AN ABSTRACT OF THE THESIS OF

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Title: Analysis of Variability of Some Forest Soils in Southwestern Oregon

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The variability of selected physical, chemical, and morphological soil properties in two landtype mapping units on the Rogue River National Forest in southwestern Oregon was studied.

The objectives of the study were (i) to quantify soil variability in several soil resource inventory mapping units, (ii) to explore methods of describing soil variability in order to make soil map information more useful to the map user, and (iii) to attempt to identify sources of variability.

Two mapping units, in the Siskyou and Cascade Mountains, were selected to represent extremes of internal variability. Eight delineations of each map unit were sampled with randomly located transects for a total of 40 sites per map unit.

Soil properties exhibited various types of frequency distributions. Normal, skewed, and multi-modal distributions were observed. Nearly half the property-horizon combinations measured in both map units had normal distributions. Chemical properties, such as extractable bases, were consistently positively skewed or approximately log-normal. Square root and logarithmic transformations of the data normalized these distributions and stabilized the variance. These results suggested that for multi-modal and badly skewed populations, assumption of a normal

distribution may lead to considerable error if the arithmetic mean and standard deviation are used for predictive purposes.

Map unit 74 in the Siskyou Mountains was considered to be more variable, over most properties measured, than map unit 33 from the Cascades. For most properties coefficients of variation (CV) were higher, the sample requirements to estimate population means were greater, and the ranges were wider in map unit 74, as compared to map unit 33.

In both map units, chemical properties were more variable than physical or morphological properties, which were about equal in their variability.

The number of samples required to estimate the means of properties varied widely and were often prohibitively large (264 for organic matter in the surface of map unit 74). This number could be reduced if the sampling scheme was stratified using estimates of within and between delineation variance.

Between 50 and 75 percent of the total variation in most properties of both map units occurred within delineations. This result is desireable from a management and broad planning perspective and tends to support the validity of the map units as designed and mapped.

When tested by analysis of variance, most properties in both map units had significantly different delineation means. These differences could often be traced to one particular delineation and were many times not of practical significance.

Large or small changes in the values of most properties were found to be as likely to occur at 660 foot separation distances as at 15 foot distances. This tends to indicate a random distribution of variation, when distance alone is considered, which could have important consequences when attempting to characterize soil properties for management interpretations or site evaluations.

Chemical properties expressed volumetrically were more variable than the same properties expressed on a weight basis. Volumetric chemical concentrations were greater in map unit 74 than in map unit 33, the reverse of the relationship found with those properties on a weight basis. The proportions of within delineation variance in map unit 74 increased as a result of conversion to volumetric concentrations.

Use of principal components analysis confirmed the chemical properties as contributing greater amounts of variation than the physical or morphological properties. Ordination of sites along axes of selected factors also confirmed the general uniformity of the map units as well as the greater variability of map unit 74.

Analysis of Variability of Some Forest Soils of Southwestern Oregon

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INTRODUCTION

The primary purpose of soil survey activities is to delineate a landscape into areas that can be managed uniformly or about which precise enough statements can be made in order to plan land use more intelligently or appropriately (Beckett and Webster, 1971). In addition, soil survey activities provide information about the characteristics of the soils in the survey area and develop interpretations as to the potential hazards of land use and the expected reponse of the soils to management treatments. All of these activities are primarily concerned with the making of reliable predictions. In general the reliability of a prediction or the uniformity of an expected response is a function of the homogeneity of the areas delineated. This homogeneity can be expressed in terms of the variability of the characteristics used to define these areas. The properties chosen are usually a combination of characteristics required by the classification system used, characteristics of the land being inventoried, and characteristics that affect present or forseeable uses of the land.

The U.S. Forest Service, in the late 1960's and early 1970's began to map and inventory the soil resources under their jurisdiction. This effort was partly in response to environmental legislation, but it was primarily a response to a perceived need for better resource information for land management planning. The number and diversity of potential land uses that needed to be considered had increased as more people used the public lands and their expectations and concerns about proper use of the land were voiced. As the planning philosophy changed from primarily functional planning for individual resources to emphasize integrated resource management, inventory procedures changed in similar ways as well. Each region was allowed to develop and carry out their inventories in order to address their particular problems as well as the unique characteristics of their landscapes and resources. The combined result of all these actions was to cause the soil resource inventory to become a land resource inventory.

In Region 6 (Oregon and Washington) the landtype approach has been adopted. In essence this represents a loose variation of the land-system approach developed in Australia (Beckett and Bie, 1978). In that approach a land system represents a recurring pattern of soil, geologic, physiographic, and vegetative components. A land unit is a more narrowly defined subdivision of a land system and is the unit on which estimates of land use potential are made. A land type (Region 6) is quite similar to a land unit in the Australian system. Although the landtype approach represents an integration of components, landforms are stressed because they exert a dominant influence on the characteristics of the other components. Therefore landtypes are defined only partially in terms of their dominant soils. A given soil type is not restricted to a particular landtype and may occur in several. Usually the soils occur as associations or complexes (Wendt and Thompson, 1978).

The two basic, intended uses of the Soil Resource Inventory (SRI) are (1) for various types of individual resource and general land management planning purposes, and (2) to serve as a basis for more detailed surveys and research (Wertz and Arnold, 1973). As the SRI information is currently used in planning land management activities, the landtypes identified quite often form the geographical basis for predicting response to management treatments. An assumption of uniformity of composition and response to management is made. The variability of landtype characteristics in terms of both reliability of interpretations and applicability of predictions to specific areas on the ground becomes critical. To date few studies are known to have been done which have examined the variability of these types of mapping units, particularly in terms of their soil components (Chittleborough, 1978). Very few studies of the variability of forest soils in general have been done, though the need for them has been expressed for quite some time (Mader, 1963).

With these rationale in mind, a study was undertaken on the Rogue River National Forest, located in Southwestern Oregon, with the following objectives:

(1) To quantify the variability of several soil properties in two Soil Resource Inventory mapping units, chosen to represent extremes in terms of their internal uniformity.

(2) To investigate various ways of describing this variability so that the usefulness of the report might be enhanced.

(3) To attempt to identify sources of variability described in (1) and (2).

LITERATURE REVIEW

Soil Variability

Introduction to Soil Variability

Soils are natural bodies which, like vegetation, vary across the landscape. In the case of both soils (Van Wambeke, 1966) and vegetation (Kershaw, 1973), questions have arisen and have been discussed at length as to whether this variation is continuous or discrete, whether natural groupings exist, and if so whether they can be identified (Pomerening and Knox, 1962).

Regardless of the answers to these questions, classification and mapping of land, vegetation, and soil continue for very practical reasons: (1) we cannot measure the soil, or any other component of the landscape, everywhere, nor can we know what the soil will be like at every place; (2) land managers cannot continually adjust their management of the land to the variation which exists but need to deal with (uniform) parcels, or parcels which are assumed to be uniform, either in reality or for the purpose at hand; and (3) by describing, grouping, and mapping we can make better use of soils information, including soil variability, and we can make more precise statements about soil behavior and occurrence than we could if we had not grouped or mapped them (Webster, 1977a).

For these reasons the study of soil variability has, in most cases, been related to soil survey and classification. Much early research, however, was done to investigate soil variability and how it affects the utility of a soil test, as well as evaluations of soil fertility (Harris, 1915; Robinson and Lloyd, 1915; Bear and McClure, 1920). And more recently, sophisticated work dealing with the variability of soil physical properties has appeared (Simmons, Nielsen and Biggar, 1979).

Many studies of soil variability concentrate primarily on the identification and description of those soil forming factors and processes which contribute to variability, as is the case with soils of forest areas (Stephens, 1956; Gaiser, 1952; Stark, 1977; Lyford, 1964; Gersper and Holowaychuck, 1970a,b; Zinke, 1962). The framework for thinking about soil variation in terms of soil forming factors can be attributed, in its original form, to Dokuchaiev of Russia and Hilgard of the U.S., and in its later theoretical quantification, to Hans Jenny (Jenny, 1941).

Other studies, which quantitatively measure and statistically desdribe the results of these factors and processes, deal more with sampling techniques (Hammond, Pritchett, and Chew, 1958), patterns of variation within and between taxonomic, mapping, or landscape units, and appropriate statistical methodology (Norris, 1972).

Soil Variability and Survey/Classification

The quality, usefulness, and effectiveness of the soil map/report, the information/interpretations contained in it, and their improvement have been the objects of many soil variability studies. These studies have approached the problem by examining the objectives, techniques, and procedures used by soil mappers and taxonomists. A significant portion of this research has come from a group of Englishmen led by R. Webster and P. H. T. Beckett. With a steady stream of papers dating from the early 1960's, they have continually stressed the importance of estimating the variability of mapping units, presenting this information to map users, and using this information for developing better survey procedures and interpretations (Webster and Beckett, 1964; Webster and Beckett, 1968; Webster and Butler, 1976; Webster, 1977b; Beckett and Bie, 1978).

One way of expressing map unit variability is in terms of taxonomic composition or purity. Traditionally the amount of allowable inclusions in single taxa mapping units has been set at 15 percent (Soil Survey Staff, 1951). In recent years, however, studies of map unit composition have shown this figure to be unrealistically low. Beckett and Webster (1971), in a review of soil variability research, concluded that on the average, about 50 percent of randomly chosen sites within a mapped series or type are occupied by soils which match the definition of the profile class for which the unit is named. In many instances, given the complexity of the landscape and soil pattern, as well as the nature of the inclusions found, the mapping is still considered to have been done well (Wilding, Jones and Schafer, 1965; McCormack and Wilding, 1969; Powell and Springer, 1965). Taxonomic purity, however, is not the same as purity for management (Bascomb and Jarvis, 1976; Webster, 1977b). The need to recognize the extent to which various types of inclusions contrast with the named soil, in terms of their response to management, has been stressed by Amos and Whiteside (1975) and incorporated into the concept of similar and dissimilar soils (National Soils Handbook, 1977).

Many reasons have been suggested for the large number of inclusions found in these studies. Proposals have been presented to improve the accuracy and utility of mapping units, as well as to remove some of the misconceptions surrounding their definition. Part of the problem is related to map scale. All soil bodies simply cannot be shown, cartographically, on maps at commonly published map scales (1:20,000 - 1:60,000). In addition the procedures used in soil survey to predict soils from interpretation of landscape features don't provide the number of observations needed to accurately estimate map unit composition (Wilding, Jones, and Schafer, 1965). These authors have suggested that the concept of a mapping unit be modified to emphasize the dominant soil of the area with no percentages stated, rather then make reference to some specified, but rather arbitrary degree of accuracy.

As soil taxa, such as soil series, become increasingly more well-defined, the ability to depict them on a soil map becomes more difficult. An increasing number of mapping units, designated as single taxa units, are in reality complexes, and should be renamed and described to reflect this (Amos and Whiteside, 1975). This recommendation seems particularly appropriate to mapping of mountainous, forested regions. In many cases in these areas the pattern of inclusions is just as important to the use of the unit as are the amount and type of inclusions present (Nortcliff, 1978; Lyford, 1974). Fifteen percent of strongly contrasting inclusions can occur in such a way as to leave the remaining 85 percent in unmanageable parcels. Lyford (1974) estimated that about 20 percent of the soil areas he studied in southern New England were composed of soil bodies <30 meters wide, and 42 percent were <60 meters. Most of these bodies were irregular, discontinuous areas bordering wet spots or at the base of slopes near drainageways. The possibility of the roots of a single tree growing in five different soil series was illustrated. He concluded that the deficiency of the published soil maps was not in the degree of accuracy or detail of boundaries shown but a lack of a means to illustrate to users the great complexity of some mapping units.

Many authors have suggested the mapping of representative portions of a survey area before the survey begins. This would allow the soil surveyors to gain an appreciation of the complexity of the soil pattern (McCormack and Wilding, 1969), the pattern of soil variability (Nortcliff, 1978), and to aid in decisions of where to best allocate sampling effort during the course of the survey (Webster and Butler, 1976). In addition, if these detailed areas were included as inserts to the regularly published maps it might counter the tendency to assume uniformity within mapped boundaries (Lyford, 1974).

The difficulties of sampling and statistical quantification of map unit composition become more acute as the scale of the survey is reduced and soils become just another component of the landscape to be mapped, rather than the main emphasis. As the scale decreases soil associations tend to be the more commonly used kind of map unit. In soil resource inventories and in landtype, or land system mapping, topography becomes as important a consideration to the use of the map and delineation of units as are soils. When inclusions are reported in terms of landtypes or soil associations, the recognition and estimation of purity and composition becomes difficult. Few variability studies of these types of units have been done. An exception is a study of Chittleborough (1978) of the soil variability within land systems and land units in an area of 35,000 ha in Australia. The purity of the map units was determined in comparison to a survey of the same area at a larger scale. It was found that the map user had a little over one in three chance of correctly predicting the profile class at any point in the survey area, using only the map and report. Scores for individual mapping units varied widely (15-71%). These variations were attributed to the complexity of the terrain and the degree of external expression of the soil as observed from the air photo pattern. The score for the entire area was 37 percent.

Evaluations of the composition or variability of any survey can only be as accurate as the sampling strategies used (Arnold, 1979). These evaluations should also be comparable to the level of intensity of use of the map (Wertz and Arnold, 1973), the level of accuracy required or specified by users (Beckett and Webster, 1971), and the scale of mapping.

Spatial Variability of Soil Properties

More often than wanting to know about a particular soil class, a user may want to know about the uniformity of some property, or set of properties, within the mapping unit or a portion of it. Mapping units are usually distinguished on the basis of sets of key properties or characteristics (Norris, 1971). It is assumed that many properties do not vary independently of each other but are correlated to some degree. The strength of the correlation between these key, diagnostic properties and other, accessory ones partially determines the variability of the mapping units created (Webster and Butler, 1976). The variability of properties is related to the variability of taxonomic classes through the allowable range of characteristics of those classes (Protz, Presant, and Arnold, 1968). Quite often, though, many properties are correlated. Consequently soil groupings created on the basis of a few key properties contain information about the combined variation of many soil properties while containing relatively little information about the variation of a particular property (Norris, 1971). One measure of the effectiveness of a classification, and a partial determinant of the "success" of mapping, is the degree to which the variation of properties or sets of properties within the created groups is reduced relative to that existing in the entire population without the classification. This measure is termed the intra-class correlation (Beckett and Webster, 1971). As the correlation approaches unity the effectiveness of the classification increases. Webster and Beckett (1968) found relatively high correlations (0.48 - 0.70) for some physical properties, with little utility gained by mapping on the basis of chemical properties (.06 - 0.33) in a 1:63,360 scale survey in England. In some cases the soil/landscape pattern is such that no classification usefully reduces the variation of any property (Webster and Butler, 1976), that is, some landscapes are not "mappable" (Beckett and Bie, 1978).

