification of 187 samples of surface soil according to texture indicated by the name of the type is given in Table 4. Practically all the samples named as sand had an exchange capacity less than 5 M.E. The exchange capacity of fine sandy loams varied from about 2 to 20 M.E., but most of the samples had an exchange capacity less than 10. Only eleven of the samples examined classed as loams and silt loams; they were quite variable, the exchange capacity ranging from less than 5 to nearly 45 M.E.

187 samples

Table 4. Relation between total exchange capacity and soil texture

Group by exchange capacity	Sands Number	Fine sandy loams Number	Loams and silt loams Number	Clay loams Number	Clays Number	Total Number
0–5.00..................	8	27	2	0	0	37
5.01–10.00..............	0	35	2	0	1	38
10.01–15.00.............	0	13	2	3	0	18
15.01–20.00.............	0	4	1	14	3	22
20.01–25.00.............	0	2	1	7	4	14
25.01–30.00.............	0	0	1	7	6	14
30.01–35.00.............	0	0	0	1	8	9
35.01–40.00.............	0	0	1	0	10	11
40.01–45.00.............	0	0	1	1	6	8
45.01 +.................	0	0	0	0	16	16
Total................	8	81	11	33	54	187

The 33 clay loams had exchange capacities varying from 10 to about 45 M.E., but most of them had an exchange capacity of 15 to 30 M.E. The soils classed as clay were also quite variable, with exchange capacities ranging from 5 to 70 M.E., but most of them had exchange capacities exceeding 30 M.E.

These differences between soils of different textures are also brought out in Table 3 and in Table 5. In Table 5 the average exchange capacities for different series and different textures are given. The average exchange capacities of the fine sandy loams varied from 5.5 to 12.9; of the clay loams, from 16.2 to 30.2; and of the clays, from 17.0 to 44.5 M.E.

Table 5. Total exchange capacity of surface soils of different series

Series	Fine sandy loams M. E.	Clay loams M. E.	Clays M. E.
Frio	5.50	25.30	31.46
Kirvin	5.76	16.20	
Miller	5.87		25.18
Trinity	6.58		44.51
Wilson	7.70	21.75	32.90
Point Isabel	8.73		17.04
Crockett	9.25	30.20	
Victoria	11.56	19.22	24.27
Lufkin	12.90	27.35	
Average	8.21	23.34	29.23

Relation to Location in the State

The exchange capacity of a number of soils averaged by textures as indicated by the name of the type for different soil regions is given in Table 6. There are more regular differences between the different regions with the fine sandy loams than between those with the clay loams or clays. The groups are arranged in order according to the average exchange capacities of the fine sandy loams. This arrangement is found to be approximately related to the rainfall, since the Gulf Coast Prairie area receives the highest rainfall, the East Texas Timber Country comes second, the Blackland Prairie ranks third, the Rio Grande Plain stands fourth, and the Rolling Plains and High Plains have the lowest rainfall. The sandy loam soils of the region with the highest rainfall have the lowest average base exchange capacity; those of the region with the lowest rainfall have the highest base exchange capacity. The base exchange complex is probably formed by weathering of the original parent material, and is decomposed and reduced in quantity by subsequent

Table 6. Average total exchange capacity of surface soils of different soil regions

Soil Region	Fine sandy loams M. E.	Clay loams M. E.	Clays M. E.
Gulf Coast Prairie	3.45	18.18	37.86
East Texas Timber	5.38	27.35	
Blackland	7.84	23.88	38.39
Rio Grande Plains	8.16	21.29	24.26
Rolling and High Plains	9.14	21.26	28.84
Average	6.79	22.39	32.34

weathering. The relation of the exchange capacity to the rainfall may be due to the exchange complex either having been decomposed to a greater extent in the regions of high rainfall than in regions of low rainfall, or having been washed down into the subsoil to a greater extent. The variations in exchange capacity may also be due to the considerable differences in the material from which the soils of these regions were originally derived. The soils of the Blackland Prairie and of the Rio Grande Plains, Rolling Plains, and High Plains were derived from more calcareous material than were those of the Gulf Coast Prairie and the East Texas Timber Country, and they still retain many properties derived from the original parent material.

