CHAPTER 17

Soil Taxonomy and Soil Survey

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ABSTRACT

Soil taxonomy was developed primarily for the practical purpose of supporting the National Cooperative Soil Survey (NCSS) Program in the United States. It was adopted nearly 40 years ago by all of the NCSS partners, and is recognized as one of our most important standards. The adoption of the classification system had several important impacts on the soil survey program. The emphasis on observable diagnostic horizons and features for defining classes tended to make all competent soil scientists, regardless of experience and rank, equally capable of accurately and consistently classifying soils. By focusing attention on qualitative class differentiae, the quantity of field data collection has increased and the quality has improved. Property ranges of soil series and their geographic distribution have generally been narrowed over time, allowing us to make more precise interpretations. Soil Taxonomy has benefited the soil correlation process by grouping the nearly 22,000 series currently established in the United States in ways that allow us to efficiently compare and differentiate competing soil series, and coordinate their use among survey areas.

One area that has presented difficulty and confusion from the beginning of Soil Taxonomy's use has been reconciling the difference between map units and taxonomic units. Our soil maps are an attempt to depict our understanding of how natural soil bodies occur within the landscape. The

delineated boundaries reflect the constraints of map scale and the conceptual landscape model of the surveyor (Hudson, 1992). We do not attempt to map taxonomic concepts. Rather, we use the taxonomy to classify the soil bodies we have mapped. Concepts such as pedons, polypedons, series, taxadjuncts, ranges in characteristics, map unit components, similar soils, dissimilar soils, and multi-taxa map units take significant effort to be mastered by soil surveyors, and are little understood outside of our profession. We must always remember that the taxonomy is simply a tool to help us organize our knowledge and transfer our experience and technology from place to place in the landscape. Our primary goal is to help individuals and society understand the soil resource by showing them where the soils are and interpreting, in as simple a manner as possible, their suitability and limitations for intended uses.

INTRODUCTION

The coupling of Soil Science, Soil Classification, and Soil Survey provides a powerful resource for the benefit of humankind. Soil science provides the foundation for our understanding of the physical, chemical, and biological properties of the soils we depend on to grow crops, sustain forests and grasslands, and support our homes and society's structures. Soil surveys put our knowledge into a spatial context so that we know the geographic distribution of the soils. Soil classification helps to organize our knowledge, facilitates the transfer of experience and technology from one place to another, and helps us to compare soil properties. It provides a link between soil science and soil survey.

A major force driving the development of Soil Taxonomy was the practical need to support the National Cooperative Soil Survey (NCSS). Dr. Guy Smith wrote

> "The system is being developed by the Soil Survey Staff to facilitate the soil survey of the United States, a cooperative work involving more than fourteen hundred soil scientists working for more than fifty different institutions. Soil maps are being made at a rate of more than sixty million acres each year. … The classification, therefore, is being developed to serve a program that has a practical objective" (Smith, 1963, p. 6).

The leaders of the NCSS program recognized the need for a classification system that could be applied by a cadre of soil scientists with varying education and experience, in a uniform manner. To do this, they devised a system that used objective criteria that focused on the properties of the soil itself, rather than on theories of its genesis, as was required by the previous classification system (Smith, 1963; Cline, 1963). One of the more ingenious devices of the system is the use of observable, quantitative diagnostic horizons and features, which reflect our understanding about soil genesis. By recognizing these diagnostic horizons and features, and by observing other key differentiating characteristics, a competent soil scientist is able to objectively observe the soil and place it into appropriate taxa.

Since 1965, Soil Taxonomy has been a standard recognized by all members of the NCSS. It has been taught in our universities, and is recognized by many scientific journals as the appropriate way to communicate about soils in scientific research.

IMPACT OF THE USE OF QUANTITATIVE CRITERIA

The adoption of Soil Taxonomy impacted soil survey operations in a number of ways. These impacts were primarily the result of the shift from a qualitative to a quantitative emphasis in observing, describing, and classifying soils (Cline, 1980). Before the adoption of Soil Taxonomy, the concept of each category in the classification scheme focused on a central concept, or typifying individual. The limits of the classes were not well defined, thus there was much latitude for soil scientists to make classification decisions, based on their judgment as to the degree of similarity to one central concept as opposed to another. Soil Taxonomy put a greater focus on observable and measurable class limits defining diagnostic horizons, features, and other differentiating characteristics. This shift from a qualitative to a quantitative emphasis had several practical effects.

