Cement Requirements of Selected Soil Series In Iowa

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Previous work has shown good correlation between cement requirements for soil-cement and specific horizons in 43 agricultural soil series in several Great Plains States, Washington, and Idaho (1).

To check the validity of such correlations further and to expand the results to Iowa, a number of loess, sand and glacial till soil series were sampled in various horizons and tested. Instead of selecting modal samples from a series, many series are represented by modal samples and by extremes to provide a more rigorous test. Zonal great soil groups represented are Brunizem and Gray-Brown Podzolic. The dominant clay mineral is montmorillonite.

Cement requirement correlations ranged from good to poor. Reasons for poor correlations are that cement requirements for some fine-grained Iowa soils were abnormally high due to freeze-thaw sensitivity, and that some series are too broadly defined to distinguish adequately the sensitive from non-sensitive soils. Major differences relating to great soil group and B horizon structure were also found.

Investigations of Iowa fine sands showed good correlation of cement requirements with geologic origin, which is not reflected in the soil series designations on published soil maps. The sands are a valuable resource for use in soil-cement.

● AGRICULTURAL soil maps are useful to highway and foundation engineers, and recently the basic mapping unit, the soil series, has proved to be a reliable criterion for judging the amount of portland cement needed to convert the soil to soil-cement (1). This correlation was demonstrated with samples from the different soil layers, or horizons, from each series. Samples were then tested to find the cement requirement. Results were checked by sampling the same series and horizons at several locations. Usually the requirements remained constant, and the variation was never more than one percent of cement. Tests were conducted on A, B, and C horizon samples from 43 soil series in several western states.

This led to the search for additional correlations, and application of the method to soils of Iowa. A wide variety of sandy, silty, and clayey soils were tested, representing glacial till, loess, and sand parent materials. In many series the sampling sites were selected not only to represent "average" or modal profiles, but also the extremes, to provide a more severe test.

Published U.S.D.A. county soil maps were helpful for series identification and sampling. Unfortunately most maps are old, and most series on the old maps have been re-defined. Therefore sampling is necessarily done by workers familiar with recent advances in soil mapping in a particular geographic area. This of course holds true whether sampling is for a research project or for an actual field use—whenever correlations are to be made with soil series.

PARENT MATERIAL

In approximately 82 percent of the area of Iowa the soils have developed in loess or in glacial drift, divided about equally between the two (2). The parent materials for soils over most of the remaining areas are alluvium.

Representative loessial and till soil series were selected for study. In addition four samples of upland glacio-fluvial and eolian sand were tested. Although a complete representation of Iowa series was impossible, the series most significant to engineers, for example those in hilltop positions where there is more likelihood of roadcuts and excavation of borrow, are represented. The loessial series are of interest because the loess parent material presents wide systematic textural variations believed related to distance from a source. This relation could be useful in correlation to cement requirement. Near major river valleys such as those of the Missouri, Mississippi, and Iowa, the loess is an A-4 silt with little or no soil profile. Fifty to eighty miles away the loess gradually changes to A-6 and then A-7-6 clay with a very strong soil profile (Fig. 1).

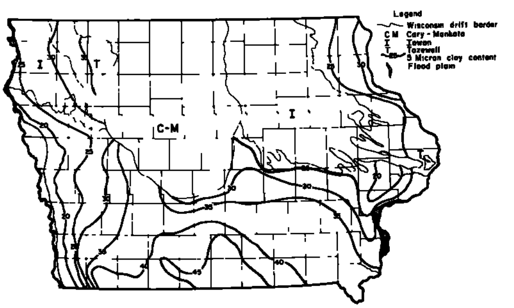

Figure 1. Map showing Wisconsin drift borders and contoured 5 micron clay contents of C horizon loess.

The Wisconsin age loess usually overlies Illinoian age (Loveland) loess or, more commonly, Kansan age glacial till which otherwise underlies the Loveland. Where loess is thin, the till outcrops on eroded valley slopes (Fig. 2) or may be intercepted by deeper roadcuts. In some roadcuts a tough, gray, clayey layer, aptly termed gumbotil, is found between the loess and glacial till. This is a paleosol, or ancient soil profile, weathered into the Kansan till during the long interval prior to loess deposition. An analogous paleosol is in the Loveland loess (3). Gumbotil is usually very high in montmorillonitic clay mineral and causes interesting problems, such as seepages, slumps, and tenaciously muddy roads. Color and morphology of the buried paleosol relate to preloess topography and erosion (4) and are somewhat predictable from the present landscape. For example, gumbotil is very clayey, thick, and gray-colored in flat, uneroded upland positions, where it is much like a modern Planosol. In better drained positions it is reddish, thinner, and resembles a Gray-Brown Podzolic.

GREAT SOIL GROUPS

Two zonal great soil groups occur in Iowa, Brunizems (formerly called Prairie soils), formed under grass, and Gray-Brown Podzolic soils, formed under forest. Brunizems cover about 68 percent of the state and are the well-drained, dark-colored topsoils currently associated with an over-abundance of corn. Gray-Brown Podzolics occur interspersed with the Brunizems but are more prominent in the eastern and southern parts of the state. The Gray-Browns are somewhat similar to Brunizems in clay content and profile, but are more acidic and have a distinctive gray-colored topsoil, or A horizon. Both groups show marked clay accumulation in the subsoil, or B horizon.

In southern Iowa, upland remnants of the Kansan till plain occur as wide flats which have been etched away at the margins to leave long, projecting interfluves that mesh into the drainage pattern like fingers. Loess on these flat areas is usually poorly drained, partly because it is underlain by the impermeable gumbotil. As a consequence two intrazonal great soil groups are prominent:

Wiesenbodens (Humic Gley soils) are the poorly drained counterpart of Brunizems, occurring where profile development has been inhibited by high water table. They are characterized by a thick, very dark brown or black A horizon over a weak, gray-colored B. With proper drainage they are excellent for agricultural use.

Somewhat similar to Wiesenbodens in position but not in profile are the Planosols. Here the poor drainage, instead of inhibiting profile development by waterlogging, has enhanced profile development due to increased infiltration and intensified leaching. Planosols formed either under forest or under grass are acidic throughout their profile, and the A horizon has a distinctive ash-gray (under grass) to white (under forest) layer, labelled the A_2 horizon. The B horizon is extremely high in clay. Planosols should logically make poor soil-cement.

