Effects of Lime on Plasticity and Compressive Strength of Representative Iowa Soils

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This paper considers the selection of 20 representative Iowa soils and the results of laboratory tests to determine the effects of a dolomitic monohydrate lime on the plastic limit and unconfined compressive strength of these soils. This is a step toward the ultimate goal of the development of a system of soil-lime stabilization in Iowa based on soil series.

The plastic limits of all the soils increased with the addition of small amounts of lime up to the lime fixation point, after which there was little change in the plastic limits. Although the late Wisconsin age tills showed strength gains with the first additions of lime, the older tills and loess C-horizon materials gained strength only after the lime fixation point had been reached. The majority of the A-horizon soils exhibited little or no strength gain.

•LIME has a long and varied history as a stabilization agent for soil (5, 8, 13, 14). Its use in road building, for example, began with the Romans and the Appian Way about 312 B.C. (15) and continues today in the building of the Interstate highway network (12).

The three basic mechanisms of soil-lime stabilization have been reported by Davidson and Handy (10). They are aggregation or flocculation of the clay particles, carbonation of the lime by carbon dioxide from the air, and the pozzolanic reactions.

Increasing unconfined compressive strength with the addition of lime to soils has been reported by many authors. Increases in the plastic limits of clayey soils with the addition of lime have also been reported. Hilt (6) related the increases in strength and plastic limits in clayey soils and reported on what he termed lime fixation. Using clay soils with a variety of clay minerals and various percentages of reagent grade calcitic lime, he reported the increase in plastic limit with the addition of lime until a point was reached at which there was little or no further increase. This is the point at which lime fixation is complete. He reported that in the same soils the unconfined compressive strengths remained constant as the plastic limits increased, after which the strengths increased and the plastic limits remained nearly constant.

For this study, a number of representative Iowa soils were treated with dolomitic lime with the objective of establishing relationships working toward a system of designing soil-lime mixes for road construction based on soil series. In addition, the following lesser objectives were also in mind:

1. To confirm the expected relationship between plastic limit and the lime fixation point.
2. To establish a relationship between the percentage of clay size material present in the soils and their lime fixation points.
3. To confirm the expected relationship between lime content and strength up to the lime fixation point.
4. To establish the relationship between lime content and strength above the lime fixation point.

SOILS

Most of the bedrock of Iowa is mantled by Pleistocene glacial drift deposits from all of the major glacial stages, shown on the Iowa Geological Survey map (Fig. 1). These stages are the Nebraskan, Kansan, Illinoian, and Wisconsin, with the latter divided into Iowan, Tazewell, Cary I, and Cary II substages. The Cary I and Cary II substages were formerly Cary and Mankato, respectively. The largest portion of the drift is till, but deposits of stratified drift are associated with it.

Much of the drift of western, southern, and southeastern Iowa is covered by loess. There are also deposits of loess, peat, volcanic ash, and alluvial materials buried within the drift. At the surface of the drift and loess, there are alluvial deposits associated with the present stream valleys. In the northeastern corner of the State, there is some residual mantle, which resulted from the weathering of the underlying bedrock.

In the interval since deposition, weathering has taken place on the exposed surfaces of the drift and loess. This weathering has produced the soil profile. Buried soil profiles are also present within the drift and loess, indicating times of past exposure to weathering. Five factors in the formation of soils profiles are considered by Jenney (9): climate, living organisms, relief (topography), parent material and time. The development of Iowa soils in light of these five factors is considered by Simonson, et al. (17). Individual soils profiles exist for each combination of the five factors. This concept began with the Russian school of soil science and was later broadened and adopted in the United States under the leadership of Marbut (18).

Parent material was used as the basic criteria for selection of the representative soils used in this study. The distribution of principal soil parent materials in the State is drift, 39 percent; loess, 42 percent; alluvium, 18 percent; and residual material, 1 percent. In view of the small percentage of residual parent material, only soils of the first three groups were considered. It was further decided to use A-horizon soils in the study, but only those occurring in flat terrain, where it would be more reasonable to use them than to remove them or bury them under better fill. In addition, soil series, geologic age, areal extent, and vegetation were considered in the selection. The locations of the sample sites are shown on the soil association area map of Iowa (Fig. 2).

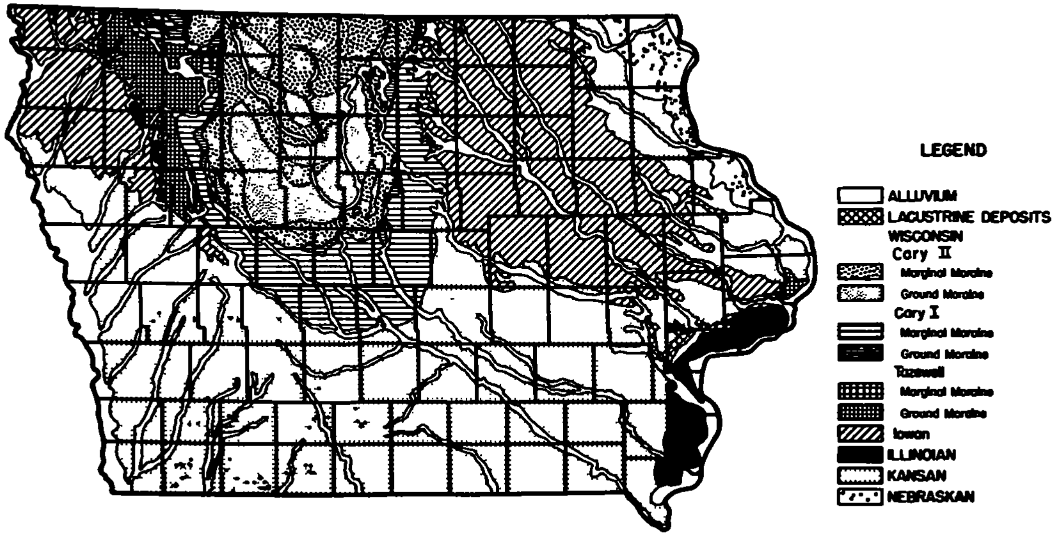

Figure 1. Preliminary map of the glacial geology of Iowa.

The soils selected for the study are given in Table 1. The three loess C-horizon and one loess B-horizon samples were obtained from the southwestern portion of the State, where there appears to be a systematic variation in particle-size distribution with distance from the Missouri River (7). They have approximately the following percent silt-clay distributions: 80-20, 70-30, 60-40, and 50-50.

Because of the limited information about Iowa tills, they were sampled in random fashion, based on geological age. Two tills were not sampled, Nebraskan because of limited exposure in Iowa and Illinoian because of limited occurrence. Because the youngest Cary II drift is mapped in greater detail, the samples were obtained from an area of ground moraine. Kansan gumbotil from southeastern Iowa was also sampled to obtain a soil with high clay content and because of its troublesome nature.

Although alluvium accounts for about 10 percent of the parent material, it is widely scattered. However, the Missouri River flood plain is the largest single area in the State, and accounts for a large portion of the total alluvial material. A sample representative of the high clay content overbank material was selected from this area.

MIX MATERIALS AND LABORATORY WORK

Commercially available dolomitic monohydrate lime, sold under the trade name Kemidol, was used throughout the study. It was manufactured by the U.S. Gypsum Company at Genoa, Ohio. Distilled water was used in all the mixes and testing procedures to eliminate experimental variables.

