Project Report: The Effect of Organic Content on Lime Treatment of Highly Expansive Clay

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Final Project Report: The Effect of Organic Content on Lime Treatment of Highly Expansive Clay

EXECUTIVE SUMMARY

The effects that organic material has on swell potential and strength of lime-treated expansive clay were determined through laboratory testing. Four soils (one natural and three manufactured) subjected to different laboratory tests were used to analysis the effects of organic material in lime treatment. The laboratory testing program consisted of Atterberg limits, Eads and Grim pH, linear shrinkage, standard compaction, one dimensional swell, and unconfined compression which were used to identify the differences between untreated and treated soils physical properties. The soils' physical properties were then graphically and statically analyzed for significant changes. The results indicate that swell potential can practically reduced to zero, while strength can only slightly improved. This Final Report also include soil chemical property data and X-Ray diffraction information.

INTRODUCTION

Expansive clays exhibit high potential for volume change because of changes in soil moisture. Jones and Jones (1987) estimated that the annual const of damage to facilities built on expansive clay in the United States exceeded $9 billion. One of the most common and effective chemical treatments of expansive clay is the addition of lime, either calcium hydroxide [$Ca(OH)_2$] or quicklime (CaO), to the soil. Lime treatment has been widely used for many years and is current used for stabilizing clay soils supporting runways, building, roads, and parking lots. Although much is know about the phenomenon of soil-lime reaction in expansive clays, little has been done to investigate the affects of organic content in the soil treated on the effectiveness of lime treatment. The focus of this research is on the effect(s) of organics on the treatment of a highly expansive clay soils with the addition of quicklime. Of particular concern were effects of organic content on the swell potential and unconfined compressive strength of lime treated soil.

PURPOSE

Over the years, rules of thumb have been developed in the treatment of organic clay soils. However, little research has been reported that has determined the precise effects of organic material on the lime treatment process. Through the financial support of Chemical Lime, Co., and the University Transportation Center of the University of Missouri–Rolla, a research project was develop to test the effects of organics material on the lime treatment of an expansive clay soil. The goals of the project were to determine the amount of lime needed to reduce the swell potential (modify) and increase the unconfined compression strength (stabilize) this clay.

BACKGROUND

Organic matter

Organic matter in general terms comes from the decomposition of plant and or animal organisms. The presence of organics can affect many soil properties. Since most organic soils are relatively young in geologic age and have not been exposed to large confinement, they have very low strengths, are extremely compressible, and have large creep potential. The degree that the organics affect soil properties depends on the degree of decomposition, chemical composition, organic content, particle charge, and Cation Exchange Capacity (CEC). Properties of organic soils are derived from the source organic material. According to Hartlen & W.Wolski (1996):

> *Organic matter to can be divided into three general categories: peat, dy and Gyttja. Peat originates from plants and denotes the various stages in the humification process where the plant structure can still be discerned. Dy denotes the stage where the plant structure is completely destroyed…Gyttja originates from remains of plants and animals rich in fats and proteins. In contrast to peat which is formed by remains of plants rich in carbohydrates.*

There are a number of different classification systems available for organic and organic soils. However, most systems are not geared toward geotechnical engineering. The most common classification system uses ash/organic carbon content as the basis of soil identification (ASTM D 2972). The particular procedures and nuisances of this method are beyond the scope of this paper. However, a general explanation is helpful since this method was used to determine the organic content of the research soils. The concept stems from the fact that organic matter is assumed to be combustible were as soil minerals are not. The percent organics is determined by placing a soil sample in a muffle furnace at a specified temperature and measuring the weight of it before and after. The percent organics is found by dividing the loss of weight on ignition by the final dry weight of the soil solids.

Lime Treatment

The purpose of lime treatment is to improve existing soil properties to achieve a desired performance level. Soils property improvements normally expected by lime treated include improved strength, improved resistance to fracture, fatigue, and permanent deformation; improved resilient modulus properties; reduced swelling; and improved resistance to the damaging effects of moisture, according to TRB State of the Art Report 5. The most substantial improvements in these properties are seen in moderately to highly plastic soils, because of their high cation exchange capacities. Lime treatment can be divided into two categories; modification and stabilization.

While these two treatment levels are closely related, for this paper a distinction between the two needs to be made. Modification is a combination of changes due to cation exchange, agglomeration & flocculation, and ion crowding. The affect of modification can be seen as a nearly immediate reduction of the Plasticity Index (PI, along with increased workability of the soil. Stabilization is long term product of Calcium Aluminate Hydrate (CAH) and Calcium Silicate Hydrate (CSH) formation and is seen as an increase in compressive strength and increase of soil modulii. Both of these procedures are applied to improve the engineering properties of highly expansive clays.

Soil composition and chemistry are integral factors in the amount of lime needed to treat soil. The effectiveness of lime treatment is dependent upon degree of soil weathering, soil-water pH, base cation concentrations, Silica-alumina concentrations, sulfate content, and organic content. Each lime-reactive clay soil has a particular level of lime needed to achieve modification and stabilization levels of treatment, the Lime Modification Optimum (LMO) and Lime Stabilization Optimum (LSO), respectively. Through the use of a proper laboratory testing program the amount of lime needed to reach a desired improvement level can be achieved. The testing program utitlized for this project included soil manufacturing processes as well as normal testing to provide known levels of organics.

LABORATORY TEST PROGRAM

Soil Manufacture

The soil chosen for the research was weathered clay shale from the Eagle Ford geologic Formation. The soil was provided by the Chemical Lime Company and shipped to the geotechnical engineering laboratory at the University of Missouri-Rolla. Upon arrival the soil was air dried and processed thru a Number 4 U.S, Series sieve. This soil will be referred to throughout this report as the Natural soil. As determined during analyses of the test results below, this soils contained insufficient sulfates to affect the reactions discussed. To insure that a sufficient amount of organic matter was present in subject soils, “organic” soils were manufacture by adding “peat” to the Natural soil. Three soils with differing organic contents were manufactured. These soils will be referred to throughout this report as Soil A, Soil B, and Soil C. The soils were batched by weighing out sixty pound of Natural soil and an amount of peat added to each soil: 6, 12, and 18 pounds, respectively.

Testing Procedure

The eight different laboratory tests were conducted on the natural and 3 subject soils. The laboratory tests were:

- Grain Size Analysis (ASTM D 422)
- Organic content (ASTM D 2974)
- Eads and Grim pH (ASTM D 6276 Rev. A)

- Atterberg Limits (ASTM D 4318)
- Linear Shrinkage (Tex-107-E)
- Standard compaction (ASTM D698)
- Unconfined Compression (ASTM D2166)
- Free Swell (ASTM D2166)
- Determination of Soluble and Exchangeable Salts (UMR Standard)
- X-Ray Diffraction of the Clay Portions (UMR Standard)

Treated and untreated specimens were tested for the properties listed above, where appropriate. Standard procedures were used unless otherwise stated. Small variations form the standards were implemented in some testing procedures. The following is summary of the testing procedure for each test.

Grain Size Analysis - ASTM standard procedure was used on sieve and hydrometer analysis. Sieves used were #4, #10, #40, #100, and #200. The Material for the hydrometer was acquired after washing the soil retained on the #40, #100, and #200 sieves.

Organic content - Determination of organic content was conducted on the 4 subject soils (untreated) and the organic soil. ASTM D 2974 procedure C was followed. The procedure utilizes a 440°C ignition oven to determine the amount of combustible carbon in the soil specimen.

Eads and Grim pH test - The standard ASTM procedure states that a soil is fully modified when the pH has reached a value of 12.45. Our test procedure was modified to state that a soil is fully modified to find the percent lime for the maximum pH.

Atterberg limits – The standard ASTM procedure was followed for Atterberg limits testing. A four point liquid limit test procedure was used to develop the liquid limit curve.

Linear shrinkage – Linear shrinkage was preformed on treated and untreated soils. Treated soil was prepared at 4 different lime treatment levels in accordance with data obtained for the Eads and Grim pH test. Lime treated soil was mellowed for one day before testing.

