Development of Series Concepts for Selected Soils in the Eastern Part of Land Resource Region M

Central Feed Grains and Livestock Region

Soil Survey Investigations Report No. 47
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Introduction

As soil survey update activities begin to attain full stride, large areas may be re-corrugated in short periods of time. These correlations will require homogeneous soil series, uniform soil interpretations, and presentation of data sufficiently precise to allow unanticipated interpretations. Series changes will be physiographic-province driven.

Soil scientists have always been excellent observers. They have in the past and still do see and record small differences in soil profiles. They have sampled many soils with the aim of elucidating these differences. To date, the National Soil Survey Laboratory Database has more than 30,000 data sets available for perusal.

This soil survey investigations report is the product of all of the above kinds of activities. Observations of differences, however small, that seem to reflect soil interpretations were used as operating hypotheses. Mostly, the National Soil Survey Laboratory Database was used to test these hypotheses. Over 650 pedon data sets were available. A literature review gathered background data. The result is a listing of some precise soil series differentiae. Also developed is a map of the boundaries of certain suites of soils in Land Resource Region M (LRR-M) that have a history of differences in series concept, areal extent, and interpretation. Additionally, this report demonstrates that it is possible to resolve many soil problems without the collection of more data.

Problem

Loamy and clayey soils developed in till occur throughout Land Resource Region M. As soil survey work progressed, a large number of soil survey crews in five states examined and described the soil independently. As mapping of the soils proceeded, ranges in character-istics of some series began to overlap significantly. Soil Taxonomy with its defined particle size classes was adopted by the National Cooperative Soil Survey (NCSS) in about 1968. This tended to cause all local and regional soil correlators to more carefully examine the particle size control section than other parts of the profile. In 1983, the series control section was extended to a depth of 150 cm or the base of a diagnostic horizon, whichever was more, not to exceed 200 cm. In most areas of Wisconsin-age till in LRR-M, a series depth limit of 150 cm includes some unleached till. Soils developed almost entirely in till have some unleached till at 100 cm or less. However, field soil scientists only needed to accommodate the particle size classes of the series. Commonly regional correlation activities concentrated on combining or at least not splitting soil series. As long as multiple surveys were not conducted along common political boundaries concurrently, the system worked. Additionally, the particle size class problem was compounded by a general disregard for geomorphology. For example, LRR-M map units on till plains usually do not separate the metastable, degrading shoulders from the metastable, aggrading footslopes. As a result of these activities, the series concept was increased for the textural range of the series. Finally, the Official Series Descriptions did not adequately attempt to describe the series concept. Rather, they present a listing of properties observed in the field at one place or another.

Purpose

The purpose of this soil survey investigations report is threefold. First, we defined more precisely the differentiating soil properties of some soils in LRR-M in which some part of the series control sections formed in loamy till. Second, we constructed a map of the region to show the areal extent of each soil suite having properties dictated by various lobes of Wisconsin-age till. We did not study the parent material of soils of small extent, such
as, the Williamstown series. The Kidder, Kidami, Miami, Miamian, Morley, and Ozaukee series are of primary interest. We use these six series to represent suites of soils that have at least part of their series control sections in the same till lobes. Approximately 50 soil series are directly involved in this investigation. Third, we provide data for possible refinement of series concepts. The areal extent of each series in the suite can be adjusted when similarity to its associated series is determined.

Background

In the first survey of Montgomery County, Ohio, all of the loamy soils developed over till were mapped as Miami (Dorsey and Coffey 1901). Five types were named ranging from sandy loam to clay loam, with clay loam being the most extensive. According to Simonson (1952) the concept of the soil series was developed by 1903. Miami was recognized as one of these series. “Prior to 1904, the Miami series (now restricted to fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs) had been mapped throughout a region which extended from Maine to Mississippi to Montana” (Simonson 1986).

Bailey (1978) published a brief history of the Miami series. He reported that the first standard description of the Miami series was prepared in Eaton County, Michigan, in 1940. The pedon centered on the loam type. The 1945 version was written in Hancock County, Indiana. The present type location is in Hendricks County, Indiana. Much of the data from nearby areas suggests that the particle size control section averages 30 to 35 percent clay. Some pedon control sections average slightly more.

We have been able to assist in the sampling of these soils and to view almost all of them in the field throughout their areal extent. Our observations, combined with critiques of manuscripts and discussions with state soil survey personnel, made us aware of use and management discrepancies, such as those influenced by particle size differences, within these soil series from place to place. Use of laboratory data, especially particle size data at individual sites, made identification of some series difficult because the data showed percentages ever so slightly outside the stated range in characteristics for the series. When a soil series control section extended 1 or 2 percent into another textural group, that group was added to the series range. Extending the range increased the number of named textures for that part of the series control section until the list included all known possibilities. Eventually, almost all soils over till in a particular particle size class came to have overlapping properties. Each series thus became and remains difficult to separate using the control section of the official series description. As a result, series concepts and soil map unit components became broadly defined or were never developed. The irregular pattern of making soil surveys on a county basis encouraged an adjustment of official series descriptions to accommodate local conditions. Areal extent is not identified in the official series descriptions. Soil interpretations therefore sometimes range beyond class or even soil survey interpretation hazard limits. Once precise criteria for a series concept and its areal extent are determined, state and regional soil survey personnel can determine which suites of soils are appropriate and can then revise the official series descriptions. Soil interpretations can be adjusted as necessary to more accurately fit the map unit components.

Methods

Approximately 675 data sets are available for the six suites of soils (tables 1-11). The data from a variety of sources (Soil Survey Staff of Indiana 1977a, 1977b, 1979, 1980, 1981, 1982, 1983, 1984, 1986, and 1988; Soil Survey Staff 1967a, 1967b, 1968, 1979, 1980, and 1997; Smith and Wilding 1972; Wash et al. 1960; and Wilding et al. 1964). There are 55 named series among the data (table 12). Only a few pedons have complete characterization data that includes particle size (PSD), organic carbon (OC), bulk density (Bd), moisture retention, calcium carbonate equivalent (CCE), exchangeable cations and base saturation, and mineralogy data. Even fewer pedons have Atterberg limit data. As many useful data sets as possible were included; none were arbitrarily excluded. Laboratory methods are those of the National Soil Survey Laboratory (Soil Survey Laboratory Staff 1996) or those deemed equivalent and in use in other laboratories.