TABLE 1

CLASSIFICATION OF MAJOR SOIL SERIES IN WESTERN, SOUTHERN AND EASTERN IOWA

Parent Material	Great Soil Group: Regosol	Gray-Brown Podzolic	Brunizen (Prairie Soil)	Wiesenboden (Humic Gley)	Planosol: Grassland	Planosol: Forest
W. Iowa loess, coarse ↓ fine	HAMBURG IDA ←	Ladoga	Monona[1] Marshall Minden SHARPSBURG Winterset			
E. Iowa loess, coarse ↓ fine		Fayette Downs Clinton Weller Pershing	Tama Muscatine Otley Mahaska Grundy Seymour	Garwin Taintor Haig	Sperry Edina	Berwick Marion
Kansan till, unweathered ↓ weathered	Steinauer	← Lindley Gara	Burchard[1] Shelby Lagonda[1] →	CLARINDA		

[1]Series showing characteristics of more than one great soil group are indicated by position or by arrows. Series more or less central in a group are capitalized.

SERIES

Series on Loess

Loessial soil series in Iowa are given in Table I. Those series with essentially the same parent material are horizontally on line; for example, the Fayette is the forested equivalent of the Tama. Intergrades are also indicated; the Downs is a Gray-Brown Podzolic with some characteristics of a Brunizem, probably because of a late invasion by trees. Similarly, the Muscatine is a wet Brunizem, with tendencies towards a Wiesenboden.

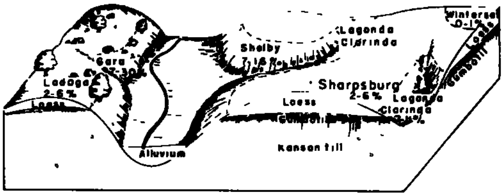

Figure 2. Block diagram illustrating typical topographic occurrences of till and loess soils in the Shelby-Sharpsburg-Winterset Soil Association area, southwest Iowa. From "Understanding Iowa Soils" (2).

The Hanburg, Ida, and Monona series are in the classic thick loess area bordering the Missouri River plain in western Iowa (Fig. 3). The Hamburg series is a Regosol, found where soil profile development has not kept pace with erosion. It is essentially unaltered C horizon calcareous loess. The Ida series is also a Regosol, but shows faint beginnings of becoming a Brunizem, with a brown, calcareous A horizon. The Monona series is a weak Brunizem, with a brown A horizon and indistinct B horizon leached of carbonates.

The Marshall series is a nicely developed Brunizem with a moderately clayey B horizon, and is found in an extensive belt to the east of the Monona-Ida-Hamburg association area. Farther to the southeast, the loess is thinner and finer, and the major Brunizem is the Sharpsburg series, with Ladoga the forested counterpart (Fig. 2).

In eastern Iowa, the Tama series is much like the Marshall and develops from similar parent material. Fayette is the common forested counterpart. The approximate eastern Iowa equivalent of the Sharpsburg, developed on moderately clayey, leached loess, is the Otley. However, the forested counterpart, the Clinton series, and the poorly drained counterparts, Mahaska and Taintor, are more abundant in this particular area.

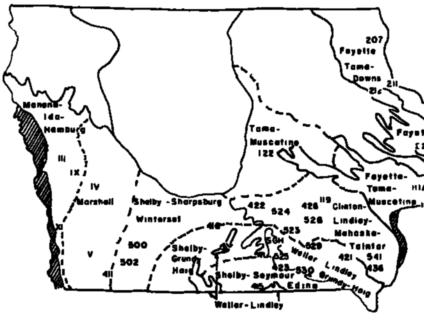

Figure 3. Soil association areas studied. Dashed lines indicate gradational boundaries. Numbers show sample locations.

In south-central Iowa the loess is progressively finer, and the Grundy and Weller series represent Brunizems and Gray-Browns, respectively. Somewhat more poorly drained and finer textured is the Seymour series, a Brunizem. Also abundant are the Haig and Edina representing planoscl influences, but the B horizons are so thick and clayey they are not well suited for soil-cement.

Series on Till

Also in western, southern, and eastern Iowa are the till soil series indicated in Table I. The nomenclature is simplified because, except for younger till sheets in northern Iowa, the glacial till parent material does not vary systematically across the state. Most is Kansan in age, but a rim of Illinoian till is in the eastern part of the state.

On rapidly eroding slopes, the essentially unweathered calcareous till Regosol is now designated the Steinauer series. The Burchard series is a weak Brunizem leached only in the A and B horizons, analogous to the Monona series on loess. These series have been mapped as Shelby in the past. Shelby is now restricted to a well-developed Brunizem on leached till. The forested counterpart of the Shelby is the Lindley; an intergrade between the two is now mapped as Gara. Surficial outcrops of gumbotil are included on older soil maps with Shelby, but now may be mapped Clarinda, a Wiesenboden, or Lagonda, a planosolic Brunizem (Fig. 2).

PROCEDURE

Sampling

Most of the series tested were represented by samples from two to four sections which were selected to represent not only the mode but also the range of each series. For example, the Marshall series was sampled at three locations, one near the center of the Marshall area and the others from near the edges, where the Marshall is transitional to the Monona on the west and the Sharpsburg on the east (Fig. 3).

Most sections are located in roadcuts or quarries. Sampling was done by trimming back to a fresh surface, then cutting a downslope channel to obtain accurate composite samples of each layer. Pedological A, B, C_1 (leached C), and C horizons were sampled after field identification by two or three experienced persons to minimize bias. Supplemental augering was done where necessary, and special zones in or under the C horizon were sampled separately.

Mapping and definitions of soil series is constantly changing as finer distinctions are made, and very few of the soil series could be accurately identified merely from location on published U.S.D.A. Soil Survey maps, many of which were prepared in Iowa in the 1920's. Each series was therefore re-identified and fitted into up-to-date nomenclature.