Standard compaction – Generation of the optimum moisture content vs. dry unit weight curve for untreated soils was constructed using five moisture content/unit weight data points. Treated soil curve generation used 4 moisture content/ unit weight data points. Lime treated soil was mellowed for one day before testing/compaction.

Unconfined Compression – Each subject soil was tested untreated and treated. Treated soil specimens were mixed at differing lime treatment levels in accordance with Eads and Grim pH test and Atterberg limit testing results. Lime treated samples were allowed to mellow one day before compaction. All specimens were statically compacted with target compaction to meet 95 percent of standard proctor maximum dry unit weight at optimum moisture content for the various soil-lime mixtures. After compaction the samples were sealed and cured in a moisture control room for 28days. A total of 29 unconfined compression tests were conducted. Unconfined compressive strengths were determined using a strain rate of 0.5 percent per minute.

Free Swell - Free Swell Tests were preformed with 150psf seating load and allowing the sample to swell vertically for 120 -168hrs (5-7days). Treated and untreated swell test were preformed on all soils. Treated swell test were conducted at LMO of the respective soil. Lime treated soils were mellowed for one day before testing/compaction. All specimens were statically compacted with target compaction to meet 95 percent of standard proctor maximum dry unit weight at optimum moisture content for the various soil-lime mixtures.

Soil chemical testing and X-ray diffraction testing were delayed by equipment availability. The procedures used were standard processes used at UMR in the geotechnical engineering and environmental engineering laboratories for extraction of ions in the soils, and in the geology and geophysics laboratory for X-ray diffraction.

RESULTS

Grain Size Analysis

Sieve and hydrometer tests were run on the Natural soil only. The result of the sieve and hydrometer analysis indicates that 35 percent of the natural soil is passing the #200 sieve. The grain size curve is shown in figure 1.

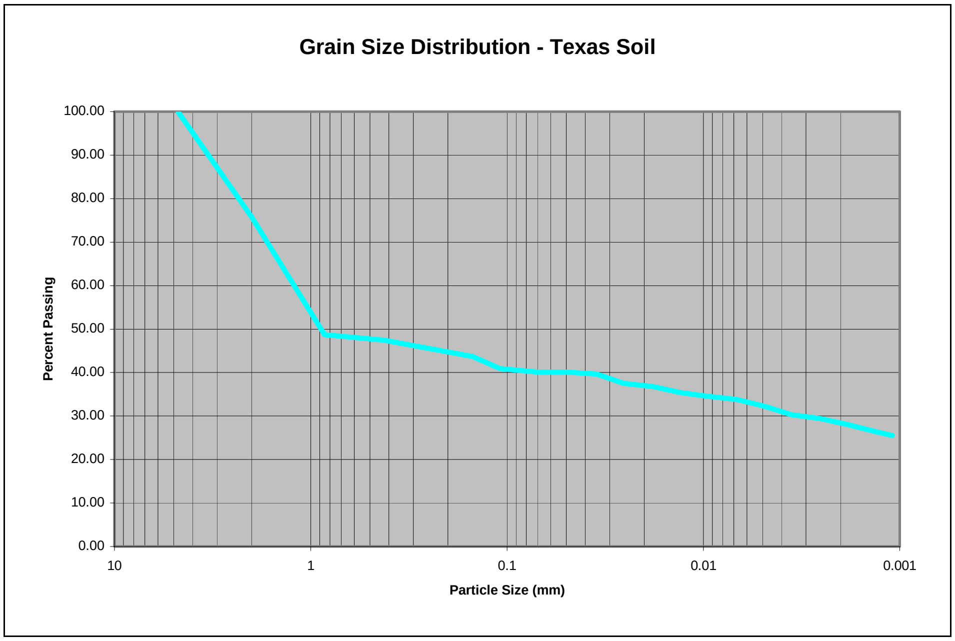

Figure 1: Grain Size Analysis distribution

Organic Content

Organic content was determined for all four subject soils plus the organic Soil. The results of this test can be seen in Table 1.

Soil	% Organics
Natural	0%
Soil A	2%
Soil B	4%
Soil C	6%
Organic Soil (Peat)	15%

Table 1: Percent Organics for Subject Soils

Eades and Grim

Figure 2 shows typical results fr0m Eades and Grim pH type testing. Two tests were run on each soil for a total of eight. Table 2 shows the results obtained for the pH testing. An increase in of approximately 2 percent lime for the LMO (maximum pH) was observed as the organic content increased in each case.

	Lime Modification Optimum
Soil	**% Lime**
Natural Soil	4
Soil A	6
Soil B	8
Soil C	10

Table 2: Results of Eades and Grim pH testing to determine soil LMO

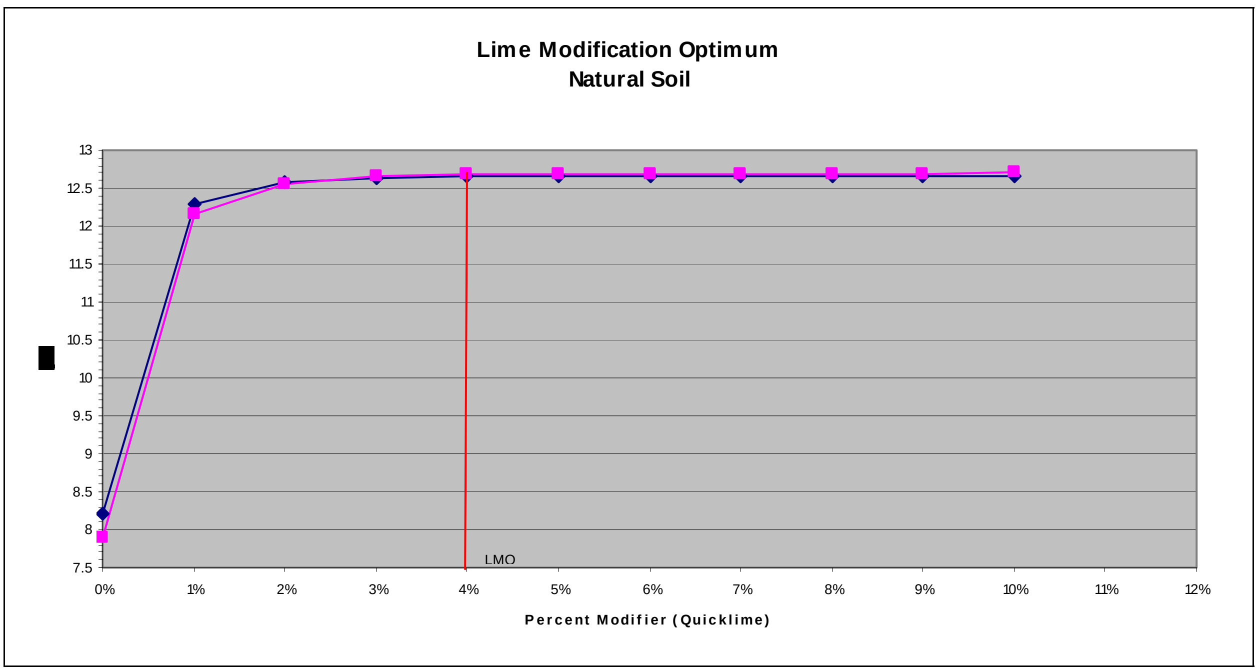

Figure 2: Eades and Grim Test Results

Atterberg limits

The Atterberg limits test results were used in soil classification along with grain size analysis and, in addition, to determine the LMO of the subject soils. Four sets of Atterberg Limits (AL's) were preformed on each subject soil. One test with untreated soil and three with treated soil of differing lime contents. Figure 3 shows a typical reduction in liquid limit as a result of lime treated. As more lime was added to the subject soil the liquid limit (LL) decreased while the plastic limit (PL) increased. This can also be seen as a reduction in the plasticity index (PI). When the PI of the soil is at a minimum the soil is said to be fully modified. Table 3 is a summary of Atterberg limits test results. As seen in Table 3 the untreated natural soil had the highest plastic limit (PI) while untreated Soil C the lowest PI. Results indicate that all soils showed a reduction of PI with the addition of lime, of the type seen in Figure 4. The greatest decrease is seen in the natural soil and the smallest in Soil C.

