

A STUDY OF THE CHEMICAL AND PHYSICAL CHANGES PRODUCED
IN A SOIL BY THE FORMATION OF THE
ORGANIC COLLOIDAL COMPLEX

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INTRODUCTION

It has long been known that organic matter plays an important part in soil fertility. It serves to improve soils from several standpoints. Among these are improved water holding power, biological conditions, capacity to hold plant nutrients and in other ways improve soil as a medium for plant growth.

The ability to hold plant nutrients and to deliver these nutrients to growing plants is closely associated with the property of base exchange. Since base exchange plays such a prominent part in soil economy, much emphasis has been placed on this topic by soil investigators during the last two decades. The general features of the exchange properties have long been known, but the intensified research of recent years has added much to the practical interpretations of the processes involved.

In view of the great importance attached to soil organic matter in general and to that entering into base exchange capacity in particular, this investigation was undertaken. The investigation involves two important factors. One, a comparison of different methods for the determination of organic matter that enters into the exchange capacity. The other, a study of base exchange in soil as affected by the presence of organic matter.

REVIEW OF LITERATURE

The bodies of dead organisms (10) and the residues of living matter deposited on and within the soil form the material known as soil organic matter. Soil organic matter theoretically comprises only the dead residue of organisms and the various products of their decomposition. It is practically impossible, however, to separate this material from the living micro-organisms that live in the soil and carry on the task of decomposing the residues. The bulk of the bodies of micro-organisms, together with their own residues, is therefore regarded as a part of soil organic matter.

Chemically, soil organic matter comprises a mixture of a great many substances that may be classified into three groups: (1) carbohydrates, (2) proteins, (3) lignin, and (4) fats, resins, waxes and similar compounds.

The term "humus" (20) is sometimes used to designate soil organic matter. "Humus" is a name given to a group of black, sticky, or waxy, complex compounds that are derived from organic matter originating from substances that the plants have synthesized.

Much of the material that constitutes humus is derived from lignin of plant residues. It has been found that lignin and lignin-like substances have base exchange properties.

McGeorge (6) has shown that the exchange capacity of organic matter is in largest part due to ligneous compounds, and that lignin possesses a chemically equivalent exchange property. As for lignin itself, he says that the exchange capacity depends upon the methods used in preparing or separating it from the mother substance, and that

it may be subject to further increase in exchange capacity by hydrolysis or fractionation. The theory is advanced that a protein linkage is in most part responsible for the exchange property of lignerous material.

Muller (9) has proved that there is an increase in base exchange capacity of organic matter with decomposition.

Miller, Smith and Brown (8) in carrying out base exchange studies on oat straw, wheat straw, etc. found that with decomposition of these materials there was an increase in base exchange capacity, although the increase was not in the same relation to one another. Also they found that mature plants differ greatly in base exchange capacity.

Meyer (7) in exchange capacity studies on mixed organic-inorganic systems determined that the resulting mixture in every case had a lower exchange capacity than the sum of the individual exchange capacities.

In consideration of the important part played by organic matter in base exchange process, it seems that investigations dealing with this phenomena would be more profitable. Possibly the reason is the lack of a definite method for making such determinations. The few determinations of the organic base exchange capacity have been made in one of the following ways (12): (a) the organic portion of the soil is removed by an alkaline extracting solution and reprecipitated by the addition of a mineral acid, and the determination of the base exchange capacity of the organic matter is made directly; (b) the organic matter of the soil is destroyed by gentle ignition, and the base exchange capacity is determined before and after treatment, the difference representing the exchange capacity of the organic matter; (c) the organic matter of the soil is destroyed by treatment with hydrogen peroxide, and the base exchange capacity is determined as in (b).

In any of the foregoing procedures, serious objections may arise. The chief objection to (a) is that this procedure requires considerable time. Also, the exchange capacity of the organic matter depends upon the method used in preparing or separating it from the mother substance.

In (b) there is a serious threat of dehydrating the soil minerals by ignition and thus reducing the base exchange capacity of the inorganic complex. A second serious threat to this procedure is that 7 or 8 hours of ignition are required to bring about the destruction of the organic matter.