Map utility is increased if the diagnostic/taxonomic criteria are also properties important to the use of the map or are highly correlated with accessory properties of management importance (Banfield and Bascomb, 1976). In forest areas, the utility of a map and the variability of the map unit are often assessed by the variation of productivity indices, such as site index (Carmean, 1975). Unfortunately, soil mapping units alone have not fared well in separating or distinguishing areas of different site productivity (Alban, 1976). The site index often differs more within a mapping unit than it does between units (Carmean, 1975), and the question of its appropriateness as a measure of productivity has also been raised (Esu and Grigal, 1979). More integrated land classification schemes, or soil mapping units which take into consideration topographic and vegetative aspects of productivity, may be less variable and more useful (Spurr and Barnes, 1980).

In some cases, the properties of importance to management are also the ones which are most readily altered as a result of it, i.e. chemical properties (Beckett and Webster, 1971). For this reason, measurement of the natural variability is important so that changes due to management can be assessed.

As with taxonomic classes, the number of observations made during a survey is usually inadequate relative to the number necessary to make statistical comparisons of mapping units in terms of soil properties (Crosson and Protz, 1974). In some cases, differences of statistical significance may not be of practical significance if management behavior is similar. These differences, therefore, do not warrant separation of mapping units (Wilding, Jones, and Schafer, 1965). In other cases, the properties which clearly separate taxonomic units, such as landscape position, degree of dissection, etc., may not be as readily quantifiable as soil properties, though perhaps in mountainous, forested, areas they should be (Retzer, 1963).

Landform characteristics are used extensively to infer changes in soils. Recently several attempts have been made to quantitatively predict soil properties from landforms alone. Some studies have utilized selected measurements of topographic characteristics such as elevation, slope gradient, slope length, and slope shape, derived either from on-the-ground measurements (Walker, Hall, and Protz, 1968b; Vreeken, 1973; Vreeken, 1975) or from stereo orthophotos (Crosson and Protz, 1973), and have correlated them with selected soil properties. Other studies have used geographical coordinates and attempted to fit polynomial equations to account for the variation of properties across selected portions of the landscape (Walker, Hall, and Protz, 1968a; Davies and Gamm, 1969). Success in prediction is quite variable, the amount of variation accounted for differing from 70 percent for some morphological features to as little as 5 percent for pH (Walker, Hall, and Protz, 1968a). Trends are often predicted, but local anomalies are missed, due to subtle changes related to microrelief, the action of soil fauna, and the previous land surface and drainage conditions of the area, as they affect subsurface properties (Walker, Hall, and Protz, 1968b). The importance of particular landform parameters also changes with the landscape position on which it is applied and the geomorphological age and history of the site (Vreeken, 1973, 1975). These studies indicate that landform alone is not sufficient for predictive purposes but should be used in conjunction with other properties, especially in areas where the topographic and geomorphic complexity is great and simple landscape models are not applicable.

This point is particularly important for broad scale survey or inventory where landform is relied on to a large degree, through interpretation of aerial photography, with a limited amount of ground truth. Chittleborough (1978) found that land system mapping was unsuccessful in reducing the variation of several morphological and physical soil properties, either at the land system or the land unit (landtype) level. Coefficients of variation (CV) were in the range of 50 to 100+ percent for most properties. Chemical properties can vary equally as much, and at this level of survey may have little direct relation to the attributes of the landscape seen on air photos (Webster and Beckett, 1964). This variability of properties suggests that the requirements that land be readily identifiable/mappable and uniform are often in conflict (Chittleborough, 1978), although specifications of what constitutes a desirable level of uniformity is rarely given. Again, integrating the different components of the landscape for predictive purposes seems desireable, although if the components bear little relation to each other; i.e. soils to topography to vegetation, then less useful information is gathered than if separate surveys were made (Beckett and Bie, 1978). Others have felt that depending on landform properties and geomorphic processes to predict soil properties, use limitations, and management response has been successful (Wendt and Thompson, 1978).

Those points on the landscape where certain predictions no longer apply become the boundaries of map unit delineations (NCSS Workshop, 1979). While these boundaries imply abrupt changes of properties, the actual variation across the boundary may be quite different, possibly being quite gradual or completely random (Campbell, 1977). The way in which key properties change across boundaries partially affects the variability measured both within and between units. Differences in the variances of properties may be as important to distinguishing units as differences in means (Campbell, 1978) and can be useful in identifying unique patterns of variation (Raupach, 1951a,b). Mathematical models have been developed to test which type of variation best describes that measured for various soil properties. As might be expected different properties exhibit different patterns of variation. In one case where Campbell (1977) applied these mathematical models, pH and silt changed extremely slowly across a boundary while the change in sand content was quite abrupt. Diagnostic properties are more likely to exhibit abrupt changes, while accessory properties may be random or gradual.

An integral part of describing the variation across a boundary first involves identifying it, at whatever the appropriate scale of the survey or study may be. The process of boundary location is generally an intuitive process, developed through training, observation, and experience. Some limited work has been done to quantify this process (Webster and Wong, 1969; Webster and Cuanalo, 1975; Webster, 1973; Webster, 1978; Beckett and Bie, 1976), primarily during the reconnaissance stage of a survey, so that some initial idea of the density and spacing of boundaries and the intricacy of their pattern can aid in later mapping. Most of the techniques employed involved exotic mathematical methods, usually outside the training of the average field scientist. They attempt to minimize the variances of one or a group of soil properties, of segments along transects through representative landscapes (Beckett and Bie, 1976; Webster, 1978).

An excellent review and statistical compilation of variability research (Beckett and Webster, 1971), as well as additional studies done since then (Courtney, 1973; Adams and Wilde, 1976; Bascomb and Jarvis, 1976; Nielsen, Biggar, and Erh, 1973; Schafer, 1979) provide much data about the relative variability of different types of soil properties.

Chemical properties are generally more variable than either physical or morphological characteristics, though the diverse landscapes studied and sampling plans used have resulted in large ranges in reported values for most properties. Exchangeable cations, organic matter, available N and P, and pH tend to be more variable than are properties such as total N and P, and cation exchange capacity. In cultivated areas this is usually attributed to the effects of management practices such as fertilization and liming (Beckett and Webster, 1971), although the same types of relationships have been found in unfertilized fields (Cipra et al., 1972). Cultivation is thought to produce a uniformity of the surface soil, as compared to the unmixed and undisturbed forest surface (Mader, 1963). Table 1 compares the results of some variability studies done on forest soils. Values are for selected properties of A horizon or surface soil and are in terms of the coefficient of variation (CV). Total elemental chemical variability can be high or low, increasing as the size of the area sampled increases (Drees and Wilding, 1973), if the whole soil rather than selected size fractions are used (Williams and Rayner, 1977), and with the geological material from which the soil is derived (Heil and Mahoud, 1978).

Most of the morphological characteristics measured in the field tend to be quite variable. Thicknesses of horizons, depths to diagnostic features such as mottling, carbonates, discontinuities or bedrock, and consistence tend to be highly variable. Only color appears to be consistently less variable. Hue is difficult to evaluate because it is

TABLE 1. Coefficient of Variation of A Horizon Properties* from Selected Forest Soil Variability Research (%).

Property	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Silt + clay				16			15-17	20		15	15-20
Coarse fragments		18-35		309							
Bulk density		10-19		10			4			8	8-10
exchangeable											
K	31		22	181	34,30		18-20	47	89		17-45
Ca	50		26	28	32,52		26-29	225	120		16-64
Mg	74		31	28	18,63		22-24	87	59		16-49
Organic matter				20		52		57		22	23-37
Total N	24		16	17	10	45			31	18	16-36
Total P	36				20,16						
Available P			30	38	29,59						26-51
pH	7		4	4		4			7		3-6

*See following page for investigator citations.

TABLE 1. Continued.

(1) Bracewell, Robertson, and Logan (1979): A2 horizon, Countesswells series, NE Scotland

(2) Irby (1967): Alderwood, Everett series, 0.1 acre plots, Cascade Range, Washington

(3) Metz, Wells, and Swindel (1966): 0-3", Loblolly pine plantation, South Carolina

(4) Mollitor et al. (1980): Floodplain soils in NE New York, NW Vermont

(5) Blyth and MacLeod (1978): 1 ha plots, sitka spruce, NE Scotland

(6) McFee and Stone (1965): A2 horizon, yellow birch-red spruce

(7) Alban (1974): Red pine + aspen stands, Minnesota

(8) Ike and Clutter (1968): A2 horizons, 0.2 acre plots, NE Georgia, Blue Ridge Mt.

(9) Larson and Wooldridge (1977): surface 10 cm, Western hemlock stands

(10) Mader (1963): Red pine, Massachusetts, 0.1 acre plots

(11) Geist and Strickler (1978): Blue Mountains, Oregon, 0-15 cm, Basalt and ash derived soils.

measured on an arbitrary, circular scale (Webster, 1977a). Structure is an inconsistent property, grade of structure often being quite variable, with class and type of structure being less so (Adams and Wilde, 1976). The reverse has been found as well (Wilding, Jones, and Schafer, 1965). Many morphological properties are not amenable to statistical description because they are expressed in terms of their presence or absence.

Physical properties such as texture, bulk density, and moisture tension appear to be rather uniform and distributed normally, unless affected by management (Tisdall, 1951; Aljibury and Evans, 1961; Andrew and Stearns, 1963), while flow characteristics such as hydraulic conductivity, diffusivity, changes in water content and storage, and infiltration are much more variable (Sartz, 1972; Nielsen, Biggar, and Erh, 1973; Mason, Lutz, and Peterson, 1957; Carvallo et al., 1976) and anormally distributed (McIntyre and Tanner, 1959).

While differences in the variability of properties in different mapping units has been shown, no clear trend in terms of the variability of any soil properties within delineations of a given mapping unit has emerged. Most studies try to sample the geographical range of the unit, but the number of delineations examined is small, usually less than ten.

In some cases, properties are more variable within delineations than between (Wilding, Jones, and Schafer, 1965) while in others, though in similar landscapes, the reverse has been found (McCormack and Wilding, 1969). Variations within delineations of a map unit can sometimes be greater than the mean differences between mapping units (Andrew and Stearns, 1963). The magnitude of the within-delineation variation found can depend on the property being measured as well as the soil horizon

(Cipra et al., 1972). Although ideally, all delineations should be the same, what this represents in terms of a desireable distribution of variation is not clear. Most often the gradual changes in climate, regional complexities of the soil pattern, and class limits chosen for mapping units interact to prevent this uniformity, though it is often assumed by map users.

The variation that is measured within and between delineations of a mapping unit is also dependent on how given properties change in relation to distance and on how much of the total variation is found at any given distance, or within any given size area (Webster and Butler, 1976). It is usually assumed that the variability of a property increases with the size of area that is sampled, up to some limits determined by the specific area studied (Beckett and Bie, 1976). Different properties exhibit different patterns of variation over different distances. Short range variation of many properties is the rule. Often as much as half the total variation of some properties in a large area may be present within any m^2 within it (Beckett and Webster, 1971). The implications of these patterns for sampling, mapping, and prediction have been alluded to earlier.

For example, the magnitude of short-range variability of soil properties affects the correlations found between site characteristics and tree growth (Blyth and MacLeod, 1978). Though this is usually not evaluated in these types of studies (Carmean, 1975), it is assumed that the variables chosen as predictors are uniform over fairly large areas. In evaluating the effects of management practices on soil properties, large small-scale variability can cause the number of samples required to document differences or effects to increase greatly (Larson and Wooldridge, 1977). The large degree of short-range variability normally present also requires mappers to adjust the spacing and technique of sampling (Webster and Butler, 1976; dos Santos, 1978) to fit the landscape and properties of importance and to gain the most useful, generalizable information (Beckett and Bie, 1978).

Temporal Variability of Soil Properties

Soil variability can be expressed in terms of spatial or temporal components. Additional variability is introduced as a result of 1) sampling error, due to our inability to sample the entire population; 2) selection error, the means by which we decide which individuals to sample; and 3) analytical error, our means of determining the magnitude of a given property (Cline, 1944). These latter three sources of variability will be assumed to be minor components for the present discussion.

Temporal variability can take many forms. It can be expressed in terms of diurnal or seasonal cycles, or longer time frames, depending on one's particular interest. That temporal variation in soil properties exists has been long recognized (Blakemore, 1966), and is the basis for important taxonomic criteria such as soil temperature regimes (Soil Survey Staff, 1975). However, isolation of the temporal patterns for selected soil properties, particularly chemical properties, and determination of the magnitude of the variations has proved difficult. In many studies the large degree of spatial variability within plots has obscured any seasonal trends that may have existed (Ball and Williams, 1968; Raupach, 1951a) despite the use of intensive sampling schemes often employing plot sizes as small as 25 cm^2 (Frankland et al., 1963). In other cases management treatments, such as fertilization, obscure, or are the cause of the seasonal pattern observed (Blakemore, 1966). The chemical properties most often found to exhibit temporal variations are the more dynamic properties such as pH (Baker and Clapham, 1939; Raupach, 1951a,b), ammonia and nitrate forms of nitrogen (Montes and Christensen, 1979; Vitousek et al., 1979), available P, and exchangeable cations (Gupta and Rorison, 1975). Variations of total elemental contents of soils, although exhibiting seasonal patterns, are much more difficult to explain (Lousier and Parkinson, 1979). Peaks observed often occur during late spring - early summer (Vitousek et al., 1979) and coincide or are correlated with changes in climatic variables such as total rainfall (Baker and Clapham, 1939) or soil properties associated with them such as moisture content (Gupta and Rorison, 1975), changes in microbial populations (Montes and Christensen, 1979) or decomposition of organic matter (Vitousek et al., 1979). This corresponds with the observations that the most intense variations are usually seen in the upper horizons and are less evident at greater depth as climatic changes are muted. The number of factors or processes which are normally operating in soils to influence temporal variations is quite large. These processes, each with their own unique temporal cycles, interact to produce the temporal variations which are found in studies, such as of nutrient cycling, which usually operate arbitrarily on an annual basis (Lousier and Parkinson, 1979).

Extremely long temporal variations, over the course of time considered for soil development, was studied by Harradine (1949), who showed that even as the absolute levels of certain soil properties change as soils age, the variability of those properties decreases as well.

Statistical Description of Soil Variability

The primary purposes of a statistical analysis or description of the variability of a sampled population of a soil class or property are: (1) to provide an estimate of the central tendency of the population, for generalization purposes; (2) to provide an estimate of the dispersion or spread of values, for predictive purposes; and (3) to provide an estimate of the reliability of this sample, as being indicative of the true population. More detailed descriptions of the population may involve its structure, i.e. the relationships of individuals to one another, as well as the pattern of variation.