Besides being used for LMO determination the Atterberg limits were used in the identification of the soil type. All untreated soils were identified as CH according to ASTM D2487. After lime treatment the Natural, A, B, and C soils were classified as ML.

Soil	% Organics	Quicklime %	PL	LL	PI
Natural	0	0	24	65	41
Natural	0	2	42	51	9
Natural	0	4	42	51	9
Natural	0	6	42	49	7
A	2	0	26	61	35
A	2	4	41	55	14
A	2	6	40	48	7
A	2	8	39	46	7
B	4	0	26	59	33
B	4	6	43	54	11
B	4	8	40	50	10
B	4	10	40	50	10
C	6	0	26	57	31
C	6	6	39	54	15
C	6	8	37	49	12
C	6	10	38	51	13

Table 3: Results form Atterberg limits testing.

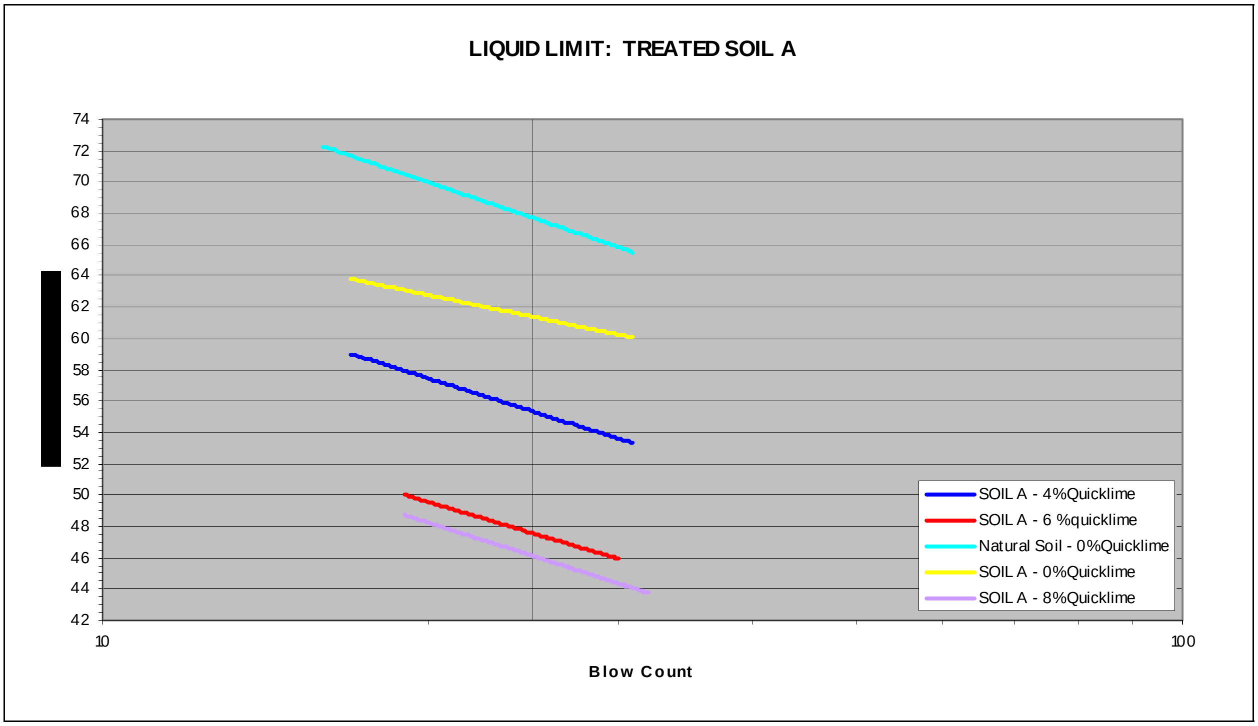

Figure 3: Liquid Limit Results for Soil A

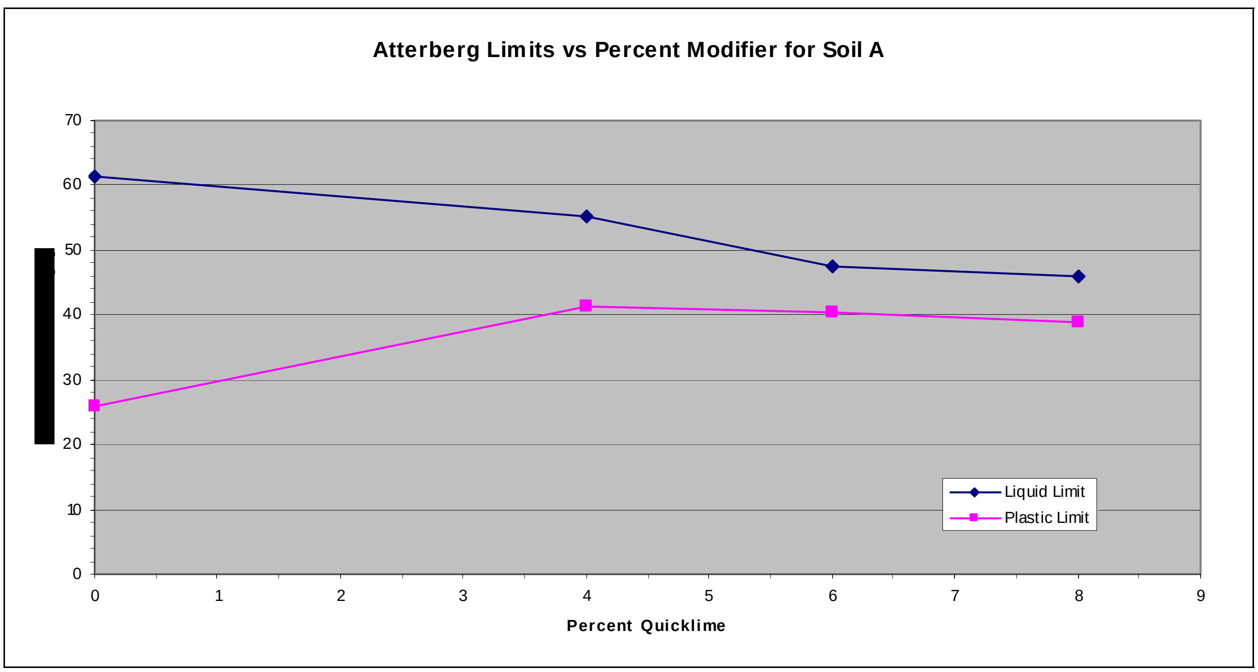

Figure 4: Liquid and Plastic Limit of Soil A vs. Percent Modifier

Linear Shrinkage

The purpose of using the linear shrinkage test was to observe the effects of organic content on shrinkage with respect to different levels of lime treatment. Four linear shrinkage (LS) tests were preformed on each subject soil. One test with untreated soil and three with treated soil at differing lime contents. A diagram depicturing the effect of organics on linear shrinkage is shown in Figure 5. For untreated soil specimens the addition of organics increased the shrinkage of the soil. Maximum shrinkage was observed in Soil C to be 17% while 13% was measured in the natural soil. As lime was added to each soil, a reduction in LS was observed. A maximum reduction, for all soils, occurred with the addition 6% lime. The LS for lime treated soils varied from a low of about 6% for Soil B, to the highest of about 9% for the Natural Soil.