Sample Preparation

After drying the field samples and breaking the larger soil clods, representative

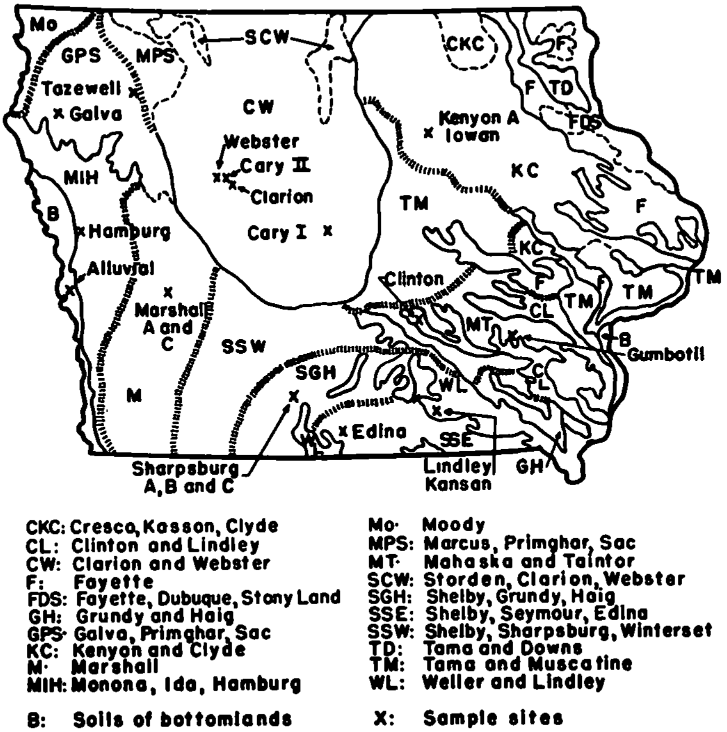

Figure 2. Map of principal soil associations of Iowa and locations of samples used, from Simonson et al. (17, p. 36).

samples of each of the 20 soils were obtained. The remaining portion of the soil was passed through a No. 4 sieve and used in molding the 2- by 2-in. specimens for the moisture-density and strength tests.

Descriptive Tests

The following descriptive tests were performed on each of the 20 soils except where differently indicated:

1. Particle size analysis. Standard mechanical analysis (ASTM Designation; D 422-54T) (1); sodium metaphosphate dispersing agent; Iowa State Air jet dispersion device (2).
2. Organic matter. A horizon soils only; potassium dichromate titration method (3).
3. X-ray diffractometer analysis. To determine the predominant clay mineral present in the soils.

TABLE 1
SAMPLE SITES

Parent Material	Sample No.	Series	Horizon	Depth In.	Plant Cover	County	Tier and Range	Section
Kansan till	423-1	Lindley	A	0-15	Trees	Appanoose	T70N, R16W	NW¼ NW¼ 2
	423-5	Lindley	C	157-205	Trees	Appanoose	T70N, R16W	NW¼ NW¼ 21
	528-8	Gumbotil	Fossil B	91-107	Grass	Keokuk	T75N, R10W	NW¼ NW¼ 7
Iowan till	-	Kenyon	A	2-14	Grass	Butler	T91N, R16W	SW¼ NW¼ 14
			C	36-60	Grass	Butler	T91N, R16W	SW¼ NW¼ 14
Tazewell till	-	-	C	36-48	Grass	O'Brien	T94N, R39W	NW¼ NE¼ 27
Cary I till	-	Clarion	C	36-72	Grass	Story	T83N, R24W	NE¼ SW¼ 5
Cary II till	-	Clarion	A	0-12	Grass	Calhoun	T87N, R32W	SE¼ SE¼ 4
			C	72-96	Grass	Calhoun	T87N, R32W	NE¼ SE¼ 30
		Webster	A	0-15	Grass	Calhoun	T88N, R44W	SW¼ SE¼ 28
Wisconsin loess	15-2	Hamburg	C	120-132	Grass	Monona	T83N, R44W	NW¼ NW¼ 10
		Marshall	A	2-12	Grass	Shelby	T79N, R37W	NW¼ NW¼ 13
	28-1	Marshall	C	72-84	Grass	Shelby	T79N R37W	NW¼ NW¼ 13
	512-1	Sharpsburg	A	1-12	Grass	Clarke	T71N, R27W	NE¼ NE¼ 4
	512-2, 3	Sharpsburg	B	12-46	Grass	Clarke	T71N, R27W	NE¼ NE¼ 4
	512-4, 5, 6	Sharpsburg	C	46-94	Grass	Clarke	T71N, R27W	NE¼ NE¼ 4
	-	Edina	A	0-15	Grass	Wayne	T69N R23W	NE¼ NE¼ 22
	524-1	Clinton	A	0-6	Trees	Mahaska	T77N, R17W	SW¼ SW¼ 29
	319-1	Galva	A	0-8	Grass	Plymouth	T92N, R43W	NE¼ NE¼ 7
Missouri River alluvium	627-1	-	-	0-48	Trees	Harrison	T79N, R45W	SE¼ SW¼ 21

4. Carbonate content. Material passing No. 40 sieve; leaching and titration with versenate and treatment with dilute HC 1 (4).

5. Determination of pH. Material passing No. 40 sieve; Leeds and Northrup Company Universal pH meter.

Atterberg Limits

Liquid limits, plastic limits, and plasticity indexes were determined for each of the 20 untreated soils. In addition, the plastic limits were determined for each soil with 1, 2, 3, 4, and 7 percent lime by dry weight of soil added. The limits were determined according to standard ASTM procedures, except that the soil-water and soil-lime-water mixes were cured for two days in a moisture room.

Moisture Density Relationships and Strength Tests

Two-in. high by 2-in. diameter specimens were prepared and cured in accordance with procedures described by Hilt (6). Unconfined compressive strength tests were carried out in the Soiltest, Inc., stability testing machine.

Nine soils were selected for the preliminary studies of moisture-density and moisture-strength relationships. For two of these soils, nine 2- by 2-in. specimens were molded at varying moisture contents, for each of 0, 6, and 12 percent lime by oven dry weight of soil. The dry density of each group of nine specimens was determined from their height and weight, and the moisture content of the mix. Three of the specimens were tested for unconfined compressive strength at the end of curing periods of 7 days, 28 days and 28 days plus 1 day immersed.

For the seven other soils in the first group, six specimens were molded at varying moisture contents, with lime contents of 0, 6, and 12 percent. Strength tests were made on three of these specimens at the end of 7- and 28-day curing periods.

Only moisture-density relationships were determined for the eleven remaining soils. Three specimens were molded at each different moisture content.

Final unconfined compressive strength tests were made on all 20 soils, with 0, 1, 2, 4, 8, and 12 percent lime added. For each lime content of each soil, 12 specimens were molded at a chosen optimum moisture content. Three of these specimens were tested after curing periods of 7 days plus one day immersed, 28 days, and 28 days plus 1 day immersed.

RESULTS

Descriptive Tests

The results of the particle-size analyses are given in Table 2. The soils are grouped according to parent material and horizon, and numbered for future reference. The groups containing more than one soil are further arranged according to the percent of 5-μ clay present in the whole sample.

The results of the analyses for carbonate content are given in Table 3. The results of the versenate test are reported as a percent of the oven dry weight of soil passing the No. 40 sieve. The results of the test with dilute HC1 are expressed as calcareous or noncalcareous, with the majority of soils noncalcareous.

From the X-ray analyses, it was determined that montmorillonite was the predominant clay mineral present in each of the 20 soils. In addition, each X-ray trace was checked for the presence of carbonates in the form of calcium or magnesium carbonate peaks. The presence of one or both of these peaks in a noticeable intensity corresponded in every case to the soils having a carbonate content of more than 9 percent as determined by the versenate test.

The results of the tests for organic matter and pH are also given in Table 3. The organic matter content is expressed as a percent of the oven dry weight of soil passing the No. 4 sieve, with variations in organic matter present in each of the A-horizon groups. Also, the values of pH lie in the 5 to 9 range, with the majority of the values in the 6 to 8 range.