The use of most of the common statistical estimators assumes that the observations belong to "normal" distributions. This assumption, as it applies to commonly measured soil properties, is discussed by Webster (1977a). He concludes that in general, the normal distribution can usefully and reliably be applied to many tasks involving estimation and prediction of soil properties, though it is understood that it never describes exactly the real distribution of any soil variable.

Basic statistics, when combined with graphs of frequency distribution, allow an initial look at the general variation of the entire population and how closely it approaches a normal distribution (Protz, Presant and Arnold, 1968; Adams and Wilde, 1976). Two statistical measures of proximity of the sampled distribution to the normal, skewness and kurtosis, describe how much the distribution tends toward extreme values and how spread out or clumped the values are about the mean. Frequency distributions are laborious to develop and take up large amounts of space in their presentation and so are of limited usefulness.

The mean, $(\bar{x})$, combined with various measures of dispersion, can generate much useful information about the variation of the population. Since the magnitude of the variance (s^2) is often exaggerated by the scale of measurement, its square root, the standard deviation, (s), is a much more useful basic statistic of variability for comparative purposes. Many authors in the variability literature have chosen to combine the mean and the standard deviation into one statistic, the coefficient of variation (CV), calculated as $s/\bar{x} \times 100$. Other authors state their preference to keep the two estimators separate (Wright and Wilson, 1979). The advantage of the CV is that it is a good general index of variability when comparing different properties or the results of various studies. Its disadvantages include: (1) it can only be used with properties which have a scale with an arbitrary zero. Therefore, it is not really justified to compare pH to other variables, based on CV, since it is measured on a logarithmic scale. (2) It assumes a normal distribution, and (3) it assumes no covariance between the mean and the standard deviation (NCSS Workshop, 1979). In this last case, two populations could have the same variance but different means and would have different CV's, though the degree of variability is similar. If the CV is going to be used, it is probably best to present all three pieces of information, namely mean, standard deviation, and CV, if possible (Snedecor and Cochran, 1967).

The variance can also be used to develop confidence intervals and valuable information for sampling purposes. The variability of a property can be expressed in terms of the number of samples required to estimate the mean within a certain desired range of accuracy (Wilding, Jones, and Schafer, 1965). The standard error, expressed as the variance divided by the number of observations, gives an indication of the reproducibility of the mean upon taking repeated samples of that size. It is also termed the sampling error. The sampling effort needed to reduce the sampling error by greater amounts tends to increase exponentially (Webster, 1977a).

Analysis of variance (ANOVA) techniques, combined with the proper sampling plan, can vastly increase one's knowledge of the variation of a population or the reduction of variation due to classification. Depending on how the population is stratified, key sources and patterns of variation can be partitioned and identified. Stratification can be by fields (Hammond, Pritchett, and Chew, 1958), mapping units (McCormack and Wilding, 1969), delineations within mapping units (Bascomb and Jarvis, 1976), landscape units (Wright and Wilson, 1979; Reynolds, 1975), distance (Bracewell, Robertson, and Logan, 1979) or other suitable criteria.

Correlation techniques have been used to evaluate (1) the variation of soil properties in terms of other landscape components (Vreeken, 1975) and, (2) the degree to which the values of a soil property are correlated or are statistically dependent at varying distances of separation (Webster and Cuanalo de la C, 1975; Campbell, 1978). Regression or trend surface analysis can be used to predict values of a soil property in three dimensions based on landscape or other parameters (Walker, Hall, and Protz, 1968a,b).

In the last fifteen years, the use of multivariate (MVA) statistical techniques to analyze and describe soil variation has been increasing. These techniques have several advantages over standard univariate methods that make it more appropriate, in a sense, for the study of variability. The first is that it allows the soil system to be treated more realistically, in terms of polythetic classes, where no one group or individual is defined solely on the basis of one property but on several, often shared properties (Webster, 1977a). Univariate methods often do not adequately take into account the interrelationships between properties. In addition soil taxonomic classes, while useful for generalizing about soil relationships, weight certain characteristics more heavily than others. Multivariate techniques allow properties to be considered equally, allowing identification of those variables which contribute most to the variation of the system (Norris, 1970). Secondly, since soils are described by large amounts of data, MVA, and particularly principal components analysis (PCA), allows the reduction of a large number of variables into a smaller set, without significant losses of information. This reduced set of variables can then be utilized in several ways. Courtney (1973) used PCA to evaluate the composition of a mapping unit in England. Nortcliff (1978) used PCA to identify patterns of soil variation as an aid during the reconnaissance stage of a soil survey. MVA can be used to show the similarities between soils, based on many properties, as well as potential groupings (Webster and Cuanalo, 1975; Wright and Wilson, 1979). Soils information can also be incorporated as just one component of the description of a land area and, along with MVA, be used to develop land classification schemes (Radloff and Betters, 1978), vegetative community groupings (Atzet, 1979) or homogenous land units for specific planning purposes (Omi, Wensel, and Murphy, 1979).

Finally MVA can serve as a tool for generating hypotheses about sources or patterns of variation, since no a priori notions about the importance of properties are used in the analysis, except in the choice of the initial variables used to describe the system (Norris, 1970).

Although these statistical techniques are not usually within the grasp of the average man in the field, with the assistance of someone skilled in their use, they can be used to advantage in providing another perspective on soil variation. Their use should increase in the future as the statistical sophistication of the soil scientist or land manager increases.

As mentioned earlier, the assumption of normality of soil properties is generally a reasonable one, yet many studies have found anormally distributed soil variables (Protz, Presant, and Arnold, 1968; Adams and Wilde, 1976; Nielsen, Biggar, and Erh, 1973). Transformations may be appropriate in some instances (Webster, 1977). However, severe deviations from normality may necessitate the use of non-parametric statistical methods (McIntyre and Tanner, 1959).

Nonparametric procedures can be used to detect differences between populations and provide confidence limits with samples where variances are unequal (McIntyre and Tanner, 1959). Correlations between anormally distributed properties can be computed (Protz, Presant, and Arnold, 1968). The goodness-of-fit of a sampled distribution to some theoretical distribution can be evaluated and the amount of error one incurs by assuming the wrong distribution (i.e. normal instead of log-normal) can be estimated (Rao et al., 1979). However, measures of central tendency or of mean values are not possible (McIntyre and Tanner, 1959). Although nonparametric methods may be simpler to use, and though they have not been applied to soils extensively, it appears that in evaluations of variability and for predictive purposes they offer little additional utility.

MATERIALS AND METHODS

Study Area Selection

The Rogue River National Forest was chosen as the site for the study based on the following criteria:

1. diversity of the area in terms of its geology, vegetation, and soils.

2. potential need for, and interest expressed in the type of information to be gathered from the study.

A detailed study of a large number of mapping units was beyond the scope of the project. Likewise, a very detailed look at only a few delineations would have provided too narrow a view of the variability present. For these reasons, the following approach was chosen. Two mapping units were selected that seemed to represent extremes in terms of their internal variability. The choice of two mapping units would allow sampling a geographic cross-section of delineations and possibly cover the range of mapping unit variability more completely. Choosing mapping units representing extremes in uniformity would provide an idea of the potential range in variability one could expect to find.

Further discussions with George Badura, the soil scientist for the Rogue River NF, led to identification of two mapping units which fulfilled the desired criteria and about which more information was desired. These units were:

1. Landtype Unit 74 (MU74), underlain by Applegate group metamorphic rocks on the Siskyou Mountains, in which variations in bedrock cause great variation in soil characteristics.

2. Landtype Unit 33 (MU33) in the High Cascades region, underlain by flow basalts and andesites, in which the soils appear to be relatively uniform.

Study Area Description

The Rogue River National Forest is located in southwestern Oregon and has its headquarters in Medford. The forest contains 633,735 acres within its unit boundaries, 584,247 acres of which are national forest system lands, the difference representing privately-owned land. The forest is divided into two sections, one in the Siskyou Mountains, the other in the Cascade Mountain region. Since the two regions are so different in regards to their soils, geology, and climate, they are best described separately.

Siskyou Mountains

The Siskyou Mountains are a portion of the larger Klamath Mountains geologic-physiographic province. The area is typified by rugged topography, diverse geology, and a harsh climate. Slopes are steep and long, with deeply incised canyons and 2,000 to 5,000 feet of relief. Some of the oldest rocks in Oregon can be found here, some possibly dating back to the Paleozoic era (Baldwin, 1976). Rock types include metavolcanic and metasedimentary formations, locally metamorphosed to schists and phyllites, as well as igneous and ultramafic intrusive bodies (Badura and Jahn, 1977). Climate is dominantly maritime (Mediterranean) in character, being strongly influenced by frontal systems originating in the Pacific Ocean.

Winters are generally cool and wet and summers hot and dry. The maritime influence is modified by several mountain ranges which occur as one moves eastward from the ocean. As a result, a steep climatic gradient exists from west to east. Annual precipitation ranges from over 100 inches (250 cm) at the coast to less than 20 inches (51 cm) at Ashland, most occurring during the winter as rain or wet snow (Waring, 1969). In the area of the MU74 study sites, average annual precipitation ranges from 25-50 inches (64-127 cm). Temperatures are generally warmer as one moves inland, and extremes of temperature are more common. Average annual, January and July temperatures at Medford are 54 (12.2^{o}C), 37.2 (2.8^{o}C), and 71.8 (22.1^{o}C) ^{o}F, respectively (Badura and Jahn, 1977). Cooler temperatures can usually be expected in the mountains.

Because of these diverse environmental conditions, and because there has been no flooding, volcanic activity, or extensive glaciation for at least 100 million years (Whittaker, 1961), the vegetation is also exceedingly diverse, and rich in endemic and relict species (Whittaker, 1960).

Waring (1969) divided the Siskyou region into two subdivisions, the East and West Siskyous, based on measured moisture and temperature gradients and associated plant distributions. He identified at least eight major vegetative types within the Eastern Siskyous by their location along these environmental gradients. These types, identified by component tree are: Mountain hemlock, Shasta red fir, White fir, Mixed Conifer, Ponderosa Pine, Black Oak, Yew, and Jeffrey Pine. Franklin and Dyrness (1973) described the Mixed Conifer type as the dominant type in the Eastern Siskyou's, being replaced by the Mixed-Evergreen type, described by Whittaker (1960), in the Western zone. The Mixed Conifer zone consists of Douglas-fir (Pseudotsuga menziesii), Sugar pine (Pinus lambertiana), Ponderosa pine (Pinus ponderosa), Incense cedar (Libodecrus decurrens), and White/grand fir (Abies concolor/grandis), occurring in a range of combinations and mixtures.

The Mixed-Evergreen zone is generally described by a mixed forest of evergreen, needle-leaved trees in the overstory, dominantly Douglas fir and sugar pine, with sclerophyllous broad-leaved trees such as tan oak (Lithocarpus densiflorus), madrone (Arbutus menziesii), golden chinkapin (Castanopsis chrysophylla (Dougl.) A.DC.), and canyon live oak (Quercus chrysolepis) in the understory (Franklin and Dryness, 1973). In addition, at the lower elevations an Interior Valley zone is defined, consisting of hardwoods, such as black oak (Quercus kelloggii), in various combinations and mixtures with conifers such as Douglas fir and ponderosa pine in the overstory and poison oak (Rhus diversiloba) in the shrub layer.

The general SRI characteristics of MU74 and its dominant soil, 7400, are listed in Table 2. Soils are tentatively classified as belonging to the loamy-skeletal, mixed, mesic family of Typic Haploxeralfs. Mapping of soils in areas adjacent to the Rogue River National Forest has been done by the Bureau of Land Management (deMoulin, Pomerening and Thomas, 1975), and by the Soil Conservation Service. The Josephine County soil survey is completed but not yet published and the Jackson County soil survey is in progress. Zinke and Colwell (1965) have also described the soils of similar terrains in northern California.

TABLE 2. Landtype and soil descriptions for MU 74.

LANDTYPE UNIT 74

Landtype unit 74 consists dominantly of Landtype 74 and minor amounts of Landtypes 93, 75, 71, 73 and 77.

The major soil profile type occurring on this Landtype is number 7400. Soils on Landtype 74 are comprised of loams and clay loams which have surface layers totaling 10-15 inches (25-40 cm) in thickness, subsoil layers 20-40 inches (50-100 cm) in thickness and contain 35-50+ percent gravel and cobble. Soils are forming in colluvium and residuum and are well drained.

Bedrock materials are comprised of soft to moderately hard, highly fractured metasedimentary and metavolcanics of the Applegate Group. Depth to bedrock ranges from 3 to 5 feet (1-1.5 m).

Typically, Landtype 74 is associated with moderately steep, slightly to moderately dissected convex (rounded) slopes and hills with slopes ranging from 35-65 percent. Stability Class II and III.

This Landtype occurs primarily in Environmental Zones I and II.

SOIL 7400

Litter:	Needles, leaves and twigs in various stages of decomposition, 1 to 2½ inches (3-4 cm) thick.
Surface Layers:	Very dark grayish brown to grayish brown, gravelly loams, loams and light clay loams; moderate to strong fine sub-angular blocky structure; non-sticky to slightly sticky and slightly plastic when wet; pH ranges from 5.8 to 6.6; 10-15 inches (25-40 cm) thick.
Subsoil Layers:	Dark brown to olive brown loams, clay loams, gravelly loams and gravelly clay loams; strong, medium to coarse sub-angular blocky structure becoming massive with depth; slightly sticky and slightly plastic to plastic when wet; pH ranges from 5.8 to 6.4; 20-40 inches (50-100 cm) thick.
Nature of Sub-Stratum:	Soft to moderately hard and locally hard, highly fractured metamorphic rocks of the Applegate Group. Depth to these materials ranges from 36-60 inches (90-150 cm).

Soil 7400 is found on Landtypes 73 and 74.

Geology. MU74 is generally considered to occur over rocks derived from the Applegate Formation, and soil characteristics are strongly related to its features. This formation composes the main Oregon portion of the Western Paleozoic and Triassic belt of rocks originally described by Irwin (1960). While selected areas of the Applegate Formation have been studied in detail (Heinrich, 1966; Godchaux, 1969; Englehardt, 1966; Kays and Ferns, 1980) in general the most complete published mapping has been at small scales (1:96,000) by Wells (1940, 1956). The formation consists of interbedded metavolcanic and metasedimentary rocks which were deposited in a deep marine basin environment approximately 230 million years ago. Subsequently, as a result of sea-floor spreading or crustal subsidence and movement these sediments were incorporated into the continental crust. Igneous intrusions, primarily quartz diorite and ultra mafic bodies, associated with the deformations of the Nevadan orogeny, occurred during the Jurassic, about 150 million years ago (McKee, 1972). Deformational activity has occurred periodically since the time of deposition with the formation being folded, faulted, uplifted and eroded several times. As a result, bedding planes generally strike north-northeast and often approach a vertical orientation. Metamorphic grade is generally low but regionally quite variable, increasing with structural depth in the formation (Kays and Ferns, 1980) and in proximity to igenous and ultramafic intrusions and fault zones (Englehardt, 1966; Godchaux, 1969). Massive metavolcanic rocks dominate the formation and consist of slightly altered basalt and andesite flows with interbedded tuffs. Remnants of the original texture are still evident in many areas. They are typically fine to very fine grained and dark to medium gray, green, or buff.