Parity and Consistency in Classifying Soils

The use of Soil Taxonomy has effectively placed all soil scientists on an equal footing with regard to their ability to classify a soil. Smith (1963) explained that the choice of differentiating criteria was intended to group soils with similar genesis, but genesis itself was not in the definitions. Instead, it was one step removed from the definitions. This allowed soil scientists to focus on soil properties, and to classify soils rather than processes. This leveled the playing field for all soil scientists, regardless of status within the NCSS Program. No longer did one have to theorize about the genesis of the soil in order to classify it, something that must have been a serious problem when there were either competing theories regarding a soil's genesis, or when the genesis was simply not known by those attempting to classify the soil. With a good morphological description and key laboratory data, a junior field soil scientist was on equal footing with the most senior correlator. As a result, Soil Taxonomy could be applied universally and consistently by any competent soil scientist.

Quantity and Quality of Data Collection

The attention of field scientists became focused on those characteristics selected as class differentiae, thus influencing the kind of information being recorded. It increased the quantity and quality of data gathering by encouraging the recording of greater detail in soil descriptions, and by encouraging laboratory analyses to document properties not readily observable in the field but required for determining taxonomic placement. The kind of information obtained was directly influenced by the need to determine the presence of diagnostic horizons and features, and to document other differentiating characteristics used as class limits. A potential downside to this focus on the properties used as differentiae was recorded in the report of the committee on the "New Soil Classification System" to the 1963 NCSS National Work Planning Conference (Soil Survey Division, 1999, p. 27–28). Guy Smith is reported as commenting

> As Dr. Simonson has pointed out again and again, it is possible to become a prisoner of one's classification. The differentiae that are used in the 7th Approximation will get very great emphasis and those that have not been used can easily be overlooked. Yet, in defining a soil, one must think of all of its properties and not just the ones that have been used in differentiae. We have been able to use only a very few soil properties to define our taxa. Soils have a great many other properties, and we must be on our guard to be sure that these others, which actually may be more important from some viewpoints than those we have used, do not get overlooked.

This caution is as valid today as it was then. As observers of soils, we tend to see what we are taught to see, and may not strive to observe more once we know enough to complete the task of classifying a soil. When the need for change in the system is recognized, however, adding or changing differentiae at the higher categories can be (and has been) done, but it requires that a proposal be developed, reviewed widely, and approved, and this can take considerable time. However, at the series level of classification, there are no predetermined differentiating properties, allowing considerable freedom to define a series based on virtually any soil property observed within the series control section. This approach, however, is only useful for separating soils that the classification system has grouped into the same family. It cannot be used to group soils that taxonomy has set apart at a higher level.

Refinement of Soil Series Concepts

Another consequence of the shift to a quantitative system was a change in the range of characteristics, geographic distribution, and precision of interpretation for some series. The soil series evolved from an early concept based on parent rock and geographic province (USDA, 1903), to one that included the recognition of common genetic horizons and morphology (Kellogg, 1937), and finally to becoming the lowest level of the classification system, thus sharing limits with each of the higher taxa to which it belongs (Soil Survey Staff, 1975). With the use of class limits for particle size, mineralogy, temperature, and other family criteria, along with soil property limits in the higher categories (including moisture class), some series ranges had to be trimmed and geographic distributions limited. As a result, some new series were established. Bailey (1978) described the impact of the implementation of Soil Taxonomy on the Miami series. Before the adoption of Soil Taxonomy in 1962, the concept of the Miami series included pedons with subsoil clay contents straddling the family particle-size class limit of 35%. Since a series could not range beyond the limit of the family, the Miamian series (fine, mixed, mesic, Typic Hapludalfs) was split out of the Miami series (fine-loamy, mixed, mesic, Typic Hapludalfs) in 1969. As Soil Taxonomy continues to be amended by revising or adding new differentiating criteria (Soil Survey Staff, 1999), series concepts continue to be refined. For example, in 1992 the International Committee on Aquic Soils introduced the Oxyaquic subgroup within several great groups to recognize soils with seasonally high water tables within 100 cm, but not meeting the criteria for higher aquic taxa. In 1996, the International Committee on Families introduced additional family classes for cation-exchange activity classes (CEC). Today, the family to which the Miami soils were originally classified has been subdivided into three (semiactive, active, and superactive) of the four CEC classes, and the new Oxyaquic subgroup. These subdivisions resulted in further narrowing the range of the series and recognition of six families, where previously there had been one. Today, the Miami series is a member of the family of fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs.