TABLE 2

PARTICLE-SIZE DISTRIBUTION OF SOIL SAMPLES

Soil			Whole Sample (%)					Percent Passing		
Group	Name	Number	Gravel	Sand	Silt	5-μ Clay	2-μ Clay	No. 4	No. 10	No. 40
I	Alluvial	627-1	0.0	2.4	28.8	68.8	57.4	100.0	100.0	99.4
II	Sharpsburg A	512-1	0.0	1.7	56.5	41.8	33.4	100.0	100.0	99.6
	Galva A	319-1	0.0	1.8	61.4	36.8	28.8	100.0	100.0	99.8
	Marshall A	-	0.0	0.7	68.3	31.0	24.8	100.0	100.0	99.9
	Clinton A	524-1	0.0	1.2	69.8	29.0	24.0	100.0	100.0	99.8
	Edina A	-	0.0	2.3	69.3	28.4	19.0	100.0	100.0	99.0
III	Sharpsburg B	512-2, 3	0.0	0.7	52.9	46.4	38.0	100.0	100.0	99.7
IV	Sharpsburg C	512-4, 5, 6	0.0	0.6	57.3	42.1	33.8	100.0	100.0	99.9
	Marshall C	28-1	0.0	0.3	70.5	29.2	23.0	100.0	100.0	100.0
	Hamburg C	15-1	0.0	0.0	81.0	19.0	15.0	100.0	100.0	100.0
V	Webster A	-	0.0	11.7	39.7	48.6	38.4	100.0	100.0	98.2
	Clarion A	-	0.2	18.1	42.5	39.2	28.0	100.0	99.8	95.9
	Kenyon A	-	0.5	37.5	38.6	23.4	15.8	100.0	99.5	90.6
	Lindley A	423-1	0.9	38.8	47.7	12.6	8.4	99.8	99.1	93.1
VI	Gumbotil	528-8	1.0	21.2	15.2	62.6	58.8	99.8	99.0	92.7
VII	Kansan	423-5	1.8	29.1	33.5	35.6	28.0	99.6	98.2	90.8
	Iowan	-	3.4	33.2	30.2	33.2	28.8	99.0	96.6	91.4
	Tazewell	-	8.0	26.5	33.1	32.4	24.6	97.7	92.0	83.5
	Cary II	-	9.1	29.9	31.0	30.0	22.2	97.1	90.9	81.7
	Cary I	-	10.0	41.2	30.2	18.6	12.8	95.3	90.0	78.4

TABLE 3

DESCRIPTIVE TEST RESULTS AND LIME FIXATION POINTS

Soil			Organic Matter (%)	Carbonates bonates			LFP[a] (%)
Group	Name	Number		%[b]	RA[c]	pH	
I	Alluvial	627-1	1.33	3.1	NC	8.05	3
II	Sharpsburg A	512-1	2.41	1.3	NC	6.72	2
	Galva A	319-1	4.61	2.1	NC	7.31	2
	Marshall A	-	0.55	2.6	NC	6.92	2
	Clinton A	524-1	2.04	1.2	NC	6.45	3
	Edina A	-	3.50	1.0	NC	5.19	1
III	Sharpsburg B	512-2, 3		2.2	NC	6.28	3
IV	Sharpsburg C	512-4, 5, 6		2.3	NC	6.88	4
	Marshall C	28-1		1.4	NC	6.98	3
	Hamburg C	15-2		10.8	C	8.40	2
V	Webster A	-	3.76	9.0	C	8.04	3
	Clarion A	-	4.77	1.9	NC	6.17	4
	Kenyon A	-	3.97	1.2	NC	6.58	1
	Lindley A	423-1	1.62	0.9	NC	6.58	0
VI	Gumbotil	528-8		1.9	NC	7.03	4
VII	Kansan	423-5		9.6	C	8.24	2
	Iowan	-		1.6	NC	6.83	2
	Tazewell	-		26.2	C	8.49	3
	Cary II	-		15.6	C	8.50	3
	Cary I	-		16.2	C	8.27	2

[a] Lime fixation point, percent lime based on oven dry weight of soil.

[b] Calculated carbonate content from amount of calcium determined from versenate test, percent carbonate based on oven dry weight of soil.

[c] Relative amount of carbonate present by dilute HCl test, reported as calcareous (C) or noncalcareous (NC).

Classification of the 20 soils according to the Highway Research Board System and the Unified System is given in Table 4.

Atterberg Limits

The liquid and plastic limits and the plasticity indexes of the 20 soils used are given in Table 4.

When the Atterberg limits are compared with the soils arranged in decreasing amount of 5-μ clay present in the whole sample, a general relationship between the two is apparent. Plots of these limit values vs the amount of 2-μ clay present in the portion of the sample passing the No. 10 sieve are shown in Figure 3. In these graphs, the single soils in groups III and VI have been combined with their respective C-horizon groups, IV and VII.

Considering groups III and IV, a straight line relationship exists for the limits and the plasticity indexes of the three group IV soils. Both the plastic and liquid limits of the group III B-horizon soil lie above the lines connecting these same values for the

TABLE 4

ENGINEERING SOIL CLASSIFICATIONS AND ATTERBERG LIMITS

Group	Soil	Soil Classification HRB	Soil Classification Unified	Liquid Limit	Plastic Limit	Plasticity Index
I	Alluvial	A-7-6 (20)	CH	72.0	26.0	46.0
II	Sharpsburg A	A-7-6 (14)	OL	47.5	27.5	20.0
	Galva A	A-7-5 (14)	OL or OH	50.0	31.0	19.0
	Marshall A	A-7-6 (11)	CL	40.5	23.5	17.0
	Clinton A	A-6 (9)	OL	37.0	24.0	13.0
	Edina A	A-7-6 (9)	OL	40.5	28.5	12.0
III	Sharpsburg B	A-7-6 (19)	CH	56.0	24.0	32.0
IV	Sharpsburg C	A-7-6 (17)	CL	48.0	20.0	28.0
	Marshall C	A-6 (10)	CL	37.5	23.0	14.5
	Hamburg C	A-4 (8)	ML	31.5	23.5	8.0
V	Webster A	A-7-5 (20)	CH	60.0	30.5	29.5
	Clarion A	A-7-5 (15)	OH	54.0	33.5	20.5
	Kenyon A	A-7-6 (11)	CL	47.5	25.5	22.0
	Lindley A	A-4 (5)	ML	21.0	17.5	3.5
VI	Gumbotil	A-7-6 (20)	CH	76.0	22.5	53.5
VII	Kansan	A-6 (9)	CL	34.0	17.0	17.0
	Iowan	A-6 (10)	CL	39.0	18.0	21.0
	Tazewell	A-6 (8)	CL	34.5	18.0	16.5
	Cary II	A-6 (8)	CL	37.0	19.0	18.0
	Cary I	A-4 (3)	SC	24.0	14.5	9.5

C-horizon soils. However, the plasticity index does lie on the line connecting the plasticity indexes for the C-horizon soils. Inasmuch as only one B-horizon soil was used, no direct conclusions can be drawn. These straight line relationships exist between the soils of group IV in spite of the nonsystematic variation of carbonate content, indicating little effect of this variable on the Atterberg limits of the untreated soils. The equations for the lines connecting the various points of the group IV soils are

Liquid limits (LL) $= 0.87 \times C + 18.0$
Plastic limits (PL) $= -0.188 \times C + 26.9$
Plasticity indexes (PI) $= 1.08 \times C - 8.8$

in which C = percent of 2-μ clay of the whole sample passing the No. 10 sieve.

In the curves for the soils of group II, it would seem that the same general relationship exists between the Atterberg limits and the clay content. However, when plotted, the points are much more scattered. In this group other variables are introduced, especially that of organic matter. Because the Sharpsburg and Clinton soils have approximately the same amount of organic matter, lines were drawn connecting their limits and plasticity indexes. These same points were connected for the Galva and Edina soils, which also have about the same organic matter content. The equations for the Sharpsburg-Clinton and Galva-Edina lines, respectively, are

Liquid limits: 1. $LL = 1.10 \times C + 10.8$
2. $LL = 0.95 \times C + 22.5$

Plastic limits: 1. $PL = 0.37 \times C + 15.3$
2. $PL = 0.25 \times C + 23.8$

Plasticity indexes:
1. $PI = 0.73 \times C - 4.6$
2. $PI = 0.71 \times C - 1.6$

in which C = percent of 2-μ clay of the whole sample passing the No. 10 sieve.

In group V, the general relationship again appears, although there are great variations on plotting. Points for similar organic matter content Webster and Kenyon soils were again connected, and the following equations were obtained:

Liquid limits (LL) $= 0.53 \times C + 39.5$
Plastic limits (PL) $= 0.27 \times C + 20.5$
Plasticity indexes (PI) $= 0.27 \times C + 18.8$

in which C = percent of 2-μ clay of the whole sample passing the No. 10 sieve.