Conformably interbedded with these rocks are metasedimentary rocks consisting mainly of argillites, some of tuffaceous origin, and graywackes, of the feldspathic and lithic varieties. The argillites are usually black to grayish black, fine grained, and slightly banded. The graywackes are generally medium to dark gray-green and quite difficult to separate from the metavolcanic rocks in the field (Heinrich, 1966).

Cascade Mountains

This area is dominated by the north-south trending Cascade Mountain range. The Cascades are divided into two sections. The Western Cascades are an older, deeply dissected and weathered range composed of Miocene and Pliocene age interbedded andesite flows and pyroclastics. The High Cascades to the east are younger (Pliocene to recent) in age. The High Cascade landscape consists of a broad rolling plateau built of basalt and andesite flows and lavas produced by shield volcanoes. Large, isolated composite cones, developed by periodic eruption of pyroclastic debris and andesitic lavas, interrupt and dominate the scenery. Mt. McLoughlin, located in the study area, is the southernmost of these stratovolcanoes in Oregon. In this southern portion of the range the vegetation is predominantly of the mixed-conifer type at the mid-elevations, 1500 to 4700 feet (750 m - 1400 m), with a white-fir zone occurring between 4700 and 5300 feet (1400 - 1600 m) (Franklin and Dyrness, 1973). The climate of the Cascades area is cooler and moister than that of the Siskyous. Average annual precipitation in the area of the MU33 study sites ranges from 40 inches (102 cm) to 60 inches (152 cm), 75 percent of which occurs between November and April. Average annual, January, and July temperatures from the nearest station at Howard Prairie are 43.4, 27.6, and

61.4°F, respectively (Badura and Jahn, 1977). MU33 occurs mainly on the High Cascade plateau and on margins of the Western Cascades. The SRI description of the map unit and range of characteristics of the dominant soil, 3300, are given in Table 3. Soil 3300 is estimated as belonging to the loamy-skeletal, mixed, frigid family of Typic Haploxeralfs (Badura and Jahn, 1977). Other mapping of the soils of this general area has been done by the Bureau of Land Management (deMoulin, Pomerening, and Thomas, 1975) and by the adjacent, Winema National Forest (Carlson, 1979).

Geology. Rocks in the study area are predominantly basaltic andesites associated with shield volcano activity. These rocks were deposited during several periods of intense activity, separated by long intervals of quiet, during which extensive weathering often took place. Most of this activity took place during the Pliocene and Pleistocene periods, was concurrent with the development of the composite cones, and continued into the Holocene era (Maynard, 1974). Due to this periodic activity and weathering, many erosional surfaces are present. In addition the weathered appearance of these different flows, such as color, is very similar, making identification in the field difficult (Maynard, 1974). Pyroclastic deposits are associated with the flows, as a result of the concurrent activity of the composite cones, and in those areas on the margins of the Western Cascades. Most flows are fine to coarse grained, range in color from light gray to black, and contain variable amounts of olivine and plagioclase phenocrysts. Western Cascade flows are more andesitic in character and have only rare olivine phenocrysts in comparison to the High Cascade flows (Naslund, 1977).

TABLE 3. Landtype and soil descriptions for MU 33.

LANDTYPE UNIT 33

Landtype unit 33 consists dominantly of Landtype 33 and minor amounts of Landtypes 30, 31, 34, 37 and 40.

The major soils profile type found on this Landtype is number 3300. Soils on Landtype 33 are comprised of loams and light clay loams which have surface layers totaling 20-30 inches (50-75 cm) in thickness, subsoil layers 30-50 inches (75-120 cm) in thickness and contain 25-60 percent cobble. Soils are forming in residuum and colluvium and are well drained.

Bedrock materials are comprised of soft to moderately hard andesites, basalts and breccias. Depth to bedrock ranges from 6 to 8 feet (2-2.5 m).

Typically, Landtype 33 is associated with gently rolling broad surfaces exhibiting considerably variable micro-relief at elevations ranging from 3500 to 5000 feet (1065-1525 m) on slopes 5-25 percent. Stability Class I.

This Landtype occurs primarily in Principal Forest Environments.

SOIL 3300

Litter:	Needles, leaves and twigs in various stages of decomposition, 2 to 3 inches (5-8 cm) thick.
Surface Layers:	Reddish brown to dark reddish brown gravelly, cobbly, very gravelly, or very cobbly loams; weak, fine, sub-angular blocky to moderate fine granular structure; non-sticky and non-plastic when wet; pH 5.8 to 6.4; 25-35 inches (65-90 cm) thick.
Subsoil Layers:	Brown to yellowish red gravelly to cobbly loams and light clay loams; moderate to strong, medium, sub-angular blocky structure; slightly sticky and slightly plastic when wet; pH 5.2 to 6.0; 30-50 inches (75-125 cm) thick.
Nature of Sub-Stratum:	Soft breccias, basalts, and andesites beginning at a depth of 72-96 inches (180-240 cm).

Soil 3300 is found on Landtypes 33 and 33-H.

Delineation Selection

All delineations for each mapping unit were identified and their area measured using a planimeter. Sizes of delineations were extremely variable. In the case of MU74, delineations ranged in size from 80 to over 800 acres, the average being 250 acres. The same was also true for MU33. In order that sampling intensities would be approximately equal across delineations, those delineations which were larger than the average were subdivided into parcels approximately equal to the average size. All parcels were arbitrarily numbered and a list of potential delineations for sampling was made up using random number tables (Steel and Torrie, 1960; Dixon and Massey, 1969). Beginning with the first delineation on the list, each delineation was visited to determine its suitability for use in the study. Criteria for selection of delineations were primarily on the basis of disturbance and accessibility. Delineations which had not had a significant portion of their area recently disturbed by management activities were considered adequate, though completely undisturbed areas were preferred. This latter condition was felt to be of importance because one possible use of variability information is to develop baseline data on soil properties so as to detect and assess their changes under various management activities. In several instances this criterion was not fulfilled, partly due to the history of management on the forest and the relative desirability and productivity of the mapping units for timber production. MU33 is highly productive and conducive to intensive management for timber. These areas have also been logged since the early 1900's. As a result it was difficult to find undisturbed delineations. The same held true for MU74.

Accessibility was the second criterion for delineation selection. The gentler topography of MU33 in the High Cascades allows relatively easy road location and stability. The rugged, steep slopes and nature of the geology make road location in MU74 more difficult. Several delineations were deleted because of inaccessibility even though they were in undisturbed condition.

If a delineation was rejected for either of the above reasons, the next delineation on the list was evaluated. Ten delineations were originally chosen from each mapping unit, but this number was reduced to eight when sampling time and evaluation of delineations took longer than originally expected. Delineations which appeared to be mismapped, from the standpoint of the modal concept of the landtype, were not removed from selection since an indication of the range of variability present in an inventory of this type was one of the major study objectives. Therefore, one, and possibly two, delineations were included in both mapping unit samples which were not modal in concept. The effect of these delineations on the variability measured will be discussed at a later point.

The delineations chosen for the study are shown on the map in Figure 1, and their names, as referred to in this study, as well as legal locations, are given in Table 4.

Sampling Scheme and Rationale

The objective of efficient sampling is to gain the best or most accurate information possible under the given restraints of time and costs (Graley and Nicolls, 1979). The importance of the knowledge of

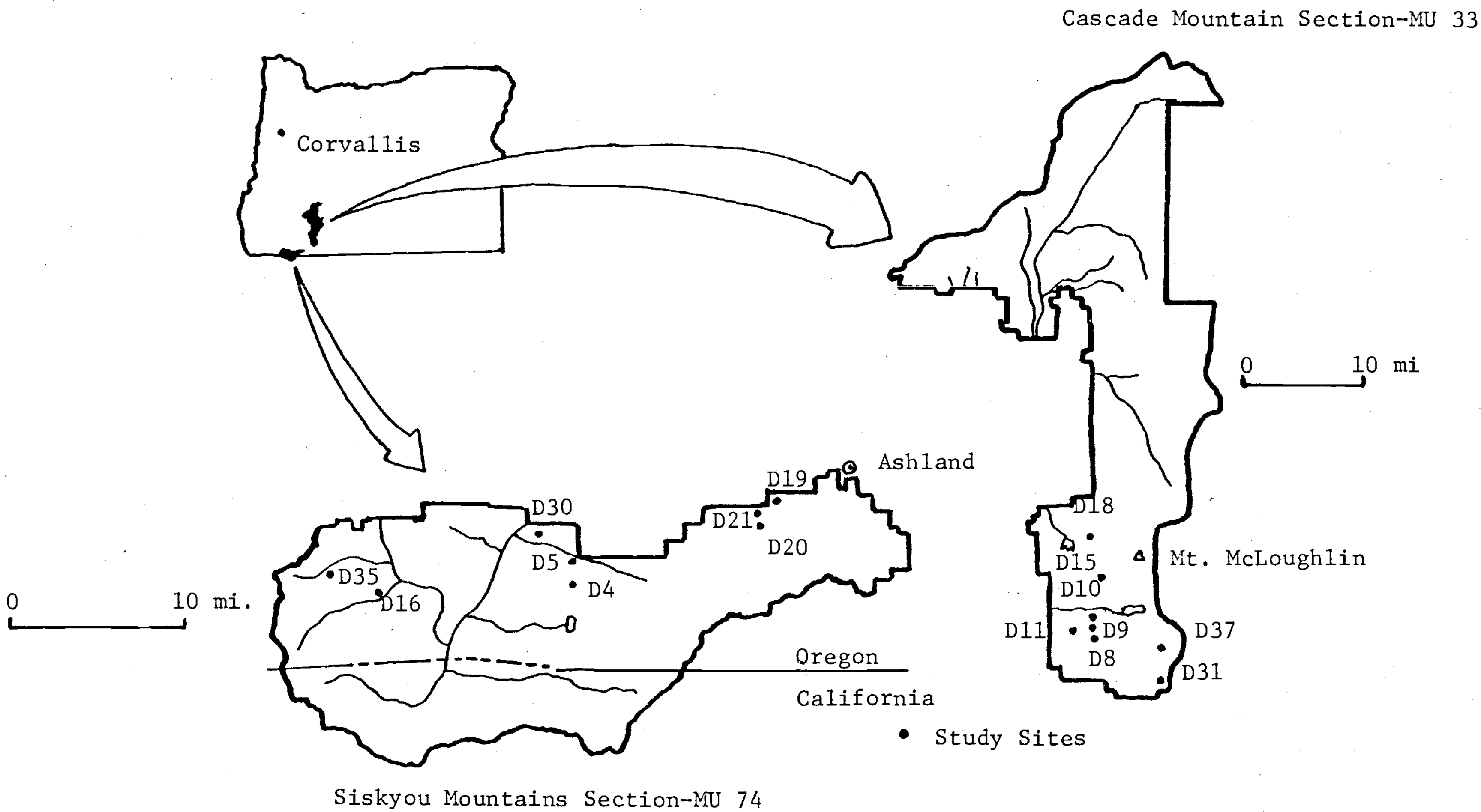


Figure 1. Location of study area in the Rogue River National Forest and sites of delineations sampled.

TABLE 4 . Names, Symbols, and Legal Locations of Delineations Sampled in MU33 and MU74.

	Name	Legal Location
	MU33	
D8	Short Creek Prairie	SW¼ NW¼ sec. 20 T37S R4E
D9	Robinson Prairie	SW¼ SE¼ sec. 13 T37S R3E
D10	Robinson Butte	SW¼ SE¼ sec. 12 T37S R3E
D11	Western Cascades	NW¼ NW¼ sec. 11 T37S R3E
D15	Porcupine Spring	NW¼ NE¼ sec. 18 T36S R4E
D18	Mosquito Camp	NW¼ SW¼ sec. 6 T36S R4E
D31	Brush Mt.	NW¼ NW¼ sec. 7 T38S R5E
D37	PCT	SE¼ SW¼ sec. 20 T37S R5E
	MU74	
D4	Squaw Peak	NE¼ SE¼ sec. 23 T40S R3W
D5	Hanley Peak	NE¼ NE¼ sec. 14 T40S R3W
D16	Osier Creek	NE¼ NW¼ sec. 30 T40S R4W
D19	Wagner Creek	SW¼ NW¼ sec. 26 T39S R1W
D20	Greeley Creek	NW¼ NE¼ sec. 4 T40S R1W
D21	Wagner Gap	NE¼ NE¼ sec. 33 T39S R1W
D30	Beaver Creek	NE¼ SE¼ sec. 4 T40S R4W
D35	Lewis Creek	SW¼ NW¼ sec. 22 T40S R5W

soil variability in designing efficient sampling schemes has been discussed earlier. Conversely, studies of soil variability must have sampling schemes which are suited to the stated purposes and objectives in order to derive the maximum amount of information.

There are four basic sampling designs which are used in studies of soil variation: simple random, stratified random, systematic, and multi-stage (Peterson and Calvin, 1965). Each has advantages and disadvantages. The simple random sample, where each unit chosen has an equal probability of being picked, has the advantage of giving "unbiased" estimates of the mean and the sampling error. However, an "unbiased" estimate of a population parameter is not necessarily an accurate estimate (Sampford, 1962). This is because the random sample which is chosen may oversample some areas and undersample others. More even coverage of a population can be gotten by the use of a stratified random or systematic sample. With the former method an area is divided into a number of smaller areas usually equal in size, a random sample of these smaller areas chosen, and sampling done within these (Wilding, Jones, and Schafer, 1965). The result is that the coverage is somewhat more even than with the simple random sample, and the estimate of sampling error, being derived from the smaller areas, is usually smaller and more precise (Webster, 1977a).

With a systematic scheme samples are taken at set intervals, either on a transect or grid. Completely even coverage is gotten. If a trend is present, then a systematic sample will represent it more accurately. However, there is the risk of encountering periodicities in the area which coincide with the sampling interval and heavily bias the sample (Peterson and Calvin, 1965). This is more likely to be encountered in an agricultural situation, where fertilizer is often applied in bands, than in a natural, forested area. A systematic sample is also usually easier, quicker, and cheaper to gather than a random sample especially in forested landscapes. The largest problem with a systematic sample is that no entirely satisfactory method of estimating the sampling, or standard error has been devised (Sampford, 1962). If the systematic sample is sited randomly, the estimate of the mean will be more precise than a random sample of equal size (Webster, 1977a; Hajek, 1977).