In (c) there is a possibility that the peroxide treatment might affect the inorganic base exchange capacity in a manner similar to that of ignition. McGeorge (6), however, showed that digestion with H_2O_2 does not affect the exchange capacity of synthetic zeolites. The principal objection to the use of this procedure is the inconsistency in the manner in which the oxidations have been carried out. Also, there is a lack of definite information concerning the effects of various concentrations of peroxide in making such determinations.

Broadfoot and Tyner (3) point out that the exchange capacity of organic residues varies with the cation used for saturation of the exchange complex. For instance, the absorptive capacity for ammonium was found in all cases to be considerably less than that for the divalent cations.

Bartlett, Ruble and Thomas (2) found, in using the hydrogen peroxide method of determining organic exchange capacity, that this reagent increased the inorganic exchange capacity in some of the soils.

Base exchange, (10) whether organic or inorganic, is a property

of soils that has very important practical applications. When a simple salt, such as KCl, is added to a soil, some potassium changes places in the colloidal particle with calcium, sodium and other mineral base elements, and these in turn enter into the soil solution. The result is that only a part of the potassium which was added in solution remains water soluble.

"Base exchange capacity" is a term that is used to denote the measure of the relative ability of a soil to retain basic elements. "Exchangeable cations" would possibly be a better term, for then hydrogen which also plays an important part in base exchange reactions would be included.

Ion exchange (base exchange) (19) may be defined as a reversible interchange of ions between a liquid phase and a solid body which does not involve any radical change in the solid structure. It was first observed in soil by Way in 1850. He passed a solution of KCl through a bed of soil, and found that all the potassium was removed from the solution and replaced by an equivalent amount of calcium and sodium from the soil.

Gedroiz and Hissink (20) have shown that base exchange obeys the chemical law of mass action and equilibrium. According to Gedroiz, the law of soil base exchange may be stated as follows: "Absorbed ions of soil compounds are displaced by other ions in equivalent ratio."

Only a limited quantity of an exchangeable basic element of a soil material can be brought into solution by the single addition of a displacing agent; but under leaching conditions, the displacement

can finally be made complete, as Gedroiz and Hissink have shown.

From the foregoing review of literature it can be seen that the methods used for the determination of organic matter as well as those used for determining the organic matter that enters into the exchange complex are far from satisfactory. It is hoped that the material presented in the following pages may throw a little more light on the problem.

PROCEDURE

A survey was made on ten representative Maryland soils (5) for organic and inorganic base exchange capacity. These soils were used because they varied in organic matter content and genealogy. It was thought that results obtained from these treatments might be applicable to Maryland soils in general. Also, these soils were subjected to determinations for total organic matter as well as the fraction of organic matter that is readily oxidizable. Samples of one soil were brought into the greenhouse and allowed to incubate with various treatments of organic matter, lime and fertilizer. Base exchange capacity and organic matter extractions were determined on these soils.

For the base exchange analysis, the leaching method of Schollenberger and Dreibelbis (13) was used with slight modifications for the soils which were extracted with barium acetate. The pH of this solution was adjusted to 7.0. In this method, ten grams of soil were weighed out and transferred to a leaching tube. However, instead of using tubes having a perforated porcelain disc covered by a filter paper, leaching tubes with sintered glass discs were employed. These speeded up the leaching process considerably. A rubber policeman was placed on the stem of the leaching tubes so that the soil might soak in the 150 m.l. of leaching solution over night. In the morning the policeman was removed and the solution allowed to leach through the soils. Then the leached soils were washed with successive portions of distilled water until the washings showed no tests for barium ions with dilute H_2SO_4 . Ninety-five percent alcohol was used in one or two small portions for

leaching in order to decrease hydrolysis. The washed soils were next leached with 150 m.l. of one normal potassium solution in order to displace all of the barium ions present in the exchange complex. The displaced barium was determined by using a slight modification of the method recommended by Scott (14).

The base exchange capacity was determined before and after oxidation of the soils. (For results see Table 2). The oxidation was accomplished with hydrogen peroxide, using six treatments of twenty-five m.l. of six percent hydrogen peroxide. Each portion was allowed to remain on the soil over night and then drained off the following morning by removing the policeman from the stem of the tube.

A pH determination was made on each of the soils by means of the Beckman pH meter.

Organic matter determinations were made on the soils before and after oxidation, using the wet method for total carbon (1). This method involves the oxidation of organic matter with a chromic-phosphoric-sulphuric acid mixture and the absorption of the carbon dioxide in standard sodium hydroxide.