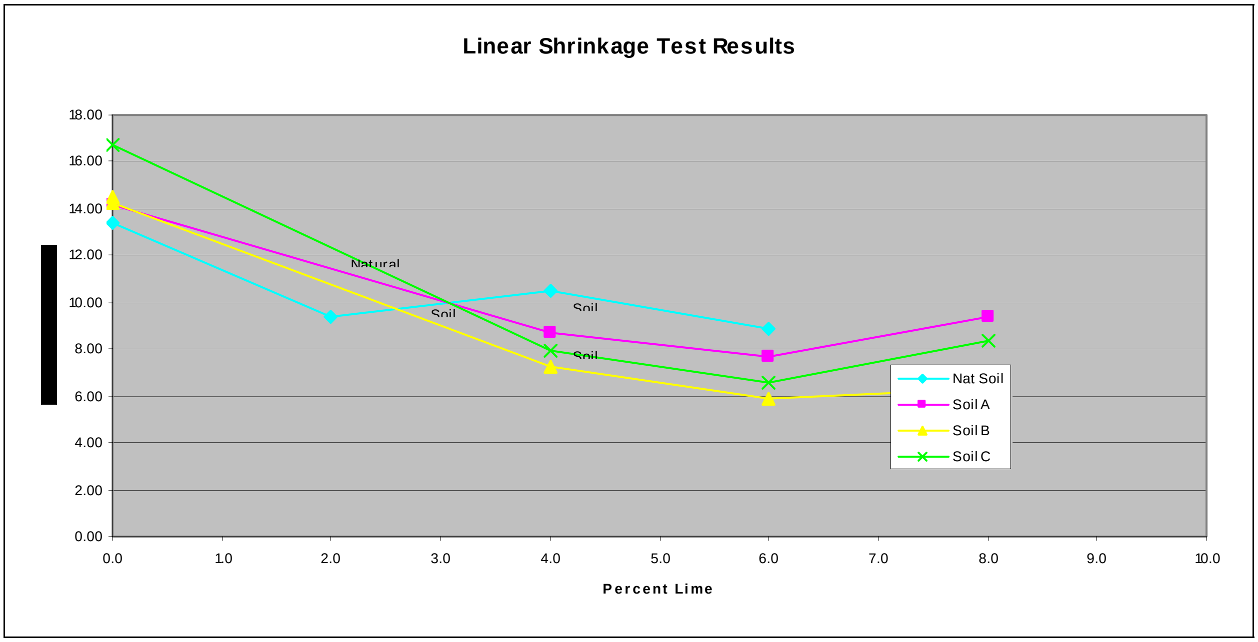

Figure 5: Linear shrinkage vs. Percent Modifier

Compaction (Proctor)

Standard Proctor compaction was used to determine the max dry unit weight and optimum moisture content (OMC) of each subject soil. A test was performed on each of the untreated soils. Do to a limitation in available soil, only two tests were conducted on treated soil. Soil A and Soil C were chosen for the treated soil compaction tests. . Figure 6 and Figure 7 show the moisture-unit weight compaction curve for the untreated and treated soils, respectively. As seen in Figure 6, as the organic content increases, the maximum dry unit weight deceases and the OMC increases. When lime was added the subject soils, the maximum dry unit weight is decreased and the OMC is increased as shown in Figure 7.

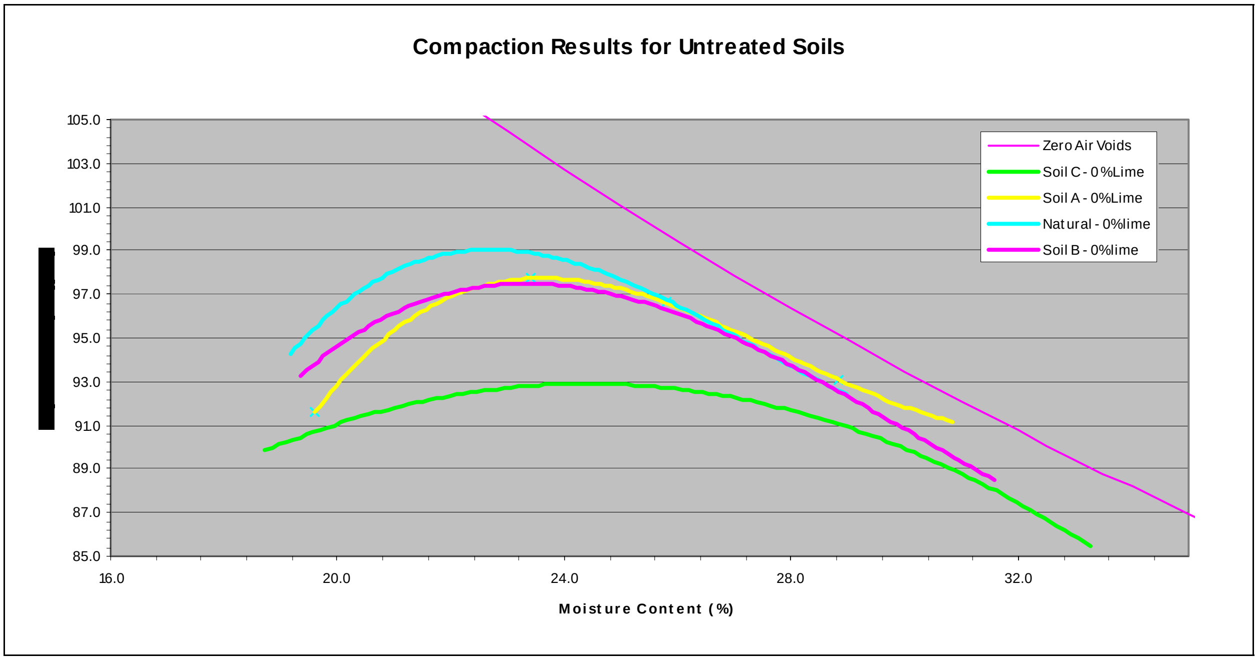

Figure 6: Compaction Results for Untreated Soils

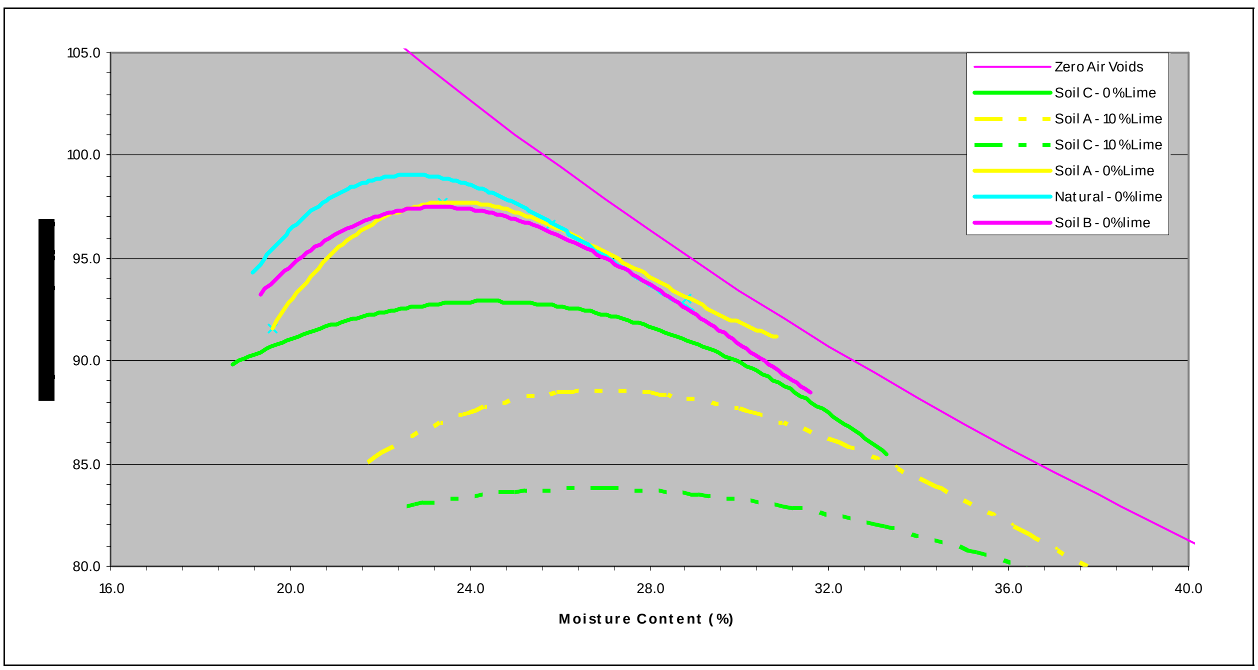

Figure 7: Compaction Results for Treated Soils

Free Swell

The purpose of the swell test was to determine if the swell potential of the subject soils could be reduced. Two swell tests were run on each soil, one with untreated soil and one with treated soil. As seen in Figure 8, as the organic content increased the swell decreased. The untreated natural soil had the most swell with 3.4% and Soil C had the lowest swell at 2%. The treated as compared with the untreated subject soils, showed no indication of swelling. The swell tests indicate that the organic soil can be effectively treated to reduce swelling potential.