Where one is concerned with estimation of the proportion of distribution of spatial variability of a soil with distance or area, multistage sampling will often be the best choice. In this case, several primary units are randomly chosen initially and further samples, at various distances or of smaller areas, are then taken within the primary units (Hammond, Pritchett, and Chew, 1958; Cipra et al., 1972; Schafer, 1979). This can be repeated for as many stages as desired. Graley and Nicolls (1979) felt that since the number of primary or first stage units affects the contribution to the variance of all further stages of the sample it should be as large as possible. Multi-stage sampling is also useful in studying the distribution of properties over large geographical areas (Heil and Mahoud, 1978; Tidball, 1976).

Since the objectives of even coverage, unbiased sampling, and validity of statistical treatment are often in conflict, an approach that has been suggested and used in several studies is to combine both random and systemtic aspects into the sampling scheme as a compromise of sorts (McIntyre, 1967; Graley and Nicolls, 1979). This can take the form of randomly oriented grids or transects (Hajek, 1977) or randomly located primary stages with systematic sampling of the lower stages of a multi-stage sampling scheme. This type of approach has been adopted for this study. Randomization was desired to facilitate estimation of statistical parameters but we wanted to use the same sample for analysis of the spatial variability of properties with distance. The sampling scheme used is outlined below.

Sampling Procedure

The eight delineations randomly chosen for each mapping unit represent the primary stage of a multi-stage sample. In each delineation five sites were sampled for a total of 40 observations per mapping unit. Selection of the five sites in each delineation proceeded as follows:

For each delineation to be sampled, an arbitrary square was placed over it on a topographic map (1:20,000) onto which the delineation boundaries had been traced. The lower left corner of the square was designated as the origin. A pair of points chosen from a random number table were treated as decimals; i.e. 73 = .73. These two decimals then represented proportions of the x and y axis, respectively, and provided the location of the first sampling site. If this first point fell outside the delineation it was discarded and another pair of coordinates chosen. The second point was chosen by traveling a predetermined distance along a randomly chosen azimuth, and was also selected using random number tables. This point was 660 feet from the first one. The third point was located by traveling 200 feet from the second along another randomly oriented transect. The fourth point was similarly located 60 feet from the third, and the fifth was only 15 feet from the fourth. These separation distances were chosen to represent a range of distances and cover a reasonable amount of area over the delineation. In addition the distances were chosen so that they were not multiples of each, to avoid periodicities in the landscape during sampling. The sample was not completely random, since each point was not totally independent of the others, and the number of possible samples from 360 azimuth directions at a fixed interval from a given point is much less than the number of possible random samples, i.e. infinite. However, as noted for the previously mentioned reasons, this particular compromise was chosen.

Site Sampling

At each site a soil pit was dug by hand or with a backhoe, where terrain and accessibility permitted. The pit was dug to bedrock where possible. Deep colluvial deposits or massive clay layers sometimes prevented this. If conditions permitted, these layers were augered to determine total depth of the solum, but large numbers of coarse fragments often prevented this. The profile was described at each site from the most uniform face, while taking note of the horizon variations occurring on the various pit faces. Not all morphologic characteristics were described. Properties recorded included horizon type, depth, thickness, color, boundary distinctness, and boundary shape. Root abundance and distribution and depth of major rooting volume were described as were the abundance, location, and thickness of clay films. Coarse fragment size class, shape, weathering characteristics and profile distribution were noted, but volume estimates were not made in the field. Variation in size classes of coarse fragments prevented accurate estimation of abundance by observation. Volume estimates were derived later from conversion of coarse fragment data on a weight basis, using bulk density information gathered during the study.

Site characteristics recorded were aspect, slope gradient (both up and downslope as well as across the slope), slope shape, slope length and position (where appropriate), elevation, and general site condition in terms of degree and type of disturbance. Vegetation was described in terms of major overstory species present, understory, shrub and herb layer species which could be identified, and general indications as to the density, condition, and age of the stand.

Soils were initially sampled at fixed intervals of 10, 40, and 90 cm because it was felt this was necessary for reasons of statistical treatment. It sson became apparent that the variability of horizon thicknesses and solum depth would cause the fixed depth approach to sometimes sample drastically different horizons which were undesirable. Sampling by genetic horizons was substituted in its place. At each depth or horizon a bulk sample was obtained from across several locations in the pit faces. Bulking of this sort will tend to reduce the large variance of certain properties often found within very short distances (Beckett and Webster, 1971). Where coarse fragments were large or abundant (very frequently in the surface) a large, complete volume of that horizon was obtained. In some cases, especially where there were cobbles, stone and boulders in some of the Cascade sites, this procedure was also inadequate, and in a few selected cases large stones were measured individually to estimate their volume (Lyford, 1964). Individual cores of 45.2 cm^3 volume were taken from selected horizons for bulk density determinations. When coarse fragments prevented taking of cores, peds were selected from the bulk samples and bulk density was determined by the paraffin-clod method (Blake, 1965).

All samples were returned to the laboratory in Corvallis, spread on a counter-top, and allowed to air-dry. Prior to chemical analysis air dried samples were sieved with a #10 ASTM (2 mm) sieve by hand, and the coarse fragments were separated and weighed. In several cases, highly-weathered metamorphic rocks from MU74 and tuff and breccia fragments from MU33 made it very difficult to distinguish rock from soil. Moderate pressure sometimes crumbled certain rock fragments, although certain peds were very hard. A horizons of MU33 samples often had large amounts of fine roots which passed through the sieve and were weighed with fine earth. Notes were made of size and shape of coarse fragments and the presence or absence of charcoal.

Selected chemical and physical data were obtained for a subset of the total samples collected. All samples from the 10 cm (or A horizon) increment of both mapping units were analyzed. Also, subsurface samples which best represented the B horizon of each site were analyzed. Criteria used to determine which subsurface sample best represented the B horizon were abundance and thicknesses of clay films, redder colors associated with Fe oxidation, degree of structural development, and weathering, as indicated by relative amounts of primary mineral grains when viewed under a binocular microscope at 30 x power. These criteria generally indicate the degree of illuviation, weathering, and development present in the B horizon. In addition, in the case of MU74, samples were selected from the 40 cm depth increment, if a B horizon sample, as determined from the above criteria, did not occur at that depth. Therefore, for MU33 there were a total of 80 samples analyzed for chemical and physical properties, 40 from the A horizon and 40 from the B horizon. For MU74, 40 samples were selected from the A horizon and 60 were from either 40 cm or deeper. A total of 180 samples for both mapping units were analyzed for chemical and physical properties. Analyses made included pH, extractable calcium, magnesium, and potassium, cation exchange capacity, organic matter, and particle size.

The properties which were selected for chemical and physical analysis, as well as those characteristics measured in the field were chosen based on several criteria:

(1) their use in the field for distinguishing different dominant soil types and landtypes.

(2) to allow comparison with properties commonly measured in other variability studies.

(3) their importance for forest management, such as assessment of site productivity (Carmean, 1975) or for interpretations of suitability for various aspects of management such as plantability (Nakamura and Jackson, 1976).

Chemical analyses were performed according to procedures used by the OSU Soil Testing Laboratory (Berg and Gardner, 1978). Particle size analysis was done using the hydrometer method according to Day (1965), with modifications. Organic matter was removed from MU74 soils using hydrogen peroxide. Organic matter was not removed from MU33 (Cascade) soils. Removal of organic matter in these soils would have required oven drying to determine sample weight of mineral soil. Wada and

Harward (1974) described the difficulties encountered in particle size analysis of soils containing both amorphous materials and large amounts of organic matter. Drying these types of soils tends to form stable aggregates which decrease the apparent clay content (Maeda, Takenaka, and Warkentin, 1977). Values for moisture content and organic matter in these soils were therefore used to back-calculate the amount of air dried sample that would be needed in order to perform the particle size determinations on the equivalent of 50 g of oven dry mineral soil. Both MU74 and MU33 soils were dispersed using sodium pyrophosphate instead of Calgon as suggested by Day (1965).

Duplicate analyses were performed on selected samples for the particle size, organic matter, and bulk density analyses. For MU74, average CV values for particle size, organic matter, and bulk density duplicates were 6.9% (n = 8), 7.8% (n = 12), and 3.4% (n = 10). In MU33, for particle size and organic matter, CV's were 4.7% (n = 7) and 10.1% (n = 14), respectively.

RESULTS AND DISCUSSION

Spatial variability of soils and soil properties lends itself to statistical analysis and description. Because quantification of soil variability requires collecting and working with literally thousands of data points, numerical techniques are needed to reduce the volume of data to comprehend their meaning. Land managers and researchers must be very careful not to allow the numerical techniques to become the end of the research itself. The ultimate research or management objectives must remain focused on better use of forest and soil resources. The approach which has been taken in this study, therefore, is to treat statistical analysis of the soils data as a tool to aid better understanding of soil variability and its use in management, rather than as an end product. Implicit in the use of these statistical techniques as tools is a knowledge of their limitations and pitfalls. The results presented here begin with an analysis of the general variability of individual soil properties, proceeds into a consideration of the spatial distribution of variability, and finally attempts to examine the variability of the system as a whole, with each step being more detailed in its scope. Particular types of information which may have direct applicability to research or management are discussed throughout.

Variability of Individual Properties

One way to quantify soil variability and evaluate its effects on land use is to individually examine several site characteristics and morphological, physical, and chemical properties that together characterize the soil system. Key site characteristics selected for this study were slope gradient and aspect. Morphological properties included the thicknesses of the O and A horizon, depth to the B2 horizon, and depth of solum. Physical properties included percent coarse fragments, silt, and clay in the A and B horizons. Chemical properties, for both the A and B horizons, were pH, percent organic matter, extractable K, Ca, and Mg, and CEC. In addition, some chemical properties were expressed on a volumetric rather than a weight basis to determine the effect on natural soil variability.

Statistical Techniques

The statistical tools required to describe and quantify the natural variability of all these properties involve applications of a few well-known and commonly used procedures. A first step is to plot histograms of the data for each property. This has been done in Figures 2-12. The vertical axis of each graph represents the number of sites, within the 40 sampled in each mapping unit, for which the property in question has values within the ranges indicated along the horizontal axis. The class intervals and, consequently, the number of classes, were chosen to most clearly illustrate the distribution of the property as well as indicate differences in terms of use or interpretation.

Histograms provide an immediate visual indicator of the likely form of the mathematical distributions of the data. For some properties, like percent silt in MU33 (Figure 5), the distribution appears to be normal. For others, like percent organic matter in the B horizon (Figure 11), the distribution is definitely skewed. A log-normal distribution may better represent these data. Still other distributions appear to be bimodal (e.g. Figure 10), and still others are multi-modal and may represent mixed distributions (e.g. Figure 6).

Knowing the mathematical distribution a property follows is important, because it affects the validity of estimates of both central tendency and variability. Properties which depart from normality raise a major concern, particularly regarding the effect these departures may have on their suitability for further statistical treatment and for management interpretations made from the results of such analyses. Webster (1977a) mentions that moderate departures from normality can usually be tolerated, though what constitutes a "moderate" departure is not clear. There is a chi-square test for normality, but it was not used because it is not very rigorous for sample sizes as small ($n = 40$) as in this study (Snedecor and Cochran, 1967).

Statistics calculated to accompany each frequency distribution included the arithmetic mean ($\bar{x}$), standard deviation (s), and coefficient of skewness (γ). The class interval where the mean for that property is located is noted by an arrow above that particular interval (Figures 2-12). These and other statistical descriptions are also given in Tables 6 to 7. For approximately normally distributed properties, the arrow generally coincides with the interval of highest frequency. Positively skewed distributions tend to shift the mean one class interval to the right of the interval of highest frequency, reflecting the effect of rarer, higher valued observations. The mean of mixed distributions provides the most ambiguous information, often occurring in the trough between two peaks (Figure 5). Rao et al. (1979) and Broadbent et al. (1980) have discussed the effect on estimates of the mean that would result if a normal distribution was assumed when in reality a log-normal distribution was more proper. Broadbent et al. (1980) estimated an error of 37% in mean total N while Rao et al. (1979) estimated a 6 to 20% error for some soil-water flux measurements.

In order to assess the seriousness of the departures from normality exhibited by some of the properties measured, as well as the utility of further statistical treatment of these data, square root and logarithmic (common log) transformations were performed on the chemical properties, with the exclusion of pH. Where appropriate throughout discussion of various aspects of the results of this study, comparison of transformed and untransformed variables will be made to evaluate the utility of these transformations.

Besides substantiating the visual impressions of the form of a distribution and assessing the seriousness of departures from normaility, the statistical descriptions have other valuable uses. One is to calculate confidence intervals for estimates of population parameters. The other is to calculate the sample size required to make estimates of means with given levels of accuracy and confidence.