All pedon data sets (laboratory data and descriptions) were reviewed to ensure that each set was an appropriate representative of its series and located in a specific lobe of till (figs. 1-10). The glacial till maps were prepared from published maps and reports in LRR-M (Frye and Willman 1985; Fullerton 1986; Goldthwait et al. 1961; Johnson 1986; Wayne 1958; Willman et al. 1978; and William and Frye 1970). Up to 14 different suites were tentatively identified for testing, but laboratory data of only six were scrutinized (tables 2-11). It was verified that at
least the lower part of the series control section of each was formed in till. Thin loess overlies some of the pedons. Series therefore were placed in suites based on particle size distribution (PSD) and on the lobe of till each occurs in, rather than the name of the series shown in table 1. PSD is used in the till part of the series control section to avoid any possible loess influence. See figures 3 to 10 for the location and sample number of each data set. The sample numbers are listed with the data in tables 2 to 11. For example, the data sets for the Morley soil suite in the Lake Michigan Lobe (LML) are listed in tables 8 and 9 as Ozaukee soils. Field observations in the LML suggested that this suite has 50 percent or more silt in the till part of the series control section. The Ozaukee soil suite is representative. Therefore, all data sets for Morley and associated soils in the LML are included in the Ozaukee suite. As was mentioned earlier, six suites were created for study. If these six can be identified and located on maps, most of the other suites can be more easily studied in similar fashion.

A soil suite as defined herein consists of all soils on a particular lobe of till that have the same till in at least the lower part of their series control section. Variations occur in drainage class, organic matter, or parent material in the upper part of each suite of soils. Soil series occupying both metastable, degrading shoulders and metastable, aggrading footslopes are common on till plains. Many soils in such footslope positions have slope alluvium influences in the upper part and lacustrine deposits in the lower part. As a result, definition of an all-inclusive series concept is almost impossible.

Criteria that can be used to separate soil series in one suite from those in another are presented. Maps displaying the expected areal extent of each soil suite are also presented (figs. 4, 6, 8, and 10). The map scale is 1:1,000,000. A map of the five-state area is also included at a smaller scale (fig. 2). The larger scale maps have sufficient detail so that the areal extent of each till deposit can be determined with adequate accuracy for MLRA soil survey update activities.

Next we used the bulk density data for all B and C horizons of the soils to calculate the percent of pores drained and those filled at 1/3-bar water content on a whole soil basis. We also used the data to derive models for predicting bulk density data for the soils using particle size data as the independent variables. Clay content proved to be the most efficient independent variable. The model is listed as a footnote to tables 2, 4, 6, and 8 and was used to calculate bulk density data given in those tables. As would be expected, the calculated bulk density data for the six soil suites are the inverse of their clay contents, i.e. clay content of C horizons show Morley > Ozaukee > Kidmi > Miami, whereas bulk density at 0.3 bar shows Miami > Kidmi > Ozaukee > Morley. The derived data are not superior to clay content for differentiating between soils but should be useful for soil interpretations.

Results

The reliability of the five soil-forming factors as controllers of soil development was reinforced by the results of this investigation. In the study area, roughly the eastern Corn Belt, the soil temperature regime is mesic, the soil moisture regime is udic, and most landforms are geologically stable. Oak-hickory forests and tall grass prairies are the native vegetation. Of the 55 series included, only Hennepin and Wolcott do not have argillic horizons (table 12). All the soils formed at least in part in late Pleistocene till that is calcareous.

Areal extent

Particle size distribution analysis was especially useful for differentiation of all suites of till soils. A composite geology map (fig. 1) after Johnson (1986) and Fullerton (1986) was used to guide segregation of data points for analysis. This analysis was prompted by field observations of mapping crews, correlators, and research soil scientists. See tables 2 to 11 for a summary of data retrieved by soil series. STATSGO maps, redrafted to a 1:1,000,000 scale, were used to separate Wisconsin-age till areas from other parent materials. These maps (figs. 4, 6, 8, and 10) and the composite geology map were used to delineate areas of till deemed similar. Figure 2 is a composite of the state maps at a slightly larger scale than the geology map. Bulk density was also measured. Differences among series were significant in only a small number of cases, perhaps because the number of bulk density samples is small. Based on these observations and the data retrieved from the NSSL Database, areas of similarity were delineated. As one would expect, these areas coincided with lobes of till that have a common source. Thirteen suites were identified and their areal extent delineated (fig. 2). Only six were studied in detail. See figures 2, 4, 6, 8, and 10 for the locations of the various suites of soils studied.
**Statistical analysis**

Although over 650 pedons had been collected by universities and the national laboratory, many of the data sets were not complete enough for all purposes. Commonly, not all horizons were included. On the more complete data set of 69 pedons, we tested the maximum clay content of Bt horizons and thickness of overlying horizons as differentiae (table 13 and fig. 11). We used only pedons formed in till to avoid the impact of loess thickness on the depth to maximum clay. The pedons selected are from the till lobes and have the sand ratios chosen for the named series.

Only four of the series are included in table 13 because the numbers of pedons available for two others were too few for statistical significance. These two, Ozaukee and Kidder, however, plot on opposite ends of the array of pedons (fig. 11). The other four soils, Morley, Miamian, Miami, and Kidami, can be differentiated through use of maximum clay as a criterion. It seems that neither Ozaukee and Morley nor Kidami and Kidder can be differentiated through the maximum clay criterion. Depth to maximum clay in the same four series is only somewhat useful. By this criterion, however, Morley and Miamian can be differentiated from Miami and Kidami (table 13). Next we tested the parent materials for differences in the series because the parent materials are within the depth limits for soil series. Using either coarse sand (0.5 to 1.0 mm) or coarse plus very coarse sand (0.5 to 2.0 mm) of the parent material as a criterion, all of the soil series except Miami and Miamian can be differentiated (table 14).

Comparison of the maximum clay content of the argillic horizons with the carbonate-free clay contents of the till suggests that the parent material accounts for most of the clay that occurs in the Bt horizons (table 15). Thorp et al. (1959) had earlier concluded that much of the clay in the Miami Bt horizon was either unaltered or translocated from clay originally present. Our data from a wider range of till derived soils support this conclusion. Although 15-bar water data are not available for a few of the samples, we assume all the samples disperse well in the particle size analyses because the 15-bar water to clay ratios are < 0.6 for A, B, and C horizons that we have tested.

**Soil properties**

Experience guided the testing of soil properties, especially soil separates, for differences in the lobes of till shown on the geology map (fig. 1). For example, even without statistical analysis of the PSD, it is not difficult to note differences between the Lake Michigan Lobe (LML) Morley and the Huron-Erie Lobe (HEL) Morley. Both are in the fine particle size class. The former is silty to the touch, and the latter is gritty. A study of the data shows that the LML till has more than 50 percent silt. No other till in the study area has as much. It can be speculated that the Maquoketa Shale Formation, gouged out of the Lake Michigan basin, is the source of this soil separate.

Observed differences in interpretations were used to initiate the search for other differences in parent material. For example, the need for Kidami till areas to be separated from Kidder till areas is primarily one of perched water. The sandy loam Kidder areas usually do not perch water, while the sandy loam and loam Kidami areas usually do. More research is needed to identify key physical properties. However, our data show that the two series can be clearly differentiated by the coarse sand plus very coarse sand content of the parent materials (tables 14 and 16).