The use of quantitative criteria defining class limits, with the resultant refinement of series ranges, has allowed for the development of increasingly precise interpretations. For example, the introduction of the Oxyaquic subgroup to separate soils with water tables of short duration within 100 cm of the soil surface (such as Miami) from otherwise similar soils in the typic subgroup of Hapludalfs (such as Amanda) allows us to better describe the suitability of these classes of soils for homes with basements or on-site sewage disposal. We must remember, however, that providing interpretations for soil series (a conceptual taxonomic class) is not the same as interpreting a soil map unit. Map units contain not only the soil(s) for which they are named, but also similar and dissimilar inclusions (Soil Survey Division Staff, 1993).

Refinements to the concept and distribution of individual soil series, while providing the benefit of improved interpretations, also present some problems. Coordination between survey areas mapped at different times requires careful correlation to achieve adequate joining of yesterday's and today's series concepts on each side of the survey boundary. This has been especially evident in recent efforts to accelerate the digitizing of soil surveys that were mapped over a period of 30 years or more in the United States. Unless adequately coordinated and joined, GIS users cannot easily achieve effective analysis across survey area boundaries. Changing series concepts are also a burden for others who use soil survey information, because they must periodically learn new names for the soils they have become familiar with. They don't understand why the soils "change."

Improvement in Soil Correlation

Soil correlation is the process the NCSS uses to define, map, name, classify, and interpret soils and to join soil map units consistently within and among soil survey areas (Simonson, 1963; Soil Survey Staff, 2001a). It is our most important quality control process. The need to provide comprehensive field descriptions and associated laboratory data to adequately classify the soils tended to result in more uniform descriptions than in the earlier periods of soil survey (Simonson, 1963). One manifestation of this improvement in the detail and precision of soil descriptions was the development and adoption of the standard form (SCS-SOI-232) for recording soil descriptions. Although this was officially a form used within the Soil Conservation Service, it was commonly used or adapted by other NCSS partners. These standard field description templates had the beneficial effect of reminding soil scientists to record many of the important properties of the soil, such as moist and dry color, percentage of coarse fragments, mottles, ped coatings, pH, horizon boundaries, etc.; and to identify diagnostic horizons and features that are present. However, Dr. Simonson (then Director, Soil Classification and Correlation in the Soil Conservation Service) expressed the concern that while it tended to set a standard for the minimum set of data to be recorded, it may also have had the unintended consequence of setting the maximum (Simonson, 1987).

Another important way that Soil Taxonomy has improved the soil correlation process is by grouping soils with similar properties into classes, thereby making it easier to understand how they relate to one another. The number of soil series recognized in the United States has grown from about 10,500 in 1975 to nearly 22,000 today, clearly too many for the human mind to organize and remember. With the aid of the classification to group the soils with similar properties, and computer technology (Soil Survey Staff, 2001c) to query our soil database and quickly deliver series descriptions for comparison, it is fairly easy for today's soil scientists to find the names of all the soil series in a given class, or closely similar class, and to coordinate the naming and interpreting of soil map units from one survey project to another.