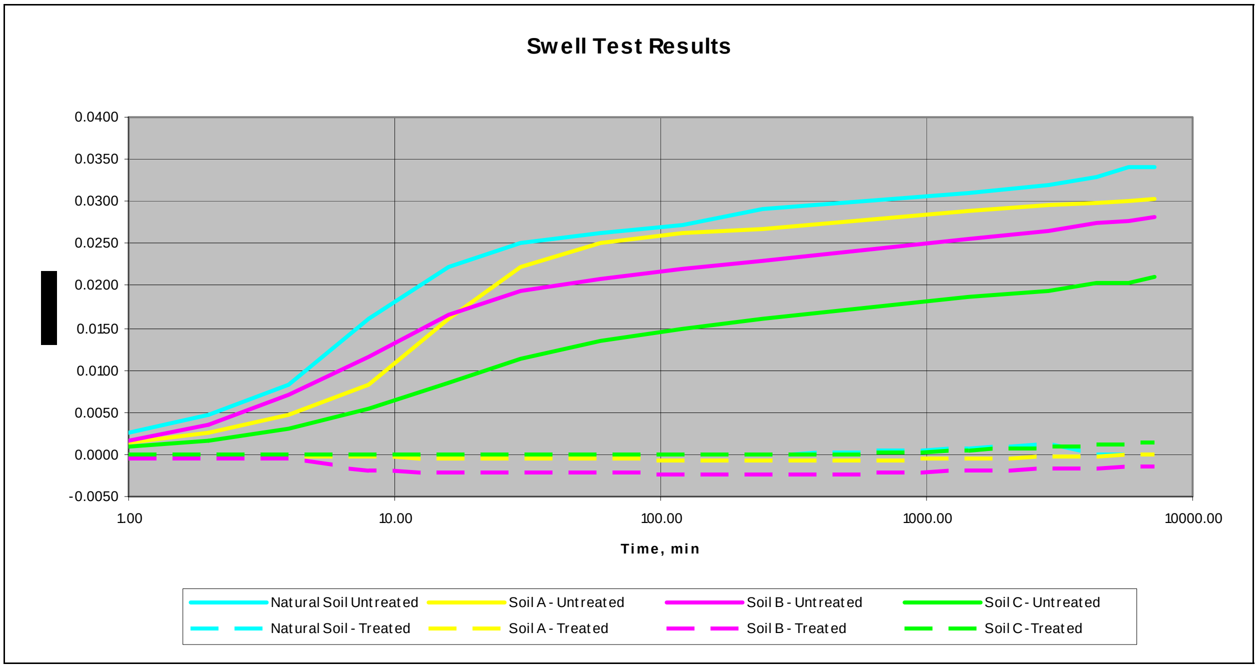

Figure 8: Free Swell Test Results

Unconfined Compressive Strength

Unconfined compressive strength test was conducted to determine the Lime Stabilization Optimum (LSO) for each soil. Figure 9 shows the unconfined compressive strength verses lime content of 28 statically compacted samples. Seven samples were manufactured for each soil, one untreated and six at varying degrees of lime content. Lime contents were determined by analyzing the LMO. The lower bound was the LMO and the upper was 2 % percent lime above 2 times the LMO. The greatest strength of untreated material was seen in the natural soil, with Soil C having the lowest strength. As seen in Figure 9 the maximum for the treated subject soils occurred at 8%, 12%, 14% lime for Natural soil, Soil A, Soil B, respectively. The maximum compressive strength value observed for Soil C occurred at 18% lime. While this likely the LSO for this soil, a definite conclusion can not be made due to data restrictions.

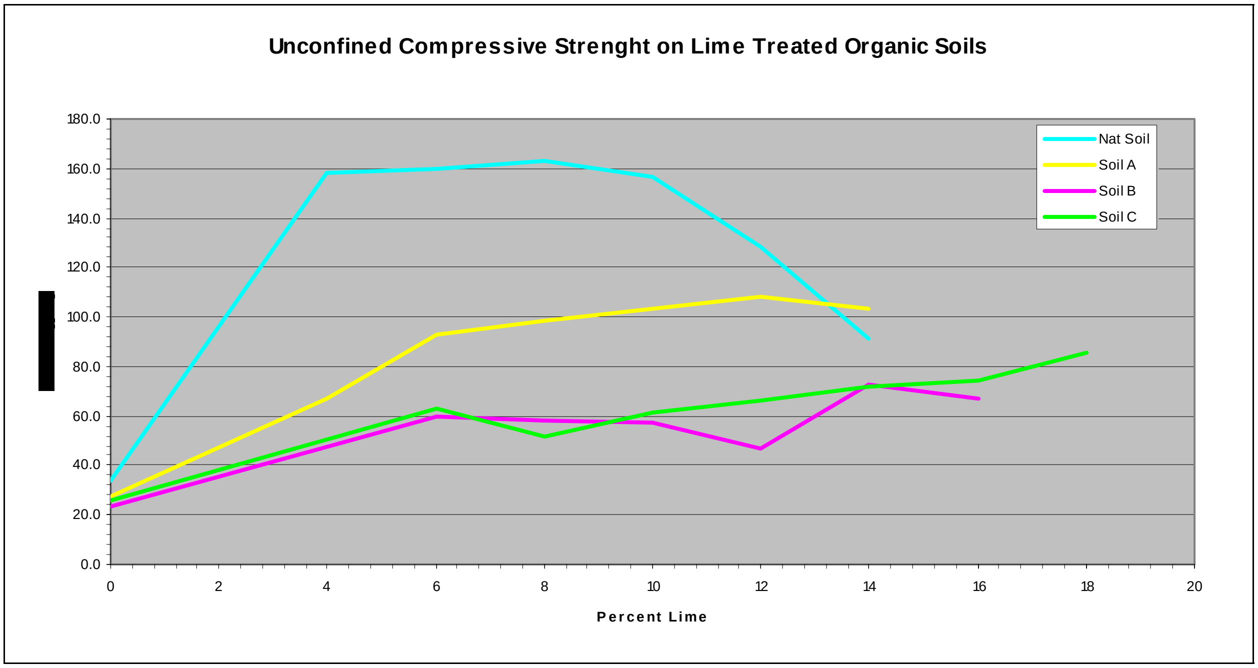

Figure 9: Unconfined Compression Strength Plot

SOIL CHEMICAL TESTING

Soil chemical testing included determination of the soluble salts and exchangeable salts in the research soils, both untreated and treated. By combining the exchangeable salts data, the soils' Cation Exchange Capacities (CEC) were calculated. The soluble salts were determined by basically making a 1:1 suspension of dry soil and deonized (DI) water. The pore fluids were extracted using a centrifuge and analyzed for concentrations of ions using an atomic absorption flame spectrophotometer. The exchangeable salts were separated from the soil using washings of ammonium acetate solution and centrifuging. The total fluids removed were measured and the fluids were analyzed for ion concentrations using the AA spectrophotometer. The values of milliequivalents (meq) of ions of each type, per liter of solution for the soluble salts and per 100 g of dry soil for the exchangeable salts, were calculated using standard equations. The results are shown in Tables 4 and 5. These are shown in comparison values in Figures 10 through 15 below.