The differences in exchange capacities between the clay loams and clays from the various regions were irregular and less marked than those between the fine sandy loams. The fine sandy loams, of course, are more porous and are therefore more susceptible to the weathering action of both water and air.

RELATIVE PROPORTION OF BASES HELD BY THE BASE-EXCHANGE COMPLEX

The bases in the base-exchange complex of neutral soils are usually composed chiefly of calcium, though some magnesium, sodium, and potassium are also present, and sometimes small amounts of hydrogen. In an acid soil, the base exchange complex contains larger relative amounts of exchangeable hydrogen than that in a neutral soil. In a solonetz soil, the base-exchange complex contains a large proportion of sodium, which makes the soil particles run together, causes the soil to be lumpy, and prevents the free entrance of air and water (1, 2, 3, 14).

In order to ascertain the character of the bases held by the base-exchange complex in Texas soils, analyses were made of a number of representative soils. In the noncalcareous soils, hydrogen was determined by electrometric titration of the ammonium acetate leachate with 0.1 N ammonium hydroxide. The other bases removed by ammonium acetate were determined by essentially the same method outlined by Schollenberger and Dreibelbis (21). The soil was leached with ammonium acetate solution, and the leachate was freed of ammonium acetate, organic matter, iron, and manganese. Calcium was determined in the filtrate by precipitation as the oxalate and conversion to the sulfate, which was weighed. Magnesium was precipitated with ammonium phosphate and ignited and weighed as the pyrophosphate. Potassium and sodium were determined in another aliquot after removing the ammonium acetate by precipitation of the other bases with ammonium hydroxide, carbonate, and oxalate, and after weighing the ignited combined chlorides of potassium and sodium secured from the filtrate, precipitating the potassium as the chloroplatinate, and estimating the sodium by difference.

An alcoholic solution of potassium chloride was used for estimating calcium and magnesium in calcareous soils, since calcium carbonate is highly soluble in ammonium acetate solution. The method was essentially that of Chapman and Kelley (5, 6). The soil was leached with two successive portions of a 0.2 N solution of potassium chloride in 63 per cent ethyl alcohol. The difference between the calcium in the first and second portions was considered to be the exchangeable calcium. The sum of the exchangeable calcium, potassium, and sodium (in M. E.) was subtracted from the total M. E. exchange capacity, and the difference was considered to be M. E. of magnesium.