Variability of Site Characteristics

Frequency distributions of slope gradient are skewed for both MU (Figure 2). This is an expected result, because the map units were defined, to a large degree, on topographic criteria, such as specific ranges of slope, which are readily observable in the field or from air photos. In both cases 70% of the sites had slopes within the ranges stated for those MU in the SRI (Badura and Jahn, 1977). Those sites that were outside that range generally had lower slope gradients. In MU74 these sites were usually associated with ridges, benches, or lower

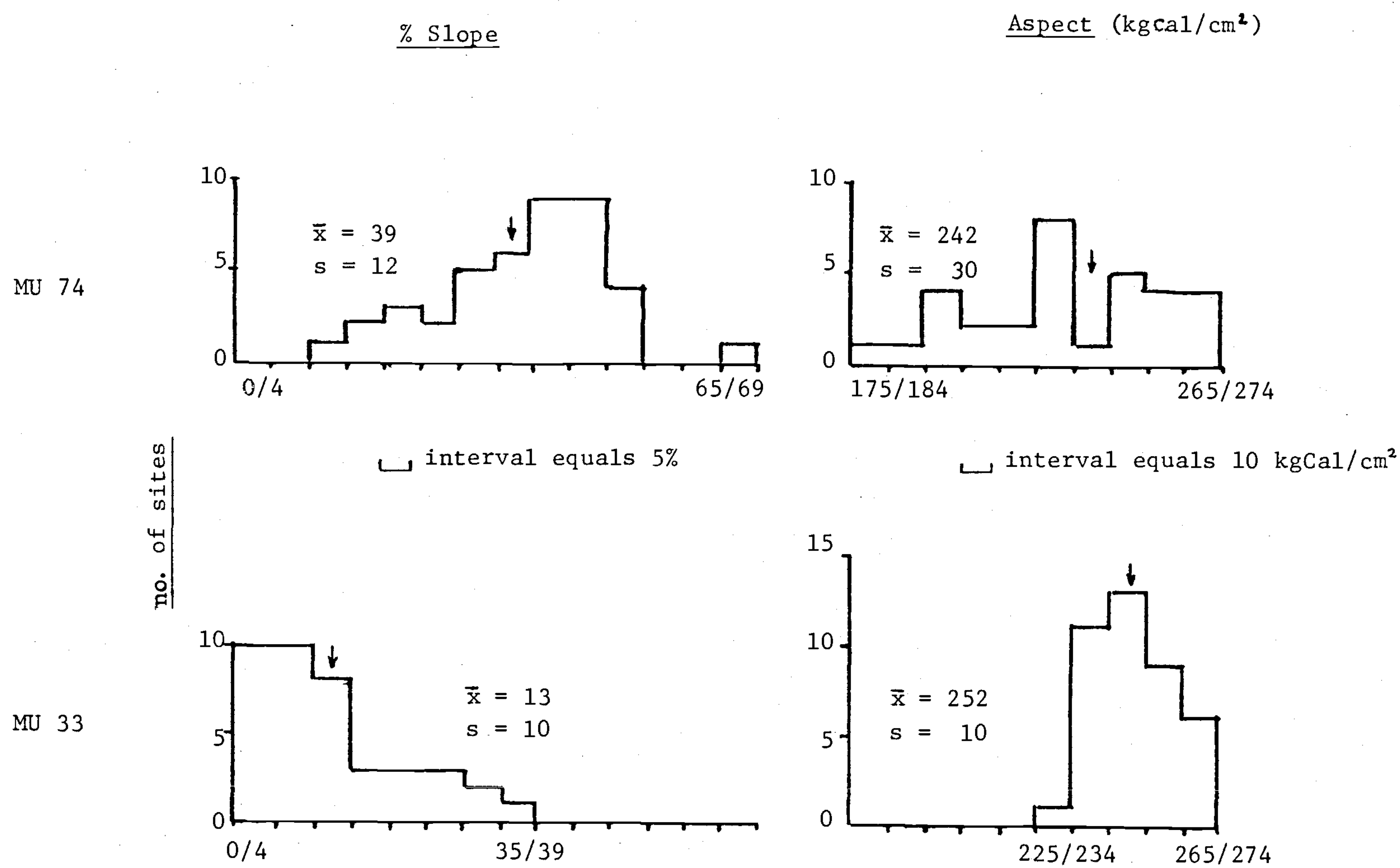


Figure 2. Frequency distributions of slope gradient (%) and aspect, as expressed by potential solar radiation (kgcal/cm^2) in both MU.

footslope positions, while those in MU33 were on flat plateaus. Those inclusions occurring in the footslope positions present little problems in terms of management and may actually represent the more productive sites. However, the ridges and benches may cause problems, depending on their size and areal extent, as well as the pattern of their distribution on the landscape. Harvesting techniques may need to be altered if, for example, benches occur in midslope positions which interfere with the operation of certain logging systems which would have been used if the slopes were smooth. Also, although inclusions such as shallower, rockier ridgetop soils are of limited areal extent they do reduce the overall productivity of the delineation.

Slope aspect influences soil development (Finney, Holowaychuck, and Heddleson, 1962) and site productivity (Carmean, 1975; Steinbrenner, 1979) on steep, forested landscapes. In general, soils on southerly and westerly exposures are shallower, stonier, less well developed, and less productive than nearby soils on northerly and easterly exposures. The Rogue River SRI, however, provides little information on dominant aspects of map units 33 and 74. Nevertheless, the potential significance of aspect for forest management was the reason for an attempt to quantify its distribution and variability.

The customary measurement of aspect on a circular scale creates some difficulty in statistical analysis (Webster, 1977a). Northerly aspects of 3 and 357 degrees are virtually the same in a practical sense, but are very different in a statistical computation. Lloyd and Lemmon (1970) used cosine functions and Brown and Loewenstein (1978) coded portions of the circular scale divided into intervals, in regression equations relating to tree growth, with varying degrees of success in attempts to alleviate this problem. Several other approaches are available, two of which have been used in this study.

One method is to express aspect, in combination with slope gradient, as an index, through potential solar radiation in kg-cal/cm^2. This index was developed using graphs based on the tables given by Frank and Lee (1966), assuming a latitude of 42^{o}N for all sites in both mapping units. Problems with the radiation index are that the effects of atmospheric absorption, diffuse radiation on cloudy days, and topographic shading are not taken into account, In addition E and W, NE and NW, and SE and SW facing slopes are treated as equivalent. For example, a site with a SE or SW facing slope and slope gradient of 30% would have a total yearly potential solar radiation figure of 279 kg-cal/cm^2 of land surface, whereas an equivalent NE or NW slope would be 205. Values above 247 kg-cal/cm^2 indicate southerly aspects while those below indicate northerly aspects.

Azimuthal aspect data can also be tabulated as frequency distributions (Table 5). North and south aspects in MU 74 were evenly distributed. Aspects of sites in MU 33 were predominantly southerly, but the lack of steep slopes, and in two cases of any dominant aspect, resulted in higher, more uniform values of solar radiation (Figure 2).

Although slope and aspect are only two of the many factors which affect soil temperature, their distribution throughout the mapping unit influences the general interpretations that should be made for activities such as seedling regeneration potential. Hallin (1968) recommended holding to a minimum timber harvesting activities on southerly slopes too steep for tractor logging until equipment was developed which would allow the use of strip or partial cuts to reduce surface temperatures.

TABLE 5. Frequency Distribution of Aspect of Both MU.

	E	W	NE	N	NW	SE	S	SW	None
MU74	2	8	4	4	8	3	7	5	
		Σ:10			Σ:16			Σ:15	
MU33	1	4	7	5	0	8	5	8	2
		Σ:5			Σ:12			Σ:21	

N = 338 - 23^{o}

NE = 24 - 68^{o}

E = 69 - 113^{o}

SE = 114 - 158^{o}

S = 159 - 203^{o}

SW = 204 - 248^{o}

W = 249 - 293^{o}

NW = 293 - 338^{o}

The relative uniformity of the potential radiation and lower slope gradients in MU33 would not appear to require different interpretations. In MU74, however, the equal distribution and dominance of north and south aspects would appear to warrant some type of distinction in regards to certain interpretations, or perhaps be incorporated into the survey as a MU phase.

Variability of Physical and Morphological Properties

Frequency distributions for thickness of the A horizon, depth of the solum, % clay, silt, and coarse fragments are shown in Figures 3-6. Statistical data are given in Table 6. Based primarily on values of the coefficient of variation (CV) the physical and morphological properties were equally variable. Average CV's for these groups were both 36%.

The thickness of the litter layer (O horizon) was the most variable morphologic property with CV's of 79 and 44% in MU74 and MU33, respectively. This may be due to it being thinner and more readily disturbed/removed by management than the mineral surface horizons. Fire has been an important natural process in the forests of southwest Oregon before control practices became dominant (Atzet, 1979) and could also exert an influence on the variability of this layer. Charcoal chips were quite common in the A horizons of profiles in MU74, an indication of the prevalance of fire. McFee and Stone (1965) attributed the high variability in weight of the forest floor to 1) uneven accumulation over mounds and pits and as litter is shifted by the wind, 2) the persistance of large logs and stumps, and 3) accumulation of bark and limbs around the trunks of trees. Color was the least variable morphologic property with an

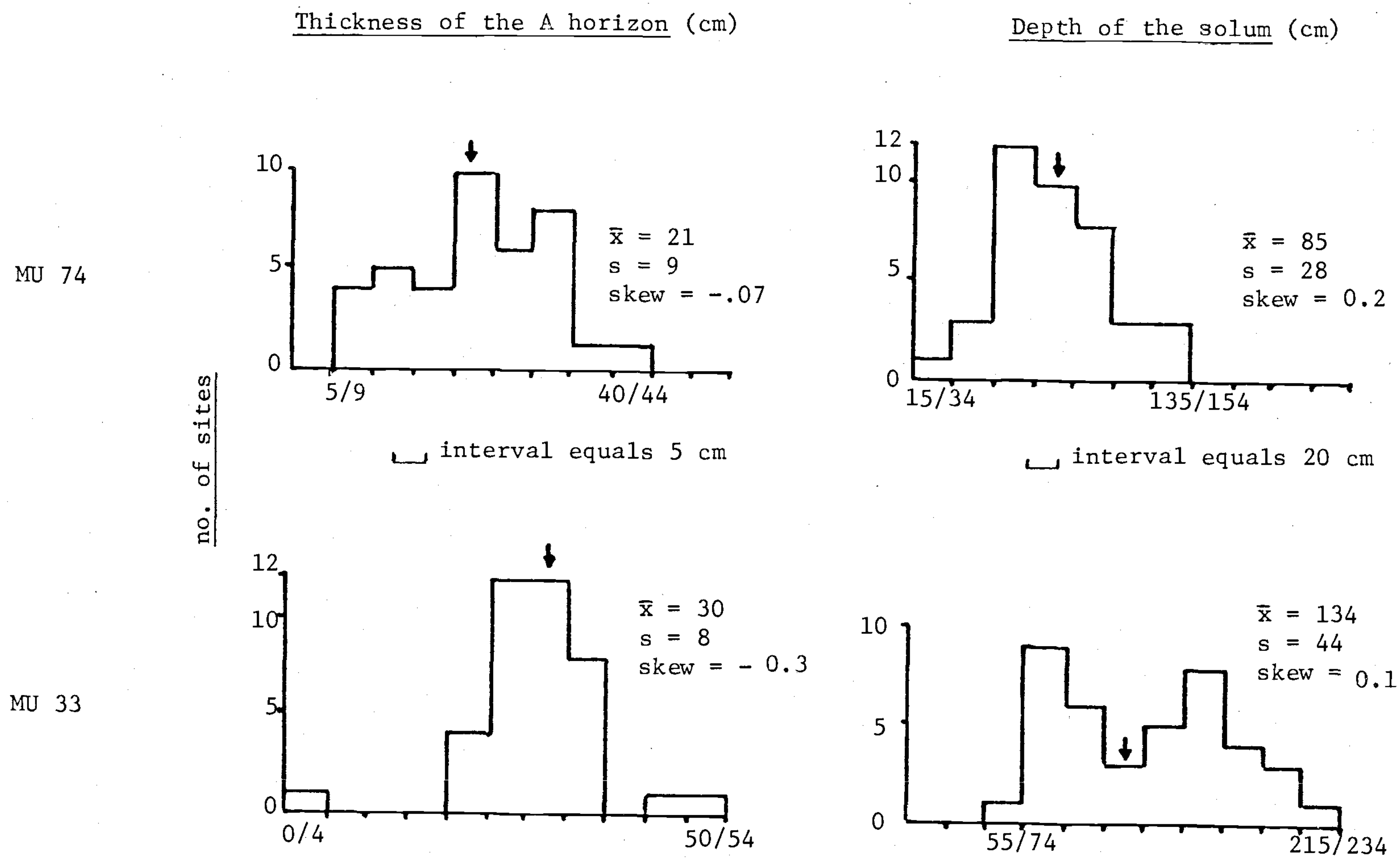


Figure 3. Frequency distributions of thickness of the A horizon and depth of the solum in both MU.

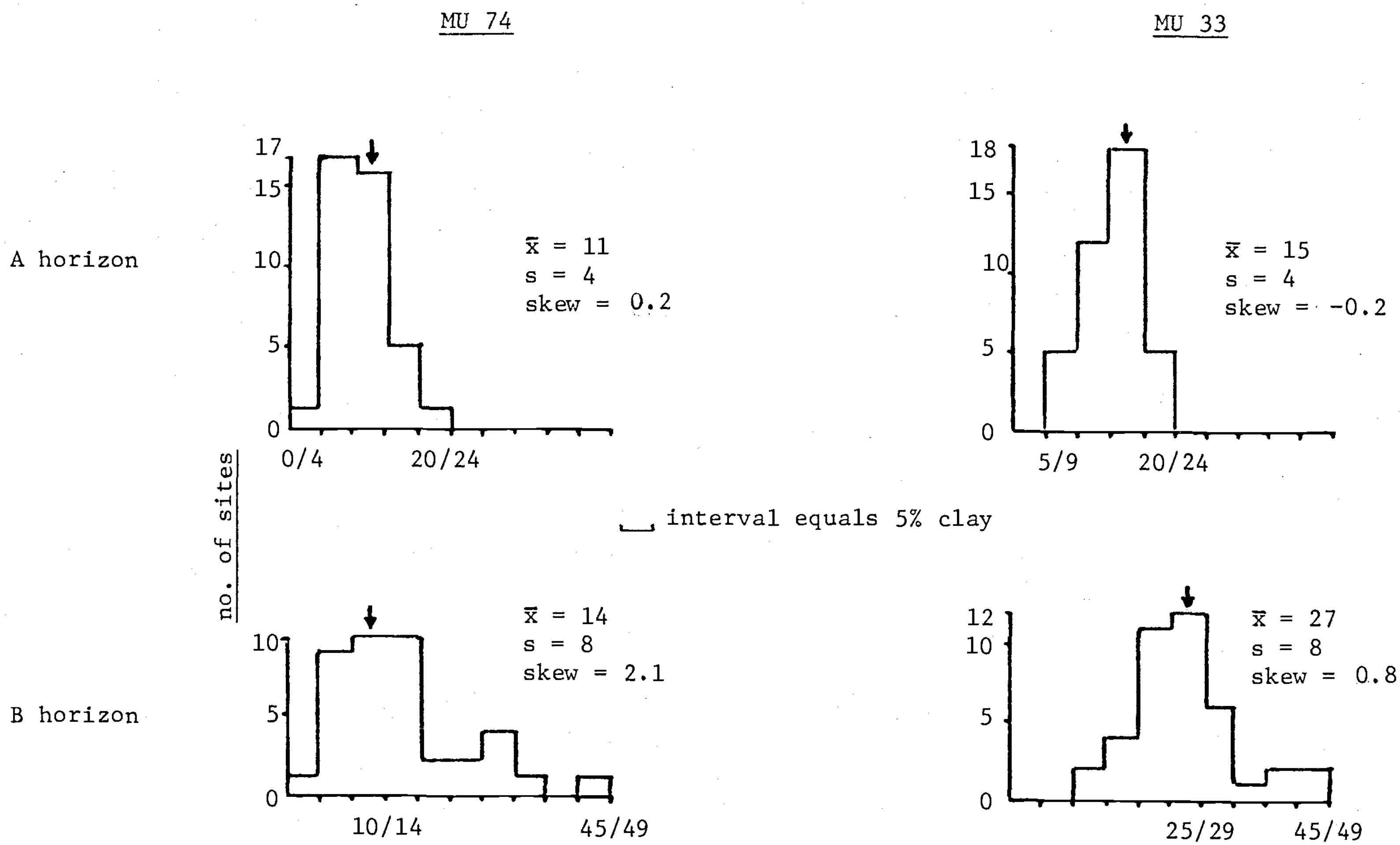


Figure 4. Frequency distributions of % clay in the A and B horizons of both MU.