Statistical analysis of soil horizon data from more than 675 pedons in the NSSL Database verified differences in parent material (tables 14 and 16). These differences were obvious in some soil series, as in the textural differences between the Kidder and Morley soils. They were only indirectly observed by different interpretations between the Kidder and Kidami soils, which classify in the same fine-loamy family (table 12). Ozaukee, Morley, and Miamian soils also are in the same fine textural family so that soil scientists that had the opportunity to observe all three of soils could not differentiate among them based on clay content alone.

W. Hilton Johnson (1986) reports that the LML till differs from HEL till in the following ways. Dolomite content relative to calcite content of the < 74 micron fraction is higher, there is a greater abundance of illite in the clay fraction, garnet-epidote ratios are 2 or less in the fine sand fraction, and the LML till has lower magnetic susceptibility values. These properties could be used as series differentiae where necessary.
This study shows that the Ozaukee suite of soils can be used to replace the Morley suite of soils in the area occupied by the Lake Michigan Lobe (figs. 1 to 8). Ozaukee soils are classified as fine, illitic, mesic Oxyaquic Hapludalfs (table 12). Soils in this suite will have the following percentages of key soil properties in the till part of their control sections (table 16). Silt content is 50 percent or more. Clay content is 25 to 42 percent. Total sand content is 4 to 21 percent with 1 to 6.5 percent very fine sand and 2 to 7 percent of coarse sand plus very coarse sand. Rock fragment content is 1 to 5 percent. The data show that soils developed almost entirely in the till of this lobe have more than 50 percent silt throughout their sola. Moist (0.3 bar tension) bulk density of the <2 mm soil as calculated from the clay content is about 1.6 g cm\(^{-3}\) in the Cd horizon (table 8). Bulk density data for eight measured values for soil fragments at field moisture contents are higher (1.9 g cm\(^{-3}\), table 9). Apparently the samples were below field capacity moisture contents when measured. The CCE ranges from 20 to 48 percent. Depth to the base of the argillic horizon is 50 to 100 cm. Field observations strongly suggest that these soils are Oxyaquic.

The Morley suite is located on the Huron-Erie Lobe (figs. 1, 2, 6, and 8). The Morley series is classified as fine, illitic, mesic Oxyaquic Hapludalfs (table 12). This study shows that soils in this suite will have the following percentages of key soil properties in the lower part of their series control sections (table 16). Silt content is 40 to 49 percent. Clay content is 27 to 42 percent. Total sand content is 17 to 30 percent. Very fine sand content is 1 to 7.5 percent. Coarse sand plus very coarse sand content is 2 to 8 percent. Rock fragment content is 3 to 37 percent. Calculated moist bulk density values of the <2 mm soil Cd horizons average 1.5 g cm\(^{-3}\) (table 6); values measured for the two samples available average 1.8 g cm\(^{-3}\) (table 7). The CCE ranges from 16 to 30 percent. Depth to the base of the argillic horizon is 50 to 120 cm.

The Miamian suite is located on the Miami and Scioto Sublobes of the Huron-Erie Lobe (figs. 1, 2, 6, and 10). The Miamian series is classified as fine, mixed, active, mesic Oxyaquic Hapludalfs (table 12). This study shows that soils in this suite have the following percentages of key soil properties in the till part of their series control sections (table 16). Silt content is 40 to 49 percent. Clay content is 12 to 27 percent. Total sand content is 24 to 45 percent. Very fine sand content is 6.5 to 9.9 percent. Coarse sand plus very coarse sand content is 6 to 13 percent. Rock fragment content is 8 to 18 percent. The CCE ranges from 36 to 45 percent. Depth to the base of the argillic horizon is 50 to 100 cm.

The Miami suite is located on the Huron-Erie Lobe and the East White Sublobe (figs. 1, 2, 6, and 8), table 12. This study shows that soils in this suite have the following percentages of key soil properties in the till part of their series control sections (table 16). Silt content is 23 to 50 percent. Clay content is 12 to 28 percent. Total sand content is 21 to 63 percent. Very fine sand content is 2 to 13 percent. Coarse sand plus very coarse sand content is 6 to 21 percent. Rock fragment content is 1 to 29 percent. The CCE ranges from 12 to 46 percent. The depth to the base of the argillic horizon is 60 to 100 cm. The calculated moist bulk density of the <2 mm soil is 1.5 g cm\(^{-3}\) (table 2) and somewhat lower than the average value measured for 19 samples, 1.9 g cm\(^{-3}\) (table 3).

The proposed Kidami suite is located on Lake Michigan Lobe till deposits (figs. 1, 2, 4, 6, and 8). The Kidami series is classified as fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs (table 12). This study shows that soils in this suite have the following percentages of key soil properties in the till part of their series control sections (table 16). Silt content is 33 to 48 percent. Clay content is 11 to 29 percent. Total sand content is 26 to 51 percent. Very fine sand content is 8 to 18 percent. Coarse sand plus very coarse sand content is 4 to 8 percent. Rock fragment content is 3 to 18 percent. The calcium carbonate equivalent ranges from 15 to 38 percent. The calculated moist bulk density of the <2 mm soil material in C horizons averages 1.79 g cm\(^{-3}\) (table 4), a value close to that of 1.83 g cm\(^{-3}\) measured for six C horizon samples (table 5).

The Kidder suite is located on the Lake Michigan Lobe (LML) (figs. 1, 2, 4, and 8). The Kidder soils are classified as fine-loamy, mixed, active, mesic Typic Hapludalfs (table 12). Almost all of the Kidder parent material is on the periphery of the lobe. All areas seem to have picked up properties from local rock formations after moving out of the Lake Michigan basin. The material contains more sand than any other till material studied. This study shows that soils in this suite have the following percentages of key soil properties in the till part of their series control sections (table 16). Silt content is 16 to 34 percent. Clay content is less than 10 percent. Total sand con-
tent is 58 to 77 percent. Very fine sand content is 11 to 20 percent. Coarse sand plus very coarse sand content is 10 to 18 percent. Rock fragment content is 5 to 30 percent. The CCE ranges from 21 to 62 percent.

Bulk densities as measured in the laboratory were too few and not sufficiently different to assist in separating any of the series. This phenomenon is especially apparent in the Ozaukee, Morley, and Miami soils, which appear to be layered, at least in the lower part. The CCE was not useful as series designator either. The CCE ranged widely in each of the till materials studied and thus always overlapped too much to be helpful. The CCE is probably different in each of them, and some probably do not overlap. Sampling error is the most likely cause of the wide ranges within the same till material. Small samples, plus lime accumulations, lime-coated rock fragments, and lime-containing rock fragments, not included in some samples and included in others, all contribute to the chances of collecting skewed samples.