Testing

Particle size analyses were made by the hydrometer method using the Iowa State air-jet dispersion device and sodium metaphosphate as the dispersing agent (5). Plasticity index and classification tests were performed according to standard ASTM methods (6). Cement requirements were determined in the Portland Cement Association Laboratory in Skokie, Illinois, according to standard methods (7). These include the following: (a) a moisture-density test to determine maximum density and optimum moisture content for compaction; (b) wet-dry and freeze-thaw tests, 12 cycles each on separate specimens, to determine how much cement is required to hold loss of loosened surficial material to within permissible limits; and (c) compressive strength tests to show if setting reactions are proceeding properly—strength should increase both with increas-

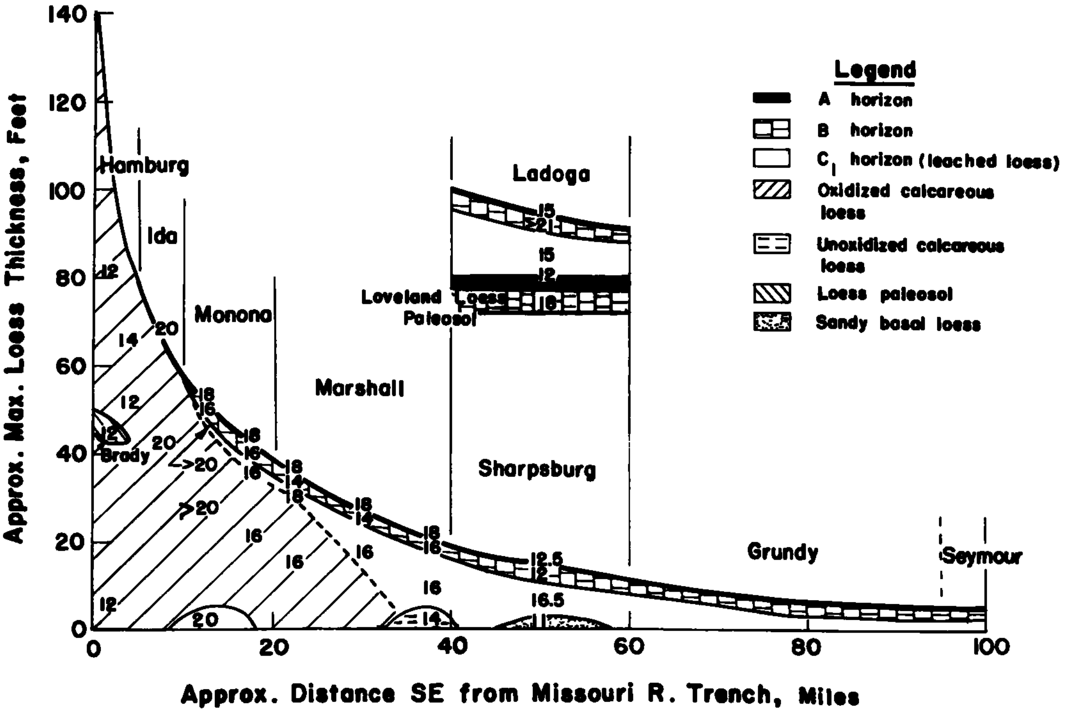

Figure 4. Cement requirements of western Iowa loessial soils. As the loess thins it becomes finer, leached of carbonates, and weathered into heavier textured soil profile. Thickness and distance scales very approximate.

ing age and cement content. Permissible weight losses during wet-dry or freeze-thaw tests are set at 10 percent for A-4 and 7 percent for A-6 and A-7 soils. Specimens are brushed between cycles to remove loose material.

RESULTS

Loess

Minimum cement requirements are indicated in Figures 4 and 5 for various loessial soil series.

Hamburg.—Four samples of coarse calcareous loess mapped in the Hamburg series required 12 percent cement, and one required 14 percent. A sample of a weak, leached paleosol identified as Brady soil (8) shows no difference in cement requirement, the requirement still being 12 percent.

Ida.—Samples of Ida A horizon and C horizon loess required 20 percent cement due to failure by excessive scaling in the freeze-thaw test. This loess is apparently in a critical clay content range for failure during freezing and thawing; the critical range is indicated by the vertical dashed lines in the top graph of Figure 6.

Monona.—Samples of coarse Monona leached and calcareous C horizon loess required over 20 percent cement, and are also in the critical clay content range (top, Fig. 6). In the B horizon samples and in a finer C horizon sample, the higher clay content reduced the requirement to 16 percent. The A horizon requirement was 18 percent.

Marshall.—Marshall C horizon samples required 16 to 18 percent cement, somewhat in the critical clay range. As in the Monona, the more clayey B horizon required less cement than the C, 14 to 16 percent, and all A horizon samples required 18 percent.

Sharpsburg.—Sharpsburg C horizon loess is less critical for freeze-thaw loss, and the requirement was found to be 16.5 percent cement. The A and B horizons required only 12.5 and 12 percent, respectively, indicating the beneficial influence of clay. A sandy basal loess sample required 11 percent. The presence of either sand or clay is apparently effective at reducing cement requirement in these western Iowa Brunizems.

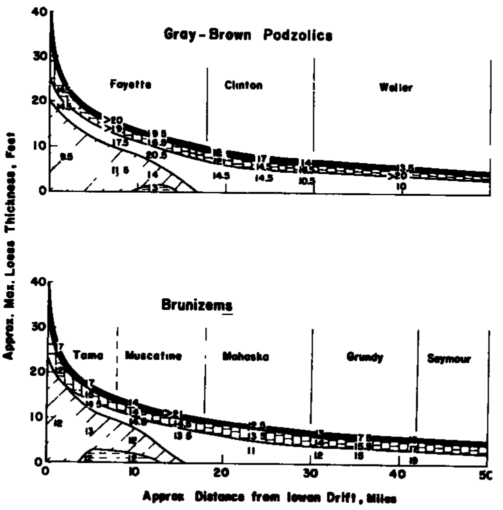

Figure 5. Cement requirements of eastern and southern Iowa loessial soils. Legend is the same as in Figure 4.

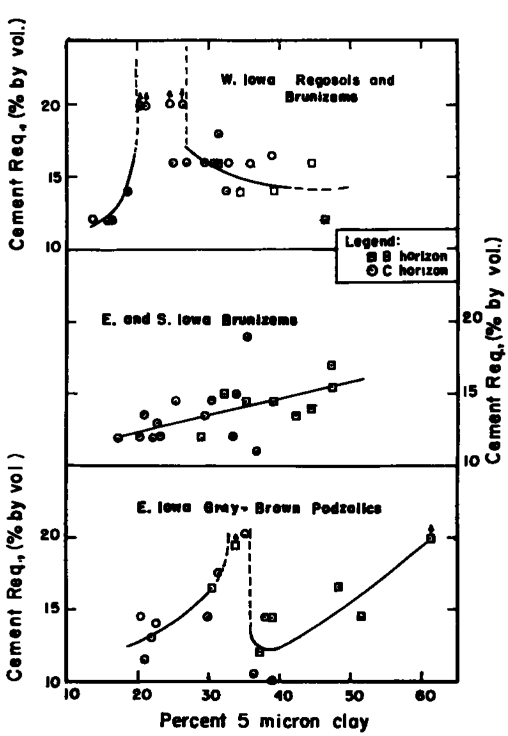

Figure 6. Relations of cement requirement of Iowa loessial soils to 5 micron clay content.