Four of the group VII soils are closely related in clay content, liquid and plastic limits, and plasticity indexes, though varying greatly in geological age and carbonate content. Although the Cary I till provides a point of lower clay content, no soil of group VII has a high clay content. In view of the relations found in groups III and IV, it would seem highly questionable to use the group VI fossil B-horizon gumbotil for a point of high clay content. The equations for the lines drawn from the Cary I points through the four bunched points are

Liquid limits (LL) $= 0.94 \times C + 10.7$
Plastic limits (PL) $= 0.35 \times C = 8.3$
Plasticity indexes (PI) $= 0.72 \times C = 1.1$

in which C = percent of 2-μ clay of the whole sample passing the No. 10 sieve. Although these lines extended pass near the gumbotil points, their relationship is suggestive of that found in the soils of groups III and IV.

The loess C-horizon soils of group IV exhibit the best straight line relationship for all the soils of a group. The till soils of group VII also seem to show this single straight line relationship, but this is somewhat uncertain because of the bunching of four of the points and the lack of a point of high clay content in the group. Both of these groups have these relationships in spite of unsystematic variation in carbonate content, leading to the belief that in parent material this variable is unimportant in the Atterberg limits of untreated soils.

The A-horizon soils, on the other hand, do not exhibit the single straight line relationship for the soils of given parent material. In the soils of group II, two groups of two soils, each two having close to the same amount of organic matter, yielded two lines for each combination of liquid limit, plastic limit, and plasticity index points, both of the lines having approximately the same slope. This leads to the theory of a family of lines for both of the limits and the plasticity index, for each type of parent material. The line families would then fall into some limiting ranges, defined by the soils found in Iowa. Certainly, many more points would be needed to prove this theory. In addition, work would be needed on the B-horizon soils to determine if they would follow the single line approach or if they would be dominated by the variables which lead to the family of lines in the A-horizon soils.

Moisture-Density Relationships and Strength Tests

Optimum Moisture Content Determinations.—From the results of the preliminary moisture-density and moisture-strength studies on nine soils, curves were plotted showing dry density and unconfined compressive strengths vs moisture content for 0, 6, and 12 percent lime added. Unconfined compressive strengths after curing periods of 7 days, 28 days, and 28 days plus 1 day immersed were obtained for the Hamburg C-horizon and Sharpsburg B-horizon soils. Curves for the first two curing periods only were obtained for the seven remaining soils. In addition, a compromise moisture content (CMC) curve was plotted for each of the nine soils. This curve was determined according to procedures given by Katti et al. (11). In determining the CMC, the strength vs moisture content curves for 0 percent lime were used only for the Hamburg C-horizon and Sharpsburg B-horizon soils. A representative graph, illustrating the dry density, strength and CMC curves is shown in Figure 4.

Table 5 gives the optimum moisture content for maximum dry density (OMC) and the CMC for each of the nine soils. In addition, Table 5 gives the correction factor and the final compromise moisture content (FCMC). The correction factor was determined initially for the nine soils as the difference between the OMC and the CMC, corrected to the nearest 0.5 percent. Other slight adjustments were made in some of the correction factors to better fit a given group or to eliminate excessive adjustment of the OMC in the rounding-off processes.

Good curves were obtained for the alluvial soil, shown in Figure 4. The value of the CMC was determined and a correction factor of 2.0 was selected.

Both loess A-horizon soils of group II exhibited less than ideal curves, the maxima on the moisture-strength curves occurring at appreciably lower moisture contents than the OMC. The differences between the OMC and CMC were 5.2 percent for the higher clay content Sharpsburg A-horizon soil and 7.3 percent for the lower clay content Clinton A-horizon soil. The correction factors were placed at 5.0 and 7.0 percent respectively.

Standard moisture-density and moisture-strength curves were obtained for the two soils of groups III and IV. For both soils, the minimum of the CMC curve occurred within 0.5 percent moisture content of the OMC. Therefore, the correction factor in both cases was selected as zero.

The curves for the soils of group V were somewhat erratic, with little difference between OMC and CMC for the Webster soil and 5.7 percent difference for the Lindley soil. The correction factors selected were 0 and 5.5 respectively.

Group VI and VII soils yielded generally good curves. With a difference of 1.4 percent between the OMC and CMC for the gumbotil and 1.7 percent for the Cary II, 1.5 percent was selected for the correction factor.

Following the extensive preliminary tests to obtain the correction factor by relating the OMC of the untreated soil to the CMC of the same soil, the OMC's were determined for the remaining eleven untreated soils. Correction factors were also selected for these eleven soils. In group II, the correction factors were selected on the basis of clay content of the soils considering two already determined, except the factor for the

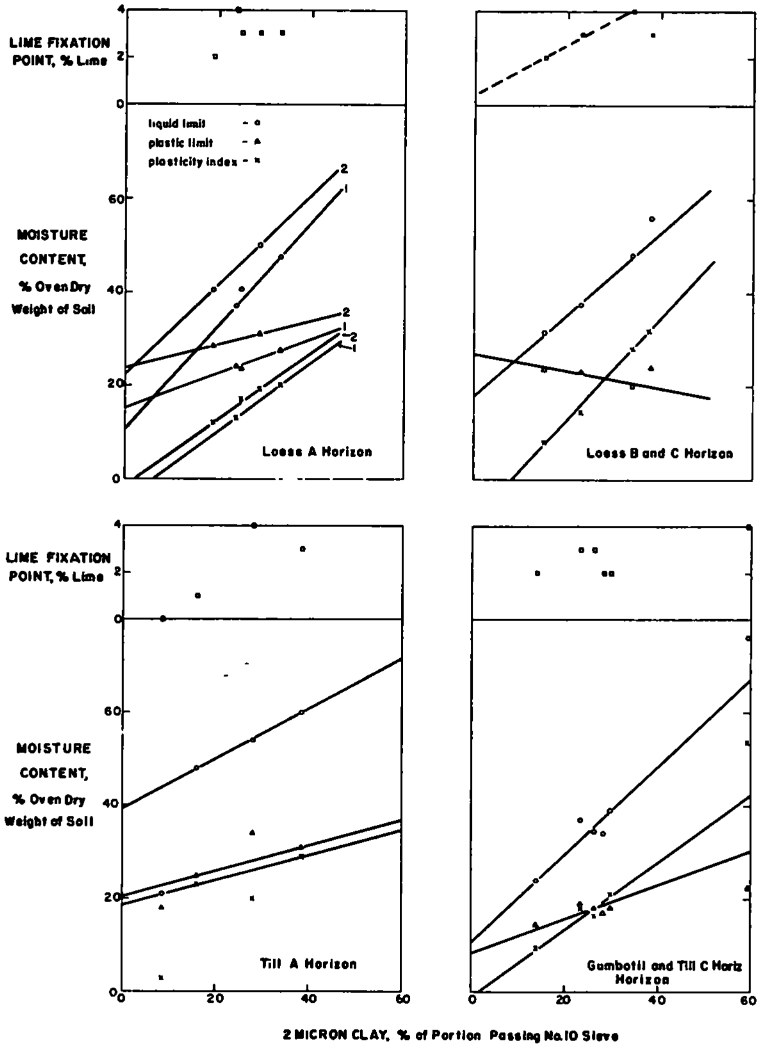

Figure 3. Atterberg limits and lime fixation points at varying clay contents.