Soil ID	Na K meq/L	K Mg meq/L	Mg Ca meq/L	Ca meq/L
Natural Soil	4.05	0.56	1.45	17.40
Soil A	4.01	0.90	5.02	16.19
Soil B	4.91	1.42	3.23	19.65
Soil C	6.80	3.19	7.01	20.80
Natural 4% Quicklime	3.02	0.64	0.00	9.00
Na Soil A 6% Quicklime	4.37	1.63	0.13	31.40
Soil B 8% Quicklime	5.01	2.57	0.00	28.32
Soil C 10% Quicklime	6.03	3.94	0.01	44.74
Na Organic Peat	23.62	59.81	15.54	18.17

Table 4: Soluble Salts in Research Soils

Soil ID	Na meq/100g	K meq/100g	Mg meq/100g	Ca meq/100g	CEC meq/100g
Natural Soil	0.91	1.46	6.11	60.79	69.27
Soil A	0.90	1.46	3.37	47.75	53.49
Soil B	1.00	1.37	4.53	72.32	79.21
Soil C	1.44	1.96	4.19	47.48	55.07
Natural 4% Quicklime	0.78	1.00	4.07	32.41	38.26
Soil A 6% Quicklime	0.70	1.18	3.45	193.49	198.81
Soil B 8% Quicklime	0.69	1.46	2.86	285.98	290.99
Soil C 10% Quicklime	1.21	1.86	2.81	434.59	440.47
Organics	0.77	1.29	5.07	29.68	36.80
Organics	5.19	2.99	4.91	33.56	46.65