Ladoga.—The Gray-Brown Podzolic equivalent of the Sharpsburg gives some interesting contrasting requirements in the A and B horizons. The Gray-Brown A and B are bad actors compared with the Sharps burg, and required 16 and over 21 percent cement, respectively. The C horizon was not affected, and required 16 percent cement. Possible influences of podzolization are discussed under Fayette.

Loveland Loess and Paleosol.—Samples of plastic Loveland loess from underneath the Wisconsin loess at the section sampled for Ladoga have cement requirements not unlike the Weller: 12 and 11.5 percent for the A and A_3-B_1 horizons, and 18 percent for the clayey B_2.

Grundy.—The Grundy continues trends initiated in the Sharpsburg: more clay, less sensitivity to freeze-thaw, less cement. This trend reached a climax in the least clayey

Grundy C horizon sample, which had a requirement of 12 percent. With more clay, however, failures began in the wet-dry test, and cement requirement mounted rapidly.

Tama.—Thick eastern Iowa loess under the Tama series, a Brunizem, required 12 percent cement in the B and C horizons and 17 percent in the A, or very close to the Hamburg C and Monona A of western Iowa. Most interesting is that the C horizon Tama is not overly sensitive to freeze-thaw, even though the clay content would put it in the critical range of the western Iowa samples (Fig. 6, middle graph).

Tama-Muscatine-Mahaska-Grundy.—Some relationships are shown between intergrading eastern Iowa loessial Brunizem soil profiles and cement requirement, but the requirements do not necessarily coincide with series breaks (Fig. 4). For example, the C horizon loess requirement was 12 to 13.5 percent cement in the Tama and Muscatine series, reached a low of 11 percent cement in the Mahaska, and climbed rapidly in the Grundy, from 12 to 17 percent, as losses in the wet-dry test became critical due to the high clay content. The major change in cement requirement thus took place within the confines of the Grundy. The cement requirements of the B horizons for these series was usually 1.0 to 2.5 percent higher than for the C. Requirement ranged from 13.5 to 15 percent to even higher in the already too clayey Grundy. The Edina series was not sampled, but it probably has cement requirements higher than the Grundy.

Fayette.—Cement requirements of the Fayette series, the Gray-Brown equivalent of the Tama (Fig. 4), are inconsistent, because the series is too broadly defined to correlate adequately with some very critical freeze-thaw losses. Coarse, sandy loess under the Fayette series required 9.5 percent cement in the C horizon and 14.5 percent in the C_1 and B. With more clay the B horizon became critically susceptible to freeze-thaw, and the requirements jumped to 17.5 and 19 percent for the C_1 and B, respectively. Then in finer loess the C horizon became critical, requiring 20.5 percent, but the B horizon was over the hump.

This critical clay content range in the Fayette but not in the equivalent Brunizems (Fig. 6, lower and middle graphs) suggests a limited delecterious influence from podzolization. This is also true in the A horizon of the Fayette, which required 13.5 to 20 percent, averaging 17.7 percent for three samples. As previously mentioned, the Ladoga, a Gray-Brown from western Iowa, also showed deleterious influence. However, the bad effect of forest vegetation does not carry over into the Clinton and Weller, which series are even more acidic than the Fayette. In the Fayette the pH is 4.5 to 5.1 in the A and B horizons; in the Weller it varies from about 3.8 to 4.5 (2).

Perhaps the slightly different array of exchangable cations or the traces of forest-derived organic matter could cause a structural effect in compacted samples, increasing capillary conductivity and causing excessive freeze-thaw losses.

Clinton-Weller.—The Clinton series is developed in finer loess than the Fayette and continues the trend toward lower cement requirement. In the coarser of the Clintons sampled, the C horizon requirement was 14.5 percent, and that in the higher clay B horizon was 12 percent. In the finest Clinton section and in the Weller section the C horizon reached an optimum for soil-cement, 10.5 percent and 10 percent, respectively. However, as previously noted for the Grundy, the B is too clayey, and required 16.5 and more than 20 percent, respectively, due to losses in the wet-dry test. The unusually high requirement for the Weller B horizon could be partly due to theft of calcium from hydrating cement by the clay, inasmuch as the natural base saturation is of the order of 50 to 60 percent.

Summary-Loessial Series.—In western Iowa the cement requirement of coarse loess usually mapped in the Hamburg series is 12 percent. However, in slightly finer loess, freeze-thaw losses suddenly become very critical, and cement requirements leap to more than 20 percent. Loess mapped as Hamburg, Ida, or Monona and containing over 17 percent 5 micron clay should always be regarded as suspect. In the Marshall and Sharpsburg the cement requirements are steadily pushed down by the increase in clay content, until the requirement again reaches a low of 12 percent in the relatively heavy textured Sharpsburg B horizon.

Eastern Iowa Brunizems on loess do not show the same susceptibility to freeze-thaw, and here in general more clay means that more cement is required. Best for stabilization are the Tama, Muscatine, Mahaska, and coarser Grundy C horizons, which require

11 to 13 percent cement. B horizons take more cement, and the requirement jumps to 19 percent in the finer Grundy B and C horizons, where wet-dry losses become critical.

The A horizons of most loessial Brunizems require 18 percent or more cement and should not be used. Exceptions may be the Sharpsburg and Mahaska, samples of which were stabilized with 12.5 percent cement.

Gray-Brown Podzolics on loess show a critical sensitivity to the freeze-thaw test, much like western Iowa Brunizems, but at higher clay contents. Cement requirements start low in the coarse Fayette, reach a peak in the medium Fayette B and the fine Fayette C, and fall off again in the Clinton. Then the clay content becomes too high in the Clinton and Weller B horizons, and failures occur in the wet-dry test. The critical clay content range occurring in the Fayette probably is related to some influence of podzolization. This influence extends through the A, B, and C_1 horizons, but not into the calcareous C. Acidity alone does not explain it, inasmuch as the acidity in the Clinton and Weller, which require less cement is equal or greater.