Field evidence of soil development (B horizons) in the limy till was not described for most of the pedons. However, effervescence with dilute acid was enough to justify the B horizon designation. The preference for C horizon designations for calcareous materials is a habit from an old directive from regional correlators. See for example the description of till-derived soils in appendix IV of the Soil Survey Manual (Soil Survey Staff 1961). Study of the soil profile from a deep pit usually will reveal soil structure and some coats on faces of peds in the first limy horizon below the argillic horizon. In these places, depth to the base of the argillic horizon and depth to the base of the solum are not identical. It might be possible to find series differentiae in this horizon.

Other competing suites not studied

*Alexandria and Amanda*—For these soils, CCE might be helpful as series differentiae. The overlap with four of the suites is 4 percent or less. The data are limited, and therefore CCE only suggests an area for future investigation. There seems to be some hope for coarse sand plus very coarse sand of 8 percent or less being a possible criterion also.

*Hickory*—This series is thought to have formed in Illinoian-aged till. There should be an age-related soil property that can be described to separate this series from other till soils that are more than 100 cm to the base of the argillic horizon.

*Hochheim*—The base of the argillic horizon is at a depth of 50 cm or less. This is not true of other series in this suite, such as Theresa. The underlying till seems to be very similar to Kidami suite till. It could have the same description as Kidami, but occurs in the coldest part of the mesic temperature regime.

*Mecan*—This series has more than 70 percent sand in the lower part of the series control section. It can be separated from Hickory, Westville, Riddles, and Russell suites by percent sand in the argillic horizon and the till part of the control section. Soil temperature can be used also.

*Riddles*—This soil suite has layered till in much of the solum. It would be very helpful if the abrupt changes in the percentages of soil separates from horizon to horizon and the rapidity of changes with depth were more accurately described.

*Waymar*—These soils have glossy features.

*Westville*—These soils are thought to have formed in pre-Wisconsin till. They have 5YR or redder hues in their argillic horizons. None of the other suites of soils studied have hues this red.

### Series differentiae

Once the unique physical properties of each lobe of Wisconsin-aged till were known, the soils were separated on this basis. The data present in the National Soil Survey Laboratory Database were used to identify some of these definitive properties. A closer examination for other collateral properties would probably have revealed other differences as well. Properties that affect permeability were especially sought as differentiae. Visual observation and a relatively few bulk density and pore volume measurements (tables 3, 5, and 7), however, do not seem to be adequate to explain the differences that occur in the movement of water through these soils.

Previously, separation of similar soils, such as Alexandria, Miamian, Morley, and Ozaukee, was based on properties, such as color, mineralogy, and subclass. The same properties were used to separate the Amanda, Kidami, Kidder, and Miami suites of soils. These separations commonly were made to accommodate soil inter-
pretations. Much of the time, suites of soils were not considered, and such series as St. Charles were mapped with a wide variety in the till part of the series control section.

Based on the findings of this study, the following statements can be used to separate suites of soils that have properties in the till part of their series control section similar to the series named below. Only one difference needs be noted for each series to justify its separation; however, the soil property named cannot overlap with the series separated. See table 16 for ranges in soil properties indicated by this research and for suggested parameters for separating each soil suite. The series named were selected to represent the soil suites.

**Alexandria official series description**
Competing Series—Morley and Ozaukee. Neither of these competing soils has >1 to 2 percent shale and sandstone fragments by weight in the till part of the series control section, so that the particle size analysis matches the field texture descriptions. None of the clay or sand measured by the PSDA is thought to come from shale or sandstone fragments in the till.

**Amanda official series description**
Competing Series—Kidder, Kidami, and Miami. The particle size of these competing soils is not significantly influenced by shale and sandstone fragments in the till part of their series control sections. Amounts of shale and sandstone are <1 to 2 percent by weight of the whole soil.

**Kidder official series description**
Competing Series—Amanda and Kidami. Amanda soils have more than 10 percent clay and >1 to 2 percent shale and sandstone fragments by weight in the till part of the series control section. Kidami soils have more than 10 percent clay in the till part of the series control section. Also, Kidami soils have less than 55 percent sand in that part.

**Miami official series description**
Competing Series—Kidami. Kidami soils have 10 percent or less coarse sand plus very coarse sand in the till part of the series control section.

**Morley official series description**
Competing Series—Alexandria and Ozaukee. Alexandria soils have >1 to 2 percent shale and sandstone fragments by weight in the till part of the series control section. Ozaukee soils have 50 percent or more silt in the till part of the series control section.

**Ozaukee official series description**
Competing Series—Alexandria and Morley. Alexandria soils have >1 to 2 percent shale and sandstone fragments by weight in the till part of the series control section. Morley soils have less than 50 percent silt in the till part of the series control section.
References


Soil Survey Staff. 1997. Soil survey laboratory characterization data. USDA, NRCS, Soil Survey Laboratory, Lincoln, NE.


Appendix

Statistical equations derived for estimating properties of till soils. Variables in the equations are in volume percentage (%) for the whole soil (WS) at 0.3 bar. The WS coarse fraction (>2 mm fraction) is a percent by weight. The relationships are significant at a 99 percent confidence level.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Equation</th>
</tr>
</thead>
</table>
| Pores drained      | \[ 43.2\% - 0.303 \times \text{WS clay content} + 0.145 \times \text{WS sand content} - 20.7 \times \text{WS Db at 0.3 bar}, \]
|                    | \[ r^2 = 64.0, \quad n = 94, \quad SE = 2.0\% \] |
| Pores filled       | \[ 53.1\% + 0.282 \times \text{WS clay content} - 0.159 \times \text{WS sand content} - 14.7 \times \text{WS bulk density at 0.3 bar}, \]
|                    | \[ r^2 = 0.84, \quad n = 94, \quad SE = 2.1\% \] |
| Ratio of drained to filled pores | \[ 1.37 - 0.00696 \times \text{WS coarse fraction }% - 0.0180 \times \text{WS clay }% - 0.399 \times \text{WS bulk density at 0.3 bar} - 0.00648 \times \text{WS silt }%, \]
|                    | \[ r^2 = 0.49, \quad n = 94, \quad SE = 0.091 \] |
| Fine earth bulk density | \[ 2.04 - 0.0129 \times \text{clay }% \]
|                    | \[ r^2 = 0.55, \quad n = 110, \quad SE = 0.11 \text{ g cm}^{-3} \] |
## Tables

### Table 1. Sample locations of till soils used to develop series concepts for soils in Land Resource Region M

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Sample Number</th>
<th>State or NSSL Number</th>
<th>County</th>
<th>State</th>
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Table 1.  Sample locations of till soils used to develop series concepts for soils in Land Resource Region M—Continued