TABLE 5

MOISTURE CONTENTS

Soil			OMC	CMC	Correction	FCMC
Group	Name	Number	(%)	(%)	Factor (%)	(%)
I	Alluvial	627-1	25.4	27.7	2.0	27.5
II	Sharpsburg A	512-1	20.5	15.3	-5.0	15.5
	Galva A	319-1	24.1	-	-5.5	18.5
	Marshall A	-	19.0	-	-6.5	12.5
	Clinton A	524-1	18.4	11.1	-7.0	11.5
	Edina A	-	24.6	-	-6.5	18.0
III	Sharpsburg B	512-2,3	21.8	21.3	0	22.0
IV	Sharpsburg C	512-4,5,6	19.5	-	0	19.5
	Marshall C	28-1	19.0	-	0	19.0
	Hamburg C	15-2	18.0	18.3	0	18.0

TABLE 5 (Continued)

Soil			OMC (%)	CMC (%)	Correction Factor (%)	FCMC (%)
Group	Name	Number				
V	Webster A	-	25.5	25.3	0	25.5
	Clarion A	-	20.3	-	0	20.5
	Kenyon A	-	20.4	-	0	20.5
	Lindley A	423-1	13.0	7.3	-5.5	7.5
VI	Gumbotil	528-8	23.2	24.6	1.5	24.5
VII	Kansan	423-5	14.4	-	1.5	16.0
	Iowan	-	12.4	-	1.5	14.0
	Tazewell	-	15.2	-	1.5	16.5
	Cary II	-	16.1	17.8	1.5	17.5
	Cary I	-	11.9	-	1.5	13.5

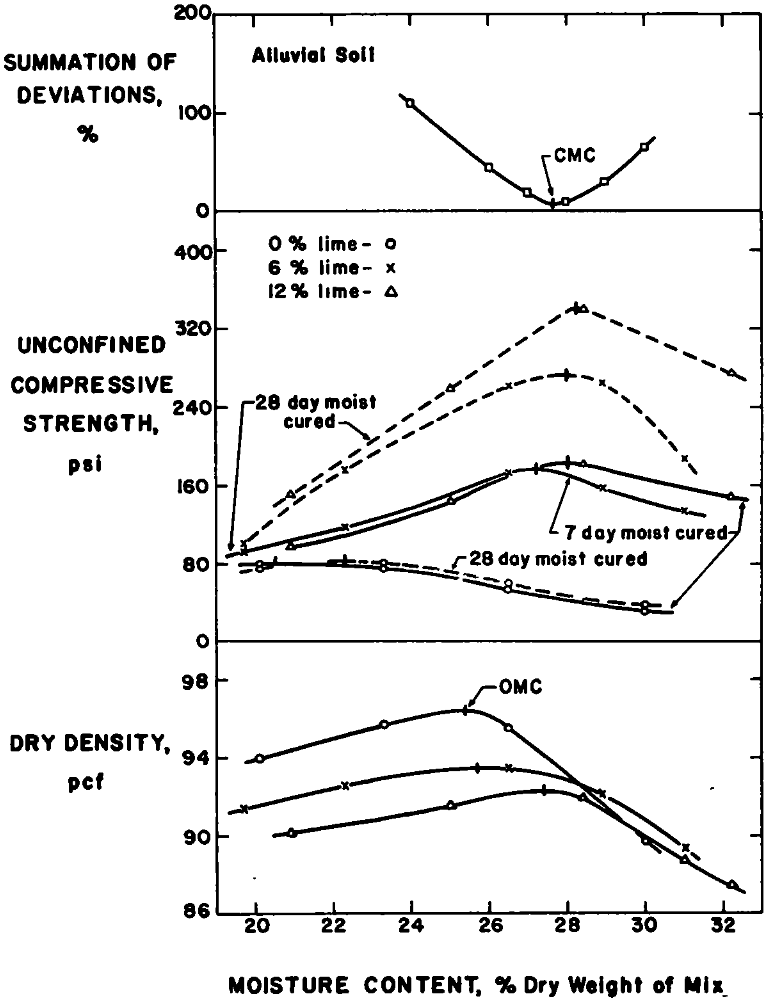

Figure 4. Unconfined compressive strengths, dry densities, and summations of deviations for alluvial soil mixed with varying amounts of lime at varying moisture contents.

Edina soil was placed below 7.0 percent because its OMC more closely resembled the soils in this range. The Marshall and Sharpsburg C-horizon soils of group IV were given correction factors of zero. The Clarion and Kenyon soils of group V were given correction factors of zero, as they appeared to more closely resemble the Webster soil. The remaining till soils of group VII were given correction factors of 1.5 percent.

The FCMC was then determined for each soil by applying the correction factor to the OMC of the untreated soil. The FCMC was used as the molding moisture content for the final strength tests.

Strength Tests. —The plotted curves of strength at FCMC vs lime content for the various curing periods are shown for each of the 20 soils in Figures 5 through 8. Figure 9 shows strength at different lime contents plotted against 2-μ clay content of the portion passing the No. 10 sieve. Groups III and IV and VI and VII are shown together.

The alluvial soil of group I, shown in Figure 5, gains a maximum 28-day dry unconfined compressive strength of 320 psi with 12 percent lime added, with a closeness of the dry and immersed strengths, particularly at the higher lime percentages. This soil was one of the five tested that showed immersed strengths with no lime added.

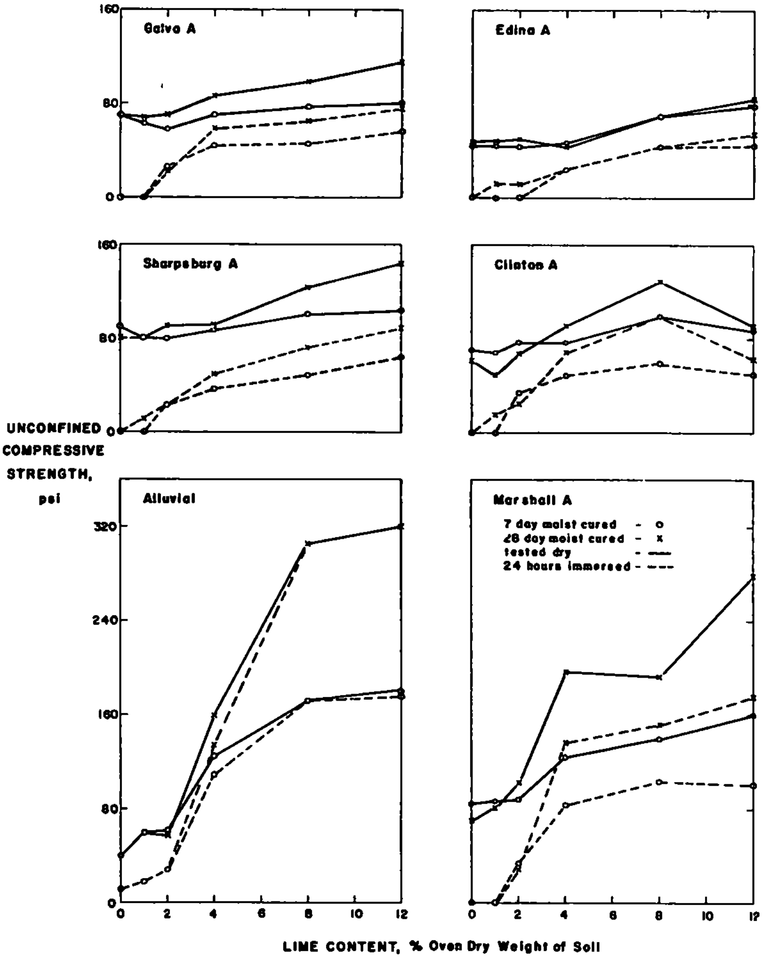

Figure 5. Unconfined compressive strengths of alluvial soil and five loess A-horizon soils at varying lime contents.

The soils of group II, also shown in Figure 5, gain little strength with the addition of lime, the Marshall showing the highest 28-day dry unconfined compressive strength of 275 psi. All of the group II soils have their highest strength at 12 percent lime, with the exception of Clinton, which has a maximum strength at 8 percent. There is little relation between clay content and strength, as shown in Figure 9. The Marshall has the highest carbonate content and lowest organic matter content of the group, apparently accounting for its much higher strength.

Soils of groups III and IV appear to behave most systematically. In the curves of strength vs clay content (Fig. 9), there is the least variation in strength with the lower lime contents. However, as the lime content increases, the inverse relationship of strength to clay content becomes more apparent. There is also a systematic change in the shape of the strength vs lime content curves (Fig. 6) as the clay content of the soil changes.

The soils of group V, shown in Figure 7, exhibit generally poor strengths, with the Webster soil having the high 28-day dry unconfined compressive strength of 280 psi at a lime content of 12 percent. There is a general decrease in strength with decreasing clay content for the three soils that appear to be most similar, with the Lindley exhibiting an increase in strength, as shown in Figure 10. Also there is a much higher carbonate content for the Webster soil. Further, though the Lindley and Kenyon soils contain approximately the same amounts of sand and gravel, the Lindley has less clay and more silt size material.