<u>Till</u>

Cement requirements of till series are given in Table 2. Note that the series correlation is not good, probably because series definitions and variability of the parent

TABLE 2

CEMENT REQUIREMENTS OF SOIL SERIES ON KANSAN AND ILLINOIAN TILL

	Brunizems				Gray-Brown Podzolic			
					Lindley			
Horizon	Burchard		Shelby		Kansan Till			Ill. Till
A	13	14	12	-	10.5	8	-	-
B	13	15	14	-	13.5	16.5	15	12.5
C_1	-	16	12	-	12.5	12.5	12.5	13
C_{ca}	13.5	-	-	-	-	-	-	-
C	17	11	15	11	13.5	12	-	-

material are too broad. Calcareous C horizon Kansan till mapped under the Shelby, Lindley, and Burchard series was usually stabilized with 11 to 13.5 percent cement, but one sample required 15 percent and another 17 percent because of high losses during the wet-dry test, probably from deleterious expansions of the montmorillonitic clay. Although C horizon cement requirements do not plot well against clay content (lower half of Fig. 7) the clay content becomes critical when the amounts are greater than about 37 percent. Eight of the 13 calcareous and leached C horizon till samples with 5 micron clay contents of 37 percent or less may be stabilized with 11 to 13.5 percent cement. The average requirement was about 12 percent. The five samples with over 37 percent clay required 13 to 17 percent cement, the average requirement being about 13 percent.

If clay content is critical, one would expect till B horizons to require more cement, and most do. However, an inverse relationship exists (top half of Fig. 7), and the higher clay content B horizons tend to require less cement—several percent less than equivalent clay content C horizon samples. Furthermore, most B horizon samples failed in the freeze-thaw test rather than the wet-dry test, as did the C horizon samples with the same clay contents. This suggests an important contribution from the characteristic blocky structure of the B horizon, reducing volume change losses during wet-dry cycles. The compacted density of five B horizon samples with an average clay content of 37.8 percent is 106.2 pcf; of ten C horizon samples with a clay content of 37.5 percent, it is 110.8 pcf. The B horizon blockiness tends to reduce density, which may be directly or indirectly related to the increased resistance to wet-dry volume change. Only the lowest clay content B horizon sample, a Lindley, failed during the wet-dry test, and requirement was boosted to 16.5 percent. A gumbotil sample also showed benefit from having been a B horizon; although it contained 53 percent 5 micron montmorillonitic clay, the cement requirement was only 12 percent, and failure was by freeze-thaw. Another gumbotil sample with 70 percent clay failed in the wet-dry test and required 18 percent cement.

The A horizon Shelby and Burchard series required 12 to 14 percent cement, compared with only 8 to 10.5 percent for Lindley A horizons. In contrast to loessial series, podzolization in the Lindley has no deleterious effect, but is beneficial in the A horizon because it reduces the clay content to 15 or 20 percent and cuts the cement requirement. Unfortunately, Lindley A horizon soil is not abundant enough to provide a source for material; these results merely point out that A horizon material in the Lindley, Shelby, or Burchard series can beneficially be incorporated into soil-cement.

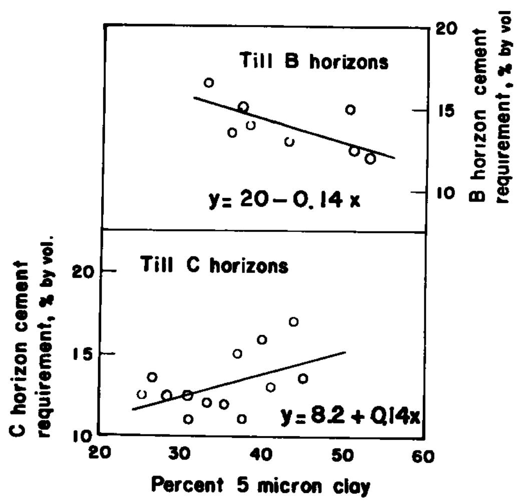

Figure 7. Relations of cement requirement of Iowa till soils to 5 micron clay content.

Sand

Because of possible economic importance, upland sand deposits on and near the Iowan drift in eastern Iowa have in recent years been extensively mapped, sampled, and the engineering properties studied (9) (Fig. 8). Four representative deposits were sampled for soil-cement tests. One sand, coarser than the rest is fluvial in origin (that is, deposited from water). The other three are finer and eolian, although one is rather coarse because of local derivation from sandy drift.

Because of difficulties in interpreting origin, the Iowa sands have been confusing for agricultural soil surveyors. As a result the sands are identified as belonging to a wide variety of series, such as Knox, Carrington, and Fayette. Although no attempt is made here to correlate cement requirement to modern series equivalents, on future soil maps the eolian Brunizem sands will probably be mapped as Hagener (Riecken, F.F., personal communication (1956))(formerly mapped as Thurman, Carrington, Lindley, Knox), and the Gray-Brown Podzolic equivalent will be the Chelsea (formerly mapped as Knox, Lindley, Sparta, Plainfield). Coarser eolian sands derived from local wind action on glacial drift will be mapped as Dickenson if a Brunizem (formerly Carrington, Shelby) or Lamont (Riecken, F.F., personal communication (1956)) if a Gray-Brown Podzolic.

TABLE 3

CEMENT REQUIREMENTS OF EASTERN IOWA SANDS

Sample No.	Origin	% Coarse Sand (> 0.42mm)	Cement Requirements, (% by vol.)
S-31-1	Fluvial	24.9	7.5
S-28-4	Eolian (drift)	16.6	9.0
S-6-2	Eolian (banded)	6.2	8.5
S-6-2a	Eolian	3.2	9.0
S-57-4	Eolian	0.8	8.5