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\(^{\dagger}\) Name listed with data before 1996.
Table 2. Particle size and carbonate data and calculated bulk density for the Miami soil suite C or Cd horizons

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1/ Carbonate was not removed before the particle size analysis.
2/ Calcium carbonate equivalent.
3/ Weight basis.
4/ Bulk density at 0.3 bar is estimated by the model B.D. = 2.04 - 0.0129 x %clay, r² = 0.55, n = 110, SE = 0.11. See appendix.
Table 3. Bulk density and other data for the Miami soil suite C or Cd horizons

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<th>B.D. @ 0.3 bar g cm$^3$</th>
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| Mean          | 0.45      | 1.89                 | 3            | 20              | 2.7                      |
| Count         | 18        | 19                   | 21           | 21              | 5                       |
| Std. Dev.     | 0.069     | 0.079                | 2.7          | 5.9             | 0.41                    |

$^1$ The percentage mica is reported to be equal to 10 times the K$_2$O content (Jackson 1956).
### Table 4. Particle size and carbonate data and calculated bulk density data for the Kidami soil suite C horizons

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1/ Calcium carbonate equivalent. Carbonate was not removed before particle size analysis.

2/ Bulk density at 0.3 bar is estimated by the model B.D. = 2.04 - 0.0129 x % clay; \( r^2 = 0.85 \), \( n = 110 \), \( SE = 0.11 \). See appendix.
Table 5. Bulk density and other data for the Kidami soil suite C horizons

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Mean 0.46 1.83 6 28 2.8
Count 10 7 7 7 4
Std. Dev. 0.042 0.086 3.8 8.0 1.50

¹/ The percent mica is reported to be equal to 10 times the K₂O content (Jackson 1956).
Table 6. Particle size and carbonate data and calculated bulk density data for the Morley soil suite C or Cd horizons

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### Table 6. Particle size and carbonate data and calculated bulk density data for the Morley soil suite C and Cd horizons—Continued

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<th>V.C.S. %</th>
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<th>&gt;2mm/</th>
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Mean 33.5 44.2 22.4 3.0 2.2 24.8 6.8 1.48
Count 62 62 62 62 62 62 45 62
Std. Dev. 1.41 2.12 0.71 1.13 0.71 7.78 9.90 0.127

1/ Calcium carbonate equivalent. Carbonate was not removed before particle size analysis.
2/ Weight basis.
3/ Bulk density at 0.3 bar is estimated by the model B.D. = 2.04 - 0.0129 x % clay, r² = 0.55, n = 110, SE = 0.11. See appendix.

### Table 7. Bulk density and other data for the Morely soil suite C or Cd horizons

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Mean 0.41 1.80 1 31
Count 2 2 2 2
Std. Dev. 0.025 0.064 0.7 1.4

1/ The percent mica is reported to be equal to 10 times the K₆O content (Jackson 1956).
Table 8. Particle size and calcium carbonate equivalent data and calculated bulk density data for the Ozaukee soil suite C or Cd horizons

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Count: 38 38 38 19 18 10 5 38
Std. Dev.: 5.03 4.31 4.86 0.86 0.86 10.67 1.58 0.065

1/ Calcium carbonate equivalent. Carbonate was not removed before particle size analysis.
2/ Weight basis.
3/ Bulk density at 0.3 bar is estimated by the model B.D. = 2.04 + 0.0129 × % clay, r² = 0.55, n = 110, SE = 0.11. See appendix.
Table 9. Bulk density and other data for the Ozaukee soil suite C or Cd horizons

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<tr>
<th>Sample number</th>
<th>Depth cm</th>
<th>Ratio 15 bar to clay</th>
<th>B.D. g cm⁻³</th>
</tr>
</thead>
<tbody>
<tr>
<td>165</td>
<td>95-110</td>
<td>0.45</td>
<td>1.96</td>
</tr>
<tr>
<td>422</td>
<td>135-165</td>
<td></td>
<td>2.04</td>
</tr>
<tr>
<td>423</td>
<td>130-165</td>
<td></td>
<td>2.09</td>
</tr>
<tr>
<td>424</td>
<td>140-175</td>
<td></td>
<td>2.09</td>
</tr>
<tr>
<td>519</td>
<td>85-115</td>
<td>0.39</td>
<td>1.82</td>
</tr>
<tr>
<td>520</td>
<td>60-90</td>
<td>0.37</td>
<td>1.97</td>
</tr>
<tr>
<td>521</td>
<td>95-115</td>
<td>0.39</td>
<td>1.74</td>
</tr>
<tr>
<td>522</td>
<td>80-110</td>
<td>0.40</td>
<td>1.94</td>
</tr>
</tbody>
</table>

Mean 0.40 1.94
Count 5 7
Std. Dev. 0.030 0.121

1/ The bulk densities are for field moist soil.
Table 10. Particle size and other data for C or Cd horizons of the Miamiam soil suite

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Depth cm</th>
<th>Clay %</th>
<th>Silt %</th>
<th>Sand %</th>
<th>V.F.S. %</th>
<th>FS. %</th>
<th>M.S. %</th>
<th>C.S. %</th>
<th>V.C.S. g cm⁻³</th>
<th>CCE %</th>
<th>&gt;2mm %</th>
</tr>
</thead>
<tbody>
<tr>
<td>454</td>
<td>84-94</td>
<td>20.0</td>
<td>47.4</td>
<td>32.6</td>
<td>9.0</td>
<td>8.7</td>
<td>6.1</td>
<td>4.4</td>
<td>4.5</td>
<td>36</td>
<td>18</td>
</tr>
<tr>
<td>458</td>
<td>95-150</td>
<td>21.3</td>
<td>47.0</td>
<td>31.7</td>
<td>8.2</td>
<td>10.2</td>
<td>6.0</td>
<td>4.3</td>
<td>3.0</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>459</td>
<td>102-150</td>
<td>26.8</td>
<td>45.6</td>
<td>27.3</td>
<td>6.6</td>
<td>9.6</td>
<td>5.1</td>
<td>3.8</td>
<td>2.2</td>
<td>38</td>
<td>4</td>
</tr>
<tr>
<td>460</td>
<td>63-108</td>
<td>20.1</td>
<td>43.1</td>
<td>36.8</td>
<td>9.7</td>
<td>11.5</td>
<td>4.6</td>
<td>6.1</td>
<td>4.9</td>
<td>37</td>
<td>12</td>
</tr>
<tr>
<td>461</td>
<td>137-150</td>
<td>19.1</td>
<td>41.9</td>
<td>39.0</td>
<td>9.5</td>
<td>12.3</td>
<td>5.0</td>
<td>5.0</td>
<td>6.3</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>662</td>
<td>128-150</td>
<td>20.3</td>
<td>40.1</td>
<td>39.6</td>
<td>9.9</td>
<td>10.8</td>
<td>6.6</td>
<td>7.3</td>
<td>5.0</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>663</td>
<td>132-150</td>
<td>12.3</td>
<td>43.0</td>
<td>44.7</td>
<td>10.1</td>
<td>14.3</td>
<td>9.2</td>
<td>7.0</td>
<td>4.1</td>
<td>40</td>
<td>15</td>
</tr>
<tr>
<td>664</td>
<td>105-150</td>
<td>23.3</td>
<td>43.5</td>
<td>33.2</td>
<td>7.9</td>
<td>9.3</td>
<td>3.7</td>
<td>5.7</td>
<td>6.6</td>
<td>38</td>
<td>9</td>
</tr>
<tr>
<td>462</td>
<td>107-150</td>
<td>26.3</td>
<td>49.4</td>
<td>24.3</td>
<td>6.5</td>
<td>8.3</td>
<td>3.7</td>
<td>4.1</td>
<td>1.7</td>
<td>45</td>
<td>11</td>
</tr>
</tbody>
</table>