Some Problems with Quantitative Limits

The use of quantitative class limits has also had some drawbacks. Webster (1968) expressed several objections regarding the system. A major problem with the approach is that while the class limits are fixed, there is inherent uncertainty in the observation and measurement of many of the properties, such as recording color by comparison to color charts, or determining rupture resistance class by attempting to crush peds in the field. Laboratory measurement of properties such as particle size, base saturation percentage, or organic matter content also contain inherent measurement error. As a result of these uncertainties, data obtained by repeating a field observation or laboratory analysis could result in a different classification for the soil. Also, with no provision for overlapping of class limits, some soil bodies that have natural distributions of one or more properties that straddle artificial class boundaries will be forced into separate taxa, even though they clearly form a natural cluster in their landscape setting. As Soil Taxonomy has evolved, it has become increasingly dependent on the need for laboratory data for supplying the required quantitative values that successfully classify a soil (e.g., spodic materials, andic soil properties, cation exchange activity classes, etc.). While this reliance on laboratory measurements can be a positive addition to the quality of the data in the soil survey, obtaining it can be time-consuming and expensive, thus hindering our ability to classify pedons with confidence at the time they are being observed. Also, it is an impediment to the effective use of Soil Taxonomy in places where analytical laboratory services are not readily available.

TAXONOMIC UNITS AND MAP UNITS

Cline (1977, p. 253), in an attempt to anticipate future developments in soil survey, wrote

> At the lowest level of the system, we will have to acknowledge the differences between taxonomic soil series and mapping units that bear the same name and will probably have to rectify the confusion

this causes. It is conceivable that soil families could become the lowest category of taxonomy, but some ingenious person may find a better solution.

Soil Individuals

The concepts of the pedon and polypedon were introduced by Johnson (1963) to relate map units depicted in soil surveys to the new classification system. These were intended to bridge the gap between the conceptual taxonomic categories of soil series with the soil bodies delineated on maps. The pedon was conceived to be the basic soil unit consisting of a volume just large enough to depict the horizons present and their relationships to one another. The pedon is likened to the unit cell of a crystal (Soil Survey Staff, 1975). It is generally considered to be the entity that we describe and sample in the field. Inherent weaknesses of the pedon concept are that while its relatively small size is convenient for study, it is too small to exhibit the full range of properties for a series, and it cannot show the nature of the boundary with adjacent soils in the landscape, the surface shape, or other site characteristics of the soil. Additionally, rarely if ever have soil scientists truly identified, described, and sampled the three-dimensional pedon in the field. It has been argued that we more commonly describe and sample soil profiles rather than pedons (Holmgren, 1988).

The concept of the polypedon was introduced to overcome some of the weaknesses inherent in the pedon concept. Johnson (1963, p. 215) described it as a real soil body consisting of contiguous pedons "all falling within the range of a single soil series." It was conceived to provide a link between pedons and the taxonomy on one hand, and to relate taxonomic units to map units on the other hand. The polypedon was considered to be the individual we classify, and, in Johnson's words, "comparable to individual pine trees, individual fish, and individual men."

These concepts presented practical difficulties. First, the relationship between real soil bodies (i.e., polypedons) and the conceptual taxonomic class of the soil series presented a serious dilemma. Soil properties within a three-dimensional soil body are not mindful of arbitrary class limits of our taxonomy. The report of the Committee on the Application of the New Classification System recorded in the 1965 NCSS Conference Proceedings (Soil Survey Division, 1999) includes a discussion of "guidelines for allowable tolerances in the stretching of family class limits by series class limits." The debate was whether the range of characteristics for a series must be within the limits of the family. Alternatively, only the typical pedon itself would be required to fit within the family, thus allowing the range of characteristics to stretch beyond the family range. It was agreed that series, as the lowest level of the taxonomy, must have ranges no wider than the family to which they belong. Having made this decision, however, the NCSS leaders wanted to avoid the possible proliferation of new series simply to cover pedons and polypedons slightly beyond the rigid family class limits. They decided to study the problem further. Two years later at the 1967 NCSS conference (Soil Survey Division, 1999) there was discussion of *taxonomic inclusions, plesioseries,* and *taxal deviants* as devices to classify pedons close to, but outside the range of, a given series. These concepts evolved into the *taxadjunct* and *variant*. While we no longer correlate variants (we establish new series for these), we frequently use the taxadjunct to this day when the pedon used to typify a series in a survey area is outside the limits of the family to which the series belongs.