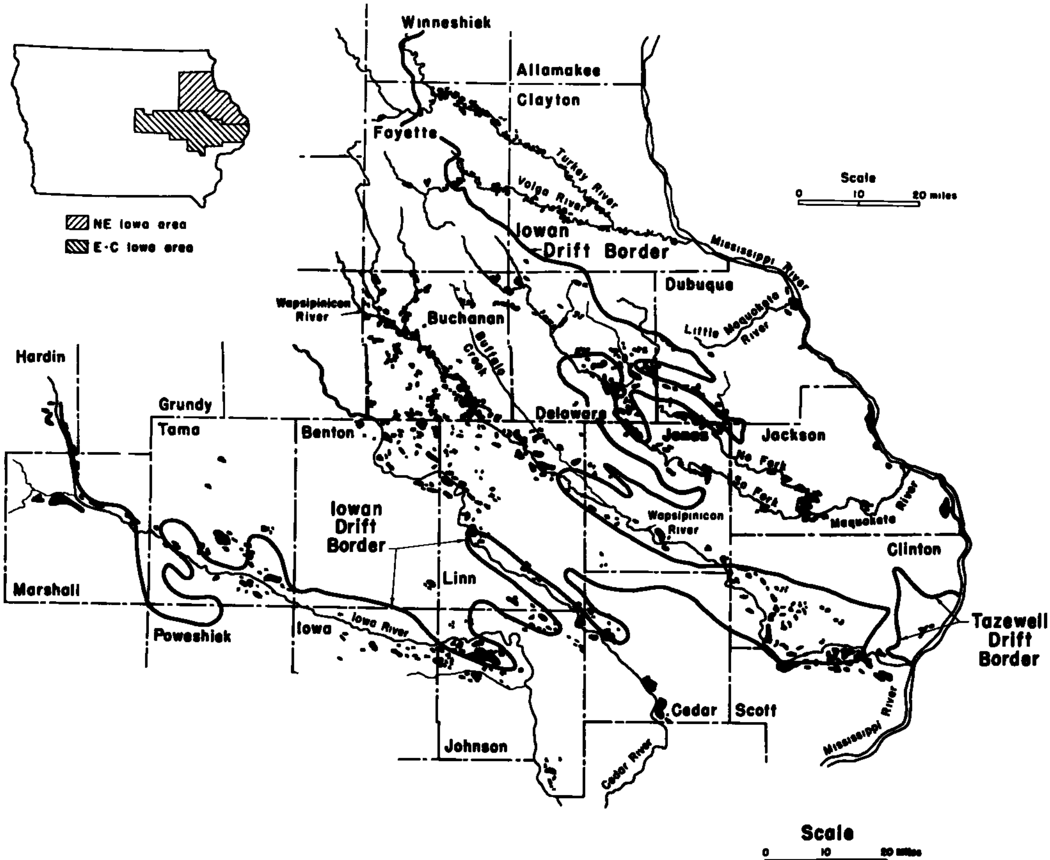

Figure 8. Sand deposits in eastern Iowa.

Many eastern Iowa sand deposits contain bands richer in clay and iron oxide minerals. Most such bands lie nearly horizontal, but many dip, intersect one another, or are wavy. They are believed to be secondary in origin, perhaps miniature repeated B_2 horizons. One severely banded section was sampled separately for soil-cement tests, to see if banding has any effect on cement requirement.

Results.—Results of soil-cement tests with the five sandy soils are given in Table 3. The fluvial sand required 7.5 percent cement; the eolian sands all required 8.5 to 9.0 percent, regardless of local derivation or secondary banding. The eastern Iowa sand deposits should be considered a valuable resource for use in soil-cement.

CONCLUSIONS

Conclusions from the investigation may be stated as follows:

1. Not all soil series may be successfully correlated with cement requirement, particularly when requirements are high because of an unusual sensitivity.

2. Medium-textured loess and loessial soils in the Ida, Monona, and Marshall series of western Iowa are critically susceptible to damage by freeze-thaw, probably due to high moisture mobility during freezing. However, this damage is reduced by increased contents of clay. Even more effective is the presence of sand.

3. Eastern Iowa Brunizems on loess do not show the critical susceptibility to freeze-thaw, but medium-textured Gray-Brown Podzolics, notably in the Fayette series, do. Perhaps differences in exchangable cations or presence of traces of forest-derived organic matter allow increased moisture movement during freezing.

4. Clay content reaches an optimum for freeze-thaw resistance in fine-textured loess or loessial B horizons. Then further increases in clay content accelerate wet-dry losses and raise the cement requirement. The optimum clay content is reached in the Clinton, Mahaska, and Sharpsburg B, and in the Clinton-Weller and Mahaska-Grundy C horizons. Weller B and Grundy-Seymour B and C horizons are too high in clay.

5. High clay contents in C horizon Kansan glacial till also accelerate wet-dry losses and increase the cement requirement. However, B horizon samples with the same clay content resist wet-dry losses and require less cement. The blocky structure in the B horizon of till series is of decided benefit.

6. Sand deposits common in eastern Iowa may be readily stabilized with 7.5 to 9.5 percent portland cement. Cement requirement correlates with postulated origin and, when the areas are re-mapped, should correlate with soil series.