Table 5: Exchangeable Salts and CEC of Research Soils

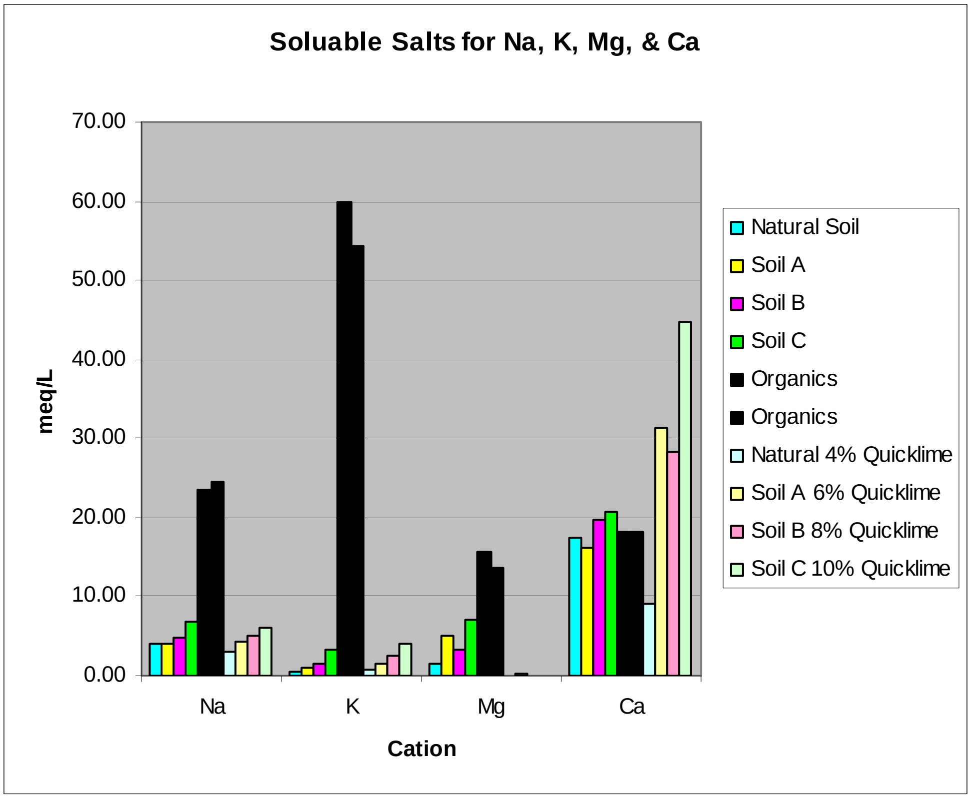

Figure 10: Comparison of Soluble Salts in Research Soils

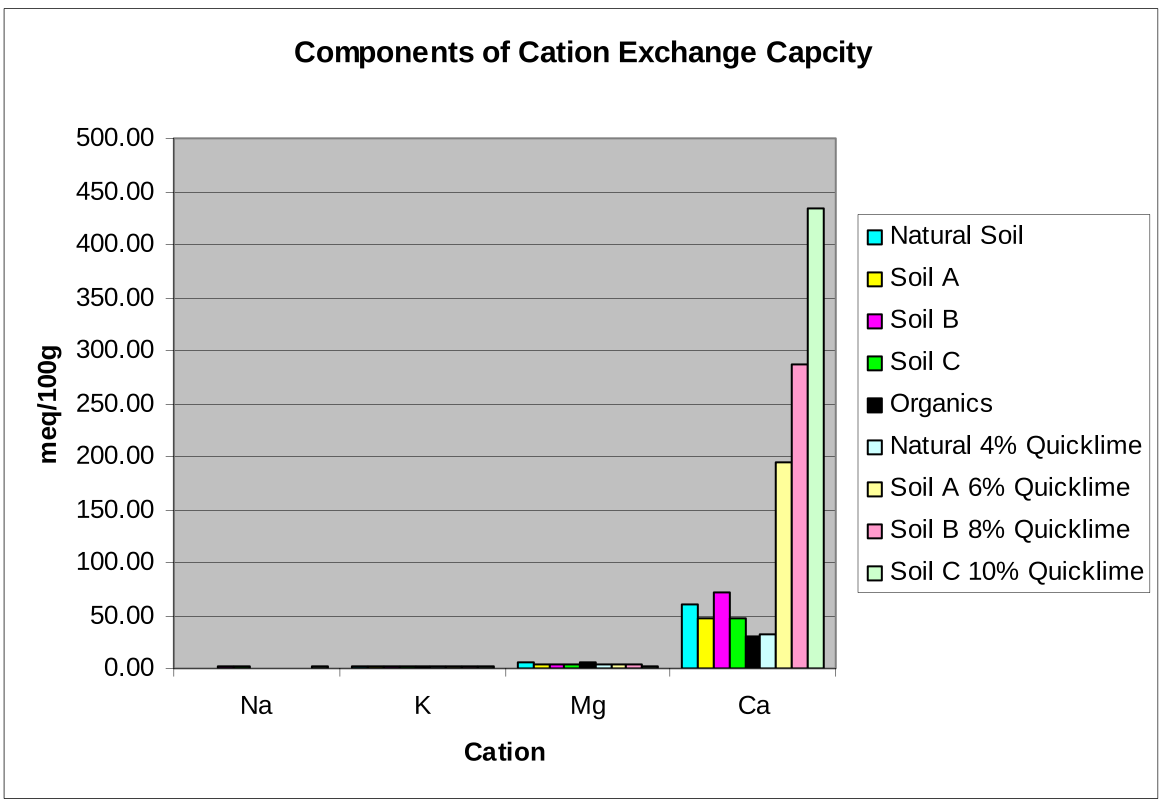

Figure 11: Components of CEC in Research Soils

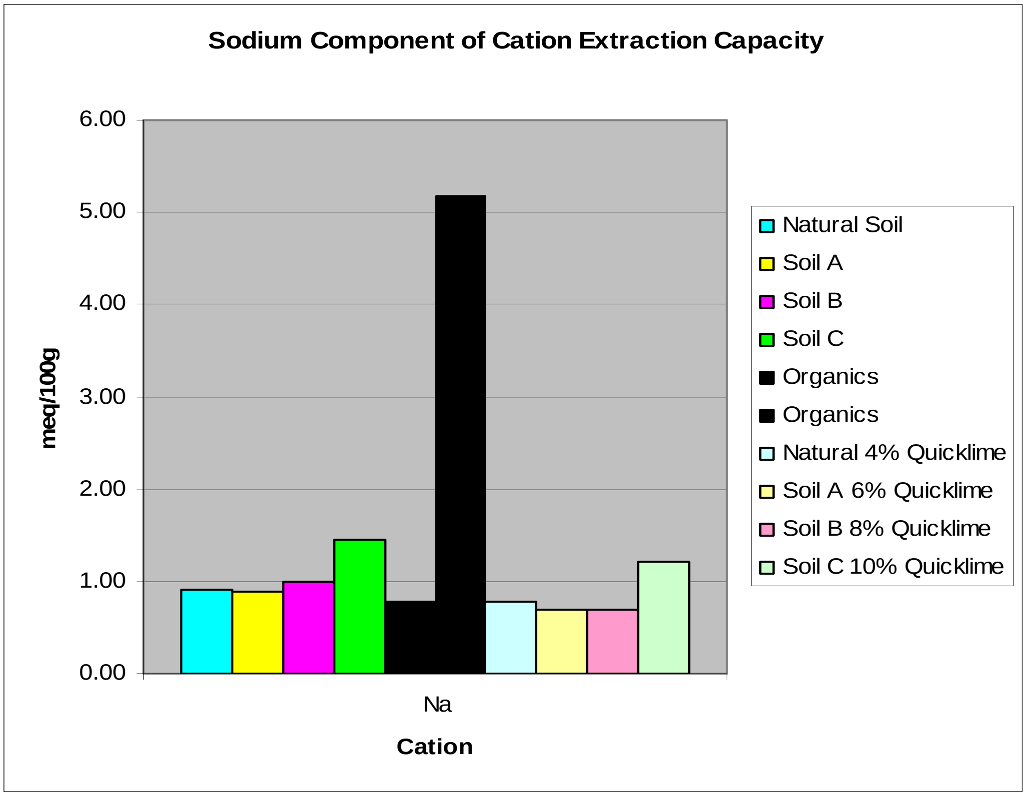

Figure 12: Sodium Component of CEC

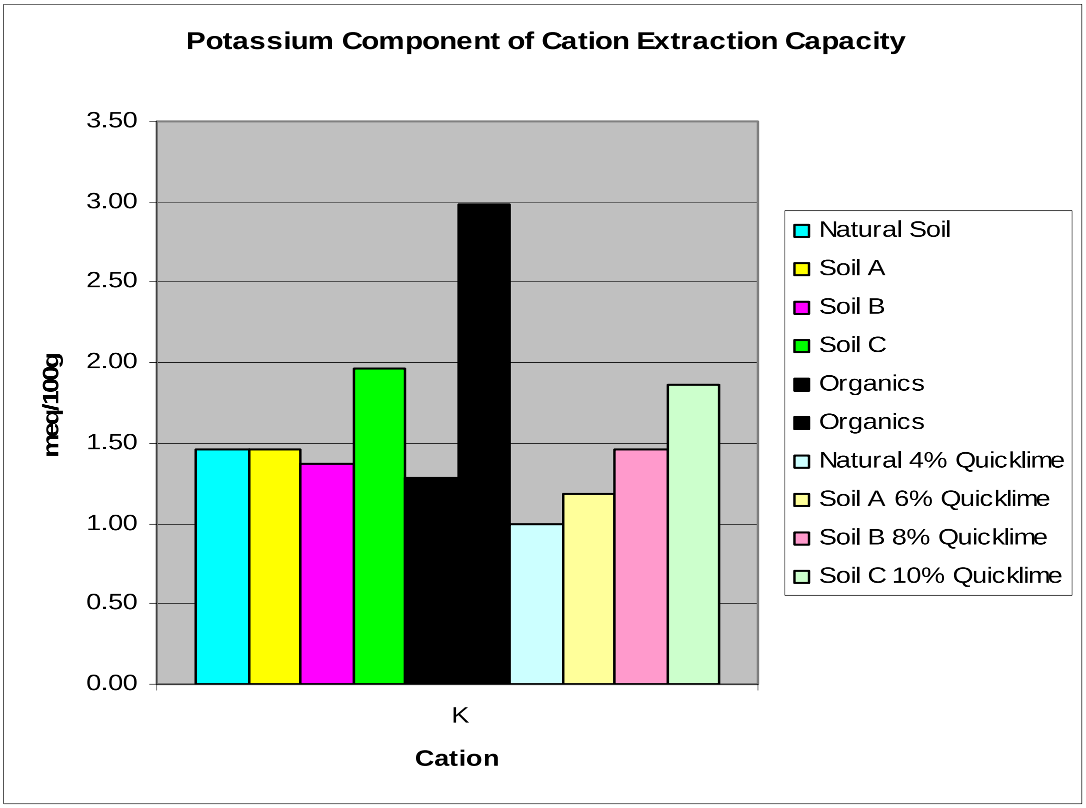

Figure 13: Potassium Component of CEC

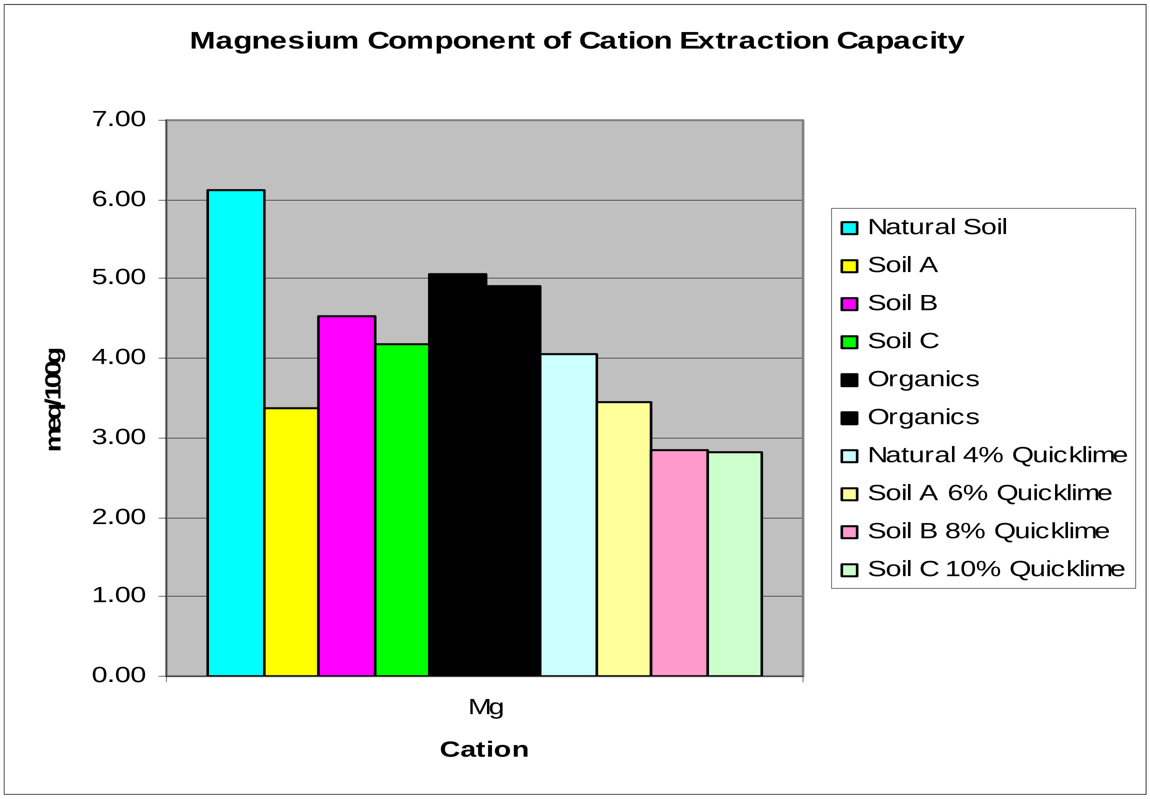

Figure 14: Magnesium Component of CEC

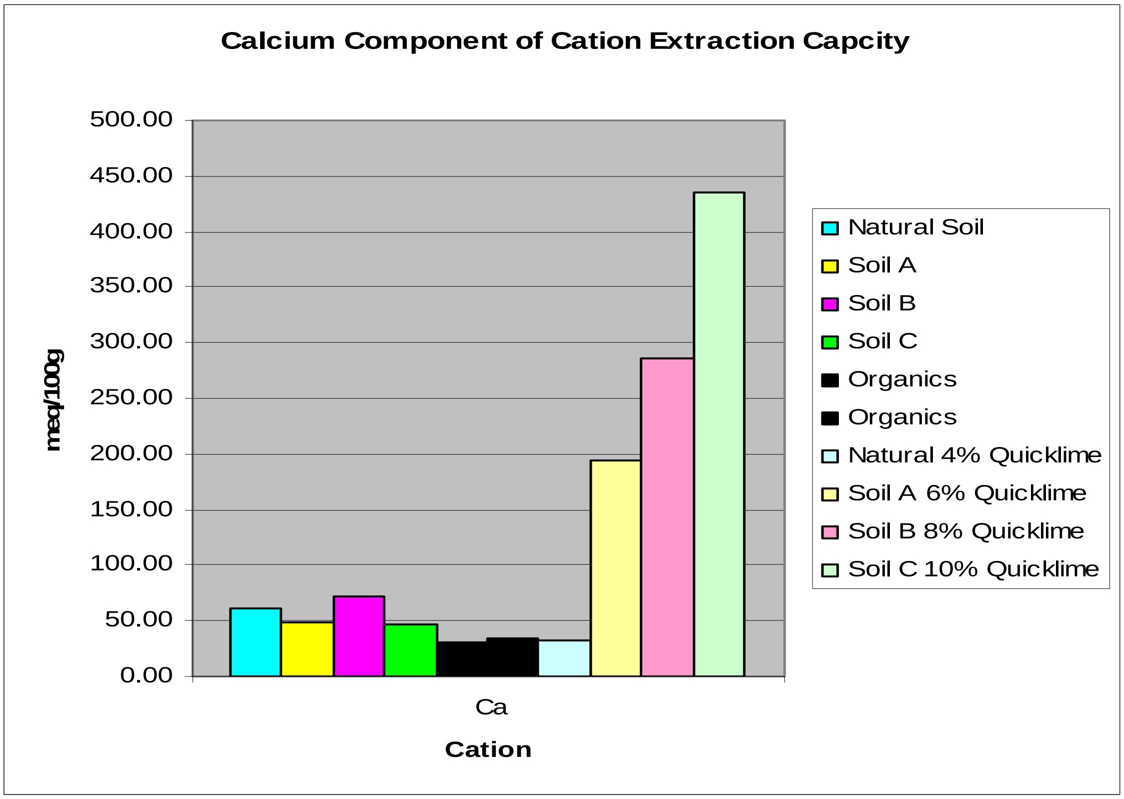

Figure 15: Calcium Component of CEC

SUMMARY

The soil tested during this study, that weathered from the Eagle Ford Shale geologic formation, known to be lime-reactive and highly active in its natural state. This soil was blended with differing amounts of Peat, which made the three soils, A,B, and C, contain 2, 4, and 6% organics, respectively. All of the four soils tested were classified as CH soils, before treatment. Their PI's ranged from 41 for the natural soil to 31 for soil C. They had linear shrinkages of 13% for the natural soil to 17% for soil C. This means that the addition of organics lowered the soil PI's, yet made them have more linear shrinkage.

When treated with a quicklime slurry the research soils responded significantly different as a natural soil and as soils A,B, and C, with organics in them. The LMO, as determined by the lime fixation point was 4% for the natural soil, and, as organics were present, required an additional 2% lime for each 2% organics present. Soil A required 6%, soil B 8% and Soil C 10% to fully fix the soil. This clearly illustrates the effects of the organics. The PI for the natural soil was reduced to 7 for both the natural soil and soil A, while those of soils B and C were only reduced to 10 and 12, respectively. At the addition of 6% lime, the natural soil had a reduction in shrinkage to 9%, while soil A's LS was reduced to 8, soil B's to 6% and soil C's to 7%. This indicates that the organic portion of the soils had more improvement in shrinkage, most likely because of the effects of lime on the organics.

The natural soil had a maximum dry unit weight of 99 pcf at an optimum water content of 22.5%. Soil A had the lowest dry unit weight of 93 pcf at 24% water content, soil B and C had nearly the same dry unit weights of about 97.2 pcf and at optimum water contents of 23%. The presence of organics beyond 2%, therefore, affected the compaction that could be achieved in the untreated state. As treated Soil A had a dry unit weight of 89 pcf at an optimum water content of 27.5% water content, and the natural treated soil would experience the same change of compaction properties. Soil C, when treated, had a dry unit weight of only 84 pcf at and optimum water content of 27.5%. As expected, these soils had higher optimum water contents and lower dry unit weights when lime treated.

The swelling potential of the natural soil at the optimum water content was 3.4%, while the presence of organics reduced this potential. Soil A expressed 3% swell, soil B showed 2.7% and soil C swelled 2.1%. The presence of organics is believed to have made these soils more compressible within their fabric so that less swell happened. All of the research soils, when treated with lime, had no swell potential, and the organic soils even compressed some under the surcharge load applied. This means that the clay within each soils was modified so that swell would not occur.