Nine different methods for determining organic matter were used on the ten soils. The hypiodite method used was that of Norman and Peavy (11). In this analysis five grams of soil are used, water added, and iodine and sodium hydroxide placed in the bottle to form NaOI. At intervals portions are withdrawn, HCl added, the iodine titrated with $\text{Na}_2\text{S}_2\text{O}_3$. For the ammonia extraction method, a modification of the method of Cameron and Breazeale (4) was carried out. Instead of using a 3% ammonia solution, as in the method above, the soil was shaken with a 10% ammonia solution, centrifuged, the clear extract poured off and

evaporated to dryness on the hot plate. The residue was taken up with a little distilled water and dilute H_2SO_4 , and total carbon determined. The bleaching powder method made use of was that of Treadwell and Hall (17). Here five grams of soil were placed in an evaporating dish along with the bleaching powder. This was made by weighing out 5 grams, adding water to make 500 m.l. and then taking out a 20 c.c. aliquot. Ten percent KI and 1 - 1 HCl were added and the titration made with $Na_2S_2O_3$. Three grams of soil were used in the $KMnO_4$ method (17). Twenty m.l. of .1093 N $KMnO_4$ were used and the excess permanganate titrated with Mohr's Salt; ortho-phenanthroline was used as an indicator. One gram of soil was used in the Ceric Sulphate Method of analysis. This was put in an 8 inch test tube with 10 m.l. of .136 N Ceric Sulphate and heated in a boiling water bath for 15 minutes. The excess Ceric Sulphate was titrated with Mohr's Salt. A blank run was made at the same time. The Walkley-Black Method (18) makes use of only one half gram of soil. This is mixed with 10 m.l. of $Na_2Cr_2O_7$ and 20 m.l. of concentrated H_2SO_4 and heated in a hot water bath for 15 minutes. The mixture is cooled, diluted, 5 m.l. of H_3PO_4 added and titrated with Mohr's Salt. This is a modification of the original method. There is much similarity between the Thomas-Williams method (16) and the Walkley-Black method. In the former 3 grams of soil are oxidized with $Na_2Cr_2O_7$ and H_2SO_4 , cooled, diluted and an aliquot titrated with Mohr's Salt. Neither the Sulfate Cerate nor the Perchlorate Cerate methods (15) have been used before in soil work, but were employed as described for the determination of glycerol. In the first method, $(NH_4)_2Ce(NO_3)_6$ was dissolved in 0.5 molar H_2SO_4

added to 1 gram soil and heated on the water bath for 15 minutes. Mohr's salt was used for titration. The second method is very much like the first, except that approximately 35% HClO_4 is used instead of the H_2SO_4 . Sodium oxalate is used to titrate the excess oxidizing agent. In both of these methods barium diphenylamine sulfonate was used and found to be preferable to any other indicator used so far.

For all the determinations the final calculation was made to give the answer in terms of percent carbon. This was multiplied by the factor 1.724 (4) for conversion to percentage organic matter.

The samples of Beltsville silt loam were collected from the first 6 inches of soil, brought in and well mixed. Thirty-four, two gallon pots were set up, thus giving 17 treatments and checks. Each pot was given treatments as shown in Table 3. The dry organic matter, consisting of wheat straw and soybean straw was added at the rate of 10 grams per kilogram of soil, or 10 tons per acre. The green organic matter used, green wheat and green alfalfa, were added at the rate of 20 grams per kilogram of soil, or 20 tons per acre. The lime added was burnt lime, 40-50% CaO and 9-10% MgO . A 10-6-4 fertilizer was used. It as a neutral mixture, made up of Uramon, 50% muriate of potash and 20% superphosphate, and applied at the rate of $\frac{1}{2}$ gram per kilogram or $\frac{1}{2}$ ton per acre. Also used were 5 pots filled with sand and treated with the same quantities as given above. Each pota was inoculated with soil bacteria. The dry organic material was ground in a Braun Mill, while the green material was ground in a Mixablend Grinder containing water. Moisture determinations were made on the soil by means of the Hilgarde Cups and the pots kept at optimum moisture by adding distilled water at intervals, Every two or three weeks the

contents of the pots were screened, and well mixed. The incubation was carried on for approximately 300 days, at the end of which the contents of the pots were well mixed, samples were taken, air dried and screened.