Mean   | 21.1  | 44.7  | 34.4  | 8.6   | 10.6   | 5.6  | 5.3    | 4.3   | 34.11       |
Count  | 9     | 9     | 9     | 9     | 9      | 9    | 9      | 9     | 9           |
Std. Dev. | 4.31  | .09   | 6.37  | 38    | 1.19   | 70   | 1.29   | 1.70  | 1.48        |

1/ Calcium carbonate equivalent. Carbonate was not removed before particle size analysis.
2/ Weight basis.

Table 11. Particle size and other data for C or Cd horizons of the Kidder soil suite

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Depth cm</th>
<th>Clay %</th>
<th>Silt %</th>
<th>Sand %</th>
<th>V.F.S. %</th>
<th>FS. %</th>
<th>M.S. %</th>
<th>C.S. %</th>
<th>V.C.S. g cm⁻³</th>
<th>CCE %</th>
<th>&gt;2mm %</th>
</tr>
</thead>
<tbody>
<tr>
<td>325</td>
<td>130-150</td>
<td>8.4</td>
<td>29.6</td>
<td>62.0</td>
<td>11.6</td>
<td>20.9</td>
<td>12.2</td>
<td>9.1</td>
<td>8.2</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>326</td>
<td>120-150</td>
<td>6.1</td>
<td>30.7</td>
<td>63.2</td>
<td>11.7</td>
<td>20.7</td>
<td>19.2</td>
<td>6.6</td>
<td>5.0</td>
<td>62</td>
<td>18</td>
</tr>
<tr>
<td>644</td>
<td>119-152</td>
<td>21.4</td>
<td>48.5</td>
<td>30.1</td>
<td>5.8</td>
<td>8.2</td>
<td>4.6</td>
<td>5.5</td>
<td>6.0</td>
<td>33</td>
<td>3</td>
</tr>
<tr>
<td>645</td>
<td>122-150</td>
<td>6.1</td>
<td>29.5</td>
<td>64.4</td>
<td>15.8</td>
<td>27.6</td>
<td>13.0</td>
<td>5.9</td>
<td>2.1</td>
<td>33</td>
<td>19</td>
</tr>
<tr>
<td>668</td>
<td>124-150</td>
<td>5.1</td>
<td>33.8</td>
<td>61.1</td>
<td>10.8</td>
<td>16.8</td>
<td>16.7</td>
<td>8.4</td>
<td>8.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>669</td>
<td>122-150</td>
<td>7.7</td>
<td>34.2</td>
<td>58.1</td>
<td>19.6</td>
<td>20.4</td>
<td>8.0</td>
<td>5.9</td>
<td>4.2</td>
<td>41</td>
<td>-</td>
</tr>
<tr>
<td>670</td>
<td>183-190</td>
<td>6.8</td>
<td>24.9</td>
<td>68.3</td>
<td>11.4</td>
<td>19.9</td>
<td>18.2</td>
<td>14.7</td>
<td>4.1</td>
<td>34</td>
<td>-</td>
</tr>
<tr>
<td>671</td>
<td>127-150</td>
<td>6.4</td>
<td>16.2</td>
<td>77.4</td>
<td>10.5</td>
<td>37.4</td>
<td>20.4</td>
<td>7.1</td>
<td>2.0</td>
<td>21</td>
<td>-</td>
</tr>
</tbody>
</table>

Mean   | 8.5   | 30.9  | 60.6  | 5.0   | 21.5   | 14.0 | 7.9    | 5.0   | 35.12       |
Count  | 8     | 8     | 8     | 8     | 8      | 8    | 8      | 8     | 8           |
Std. Dev. | 5.31  | 9.14  | 13.83 | 2.44  | 8.40   | 5.63 | 3.02   | 5.95  | 13.07        |

1/ Calcium carbonate equivalent. Carbonate was not removed before particle size analysis.
2/ Weight basis.
### Table 12. Classification of the soil series used in the study