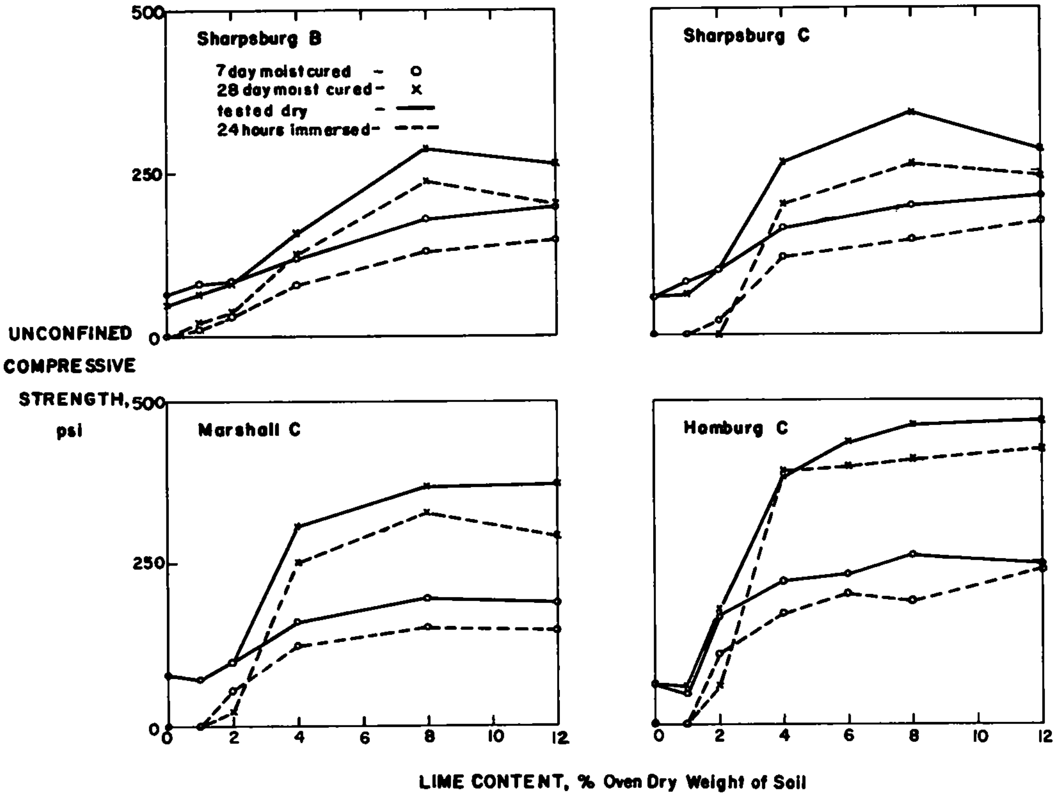

Figure 6. Unconfined compressive strengths of the loess B-horizon soil and three loess C-horizon soils at varying lime contents.

As mentioned earlier, the soils of group VII are alike in many respects and differ greatly in others, with some overlapping between groups depending on the point of division. For example, four of the soils have very high carbonate contents, whereas another grouping of four show much similarity in clay content and Atterberg limits. If the gumbotil of group VI is also considered, three of the soils are of relatively recent age (16,000 years or younger) whereas three are of Iowan age or older.

It is particularly in the consideration of strength that a division on the basis of geological age shows up to the best advantage. The younger tills (Tazewell, Cary I, and Cary II) gain strength immediately with the addition of small amounts of lime, rise to a peak strength, and then decline in strength as more lime is added. The strength of the Kansan till rises rather abruptly with additions of lime, after remaining constant for a short period, and the gumbotil and Iowan till strengths rise steadily as lime is added. Although the younger tills have a 28-day dry unconfined compressive strength of no less than 520 psi with 4 percent lime added, the older tills and the gumbotil exhibit a maximum strength of 285 psi with the addition of 12 percent lime, as shown in Figures 8 and 9.

In general, the shapes of the curves for 28-day unconfined compressive strength vs lime content fit into one of the following four cases:

1. Case A. —Strength gains begin immediately with the addition of small amounts of lime, and the curve rises abruptly to a peak strength with the possibility of a slight decrease in slope before the peak is reached. Strength decreases after the peak with further additions of lime. The Tazewell, Cary I, and Cary II tills follow this pattern.

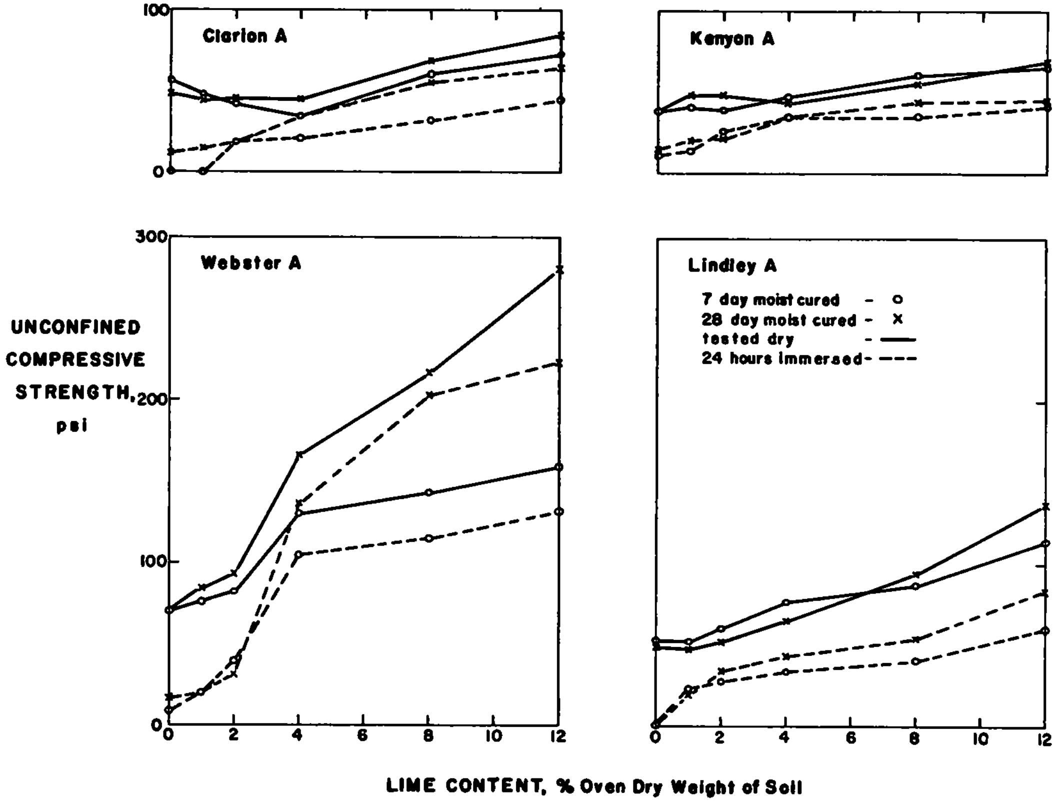

Figure 7. Unconfined compressive strengths of four till A-horizon soils at varying lime contents.

2. Case B.—Strength increases slightly, remains the same, or decreases slightly as the first amounts of lime are added. After a point, an abrupt strength increase takes place with the addition of more lime, until another break point is reached, after which strength remains constant or increases or decreases slightly with further additions of lime. This case includes all soils of groups I, III, and IV and the Kansan till soil of group VII.

3. Case C.—Strength tends to increase slightly, remain the same, or decrease slightly with the addition of small amounts of lime. Thereafter, strength tends to increase continuously with the further addition of lime. Soils in this case include Iowan till, gumbotil, Webster A-horizon and Marshall A-horizon.