Table 7. Exchangeable bases, in M. E., in some Texas soils

Laboratory Number	Soil type	Basicity per cent	Total Exchange capacity M.E.	Sum of bases M.E.	Calcium M.E.	Magnesium M.E.	Potassium M.E.	Sodium M.E.	Hydrogen M.E.
23962	Norfolk fine sand	.24	1.24	1.66	.93	.32	.07	.17	.17
24009	Ruston fine sandy loam	.40	1.88	2.34	1.22	.39	.07	.13	.53
12598	Susquhanna gravelly loam	.20	2.32	3.77	1.85	.45	.17	.18	1.12
29431	Miller fine sandy loam	1.21	2.88	4.98	3.56	.60	.16	.19	.47
21785	Norfolk fine sandy loam	.07	3.16	3.24	1.48	.36	.15	.26	1.25
20724	Hockley fine sandy loam	.23	4.13	6.40	5.28	.65	.19	.10	.18
12590	Caddo fine sandy loam	.45	5.48	10.38	8.28	1.15	.36	.17	.42
24007	Kirvin fine sandy loam	.59	6.03	6.24	4.30	.94	.29	.27	.44
22226	Vernon very fine sandy loam	.45	6.16	7.33	5.40	1.43	.33	.17	0
31896	Brennan fine sandy loam	.16	6.31	7.68	4.36	1.14	.49	.18	1.51
26097	Wilson fine sandy loam	.31	6.40	8.18	4.72	.98	.21	.28	1.99
25969	Crockett fine sandy loam	.30	7.12	6.88	4.15	1.37	.45	.32	.59
31880	Duval fine sandy loam	.23	7.31	8.14	4.88	1.17	.29	.15	1.65
12671	Susquehanna fine sandy loam	.69	8.28	12.06	5.85	2.97	.31	.29	2.64
31890	Miguel fine sandy loam		8.28	11.27	5.68	2.03	.71	.27	2.58
31331	Amarillo fine sandy loam	.52	8.33	●8.33	5.66	●2.05	.43	.19	0
25869	Point Isabel fine sandy loam	5.78	8.46	●9.08	7.50	●0	.54	1.04	0
31888	Webb fine sandy loam	.26	8.58	10.32	5.49	1.82	.37	.87	2.27
21805	Ochlockonee very fine sandy loam	.50	9.25	11.53	6.86	2.53	.31	.24	1.59
29440	Lufkin fine sandy loam	.33	9.48	11.15	6.83	2.13	.54	.16	1.49
22122	Orangeburg silt loam	.30	9.61	10.60	5.98	2.25	.54	.31	1.52
31804	Fritch fine sandy loam	.75	11.56	15.33	10.63	2.55	.75	.17	1.23
25883	Willacy fine sandy loam	1.06	11.61	●11.61	7.80	●2.84	.69	.28	0
25865	Lomalto clay loam	2.07	13.40	●18.93	3.9	●0	.59	14.44	0
25781	Victoria fine sandy loam	1.38	15.88	●15.88	11.10	●3.20	.78	.80	0
25971	Wilson clay loam	.76	18.00	15.45	6.28	8.10	.20	.46	.41
25891	Raymondville clay loam	2.51	19.12	●19.12	13.60	●2.39	1.96	1.17	0
21779	Victoria clay loam	1.64	19.60	●22.70	19.60	●0	1.69	1.41	0
29317	Randall clay	1.43	30.08	●30.08	19.80	●7.47	.81	1.00	0
26099	Crockett clay loam	1.42	31.54	●31.54	25.00	●4.98	.62	.94	0
25967	Houston clay	1.72	35.78	●35.78	28.60	●4.92	.79	1.47	0
23967	Miller clay	9.46	35.96	●35.96	29.80	●2.94	.96	2.26	0
26075	Irving clay	1.76	36.86	●36.86	31.20	●2.69	.25	1.28	0
12643	Trinity clay	2.33	39.56	●39.56	30.60	●7.32	.76	.88	0
25961	Houston black clay	5.11	43.88	●43.88	38.60	●3.92	.78	.58	0

●Caculated

Data secured by the procedures outlined on 35 representative soil types are presented in Tables 7 and 8. In practically all of the non-calcareous soils, in which magnesium was determined and not calculated, the sum of the bases in M. E. was greater than the M. E. of total exchange capacity. That is, the quantity of bases going into solution was greater than the quantity which was taken up by the soil. This means that the ammonium acetate solution removed bases from soil materials in addition to replacing those in the base-exchange complex. It is probable that a similar error due to solubility also occurs in the case of the soils for which the magnesium was calculated, and that the value given for magnesium in these soils is correspondingly low.