The determinations made on the pots were as follows: pH value, organic matter determinations by the Thomas-Williams, Walkley-Black and by the total carbon method. Also, base exchange capacity was run before and after oxidation with H_2O_2 . All these methods have been described above and the results are given in Table 3.

DISCUSSION

Even though the data shown in the tables are more or less self explanatory, the discussion is given to emphasize certain important points and to point out the relation of the various factors. For instance, in Table 1, there can be seen the effectiveness of the methods for determining the organic matter content of the various soils. The total carbon determinations is taken as the standard.

The ammonia took out about 20% of the organic material. There seemed to be no relation between the organic matter dissolved and either the total organic matter or organic base exchange capacity. It is possible that if dilute HCl had been used prior to the ammonia treatment, higher and more significant values would have been obtained. Hypiodite removed 25-50% of organic material. The $KMnO_4$ method was much less effective, giving values a little less than half of the hypiodite. The Thomas-Williams method is similar in principle to the Walkley-Black procedure but employs a weaker oxidizing solution. It is presumable that this method evaluates the organic matter that may be expected to be well incorporated in the soil. These two methods appeared to give better and more significant values.

The three oxidizing solutions involving cerate as an oxidizing medium bear a certain relationship to one another but vary in their effectiveness. The perchlorate cerate being the mildest oxidizing medium of the group. These three methods removed the organic matter more in proportion to the organic exchange capacity than the other methods.

Bleaching powder was also used as an oxidizing agent but the results

were not included in the table. This method needs further investigation in view of the fact that only slight variations were shown in the results for highly varying soils. The values obtained ranged from 2.03 to 2.38 percent organic matter.

There is shown in Table 2 the base exchange capacity of the un-oxidized and oxidized soils and the base exchange capacity due to the organic matter alone. If the organic exchange capacity for each soil is divided by the percentage organic matter found by the different methods it is believed a relationship will be obtained. If the same numerical value is obtained for all ten soils then there is a definite relationship. This was done as is shown by the results in Table 4. A casual survey of those data indicate that for some of the methods there does seem to be a relationship between the oxidized organic matter and the organic exchange capacity. In order to check this, the standard deviation as well as the coefficient of variation were calculated for these values as well as those in Table 3. In Table 4 the smallest coefficient of variation appears in the Sulfato Cerate method where it is 0.160, and 0.195 for the Perchlorato Cerate method. The latter is not as good a value as the Sulfato Cerate method. However, when the eight soils that have the least variation are subjected to such a statistical analysis the coefficient of variation is 0.091 for the Perchlorato Cerate method and 0.118 for the Sulfato Cerate method.

The coefficient of variation value of 0.091 is considered to be very significant. The coefficient of variation values obtained for the other values which were secured by dividing the organic exchange capacity by the soluble organic matter are not considered to be significant. It would appear that the values obtained for the eight soils by the Per-

chlorato Cerate method is approximately one-tenth that of the organic exchange capacity. This would indicate that this rapid method might be used as a means of evaluating the organic exchange capacity. Although more data will have to be obtained before this can be justified. It appears as if one can estimate fairly closely the organic exchange capacity by multiplying the amount of organic matter oxidized by the Perchlorato Cerate procedure by ten.

In Table 3 it can be seen that the treatment definitely influences the organic exchange capacity. In order that the effects of this treatment can be more clearly seen the results of Table 3 are summarized in Table 5. Of the green material, green wheat very definitely decreases the base exchange capacity while green alfalfa did not lower it quite so much. In dry material the high nitrogen content had little effect on the organic exchange capacity while low nitrogen material decreased it. Organic material alone and fertilizer alone decreased the organic base exchange capacity. Also lime and fertilizer together did about the same thing. Lime alone did not decrease the values, but gave even a little higher ones. Then from these data it would seem that the organic exchange capacity can only be built up by the use of organic residues high in nitrogen that do not decompose too readily along with the judicious use of lime.

In the past the difficulty experienced in attempting to oxidize organic matter has probably been due to its close association with inorganic and mineral matter. Since a great deal of both organic and inorganic active matter is in the colloidal form this means that the organic and inorganic colloids are very closely related. The impression acquired from the literature bears out this observation as well as those

data assembled in this investigation. In the latter case the Sulfate
Cerate and Perchlorate Cerate probably oxidize the organic matter in
the relation in which it exists in the organic exchange complex.