ACKNOWLEDGMENT

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Appendix

TABLE 4

TEST RESULTS FROM WESTERN IOWA LOESS SOILS

Series and Iowa No.	Horizon	Gradation: Gravel, >2mm	Gradation: Sand, 0.074-2mm	Gradation: Silt, 5-74μ	Gradation: Clay, < 5μ	Consistency: LL	Consistency: PI	Maximum Density (pcf)	Optimum Moisture, (%)	Required Cement Content, (% by vol)
W. Iowa Loess:										
Hamburg I	C	0	3.2	80.3	16.5	30.3	5.2	102.9	17.9	12
	AB, Brady	0	6.2	70.9	22.9	31.8	9.4	107.8	16.5	12
	C	0	8.2	78.2	13.7	27.3	2.6	107.7	15.8	12[1]
" X	C	0	0.9	80.6	18.5	32.1	10.1	103.0	18.5	14
	D, Stratified	0	0.7	83.3	16.0	33.9	10.9	102.3	19.0	12
Ida III	A	0	0.0	67.7	32.3	46.1	20.2	99.4	19.5	20
	C	0	0.5	75.0	24.5	35.2	11.8	100.0	18.5	20
Monona XI	A	0	0.1	82.5	17.4	42.9	19.5	98.5	22.5	18
	B	0	0.4	68.7	30.9	45.8	23.5	98.7	22.0	16[1]
	C_1	0	0.4	73.2	26.4	39.9	17.0	105.0	18.0	> 20
	C	0	0.6	74.8	24.7	33.5	9.8	102.0	18.6	> 20
	C, Fe-rich	0	0.3	78.3	21.4	35.7	11.9	101.3	19.3	> 20
	C_1	0	0.2	79.2	20.6	34.9	10.8	102.0	18.3	> 20
" IX	A	0	0.7	65.7	33.6	44.7	21.4	98.6	21.0	18
	B	0	0.5	68.3	31.2	41.8	20.3	103.2	18.3	16
	C_1	0	0.5	70.1	29.4	41.2	19.7	103.3	19.0	16
	C	0	0.7	74.3	25.0	57.9	16.2	103.8	18.7	16
Marshall IV	A_3	0	0.8	59.3	39.9	45.8	23.1	94.5	23.3	18
	B	0	0.4	65.2	34.4	46.0	25.9	102.3	18.8	14
	C_1	0	0.3	68.2	31.5	41.7	21.0	103.0	18.8	18
	C	0	0.4	72.6	27.0	38.0	26.8	99.6	19.5	16
" V	A	0	0.5	64.7	34.8	42.6	19.7	98.3	21.5	18
	B	0	0.3	60.4	39.3	48.0	27.9	99.0	21.5	14
	C_1	0	0.4	66.6	33.0	39.6	21.3	104.2	18.7	16
Marshall VIII	A	0	0.4	58.3	41.3	49.2	27.6	98.4	21.3	18.0
	B	0	0.4	54.8	44.8	56.3	33.2	98.8	22.0	16
	C_1	0	0.4	63.6	36.0	43.6	22.5	103.3	18.7	16
	C, unoxidized	0	0.8	66.6	32.6	40.4	19.7	98.4	21.3	14
Sharpsburg, 500	A	0	2.0	57.0	41.0	46.1	21.9	96.0	21.0	12.5
	B	0	1.0	52.5	46.5	55.1	33.6	95.5	22.7	12
	C_1	0	1.0	60.0	39.0	47.7	26.1	100.0	22.0	16.5
	Sandy loess	0	15.0	55.0	30.0	35.5	16.4	112.3	13.5	11
Ladoga 502	A	0	2.3	63.9	33.8	35.6	13.9	102.5	17.1	15
	B	0	1.0	50.0	49.0	37.4	21.0	99.3	19.7	21[1]
	C_1	0	2.4	60.4	37.2	51.7	31.2	100.2	19.7	15
(Paleosol on	A_p	0	5.0	58.0	37.0	34.0	16.0	107.9	16.4	12
Loveland	B_{1p}	0	6.1	56.5	37.4	39.1	22.1	107.2	17.0	11.5
loess, 502)	B_{2p}	0	4.2	42.2	53.6	61.9	40.4	95.6	23.0	18[1]

[1]Wet-dry losses exceed losses from freeze-thaw.

TABLE 5

TEST RESULTS FROM EASTERN AND SOUTHERN IOWA LOESS SOILS

Series and Iowa No.	Horizon	Gradation: Gravel, >2mm	Gradation: Sand, 0.074-2mm	Gradation: Silt, 5-74µ	Gradation: Clay, <5µ	Consistency: LL	Consistency: PI	Maximum Density (pcf)	Optimum Moisture (%)	Required Cement Content, (% by vol)
Gray-Brown Podzolics:										
Fayette 100	A	0	2.1	62.6	35.4	41.0	17.7	102.7	19.3	13.5
	B	0	0.1	60.9	39.0	54.1	33.8	101.5	18.7	14.5
	C_1	0	1.0	78.2	20.8	30.0	9.1	105.4	17.0	14.5
	Sandy loess	0	8.3	79.4	12.3	25.5	6.3	109.2	15.3	9.5
" 211	A	0	2.0	77.8	20.1	30.0	7.5	102.0	17.3	>20
	B	0	0.8	65.2	34.0	43.4	21.5	104.0	16.5	>19
	C_1	0	0.5	67.8	31.7	45.8	23.9	104.3	17.8	17.5
	C	0	0.7	78.2	21.1	28.9	8.2	106.6	16.2	11.5
207	A	0	1.7	75.1	23.1	33.3	4.3	100.0	18.9	19.5
	B	0	0.4	68.9	30.7	38.0	15.0	102.7	19.2	16.5
	C_1	0	0.5	64.3	35.2	41.7	19.3	101.3	18.1	20.5
	C	0	0.4	76.7	22.9	30.2	8.4	108.1	16.6	14
	C, unoxidized	0	0.3	77.5	22.2	28.6	6.7	109.6	15.8	13
Clinton 524	A	0	1.1	68.4	30.5	35.9	10.8	97.0	19.6	12
	B	0	0.7	61.8	37.4	43.9	22.4	98.8	20.0	12
	C_1	0	0.3	69.7	30.0	36.2	15.9	103.7	19.0	14.5
" 119	A	0	1.2	64.8	34.0	36.9	12.9	96.1	22.1	17
	B	0	0.7	56.6	42.7	51.8	30.0	100.1	21.7	14.5
	C_1	0	3.4	62.9	34.7	38.1	19.9	103.5	19.8	14.5
" 523	A	0	2.2	64.3	33.5	43.3	14.5	93.4	23.8	14
	B	0	2.8	58.0	39.5	48.5	24.1	98.3	19.5	16.5[1]
	C_1	0	4.6	58.9	36.5	36.8	18.8	105.3	18.5	10.5
Weller 530	A	0	4.7	65.3	30.0	32.4	11.9	97.0	19.5	13.5
	B	0	1.8	46.4	51.8	61.9	40.0	95.3	22.0	>20[1]
	C_1	0	4.8	55.2	40.0	39.1	21.4	104.3	19.6	10
Brunizems:										
Tama 122	A	0	2.3	71.5	26.2	32.9	8.9	102.8	18.4	17
	B	0	2.4	68.6	29.0	33.9	12.7	105.2	17.5	12
	C	0	5.0	77.6	17.4	25.4	1.8	107.8	16.0	12
" 212	A	0	3.4	71.6	25.0	35.7	11.7	99.8	19.2	17
	B	0	2.3	74.9	32.2	47.7	25.7	104.8	18.0	15
	C_1	0	3.1	71.4	25.5	39.1	17.3	106.7	17.5	14.5
	C	0	1.2	66.6	22.8	32.8	10.7	106.0	17.3	13
	C, unoxidized	0	2.4	74.5	23.1	29.6	8.8	107.9	15.7	12.0
Muscatine 223	A	0	0.8	67.6	31.6	40.7	17.2	99.6	19.7	14
	B	0	0.7	63.9	35.4	45.5	25.5	100.1	18.5	14.5
	C_1	0	0.3	69.0	30.7	37.4	15.9	105.1	18.0	14.5
	C	0	0.8	78.6	20.6	26.6	3.6	106.8	16.5	12
	C, Fe-rich	0	0.9	78.1	21.0	26.8	6.4	110.4	15.2	13.5
	C, unoxidized	0	1.4	76.3	22.3	28.2	9.1	107.6	17.3	12
" 111A	A	0	3.3	64.7	32.0	39.2	13.0	91.3	24.3	>21
	B	0	2.1	57.6	39.3	39.1	15.1	99.8	20.2	14.5
	C_1	0	0.8	69.4	29.8	30.8	9.0	108.9	16.7	13.5
Mahaska 528	A	0	1.4	69.1	29.5	33.8	9.4	97.5	18.2	12.5
	B	0	0.7	57.8	42.5	49.5	26.2	102.0	20.5	13.5[1]
	C_1	0	1.6	61.4	37.0	46.0	25.1	101.5	19.5	11
Grundy 529	A	0	2.5	62.5	35.0	34.3	14.1	97.5	21.4	13
	B	0	0.7	54.5	44.8	50.5	31.2	96.3	23.4	14[1]
	C_1	0	0.5	65.8	33.6	38.0	20.2	104.0	17.8	12
" 525	A	0	2.7	63.3	34.0	38.4	11.5	97.5	21.3	17.5
	B	0	0.9	51.8	47.4	52.5	27.6	93.5	22.5	15.5
	C_1	0	0.4	65.6	34.0	38.8	19.1	101.3	19.5	15[1]
" 541A	A	0	3.6	57.4	39.0	41.5	15.2	96.7	20.0	18
	B	0	1.5	51.0	47.5	55.2	29.9	96.6	22.5	17[1]
	C_1	0	1.0	63.5	35.5	45.7	24.6	102.6	18.3	19[1]