The difficulties presented by the concept of pedons and polypedons, and the constraints on allowable ranges for soil series, have been debated ever since that time. Soon after Johnson's introduction of the pedon and polypedon, Knox (1965, p. 83) pointed out that polypedons have no real existence apart from series concepts. He stated that "*their significance as individuals seems less than the significance of individual pine trees, individual fish, and individual men.*" Webster (1968) suggested that in order to define and maintain effective series concepts, there is a need for an "unconformity" between the series and higher taxonomic classes. Guthrie (1982) recognized that the use of the correlation devices of taxadjuncts and variants are a manifestation of the problem. He suggested two alternatives when a pedon is chosen to typify the central concept of a series that is slightly beyond the concept of a taxonomic class. Either the soil can be classified at the lowest taxonomic level that it fits, or it can be correlated to the closest available series and any properties that are outside the range of the selected series can simply be disregarded in the taxonomic description (presumably to be handled as inclusions in mapping). In most instances, soil survey practitioners have followed the second alternative, although not always. For example, the soil survey of the Flathead National Forest (Martinson and Basko, 1998) correlated the soils at the family level, and constructed map unit names using phases of higher categories for brevity. Two examples are *Fluvents, alluvial fans* and *Typic Eutroboralfs, silty till substratum, hilly.* Despite the passage of 18 years since the decision was made to restrict series ranges to the limits of higher categories, Alexander (1983) and Borst (1983), each reacted to Guthrie by arguing that series should be allowed to encompass a range reflecting the properties observed in the field, even if they cross higher class limits. Nettleton et al. (1991), describing what they called the "taxadjunct problem," reported that about half of the pedons analyzed by the National Soil Survey Laboratory have one or more properties outside the family limits for the series identified in the field. They suggested that we classify the central concept of the soil and allow the described range in characteristics to cross the boundaries of higher taxa (one of the original alternatives discussed 28 years earlier at the NCSS conference). Holmgren (1988) suggested that an operational definition should have been developed to depict the procedure for describing a pedon in a spatial context. He contends it was a mistake to develop an operational definition for the pedon itself. While he did not propose an operational definition, it seems that he envisioned a set of multiple observations, related to each other geographically (similar to "satellite sampling"), to characterize the pedon. In this way, there would be multiple possible outcomes that could be realized as one observes a pedon repeatedly. A polypedon, then, would have some "probability" or "expectation" of meeting a particular classification.

Today we still talk of pedons, although rarely do we truly identify, describe, and sample this three-dimensional body. More often than not, the pedon becomes a spoil pile next to the pit and we describe a two-dimensional soil profile. Perhaps we need a procedure to "dissect a pedon" rather than simply "digging a pit." The polypedon concept has been largely ignored because it is too difficult to locate it's boundary in the field, and it's very concept is contradictory and relies on circular reasoning (Soil Survey Division Staff, 1993).

Taxonomic Purity of Map Units

A number of pedologists have looked at the taxadjunct problem in the context of the composition of map unit delineations to estimate the proportion of pedons not fitting within the taxonomic class for which the map unit is named. McCormack and Wilding (1969) studied a portion of northwestern Ohio that had been mapped before the introduction of Soil Taxonomy. It was considered to have very complex soil patterns, resulting in a high degree of variability. Overall, they found that 74% of the more than 200 pedons observed fit the expected Order, while just 17% fit the expected Family and Series. An additional 26%, however, were close enough to be considered taxadjuncts. Despite the low taxonomic purity, they concluded that only a few of the delineations observed were improperly mapped.

Nordt et al. (1991) studied the taxonomic makeup of four map units in east Texas. The soils observed were Crockett (fine, montmorillonitic, thermic Udertic Paleustalfs), Rader (fine-loamy, mixed, thermic Aquic Arenic Paleustalf), Robco (loamy, mixed, thermic Aquic Arenic Paleustalfs), and Spiller (fine, mixed, thermic Udic Paleustalfs). The taxonomic purity of the map units, following a pattern similar to that found by McCormack and Wilding (1969), is highest at the Order, Suborder, and Great group levels, and drops with progressively lower taxa, with the percent of pedons classifying in the named series ranging from just 11% for Rader to 49% for Crockett. In addition to the taxonomic purity, they also considered the interpretive purity of the map units. When soils considered to be similar to the named series were added, the percentage of "interpretive purity" was estimated to be 48 for Rader, 52 for Robco, 81 for Spiller, and 86 for Crockett. The Rader and Robco map units, therefore, do not meet the definition of a consociation type of map unit as defined in the Soil Survey Manual (Soil Survey Division Staff, 1993), and the authors recommended that a multitaxa unit be correlated. If done, the two map units would presumably have significantly higher taxonomic and interpretive purities.