Table 8. Individual exchangeable bases (M.E.) in percentage of the total bases

Laboratory Number	Soil type	Total Exchange capacity M.E.	Calcium per cent	Magnesium per cent	Potassium per cent	Sodium per cent	Hydrogen per cent
23962	Norfolk fine sand	1.24	75.0	25.8	5.6	13.7	13.7
24009	Ruston fine sandy loam	1.88	64.9	20.7	3.7	6.9	28.2
12598	Susquehanna gravelly loam	2.32	79.7	19.4	7.3	7.8	48.3
29431	Miller fine sandy loam	2.88	123.6	20.8	5.6	6.6	16.3
21785	Norfolk fine sandy loam	3.16	46.8	11.4	4.7	8.2	39.6
20724	Hockley fine sandy loam	4.13	127.8	15.7	4.6	2.4	4.4
12590	Caddo fine sandy loam	5.48	151.1	21.0	6.6	3.1	7.7
24007	Kirvin fine sandy loam	6.03	71.3	15.6	4.8	4.5	7.3
22226	Vernon very fine sandy loam	6.16	87.7	23.2	5.4	2.8	0
31896	Brennan fine sandy loam	6.31	69.1	18.1	7.8	2.9	23.9
26097	Wilson fine sandy loam	6.40	73.8	15.3	3.3	4.4	31.1
25969	Crockett fine sandy loam	7.12	58.3	19.2	6.3	4.5	8.3
31880	Duval fine sandy loam	7.31	66.8	16.0	4.0	2.1	22.6
12671	Susquehanna fine sandy loam	8.28	70.7	35.9	3.7	3.5	31.9
31890	Miguel fine sandy loam	8.28	68.6	24.5	8.6	3.3	31.2
31331	Amarillo fine sandy loam	8.33	67.9	24.6	5.2	2.3	0
25869	Point Isabel fine sandy loam	8.46	88.7	0	6.4	12.3	0
31888	Webb fine sandy loam	8.58	64.0	21.2	4.3	10.1	26.5
21805	Ochlockonee very fine sandy loam	9.25	74.2	27.4	3.4	2.6	17.2
29440	Lufkin fine sandy loam	9.48	72.0	22.5	5.7	1.7	15.7
22122	Orangeburg silt loam	9.61	62.2	23.4	5.6	3.2	15.8
31804	Fritch fine sandy loam	11.56	92.0	22.1	6.5	1.5	10.6
25883	Willacy fine sandy loam	11.61	67.2	24.5	5.9	2.4	0
25865	Lomalto clay loam	13.40	29.1	0	4.4	107.8	0
25781	Victoria fine sandy loam	15.88	69.9	20.2	4.9	5.0	0
25971	Wilson clay loam	18.00	34.9	45.0	1.1	2.6	2.3
25891	Raymondville clay loam	19.12	71.1	12.5	10.3	6.1	0
21779	Victoria clay loam	19.60	100.0	0	8.6	7.2	0
29317	Randall clay	30.08	65.8	24.8	2.7	3.3	0
26099	Crockett clay loam	31.54	79.3	15.8	2.0	3.0	0
25967	Houston clay	35.78	79.9	13.8	2.2	4.1	0
23967	Miller clay	35.96	82.9	8.2	2.7	6.3	0
26075	Irving clay	36.86	84.6	7.3	.7	3.5	0
12643	Trinity clay	39.56	77.4	18.5	1.9	2.2	0
25961	Houston black clay	43.88	88.0	8.9	1.8	1.3	0
	Average % (35 soils)		76.8	18.4	4.8	7.6	11.5
	Average		70.4				

In one soil, No. 25865, a Lomalta clay loam, the quantity of sodium found exceeded the total exchange capacity, probably because of the presence of soluble sodium salts. The data for all the soils except this one show that a very small proportion of the exchange complex is combined with sodium and potassium in the soils studied. Calcium is by far the most abundant of the bases, while magnesium is intermediate. A number of the sandy or loamy soils contained considerable quantities of exchangeable hydrogen. The ammonium acetate solution leached through the heavy soils was alkaline, indicating an absence of exchangeable hydrogen in these soils.

On the average, about 65 per cent of the exchange complex acids (expressed as M. E.) are combined with calcium, 15 per cent with magnesium, 4 per cent with potassium, 7 per cent with sodium, and 10 per cent with hydrogen, but many soils contain no hydrogen at all in the base exchange complex, as measured by the method used.

From the work of Wilson (23), the exchangeable calcium, magnesium, and potassium extracted by ammonium chloride from 12 New York soils can be calculated to be in the average proportion of 68.7 per cent calcium, 22.7 per cent magnesium, and 8.0 per cent potassium in percentage of the total M. E. of the three. Sodium and hydrogen were not reported. These New York soils contain, on the average, larger proportions of potassium and magnesium and smaller proportions of calcium than the Texas soils.