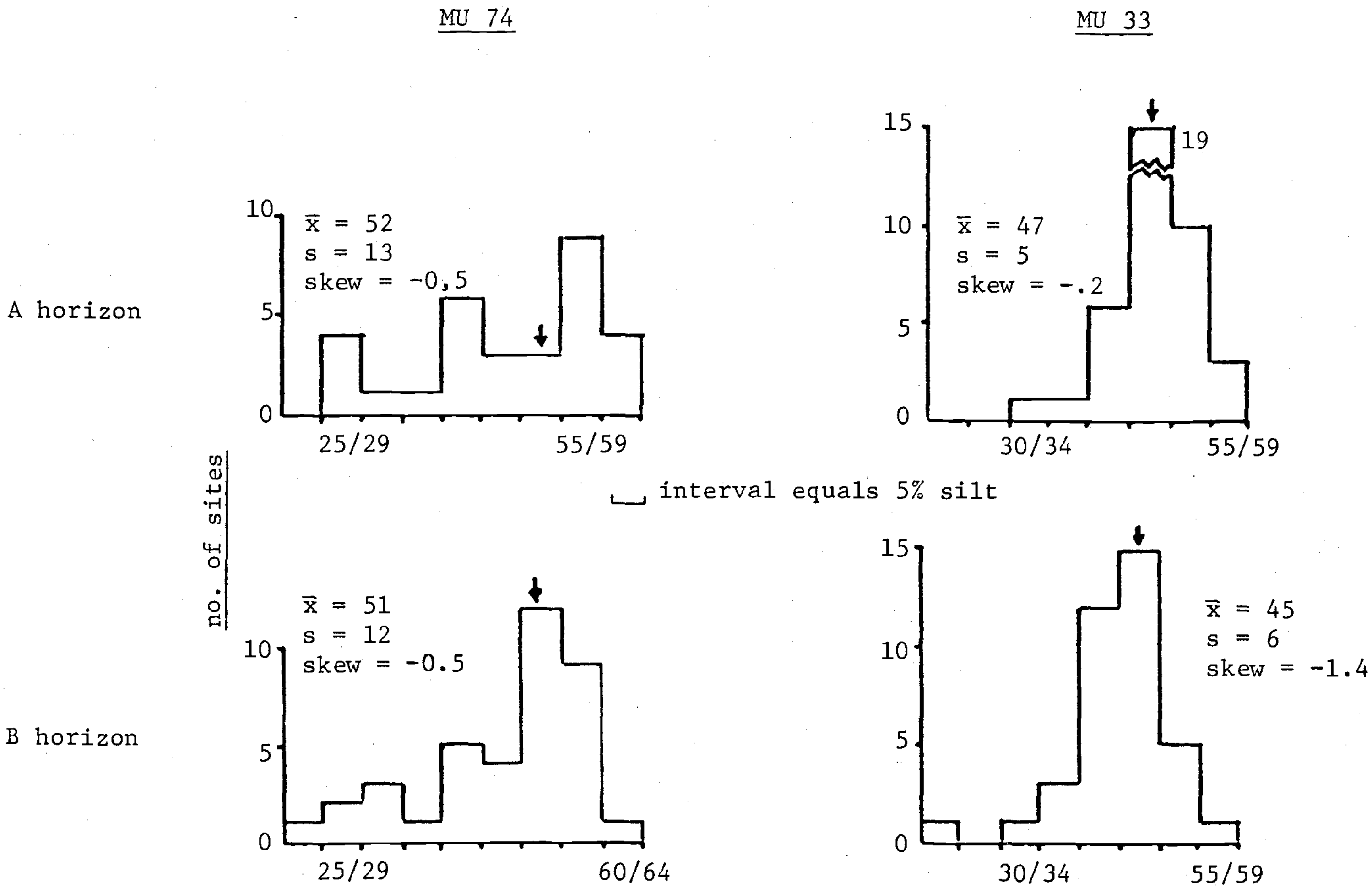


Figure 5. Frequency distributions of % silt in the A and B horizons of both MU.

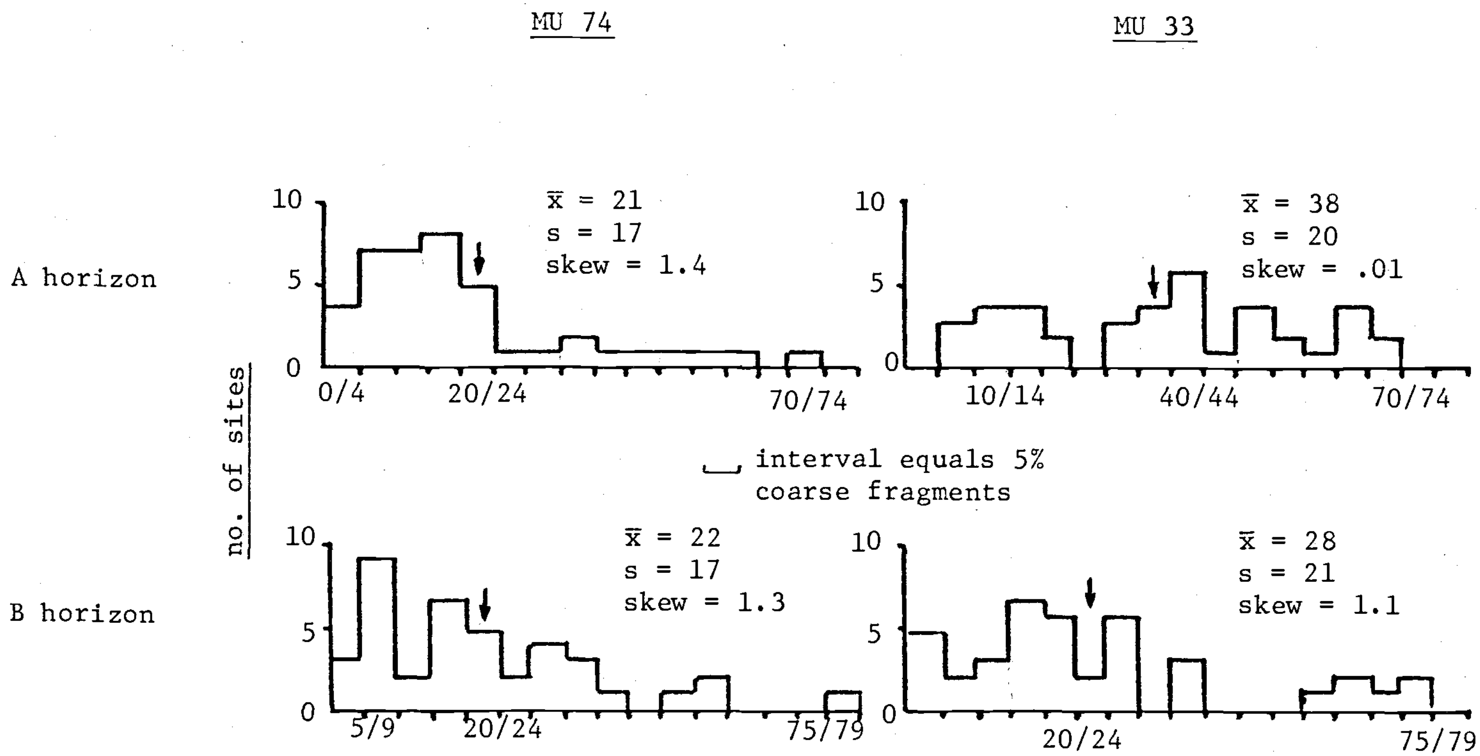


Figure 6. Frequency distributions of % coarse fragments in the A and B horizons of both MU.

TABLE 6. Descriptive Statistics for Selected Physical and Morphological Properties in MU74 and MU33.

		$\bar{X}$	S	SE	CV	Skew	Kurt	Range
				Morphological Properties - MU74				
THK A (cm)		21	9	1.4	42	-.07	-.80	5 - 40
Depth Solum (cm)		85	28	4	33	.20	-.70	30 - 137
Depth to B2 (cm)		39	19	3	49	.73	.29	10 - 90
THK O (cm)		3	2.4	.39	79	.81	.39	0 - 9
	Horizon							
Value	A	3	.7	.1	21	-.10	-.50	2 - 4
	B	3.7	.6	.1	15	.09	-.24	3 - 5
Chroma	A	2	.6	.1	26	0.40	.50	1 - 4
	B	3.6	.9	.1	26	.34	1.04	2 - 6
				Physical Properties - MU74				
Silt (%)	A	52	13	2	24	-.50	-.40	27 - 77
	B	51	12	2	23	-.53	-.13	23 - 74
Clay (%)	A	11	4	0.6	37	.20	-.01	3 - 22
	B	14	8	1.2	57	2.05	6.92	2 - 46
Coarse Fragments (% vol.)	A	21	17	3	79	1.4	1.5	2 - 72
	B	22	17	3	77	1.3	2.0	1 - 79

TABLE 6. Continued

	Horizon	$\bar{X}$	S	SE	CV	Skew	Kurt	Range
				Physical Properties - MU74 (continued)				
Bulk Density (g/cm^3)	A	1.36	.20	0.03	14	--	--	0.89 - 1.59
	B	1.58	.14	0.02	9	--	--	1.32 - 1.88
				Morphologic Properties - MU33				
THK A (cm)		30	8	1	27	-.30	3.9	2 - 50
Depth Solum (cm)		134	44	7	33	.10	-1.1	60 - 223
Thick O (cm)		5	2.2	0.4	44	--	--	1 - 11
Depth to B2 (cm)		46	14.1	2.2	31	--	--	28 - 74
	Horizon							
Value	A	2.9	0.3	.05	10	-2.5	5.1	2.0 - 3.0
	B	3.2	0.4	.06	12	1.5	.71	3.0 - 4.0
Chroma	A	2.9	0.8	.10	26	.30	-1.2	2.0 - 4.0
	B	3.9	0.9	.14	22	.83	1.9	2.0 - 6.0
				Physical Properties - MU33				
Clay (%)	A	15	4	0.6	28	-.2	.03	5 - 24
	B	27	8	1.3	31	.75	.84	11 - 49

TABLE 6. Continued

		$\bar{X}$	S	SE	CV	Skew	Kurt	Range
				Physical Properties - MU33 (continued)				
Silt (%)	A	47	5	0.8	11	-.2	1.0	33 - 58
	B	45	6	1.0	13	-1.4	4.3	22 - 55
Coarse Fragments (% vol.)	A	38	20	3	53	.01	-1.1	7 - 73
	B	28	21	3	76	1.1	0.45	1 - 77
Bulk Density (g/cc)	A	.91	.22	.04	24	--	--	0.58 - 1.27
	B	1.27	.21	.04	16	--	--	0.76 - 1.55

average CV of 20, chroma being more variable than value. Part of the reason for the low variability of color was the narrow range of values which were found and the fact that, as it is commonly used, the measurement scale is discrete rather than continuous. Frequency distribution (Figure 3) for thickness of A in both MU and for depth of solum in MU74 were approximately normal. Solum depth in MU33 exhibited a bimodal distribution. This bimodal type of distribution of solum depth may be the result of two distinct populations associated with two distinct kinds of underlying bedrock, the shallower sites on basalt and the deeper ones over tuff. Percent coarse fragments exhibited multi-modal distributions and was the most variable physical property, having ranges of 66 to 78 percentage points on a possible scale of 0 to 100. Standard deviations were nearly as large as the means (Tables 6 and 7). The multi-modal or "mixed" distributions found for coarse fragments, silt, and solum depth can arise in several ways. If a mapping unit consists of a complex of soils, which these mapping units most likely do, each soil may possess a different maximum for a given property, resulting in several peaks in the frequency distribution. McIntyre and Tanner (1959) presented such multi-peak histograms for mixed distributions of bulk density sampled from a complex mapping unit. Mixed distributions can also result from inadequate stratification during the mapping process with the result that delineations are included which do not fit the mapping unit concept. Characterization of particle size distributions as mixed is also evident in the geological literature. Size distributions of stream gravels are related to different stream processes acting to sort the rocks (Koch and Link, 1970).

Variability of Chemical Properties

Frequency distributions for chemical properties are shown in Figures 7-12. Statistical data are given in Table 7. Chemical properties in general possessed positively skewed frequency distributions, i.e. toward the left or lower values. Chemical properties which had normal-like distributions were B horizon Ca in MU74, A horizon Ca and OM in MU33, and CEC in both MU (Figures 9, 11, and 12).

The size of the mean and observed frequency distribution influences the perceived variability. For example, Ca in both MU have approximately the same means, standard deviations, and ranges (Table 7). This is also the case for Mg in both MU. Ca tends to have a much wider range than Mg. However, the CV for Mg (small value of $\bar{x}$ and a skew distribution) in MU33 is much larger than for Ca (normal distribution), while in MU74 they are about the same.

Coefficients of variation indicate that the chemical properties taken as a group, are more variable than the physical or morphological properties. This trend is in general agreement with the results of previous studies discussed earlier. The average CV's for chemical properties, on a weight basis and excluding pH, were 51 and 58% for the A and B horizons, respectively. This compares with 34 and 38% for physical properties and 36% for morphological properties. Chemical properties calculated volumetrically had average CV's of 59 and 73%. The values of CV for properties reported in Table 7 are also comparable to results reported by other investigators for forest soils (Table 1).