TABLE 1. Organic Matter Content of 10 Maryland Soils as Determined by Various Methods

Soil Types Used	Percent of Organic Matter Obtained by the Different Methods								
	Hypiodite	Ammonia Extraction	Potassium Permanganate	Ceric Sulphate	Walkley- Black	Thomas- Williams	Sulfate Cerate	Perchlorate Cerate	Total Carbon
	%	%	%	%	%	%	%	%	%
Elkton Silt Loam	1.02	0.67	0.50	1.8	3.44	2.24	1.7	0.87	2.6
Sassafras Silt Loam	1.07	0.08	0.45	1.6	1.92	0.59	1.5	0.72	1.8
Portsmouth Loam	0.89	0.85	0.41	2.5	3.68	2.47	2.5	1.25	4.02
Sassafras Sandy Loam	1.10	0.24	0.57	0.73	0.79	0.11	0.98	0.33	0.75
Chester Loam	1.02	0.45	0.39	1.9	2.16	1.77	2.08	0.94	1.95
Manor Loam	1.05	0.24	0.29	2.1	2.55	1.53	2.2	0.93	2.45
Hagerstown Silt Loam	1.02	0.22	0.27	2.6	3.85	2.00	2.6	1.22	3.22
Congaree Silt Loam	1.02	0.71	0.44	2.1	3.56	2.24	2.3	0.86	1.93
Ash Gravelly Loam	0.97	0.45	0.18	2.5	5.20	3.89	2.6	1.44	5.60
Penn Silt Loam	1.03	0.37	0.36	2.3	2.88	2.00	2.5	1.05	2.56

TABLE 2. The Exchange Capacity, Percentage of Organic Matter and pH Values for the 10 Maryland Soils

Soil Types Used	Base Exchange Capacity			Percentage of Organic Matter			pH Value
	Unoxidized	Oxidized	Organic	Unoxidized	Oxidized	Lost by Oxidization	
	m.e.	m.e.	m.e.	%	%	%	
Elkton Silt Loam	11.45	5.80	5.65	2.60	0.79	1.81	4.08
Sassafras Silt Loam	10.30	2.00	8.30	1.80	0.52	1.28	7.58
Portsmouth Loam	16.62	4.00	12.62	4.02	1.19	2.83	4.57
Sassafras Sandy Loam	6.14	1.40	4.74	0.75	0.23	0.52	5.63
Chester Loam	12.27	2.80	9.47	1.95	0.58	1.37	5.16
Manor Loam	15.09	4.30	10.79	1.21	0.73	0.48	6.57
Hagerstown Silt Loam	18.29	6.90	11.39	1.59	0.95	0.64	6.98
Congaree Silt Loam	12.23	3.30	8.93	0.95	0.56	0.39	4.64
Ash Gravelly Loam	16.80	2.50	14.30	2.73	1.68	1.05	6.78
Penn Silt Loam	14.82	5.20	9.62	1.26	0.77	0.49	5.77

TABLE 3. The Effect of Organic Materials, Lime and Fertilizer on the pH Value, Organic Matter and Exchange Capacity of Beltsville silt loam soil.