[1]Wet-dry losses exceed losses from freeze-thaw.

TABLE 6

TEST RESULTS FROM KANSAN AND ILLINOIAN TILL SOILS

Series and Iowa No.	Horizon	Gradation: Gravel, >2mm	Sand, 0.074-2mm	Silt, 5-74μ	Clay, <5μ	Consistency: LL	PI	Maximum Density (pcf)	Optimum Moisture (%)	Required Cement Content (% by vol)
Brunizems:										
Burchard 411	A	3.0	30.0	30.5	36.5	43.3	20.3	100.5	18.7	13
	B	3.5	23.5	30.0	43.0	49.5	28.4	103.0	20.0	13
	C_{ca}	1.5	24.5	29.0	45.0	45.4	30.2	108.6	16.3	13.5
	C	3.0	24.5	28.5	44.0	41.1	25.7	108.1	16.0	17
Shelby 415	A	0.8	31.6	39.6	28.0	35.6	15.1	99.3	21.0	14
	B	2.7	29.2	30.9	37.2	47.4	29.4	103.0	19.3	15
	C_1	2.3	23.4	34.3	40.0	45.8	28.6	99.7	22.0	16
	C	2.0	25.1	35.3	37.6	39.6	25.0	114.0	15.0	11
" 416	A	8.0	36.5	29.5	26.0	38.4	14.6	104.6	17.3	12
	B	3.5	32.2	25.1	39.2	44.2	23.1	109.7	15.5	14
	C_1	11.2	27.8	27.8	33.2	38.8	19.8	113.5	15.0	12
	C	1.3	32.6	29.1	37.0	38.2	23.1	112.5	15.5	15[1]
" 425	C	2.5	35.6	30.9	31.0	29.0	12.0	117.8	13.0	11
Gray-Brown Podzolics:										
Lindley 422	A	4.0	43.0	32.0	21.0	28.1	11.7	106.5	15.5	10.5
	B	1.2	37.1	25.2	36.5	39.3	23.0	108.3	15.7	13.5
	C_1	6.2	41.3	27.0	25.5	33.0	20.0	116.3	13.7	12.5
	C	1.0	40.8	31.7	26.5	28.9	14.8	118.4	11.0	13.5[1]
" 423	A	0	40.2	44.8	15.0	22.4	4.7	113.0	13.5	8
	B	0.4	41.6	25.0	33.0	39.6	22.8	107.0	16.5	16.5[1]
	C_1	2.0	40.0	27.0	31.0	36.2	21.4	111.0	15.5	12.5
	C	0.8	28.7	35.0	35.5	40.9	22.6	113.1	14.2	12
" 429A	B	1.2	30.7	17.7	50.4	35.6	18.5	101.0	21.0	15
	C_1	2.0	41.5	28.1	28.4	27.6	12.9	113.6	14.1	12.5
" 436	B	5.0	19.0	25.0	51.0	56.5	35.3	107.4	18.0	12.5
(Illinoian till)	C_1	1.0	26.0	32.0	41.0	56.2	35.7	109.3	14.5	13.0
Paleosols:										
Gumbotil, 500-5C	B_p	5.0	21.5	21.0	52.5	41.0	24.0	101.9	20.9	12
Gumbotil, 528-4C	B_p	0.3	16.1	13.1	70.5	85.0	53.3	99.3	21.4	18[1]

[1]Wet-dry losses exceed losses from freeze-thaw.

TABLE 7

TEST RESULTS FOR EASTERN IOWA SANDS

Origin and Iowa No.	Horizon	Gradation: Coarse Sand, 2-0.42mm	Fine Sand, 0.42-0.74mm	Silt, 5-74μ	Clay, <5μ	PI	Maximum Density (pcf)	Optimum Moisture (%)	Required Cement Content (% by vol)
Fluvial[2] S-31-1	C_1	37.0	59.2	1.6	2.2	NP	117.0	8.8	7.5
Eolian, local[1] S-28-4	C_1	24.4	74.4	0.2	1.0	NP	110.6	9.5	9.0
Eolian[1]	C_1	9.1	87.7	1.7	1.5	NP	113.6	9.1	8.5
S-6-2	B_3 (band)	12.9	81.5	1.6	4.0	NP	116.0	9.5	9.0
Eolian[2] S-57-4	C_1	1.7	86.9	8.6	2.8	NP	113.6	10.0	8.5

[1]Old series name indicates Brunizem.
[2]Old series name indicates Gray-Brown Podzolic.