Other authors have conducted assessments of the taxonomic purity of map units, and have reported results similar to the two studies described above. Edmonds et al. (1982) suggested that taxonomic criteria that require laboratory methods to be determined often cannot be reliably inferred in the field, and therefore are not easily mapped. They showed that for an area studied in Virginia, variability that gives rise to mixed and oxidic mineralogy classes could be found within a distance of 7 m. In this landscape, then, not only is it impractical to map this class difference at scales commonly used in soil survey, soil volumes as small as individual pedons will likely contain properties of both classes. Ransom et al. (1981), Edmonds et al. (1985), and Edmonds and Lentner (1986) all point out that because soil series have property ranges limited by taxonomic boundaries, and interpretations have generally been generated based on series properties, our ability to interpret map units adequately is hampered. They suggest that we need to be able to record property ranges for map units themselves, and then interpret the map units.

Today, by taking advantage of improved computer technology, we have begun to move from interpreting soil series in our survey reports to interpreting components of map units. Soil series are conceptual soil classes defined by limits of key diagnostic properties. Components of map units are natural bodies of soils in a particular landscape. Whereas the soil series is the lowest class in our taxonomy and is constrained by higher class limits, a soil component is that portion of a map unit either fitting within the concept of the series or is close enough in its properties to interpret in essentially the same way for most uses. In the past, interpretations were generated and stored for each series nationally, and then used locally for the soil survey. While they could be adjusted, this was a cumbersome process. Today we can store soil property values for individual map unit components and generate interpretations based on the property ranges recorded for that specific soil survey area. While our Official Series Descriptions remain the lowest level of Soil Taxonomy, and are therefore required to have ranges extending no further than higher taxa limits, the National Soil Information System (NASIS) allows soil scientists to record soil property values for components of map units that more closely reflect ranges of properties in the field. Low and high values depicting the range, along with a "representative value" (RV), are recorded. The RV is required to be within the range of the taxonomic class (generally series), but the low and/or high value may *"extend beyond the established limits of the taxon from which the component gets its name, but only to the extent that interpretations do not change"* (Soil Survey Staff, 2001b). Thus in effect, the soil survey has developed a procedure to effectively accomplish what was debated by the NCSS leaders at the 1963 conference. Rather than allowing the series to "stretch family class limits," we have allowed the map unit component to stretch the series class limits. Interpretive criteria are then applied to the component data.

REFERENCES

Alexander, E.B. 1983. Comment on "The relationship between Soil Taxonomy and soil mapping." *Soil Surv. Horiz.* 24:15–16.

Bailey, G.D. 1978. A brief history of the Miami soil series. *Soil Surv. Horiz.* 19:9–14.

Borst, G. 1983. Taxonomy and soil mapping units: A reply to R.L. Guthrie., *Soil Surv. Horiz.* 23:16–19.

Cline, M.G. 1963. Logic of the new system of soil classification. *Soil Sci.* 96:17–22.

Cline, M.G. 1977. Historical highlights in soil genesis, morphology, and classification. *Soil Sci. Soc. Am. Proc.* 41:250–254.

Cline, M.G. 1980. Experience with soil taxonomy of the United States, *Adv. Agron.* 33:193–226.

Edmonds, W.J., Iyengar, S.S., Zelazny, L.W., Lentner, M., and Peacock, C.D. 1982. Variability in Family differentia of soils in a second-order soil survey mapping unit. *Soil Sci. Soc. Am. J.* 46:88–93.