Table 9. Average relation between total exchange capacity and chemical composition of surface soils

Total exchange capacity M.E.	Number of soils	Average total exchange capacity M.E.	Nitrogen per cent	Phosphoric Acid		Potash			Lime per cent	Alumina and iron oxide per cent	Basicity per cent	pH
				Total per cent	Active ppm.	Total per cent	Acid soluble per cent	Active ppm.				
0–5.00	36	3.01	.038	.034	43	0.75	.10	127	0.14	1.73	0.27	6.79
5.01–10.00	38	6.77	.058	.045	52	0.98	.20	228	0.51	3.34	0.83	7.02
10.01–15.00	18	12.47	.082	.054	123	1.48	.45	439	0.65	5.00	1.83	7.35
15.01–20.00	22	17.83	.116	.086	220	1.43	.47	410	1.77	6.47	2.25	7.21
20.01–25.00	14	22.08	.119	.100	267	1.63	.65	548	2.03	8.47	2.82	7.43
25.01–30.00	14	28.07	.111	.076	98	1.26	.62	336	4.54	9.86	2.88	7.08
30.01–35.00	9	32.19	.106	.085	115	1.48	.54	322	3.82	12.20	1.41	7.15
35.01–40.00	11	37.16	.117	.073	96	1.27	.45	294	2.72	11.56	3.33	7.36
40.01–45.00	6	44.40	.146	.099	117	1.17	.62	361	3.60	13.80	5.27	7.38
45.01–50.00	10	46.92	.155	.099	112	1.10	.53	297	3.76	14.54	4.39	7.23
50.01–55.00	6	52.77	.135	.086	142	1.19	.50	448	3.02	14.72	5.56	7.28
55.01–60.00	1	55.62	.132	.045	195	0.64	......	479	......	......	5.13	7.32
70.01–75.00	2	72.43	.047	.069	195	0.68	.68	422	3.34	14.17	7.08	7.40

Relation Between the Total Exchange Capacity of Soils And Their Chemical Composition

The total exchange capacities of 187 surface soils and 185 subsoils were compared with the chemical composition of the soils. The average data secured in the study are given in Table 9 for surface soils and in Table 10 for subsoils; the soils are grouped with reference to their total exchange capacity.

The nitrogen, phosphoric acid, potash, lime, alumina and iron oxide, and basicity on an average increased regularly with increase in total exchange capacity until the total exchange capacity exceeded about 20 M. E., after which there was little relation of these constituents to the exchange capacity. The active phosphoric acid, active potash, and nitrogen in a given group of surface soils was considerably higher than that in the subsoils, but there was very little difference between surface and subsoils with respect to the other constituents. The variation in pH was not sufficient in any of the groups to be significant, and the data under that heading show simply that the most of Texas soils are either neutral or slightly alkaline. The data presented show that soils which are low in total exchange capacity are also low in soluble chemical constituents, though high in insoluble silicate and silica.

Table 10. Average relation between total exchange capacity and chemical composition of subsoils

Total exchange capacity	Number of soils	Average total exchange capacity M.E.	Nitrogen per cent	Phosphoric acid		Potash			Lime per cent	Alumina and iron oxide per cent	Basicity per cent	pH
				Total per cent	Active ppm.	Total per cent	Acid soluable per cent	Active ppm.				
0–5.00	24	2.53	.023	.023	22	0.79	.11	93	0.17	2.13	0.25	6.81
5.01–10.00	23	8.04	.043	.032	15	0.89	.21	174	0.44	5.84	0.61	6.71
10.01–15.00	20	11.70	.056	.061	96	1.33	.40	266	1.70	6.42	2.17	7.22
15.01–20.00	25	17.41	.072	.056	91	1.45	.44	338	1.62	10.41	1.90	7.12
20.01–25.00	27	22.53	.079	.066	155	1.39	.53	308	2.59	9.01	2.67	6.64
25.01–30.00	20	27.41	.073	.060	84	1.36	.46	258	3.43	10.00	2.43	7.29
30.01–35.00	9	31.64	.082	.061	30	0.98	.43	162	4.54	16.41	1.64	7.25
35.01–40.00	16	37.12	.091	.068	76	1.16	.44	255	3.87	13.19	3.05	7.21
40.01–45.00	11	44.49	.120	.094	108	1.13	.61	226	7.84	15.08	5.92	7.60
45.01–50.00	3	49.15	.089	.051	44	0.84	.17	203	1.00	16.11	4.17	7.00
50.01–55.00	6	51.76	.111	.079	139	1.33	.68	318	2.43	16.29	5.79	7.50
60.01–65.00	1	60.64	.103	.069	206	1.07	.27	185	4.29	13.95	6.43	7.55

Relation Between Exchange Capacity and Quantity of Iron and Aluminum Oxide Soluble in Strong Acid