4. Case D.—Strength shows very little increase regardless of the amount of lime

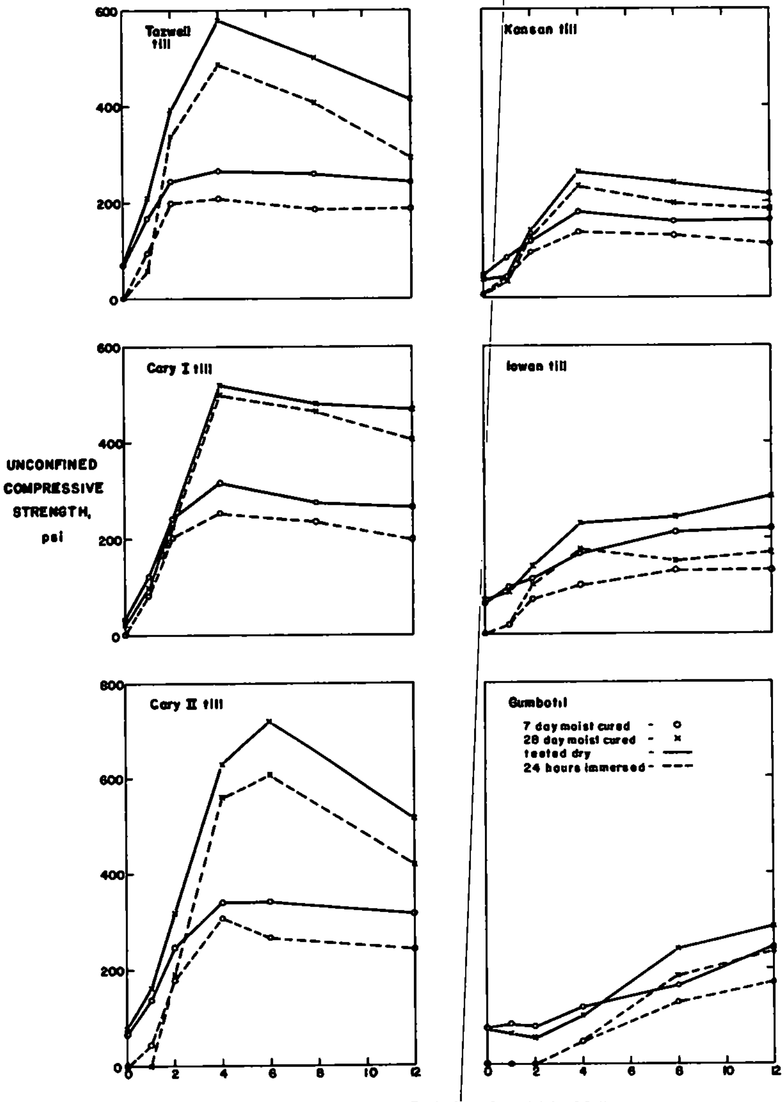

Figure 8. Unconfined compressive strengths of gumbotil and five till C-horizon soils at varying lime contents.

added. This case includes all the loess and till A-horizon soils with the exception of the Webster and Marshall soils.

It is particularly evident cases B, C, and D are gradational. The peaks on the curves of case B smooth out to approach more closely a straight line (as in Case C), and the straight line gradually decreases in slope as the total strength gain becomes less until there is little total strength gain (as in Case D).

Lime Fixation Point

Plastic limits at various lime contents were plotted against lime content to ascertain the lime fixation point. These curves are shown in Figure 11. The lime fixation point was selected from the curves as the point at which plastic limits no longer increased with the addition of more lime. As a check, plots were also made of equivalent 28-day dry unconfined compressive strength vs plastic limit, with selected curves shown in Figure 10.

Because lime does not react with material of greater than silt size (16), there would be a greater concentration of lime to reaction size material in the strength specimens than in the material for the plastic limit tests if the same lime content was used in both cases. Therefore, the equivalent lime content was first determined according to

$$L_E = L \times \frac{P_{40}}{P_4}$$

in which

L_E = equivalent lime content;
L = original lime content;

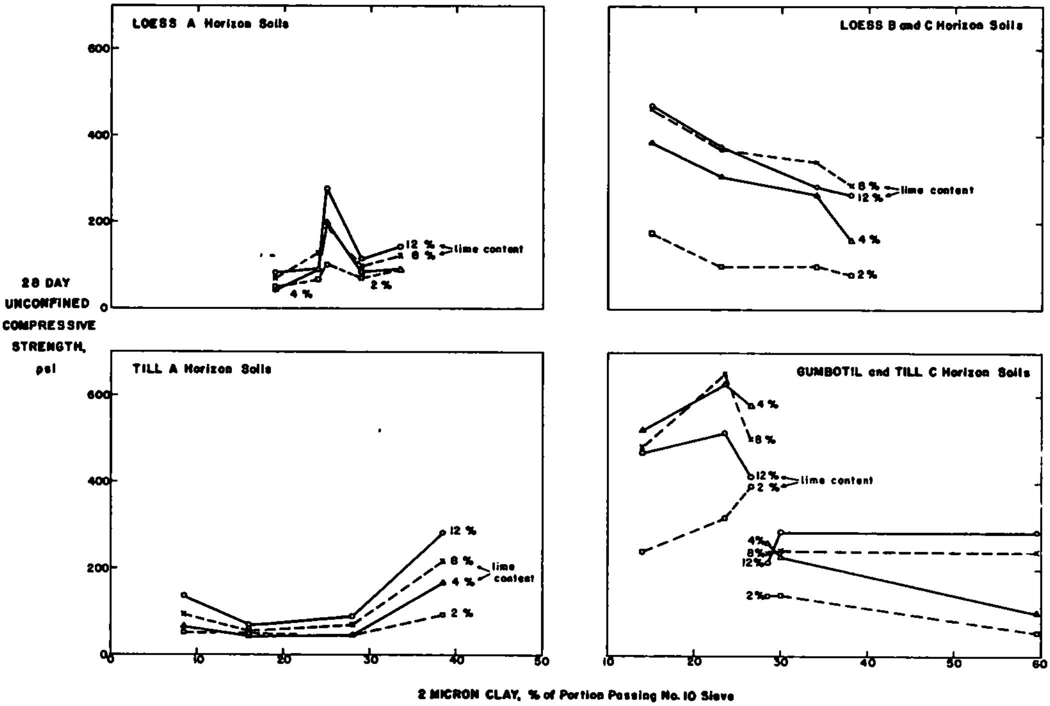

Figure 9. Unconfined compressive strengths at varying lime contents after 28 days.

P_{40} = percentage of soil passing No. 40 sieve; and
P_4 = percentage of soil passing No. 4 sieve.

The equivalent unconfined compressive strength was then determined using the equivalent lime content, which was lower than the lime content for the corresponding plastic limit test. Corrections were made only for groups V, VI, and VII, because in the other five groups at least 99 percent of the sample passed the No. 40 sieve.

To eliminate the problem of bias in the selection of the LFP from the plastic limit vs lime content curves, the LFP was chosen as the point at which there was an abrupt change to a slope of opposite sign or the point after which the slope of the curve was one or less. The values determined for the LFP are shown in Table 3.

The values obtained from the plastic limit vs lime content curves were then compared to those obtained from the strength vs plastic limit curves. Most of the values compared rather well. In the Sharpsburg and Edina A-horizon soils, there was a lag between the percent lime at which the plastic limit stopped increasing and the percent lime at which strength started increasing. Also, the Tazewell, Cary I and Cary II soils plots of strength vs plastic limit were irregular, in that the strength began increasing immediately on the addition of lime, rather than after an amount of lime sufficient for lime fixation had been added. There were also some discrepancies in