Edmonds, W.J., Baker, J.C., and Simpson, T.W. 1985. Variance and scale influences on classifying and interpreting soil map units. *Soil Sci. Soc. Am. J.* 49:57–961.

Edmonds, W.J. and Lentner, M. 1986. Statistical evaluation of the taxonomic composition of three soil map units in Virginia. *Soil Sci. Soc. Am. J.* 50:997–1001.

Guthrie, R.L. 1982. The relationship between soil taxonomy and soil mapping. *Soil Surv. Horiz.* 3:5–9.

Holmgren, G.S. 1988. The point representation of soil. *Soil Sci. Soc. Am. J.* 52:712–716.

Hudson, B.D. 1992. The soil survey as a paradigm-based science. *Soil Sci. Soc. Am. J.* 56:836–841.

Johnson, W.M. 1963. The pedon and the polypedon. *Soil Sci. Soc. Am. Proc.* 27:212–215.

Kellogg, C.E. 1937. Soil Survey Manual. USDA Misc. Publ. 274, Washington, DC.

Knox, E.G., 1965. Soil individuals and soil classification. *Soil Sci. Soc. Am. Proc.* 29:79–83.

Martinson, A.H. and Basko, W.J. 1998. Soil Survey of Flathead National Forest Area, Montana. USDA Forest Service and Natural Resources Conservation Service.

McCormack, D.E. and Wilding, L.P. 1969. Variation of soil properties within mapping units of soils with contrasting substrata in Northwestern Ohio. *Soil Sci. Soc. Am. Proc.* 33:587–593.

Nettleton, W.D., Brasher, B.R., and Borst, G. 1991. The taxadjunct problem. *Soil Sci. Soc. Am. J.* 55:421–427.

Nordt, L.C., Jacob, J.S., and Wilding, L.P. 1991. Quantifying map unit composition for quality control in soil survey, in M.J. Mausbach and L.P. Wilding, Eds. Spatial Variability of Soils and Landforms. SSSA Spec. Publ. No. 28, Soil Sci. Soc. Am., Inc., Madison, WI.

Ransom, M.D., Phillips, W.W., and Rutledge, E.M. 1981. Suitability for septic tank filter fields and taxonomic composition of three soil mapping units in Arkansas. *Soil Sci. Soc. Am. J.* 45:357–361.

Simonson, R.W. 1963. Soil correlation and the new classification system. *Soil Sci.* 96:23–30.

Simonson, R.W. 1987. Historical aspects of soil survey and soil classification. Part VI. 1951–1960. *Soil Surv. Horiz.* 28:39–46.

Smith, G.D. 1963. Objectives and basic assumptions of the new soil classification system. *Soil Sci.* 96:6–16.

Soil Survey Division. 1999. Proceedings of the National Cooperative Soil Survey conferences and other soil survey documents 1963–1997. CD-ROM computer file. National Soil Survey Center, Lincoln, NE.

Soil Survey Division Staff. 1993. Soil Survey Manual. USDA-SCS Agric. Handbook 18, U.S. Government Printing Office, Washington, DC.

Soil Survey Staff. 1975. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA-SCS Agric. Handbook. 436, U.S. Government Printing Office, Washington, DC.

Soil Survey Staff. 1999. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys, Second Edition. USDA-NRCS Agric. Handbook 436, U.S. Government Printing Office, Washington, DC.

Soil Survey Staff. 2001a. National Soil Survey Handbook. Soil Correlation (Part 609.06). Online at *http://soils.usda.gov/procedures/handbook/main.htm* (verified October 8, 2002).

Soil Survey Staff. 2001b. National Soil Survey Handbook. Soil Properties and Qualities (Part 618.03). Online at *http://soils.usda.gov/procedures/handbook/main.htm* (verified October 8, 2002).

Soil Survey Staff. 2001c. Official Soil Series Descriptions. Online at *http://ortho.ftw.nrcs.usda.gov/osd/osd.html* (verified October 8, 2002).

USDA. Bureau of Soils. 1903. Instructions to field parties and descriptions of soil types. Washington, DC.

Webster, R. 1968. Fundamental objections to the 7th Approximation. *J. Soil Sci.* 19:354–366.