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Soil Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alexandria</td>
<td>Fine, illitic, mesic Oxyaquic Hapludalfs</td>
</tr>
<tr>
<td>Amanda</td>
<td>Fine-loamy, mixed, active, mesic Typic Hapludalfs</td>
</tr>
<tr>
<td>Bennington</td>
<td>Fine, illitic, mesic Aeric Epiaqualfs</td>
</tr>
<tr>
<td>Birkbeck</td>
<td>Fine-silty, mixed, superactive, mesic Oxyaquic Hapludalfs</td>
</tr>
<tr>
<td>Blount</td>
<td>Fine, illitic, mesic Aeric Epiaqualfs</td>
</tr>
<tr>
<td>Brookston</td>
<td>Fine-loamy, mixed, superactive, mesic Typic Argiaquolls</td>
</tr>
<tr>
<td>Cardington</td>
<td>Fine, illitic, mesic Aquic Hapludalfs</td>
</tr>
<tr>
<td>Celina</td>
<td>Fine, mixed, active, mesic Aquic Hapludalfs</td>
</tr>
<tr>
<td>Chenoa</td>
<td>Fine, illitic, mesic Aquic Argiudolls</td>
</tr>
<tr>
<td>Condit</td>
<td>Fine, illitic, mesic Typic Epiaqualfs</td>
</tr>
<tr>
<td>Conover</td>
<td>Fine-loamy, mixed, active, mesic Udollic Endoaqualfs</td>
</tr>
<tr>
<td>Corwin</td>
<td>Fine-loamy, mixed, active, mesic Oxyaquic Argiudolls</td>
</tr>
<tr>
<td>Crosby</td>
<td>Fine, mixed, active, mesic Aeric Epiaqualfs</td>
</tr>
<tr>
<td>Crosier</td>
<td>Fine-loamy, mixed, active, mesic Aeric Epiaqualfs</td>
</tr>
<tr>
<td>Dana</td>
<td>Fine-silty, mixed, superactive, mesic Oxyaquic Argiudolls</td>
</tr>
<tr>
<td>Dodge</td>
<td>Fine-silty, mixed, superactive, mesic Typic Hapludalfs</td>
</tr>
<tr>
<td>Elliott</td>
<td>Fine, illitic, mesic Aquic Argiudolls</td>
</tr>
<tr>
<td>Fincastle</td>
<td>Fine-silty, mixed, superactive, mesic Aeric Epiaqualfs</td>
</tr>
<tr>
<td>Flanagan</td>
<td>Fine, smectitic, mesic Aquic Argiudolls</td>
</tr>
<tr>
<td>Glynwood</td>
<td>Fine, illitic, mesic Aquic Hapludalfs</td>
</tr>
<tr>
<td>Graymont</td>
<td>Fine-silty, mixed, superactive, mesic Oxyaquic Argiudolls</td>
</tr>
<tr>
<td>Hayden</td>
<td>Fine-loamy, mixed, superactive, mesic Glossic Hapludalfs</td>
</tr>
<tr>
<td>Hennepin</td>
<td>Fine-loamy, mixed, active, mesic Typic Eutrudepts</td>
</tr>
<tr>
<td>Hochheim</td>
<td>Fine-loamy, mixed, mesic Typic Argiudolls</td>
</tr>
<tr>
<td>Kidami</td>
<td>Fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs</td>
</tr>
<tr>
<td>Kidder</td>
<td>Fine-loamy, mixed, active, mesic Typic Hapludalfs</td>
</tr>
<tr>
<td>Kokomo</td>
<td>Fine, mixed, superactive, mesic Typic Argiaquolls</td>
</tr>
<tr>
<td>La Rose</td>
<td>Fine-loamy, mixed, superactive, mesic Typic Argiudolls</td>
</tr>
<tr>
<td>Lewisburg</td>
<td>Fine, mixed, active, mesic, shallow Aquic Hapludalfs</td>
</tr>
<tr>
<td>Locke</td>
<td>Fine-loamy, mixed, mesic Aquolllic Hapludalfs</td>
</tr>
<tr>
<td>Lowell</td>
<td>Fine, mixed, active, mesic Typic Hapludalfs</td>
</tr>
</tbody>
</table>
Table 12. Classification of the soil series used in the study—Continued

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Soil Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>McHenry</td>
<td>Fine-loamy, mixed, superactive, mesic Typic Hapludalfs</td>
</tr>
<tr>
<td>Miami</td>
<td>Fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs</td>
</tr>
<tr>
<td>Miamian</td>
<td>Fine, mixed, active, mesic Oxyaquic Hapludalfs</td>
</tr>
<tr>
<td>Millsdale</td>
<td>Fine, mixed, active, mesic Typic Argiaquolls</td>
</tr>
<tr>
<td>Milton</td>
<td>Fine, mixed, active, mesic Typic Hapludalfs</td>
</tr>
<tr>
<td>Morley</td>
<td>Fine, illitic, mesic Oxyaquic Hapludalfs</td>
</tr>
<tr>
<td>Octagon</td>
<td>Fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs</td>
</tr>
<tr>
<td>Odell</td>
<td>Fine-loamy, mixed, superactive, mesic Aquic Argaudolls</td>
</tr>
<tr>
<td>Ozaukee</td>
<td>Fine, illitic, mesic Oxyaquic Hapludalfs</td>
</tr>
<tr>
<td>Parr</td>
<td>Fine-loamy, mixed, aquic, mesic Oxyaquic Argaudolls</td>
</tr>
<tr>
<td>Pewamo</td>
<td>Fine, mixed, aquic, mesic Typic Argaudolls</td>
</tr>
<tr>
<td>Raub</td>
<td>Fine-silty, mixed, superactive, mesic Aquic Argaudolls</td>
</tr>
<tr>
<td>Rawson</td>
<td>Fine-loamy, mixed, aquic, mesic Oxyaquic Hapludalfs</td>
</tr>
<tr>
<td>Russell</td>
<td>Fine-silty, mixed, superactive, mesic Typic Hapludalfs</td>
</tr>
<tr>
<td>Saybrook</td>
<td>Fine-silty, mixed, superactive, mesic Oxyaquic Argaudolls</td>
</tr>
<tr>
<td>Sidell</td>
<td>Fine-silty, mixed, mesic Typic Argaudolls</td>
</tr>
<tr>
<td>Strawn</td>
<td>Fine-loamy, mixed, active, mesic Typic Hapludalfs</td>
</tr>
<tr>
<td>Swygert</td>
<td>Fine, mixed, superactive, mesic Aquertic Argaudolls</td>
</tr>
<tr>
<td>Symerton</td>
<td>Fine-loamy, mixed, superactive, mesic Oxyaquic Argaudolls</td>
</tr>
<tr>
<td>Toronto</td>
<td>Fine-silty, mixed, superactive, mesic Udollic Epiaqualfs</td>
</tr>
<tr>
<td>Varna</td>
<td>Fine, illitic, mesic Oxyaquic Argaudolls</td>
</tr>
<tr>
<td>Williamstown</td>
<td>Fine-loamy, mixed, active, mesic Aquic Hapludalfs</td>
</tr>
<tr>
<td>Wolcott</td>
<td>Fine-loamy, mixed, mesic Typic Endoaquolls</td>
</tr>
<tr>
<td>Xenia</td>
<td>Fine-silty, mixed, superactive, mesic Aquic Hapludalfs</td>
</tr>
</tbody>
</table>

1/ Soils are classified according to Soil Taxonomy (Soil Survey Staff 1999).
Table 13. Multiple range tests for comparison of maximum clay contents in the Bt horizons of four of the six soil series and depths to maximum clay content of the Bt horizons  

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Pedons: Total number</th>
<th>Maximum clay content in Bt Horizon</th>
<th>Depth to maximum Bt clay</th>
<th>Homogeneous Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morley</td>
<td>24</td>
<td>46.6</td>
<td>4.5</td>
<td>35.7</td>
</tr>
<tr>
<td>Miamian</td>
<td>10</td>
<td>38.4</td>
<td>3.8</td>
<td>35.3</td>
</tr>
<tr>
<td>Miami</td>
<td>21</td>
<td>33.5</td>
<td>3.1</td>
<td>25.5</td>
</tr>
<tr>
<td>Kidami</td>
<td>14</td>
<td>28.8</td>
<td>6.0</td>
<td>20.5</td>
</tr>
</tbody>
</table>

1/ Pedons were selected using the definitions of the series given in the section under Series Differentia. Note that these definitions apply to the till part of the series control section, not to the Bt horizon. The Ozaukee and Kidder series were not included in the analysis. There were only four pedons of Ozaukee and two of Kidder available.
2/ The multiple range test shows differences in means based on a 95% least significant difference. Series with the same letter are not significantly different at the 95% level.