Plot Number	Soil Treatment	pH Value	Percent of Organic Matter			Base Exchange Capacity		
			Thomas-Williams %	Walkley-Black %	Total Carbon %	Unoxidized m.e.	Oxidized m.e.	Organic m.e.
1 & 2	None	4.4	2.36	2.18	1.85	12.9	6.6	6.3
3 & 4	Wheat Straw	5.0	1.29	1.94	1.82	11.3	7.5	3.8
5 & 6	Wheat Straw (F)	4.7	1.49	1.85	1.97	10.4	6.7	3.7
7 & 8	Wheat Straw (L) (F)	5.1	1.42	2.04	1.90	12.0	6.3	5.7
9 & 10	Wheat Straw (L)	5.1	2.00	2.46	1.80	13.8	6.3	7.5
11 & 12	Green Wheat	4.5	1.77	2.01	1.85	8.1	6.9	1.2
13 & 14	Green Wheat (F)	4.5	1.48	2.14	1.83	12.0	6.8	5.2
15 & 16	Green Wheat (L) (F)	4.5	1.48	1.81	1.78	8.5	7.4	1.1
17 & 18	Green Wheat (L)	4.9	1.54	2.07	1.83	11.6	6.4	5.2
19 & 20	Soybean Straw	4.9	2.12	2.25	1.82	11.7	6.7	5.0
21 & 22	Soybean Straw (F)	4.7	1.83	1.70	1.78	10.7	5.2	5.5
23 & 24	Soybean Straw (L) (F)	5.5	1.55	1.75	1.83	12.2	4.7	7.5
25 & 26	Soybean Straw (L)	4.2	1.72	1.63	1.83	12.2	4.9	7.3
27 & 28	Green Alfalfa	4.6	1.48	1.78	1.78	12.5	5.8	6.7
29 & 30	Green Alfalfa (F)	4.6	1.24	2.32	1.82	11.5	5.4	6.1
31 & 32	Green Alfalfa (L) (F)	5.6	1.48	1.86	1.82	10.0	5.1	4.9
33 & 34	Green Alfalfa (L)	5.1	1.90	1.91	1.80	9.8	4.7	5.1
35	None (L) (F)	7.0	0	0	2.44	1.0	0	1.0
36	Green Wheat (L) (F)	7.0	0	0	2.37	0	0	0
37	Green Alfalfa (L) (F)	7.0	0	0	2.33	0	0	0
38	Wheat Straw (L) (F)	7.0	0	0.65	2.31	3.0	1.5	1.5

(L). Lime
(F). Fertilizer

TABLE 4. The Value Obtained by Dividing the Milliequivalent of the Organic Exchange Capacity by the Percent of Organic Matter Secured with the Different Methods of Determinations on the 10 Maryland Soils.

Soil Types Used	The Numerical Values for the Different Methods								
	Hypiodite	Ammonia Extraction	Potassium Permanganate	Ceric Sulphate	Walkley-Black	Thomas-Williams	Sulfato Cerate	Perchlorato Cerate	Total Carbon
Milton Silt Loam	5.54	8.45	11.30	3.14	1.64	2.52	3.32	6.50	2.18
Sassafras Silt Loam	7.75	10.30	1.84	5.20	4.32	14.00	5.50	11.50	4.60
Portsmouth Loam	14.10	14.90	30.04	6.00	3.44	5.15	5.05	11.01	3.14
Sassafras Sandy Loam	4.30	1.97	8.30	6.50	6.00	47.30	4.82	14.30	6.30
Chester Loam	9.25	9.25	24.20	5.00	4.38	4.35	4.55	10.10	4.85
Manor Loam	10.02	44.50	37.00	5.15	4.22	7.05	0.90	11.60	4.40
Hagerstown Silt Loam	11.01	51.50	42.00	4.36	2.95	5.68	4.35	9.30	3.52
Congaree Silt Loam	8.75	12.50	12.20	3.42	2.50	4.00	3.88	10.04	4.60
Ash Gravelly Loam	14.70	31.80	79.50	5.70	2.75	3.69	5.50	9.90	2.56
Penn Silt Loam	9.35	26.00	26.80	4.18	1.85	4.80	3.82	9.15	3.76
Averages	9.48	30.39	27.32	4.87	3.41	9.95	4.57	10.33	4.00

TABLE 5. The Effects of Soil Treatments on the Organic Exchange Capacity of a Soil.

Soil Treatments	Average Organic Exchange Capacity m.e.
Wheat Straw	5.2
Green Wheat	3.2
Soybean Straw	6.4
Green Alfalfa	5.2
Organic Materials Alone	4.2
Fertilizer Alone	4.1
Fertilizer and Lime	4.8
Lime Alone	6.3

SUMMARY

Ten representative Maryland soils were oxidized with nine different methods for determining the organic matter content. Also the base exchange capacity was determined before and after oxidation of the soils. Oxidation was performed by means of 6% H_2O_2 .

One soil was brought into the greenhouse and incubated with varying treatments of organic matter, lime and fertilizer. The base exchange capacity was also determined on these samples before and after oxidation.

From the results of all these treatments it is concluded that:

1. There is an indication that a rapid method can be devised to estimate the organic exchange capacity of the soil.
2. The use of organic materials alone may actually decrease the organic exchange capacity of a soil.
3. The most satisfactory method to increase base exchange capacity is by the use of nitrogenous organic material and lime.

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