Unconfined compression strength of the untreated natural soil was about 30 psi, while that of the soils containing organics was about 25 psi. When treated, the natural soil was able to exhibit unconfined strengths of 163 psi at 8% lime (its LSO), while the organic soils did not respond nearly as well. Soil A had a maximum unconfined compression strength of 109 psi with the addition of 12% lime, while soil B had only 70 psi at 14% lime. Soil C did not reach a maximum unconfined compression strength, but exhibited a strength of 85 psi at 18% lime. It is clear that the presence of organics significantly affects the strengths achieveable with the addition of lime and the LSO's shown make the stabilization of these organic soils unpractical.

Past X-ray diffraction studies of the Eagle Ford clay soils have indicated, as was the case this time, that this highly active soil contains significant amounts of Smectite clays, as well as Illite and Kaolinite clays. When treated with lime, all of the X-ray responses for these clays were diminished significantly, even to the point of not clearly identifying the clays present.

It is clear, when studying the soluble salts and exchangeable salts information, that Calcium ions are the most prevalent in the natural soil, as well as the soils containing organics. In fact, there is an order of magnitude more Calcium than any of the others. This is, not surprisingly the same for the exchangeable ions. When treated with lime the numbers changed some for the natural soil, but by very large margins for the organic soils. This indicates why there is such a higher need for lime to modify and stabilize these organic soils. The organic matter takes on the Calcium, preventing from reacting with the clay. The CEC of the natural soil appeared to contain somewhat more ions than the organics soils, but, when treated, the CEC's of the organic soils as indicated by the ions present, were very much higher. Some have proposed determination of the CEC for soils by just adding up what was there. This research indicates that the CEC should be determined by introducing an ion to fill the CEC, then washing it out and measuring what was in the complex. The results of this research indicate that, as expected, when large concentrations of lime are added, the CEC can then be filled and emptied to determine the CEC. It is believed,

therefore, that the CEC'c found after lime treatment are actually those of the soils. The effects of only these small percentages of organics have dramatically increased the soils' CEC, and have significantly reduced the response to lime treatment.

CONCLUSIONS

The results of this study of the effects of the presence of organics on the lime treatability of clay soils are indicate that organics in even relatively small percentages will significantly affect the outcomes:

1. This clay soil with organics in it exhibited a lowering of the PI, but the soils were CH's.
2. This clay soils had higher shrinkage, untreated, when organics were present.
3. This clay soil was less compactable when organics were present.
4. The LMO's of this soil are significantly higher when organics are present, since the organics take on the Calcium, preventing it from reacting with the clay.
5. All the research soils displayed reduction in plasticity and dramatically lower swell potentials when treated with lime, even though the soils containing organics required more lime to have this behavior change.
6. The natural soil can be stabilized with the addition of lime, yet the soils containing organics required much more lime to have significantly lower, and in soils B and C, less than acceptable unconfined compression strengths.
7. Even though all the soils tested were modified by the addition of lime, soils B and C, with 4 and 6% organics respectively, could not be stabilized. In addition, the amounts of lime to modify or stabilize soils B and C are excessive and uneconomical.

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