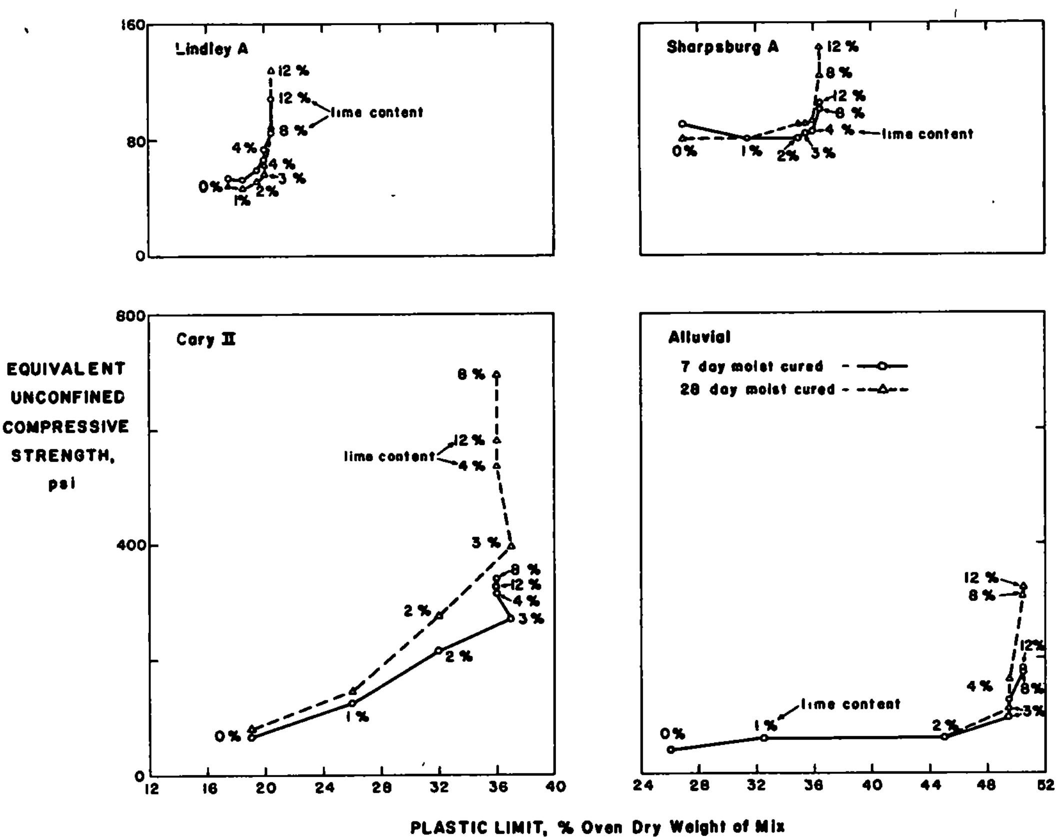

Figure 10. Comparison of equivalent unconfined compressive strengths and plastic limits for four soils.

the Kenyon and Lindley A-horizon soils, but the smaller, more practical values of LFP from the first curves were used because of the very small total increase in the plastic limits of both soils.

The lime fixation points were also plotted vs clay content for each of the soils, except the alluvial soil, as shown in Figure 3. Again, the group IV loess C-horizon soils yield the best straight line relationship. The range of LFP values for the soils of groups II and III is 1 to 3 percent; for group IV soils, 2 to 4 percent.

The group V till A-horizon soils had lime fixation points in the 0 to 4 percent range, with the group VII soils in the 2 to 3 percent range. The LFP of the alluvial soil was 3 percent and that of the gumbotil 4 percent.

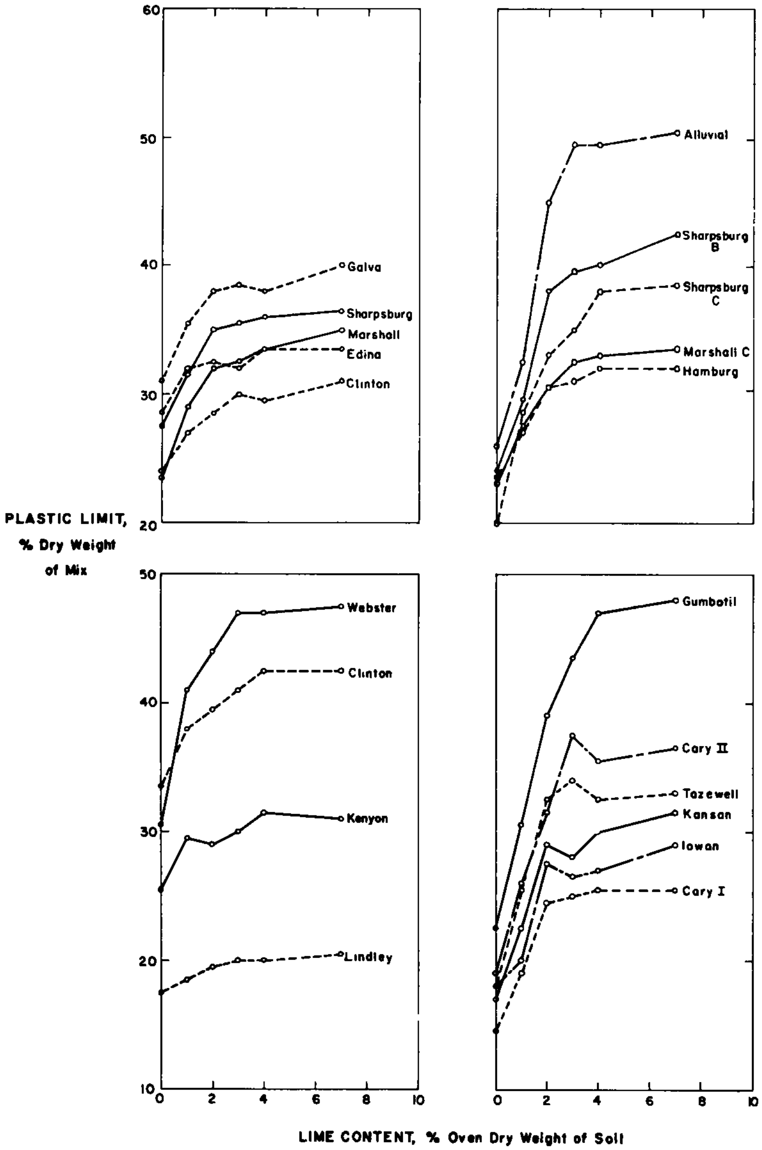

Figure 11. Plastic limits of 20 soils at varying lime contents.

CONCLUSIONS

1. A straight line relationship exists in the loess C-horizon soils of Iowa between the Atterberg limits and the 2-μ clay content. The general trend of this relationship continues into other Iowa soil groups studied, but no definite conclusions can be drawn about these groups.

2. Additions of lime increase the plastic limits of Iowa soils up to the lime fixation point, even though the total increase in plastic limit may be small or the leveling off of plastic limit values after the lime fixation point is reached may not be as apparent in some soils as in others.

3. Lime fixation occurs in the loess C-horizon soils of Iowa in the 2 to 4 percent lime range, the amount required being proportional to the amount of clay size material in the soil and independent of carbonate content of the soil. The range of lime fixation for loess A- and B-horizons is 1 to 3 percent, with no definite relation to clay content.

4. Lime fixation occurs in till C-horizon soils of Iowa in the 2 to 3 percent lime range, and appears to be interrelated to particle size and geological age. The range of lime fixation in till A-horizons is 0 to 4 percent.

5. Iowa loess B- and C-horizon soils exhibited marked strength gains with the addition of lime in amounts above the lime fixation point. The strength gain was inversely proportional to the clay content. Loess A-horizon soils had small strength gains, not directly related to clay content or other single variables.

6. The gumbotil and till C-horizon Iowa soils treated with lime can be placed in two general strength categories on the basis of geological age. Relatively younger tills had far better maximum strengths than the Iowan and older tills and gumbotil. Till A-horizon soils gave generally low strengths.

7. It would appear that loess C-horizon soils of Iowa would better fit a soil-lime design system for road construction based on particle-size distribution than one based on soil series. Till C-horizon soils of Iowa would seem to best fit into a design system based on geological age. However, it would seem that modification to fit into a system based on soil series would be possible for both groups with further study.

8. Much further work would be needed to fit the loess A- and B-horizon soils, till A- and B-horizon soils and alluvial soils of Iowa into a soil-lime stabilization design system for road construction purposes.

ACKNOWLEDGMENTS

The subject matter of this investigation was obtained as part of the research being done under Project 449-S at the Iowa Engineering Experiment Station of the Iowa State University of Science and Technology. Project 449-S is under contract with the Iowa Highway Research Board of the Iowa State Highway Commission.

The lime used in this work was generously furnished by the U. S. Gypsum Company, Chicago, Ill.

The authors express their appreciation to members of the staff of the Engineering Experiment Station for their advice and assistance in this investigation and in the preparation of this paper.

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