The relation of the total exchange capacity to the ratio of silica to alumina in the colloids extracted from the soil has been studied by a number of investigators (4). No attempt to isolate and analyze the soil colloids was made in the work reported in this Bulletin. For many of the soils used, however, data were available relative to the total content of alumina and ferric oxide soluble in strong hydrochloric acid. These were extracted from 10 grams of soil by 100 cc of 1.115 sp. gr. hydrochloric acid heated for 10 hours in a boiling water bath. The percentages of the combined oxides of iron and aluminum dissolved by this treatment compared with the total exchange capacity of 259 soils are summarized in Table 11.

Table 11. Relation between total exchange capacity and alumina and ferric oxide dissolved by strong acid

Total exchange capacity M. E.	Alumina and ferric oxide							
	0–3 per cent	3–6 per cent	6–9 per cent	9–12 per cent	12–15 per cent	15–18 per cent	18–21 per cent	Number of soils
0–5	43	7	0	0	1	0	0	51
5–10	16	20	2	1	2	0	0	41
10–15	1	17	7	2	0	0	0	27
15–20	0	8	20	2	2	1	0	33
20–25	0	2	11	9	2	1	0	25
25–30	0	2	6	11	3	0	0	22
30–35	0	0	0	5	5	1	0	10
35–40	0	0	1	5	14	1	0	21
40–45	0	0	0	4	7	4	0	15
45–50	0	0	0	0	3	5	1	9
50–55	0	0	0	0	2	2	1	5
Total number of soils	60	56	47	39	36	15	2	259

A high degree of correlation between the M. E. of exchange capacity and the percentage of iron and aluminum oxides dissolved from the soils is evident from the data. Of 92 soils with less than 10 M. E. exchange capacity, 59 contained less than 3 per cent iron and aluminum oxides, and 86 contained less than 6 per cent. Of 29 soils with more than 40 M. E. exchange capacity, none contained less than 9 per cent iron and aluminum oxides, and 25 contained more than 12 per cent. Of 60 soils with less than 3 per cent oxides, 59 had exchange capacities of less than 10 M. E. Of 53 soils containing more than 12 per cent oxides, 40 had exchange capacities greater than 35 M. E. The correlation coefficient was + .878 ± .010.

The curve which best shows the relation between total exchange capacity and oxides of iron and aluminum corresponds to the equation

$$y = 1.75\ x + .08\ x^2$$

in which y is the exchange capacity in M. E. and x is the percentage of iron and aluminum oxides dissolved by strong acid. The relation between the exchange capacity and the iron and aluminum oxides in M. E. per 100 grams of soil was also calculated ($Al_2O_3 = 6$ M. E.). Since iron and alumina were not separately determined in all the soils considered, the calculation was based upon the assumption that they were present in equal molecular proportion, which is not exactly correct. On this basis, 1 per cent of combined oxides was equivalent to 45.85 M. E. The equation for the relation between exchange capacity and combined iron and aluminum oxides, when both are expressed as M. E. per 100 grams of soil, is

$$y\ (\text{exchange capacity}) = .06\ x + .0002\ x^2$$

SUMMARY

The absorption of ammonia from ammonium acetate was used to measure the base exchange capacity of about 360 soils representing the principal types of Texas soils.

Titration methods of Puri and Kappen give approximate values for exchange capacity. The ammonium acetate method was more accurate than either of them.

Variations in exchange capacity between different samples of the same soil type may be as large as variations between different soil series for soils of the same physical character. The exchange capacity of heavy soils is greater than that of light soils. Soils from arid regions have higher exchange capacities than soils of similar physical character from humid regions.

The M. E. of bases combined with the exchange complex of 35 Texas soils averaged about 65 per cent calcium, 15 per cent magnesium, 4 per cent potassium, 7 per cent sodium, and 10 per cent hydrogen. Many soils, however, contained no exchangeable hydrogen, as measured by the methods used.

The nitrogen, phosphoric acid, potash, lime, alumina and iron oxide, and basicity on an average increased regularly with increase in total exchange capacity up to 20 M. E. per 100 grams, after which there was little relation of these constituents to the exchange capacity.

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