Table 14. Multiple range test for comparison of parent material differences in the six suites of soils

| Suites of soils | Homogeneous Groups of soils for the named particle size fraction  
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse sand, 0.5-1.0 mm</td>
<td>Coarse and very coarse sand, 0.5-2.0 mm</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>Means</td>
<td>Relationship</td>
<td>Number</td>
</tr>
<tr>
<td>Ozaukee</td>
<td>18</td>
<td>2.1</td>
<td>A</td>
</tr>
<tr>
<td>Morley</td>
<td>62</td>
<td>3.0</td>
<td>B</td>
</tr>
<tr>
<td>Kidami</td>
<td>23</td>
<td>3.8</td>
<td>C</td>
</tr>
<tr>
<td>Miamian</td>
<td>9</td>
<td>5.4</td>
<td>D</td>
</tr>
<tr>
<td>Miami</td>
<td>56</td>
<td>5.8</td>
<td>D</td>
</tr>
<tr>
<td>Kidder</td>
<td>6</td>
<td>8.6</td>
<td>E</td>
</tr>
</tbody>
</table>

1/ The multiple range test of the difference in means based on a 95% least significant difference. The pedons were selected using the definitions of the series given in the section under Series Differentia.
2/ Suites with the same letter are not significantly different at the 95% level.
Table 15. Comparison of clay and carbonate equivalent contents of the Bt and C or Cd horizons of the till-derived soils

<table>
<thead>
<tr>
<th>Statistic</th>
<th>All drainage classes</th>
<th>Well and moderately well drained classes</th>
<th>Basal till</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bt horizon</td>
<td></td>
<td>C or Cd horizon</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>Maximum</td>
<td>Control section</td>
</tr>
<tr>
<td></td>
<td>clay</td>
<td>clay</td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>38.7</td>
<td>38.0</td>
<td>36.5</td>
</tr>
<tr>
<td>std. dev.</td>
<td>8.74</td>
<td>9.0</td>
<td>8.8</td>
</tr>
</tbody>
</table>

1/ Data are for 153 samples of Bt horizons and the tills in the six suites of soils in all drainage classes. The clay data for both sets of samples are on a carbonate-free basis. Clay-size carbonate occurs in some of the Bt horizons. This was subtracted out in the calculations. We assumed that the remainder of the carbonate is in the silt and sand fractions. Clay content on a carbonate-free basis = \(100 \times (\text{total clay} - \text{carbonate clay})/((\text{sand + silt}) - (\text{total carbonate} - \text{carbonate clay}))\).

2/ Data are for 89 samples of the six suites of soils that are in well and moderately well drained classes. The mean clay content of the Cd horizons of the 99 samples of the well and moderately well drained soils calculated on a carbonate-free basis is 32.3 ± 12.1%. The mean carbonate content measured is 28.2 ± 9.2%.

Table 16. Ranges in properties in the lower part of the series control section as determined by analysis of the National Soil Survey Laboratory data and ranges suggested for separating the suites of soils

<table>
<thead>
<tr>
<th>Suites</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
<th>V.F.S.</th>
<th>C.S. + V.C.S.</th>
<th>C. Frags.</th>
<th>CCE</th>
<th>B.D. @ 0.3 bar for the &lt;2mm soil g cm⁻³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;.002mm</td>
<td>0.002-0.050 mm</td>
<td>0.05-2.0 mm</td>
<td>0.05-0.10 mm</td>
<td>0.5-1.0 mm</td>
<td>&gt;2.0 mm</td>
<td>&lt;2 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>%</td>
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<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Kidder</td>
<td>2&lt;10</td>
<td>16-34</td>
<td>58-77</td>
<td>11-20</td>
<td>10-18</td>
<td>5-30</td>
<td>21-62</td>
<td></td>
</tr>
<tr>
<td>Kidami</td>
<td>11-29</td>
<td>33-48</td>
<td>26-51</td>
<td>8-18</td>
<td>4-8</td>
<td>3-18</td>
<td>15-38</td>
<td></td>
</tr>
<tr>
<td>Miami</td>
<td>&gt;12</td>
<td>&gt;23&lt;50</td>
<td>21-63</td>
<td>2-13</td>
<td>6-21</td>
<td>1-29</td>
<td>12-46</td>
<td></td>
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<tr>
<td>Miamian</td>
<td>&gt;12&lt;27</td>
<td>40-49</td>
<td>24-45</td>
<td>6.5-9.9</td>
<td>6-13</td>
<td>8-18</td>
<td>36-45</td>
<td></td>
</tr>
<tr>
<td>Morley</td>
<td>27-42</td>
<td>40-49</td>
<td>17-30</td>
<td>1-7.5</td>
<td>2-8</td>
<td>3-37</td>
<td>16-30</td>
<td></td>
</tr>
<tr>
<td>Ozaukee</td>
<td>25-42</td>
<td>&gt;50</td>
<td>4-21</td>
<td>1-6.5</td>
<td>2-7</td>
<td>1-5</td>
<td>20-48</td>
<td></td>
</tr>
</tbody>
</table>

Ranges in properties that can be used to separate the suites of soils.

| Kidder  | <10 | <34 | >55 | >10 | ≥9 | >5 | 2/ | 2/ |
| Kidami  | 10-28 | <48 | <55 | >10 | <10 | 3-18 | - | - |
| Miami   | 12-28 | <60 | <63 | <13 | >8 | 1-29 | - | - |
| Miamian | 12-27 | <50 | <45 | <10 | >8 | 8-18 | - | - |
| Morley  | >27 | <50 | <30 | <10 | <8 | 3-37 | - | - |
| Ozaukee | >25 | >50 | <21 | <10 | <8 | <5 | - | - |

1/ Calcium carbonate equivalent.
2/ No limits set.
Figure 1. Composite map of the eastern part of the late Wisconsin age glacial geology of Land Resource Region M after Johnson, W.H. (1986), and Fullerton, D.S. (1986)
Figure 2. Soil suites on Wisconsin age till, five State area—Illinois, Indiana, Ohio, Michigan, and Wisconsin
Figure 3. Map of the sample site locations in Illinois
Figure 4. Map of the location of soil suites studied in Illinois
Figure 5. Map of the sample site locations in Indiana
Figure 6. Map of the location of soil suites studied in Indiana
Figure 7. Map of the sample site locations in southern Michigan

Figure 8. Map of the location of soil suites studied in southern Michigan
Figure 9. Map of the sample site locations in Ohio.
Figure 10. Map of the location of soil suites studied in Ohio
Figure 11. Plot of the mean and standard deviation of the maximum Bt horizon clay in the six soil suites.