Within the group of chemical properties expressed on a weight basis, organic matter in MU74 was the most variable. Changes in aspect

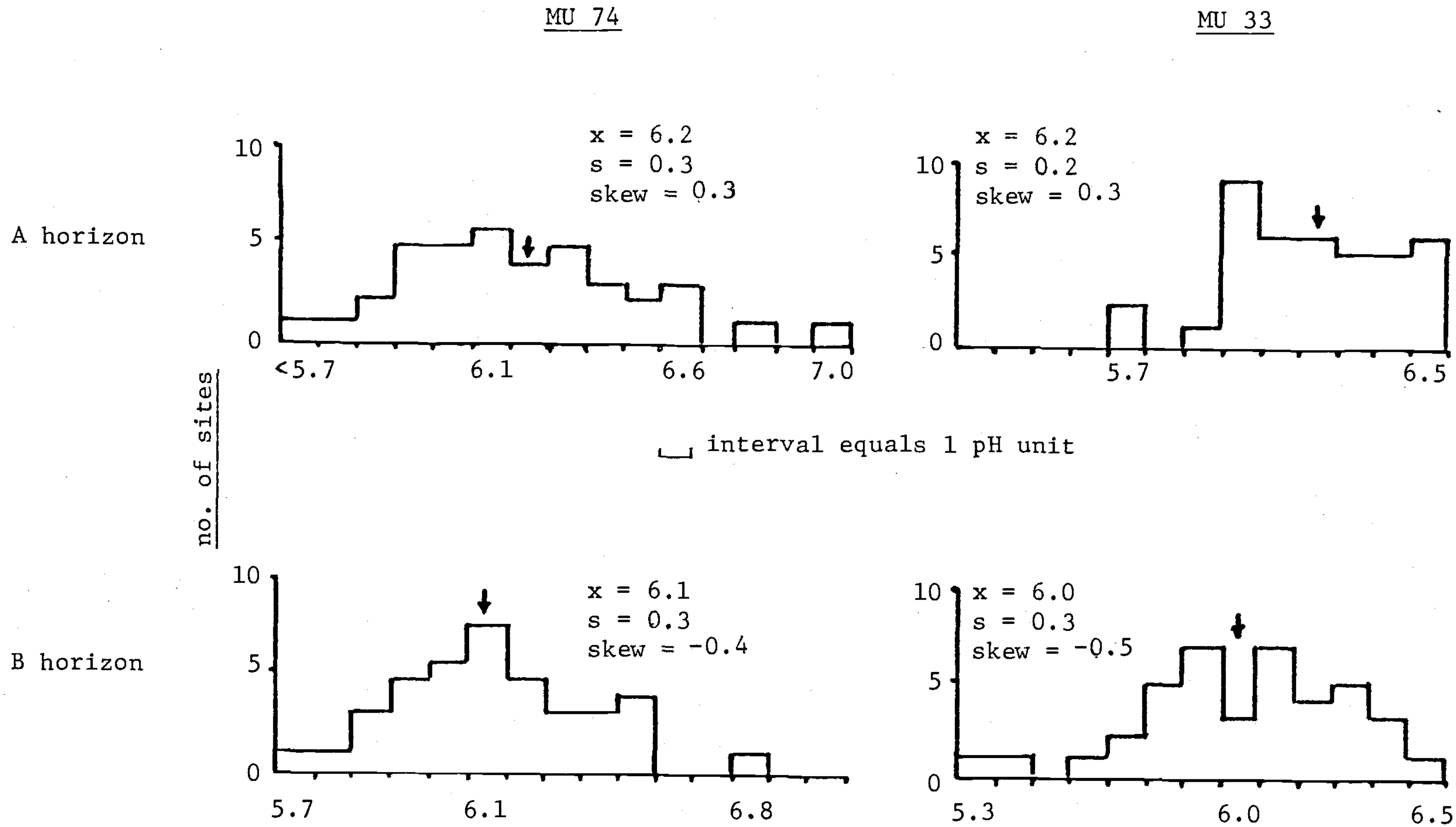


Figure 7. Frequency sitributions of pH in the A and B horizons of both MU.

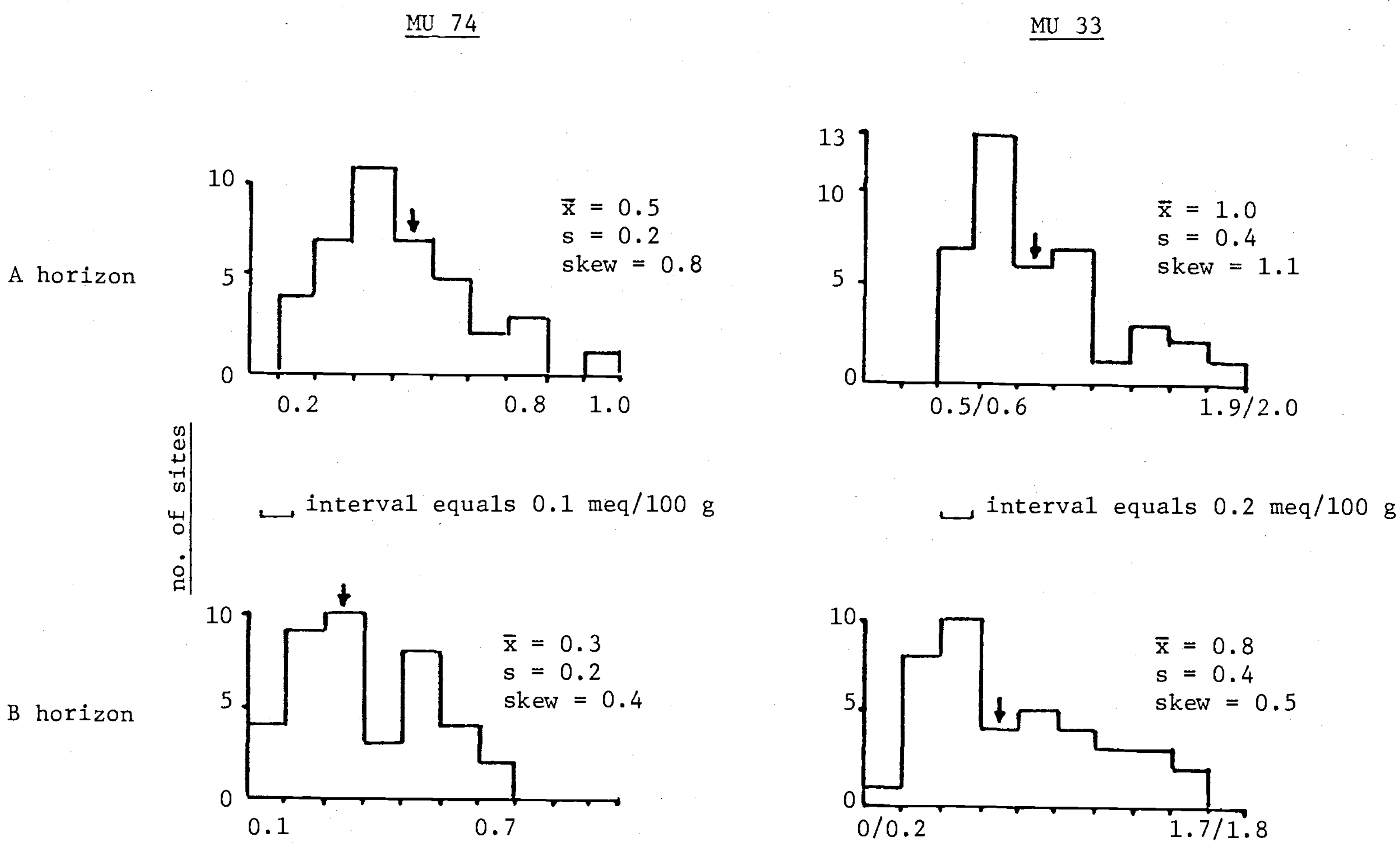


Figure 8. Frequency distributions of extractable K in the A and B horizons of both MU.

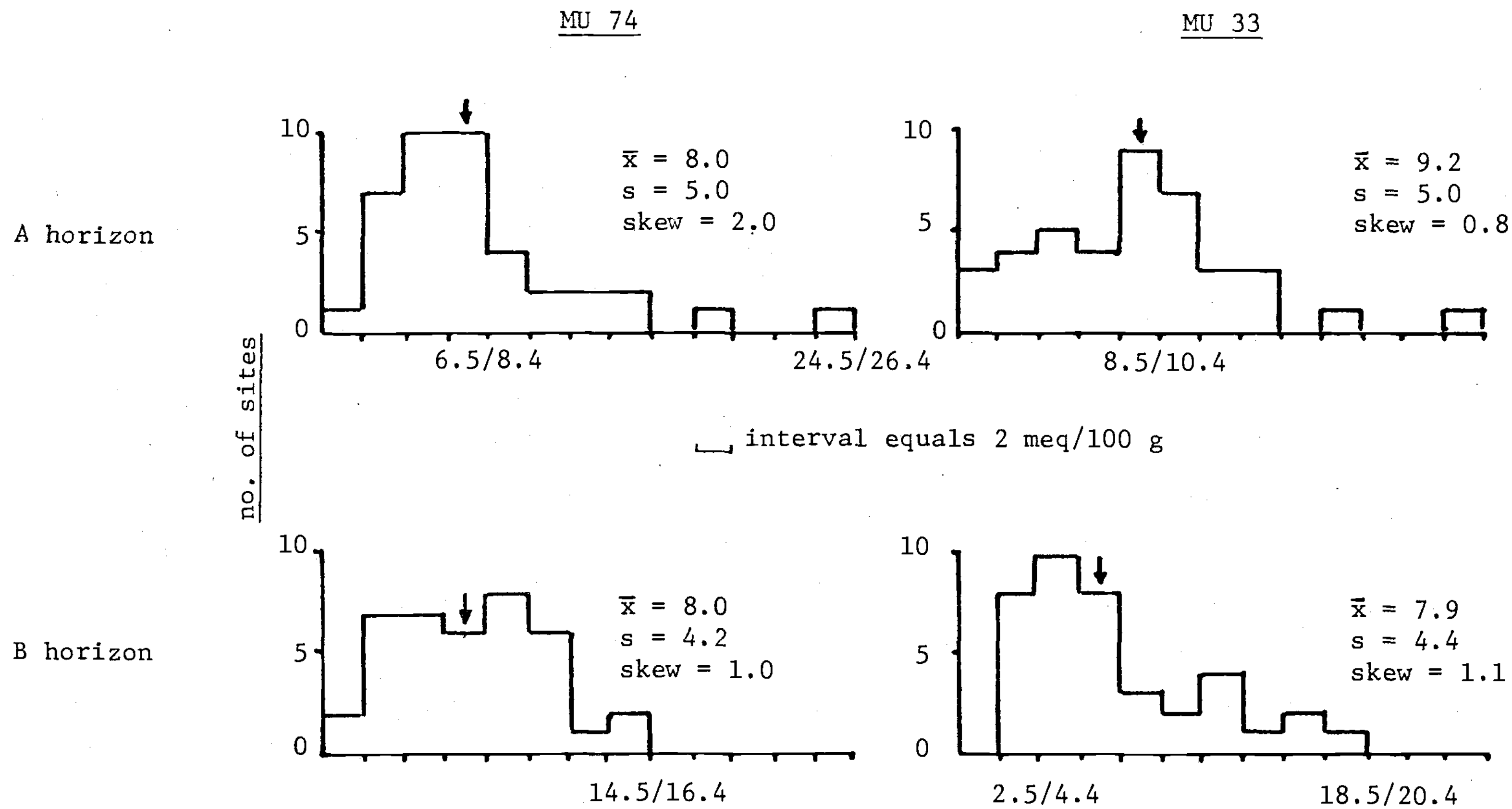


Figure 9. Frequency distributions of extractable Ca in the A and B horizons of both MU.

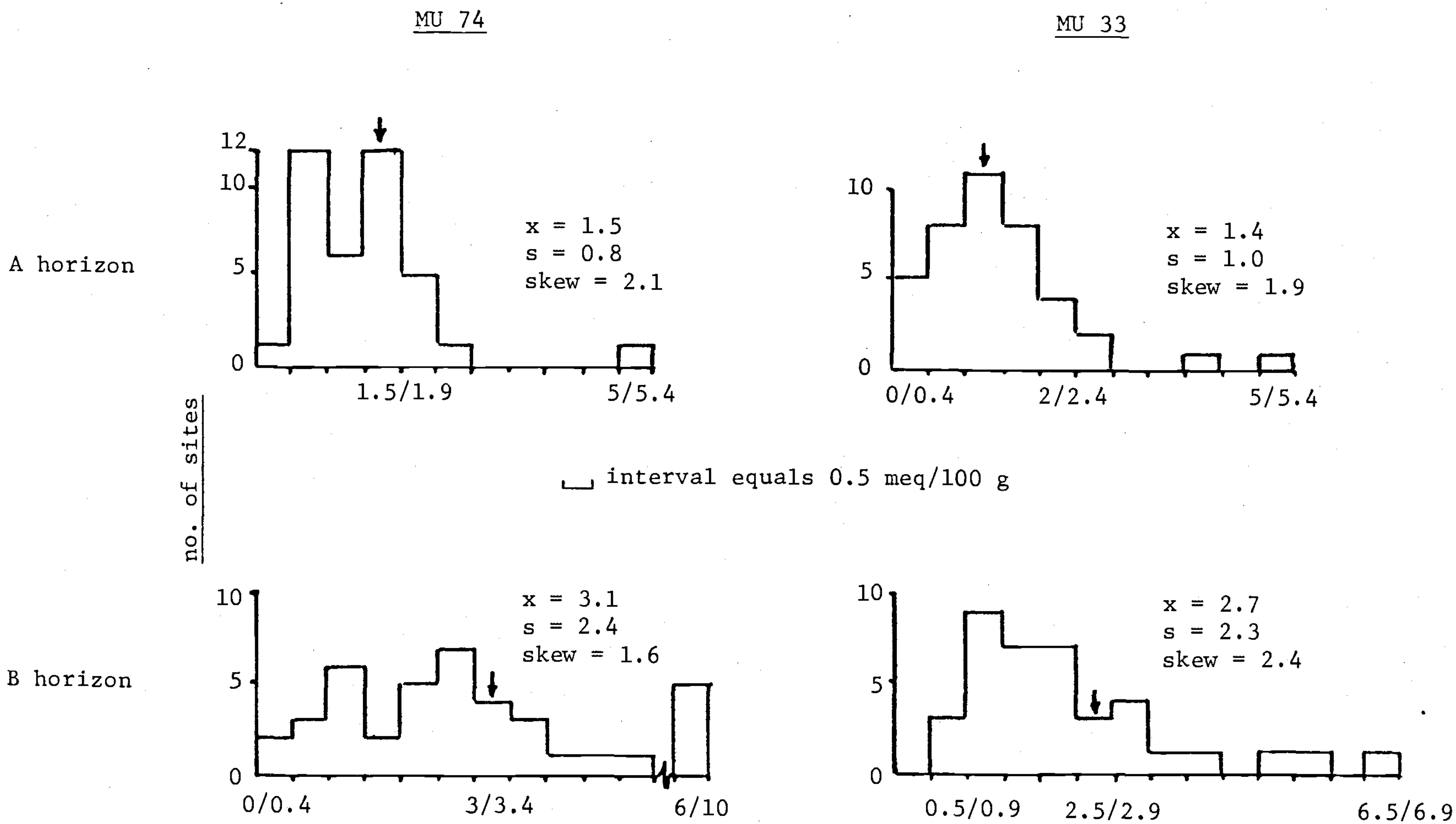


Figure 10. Frequency distributions of extractable Mg in the A and B horizons of both MU.

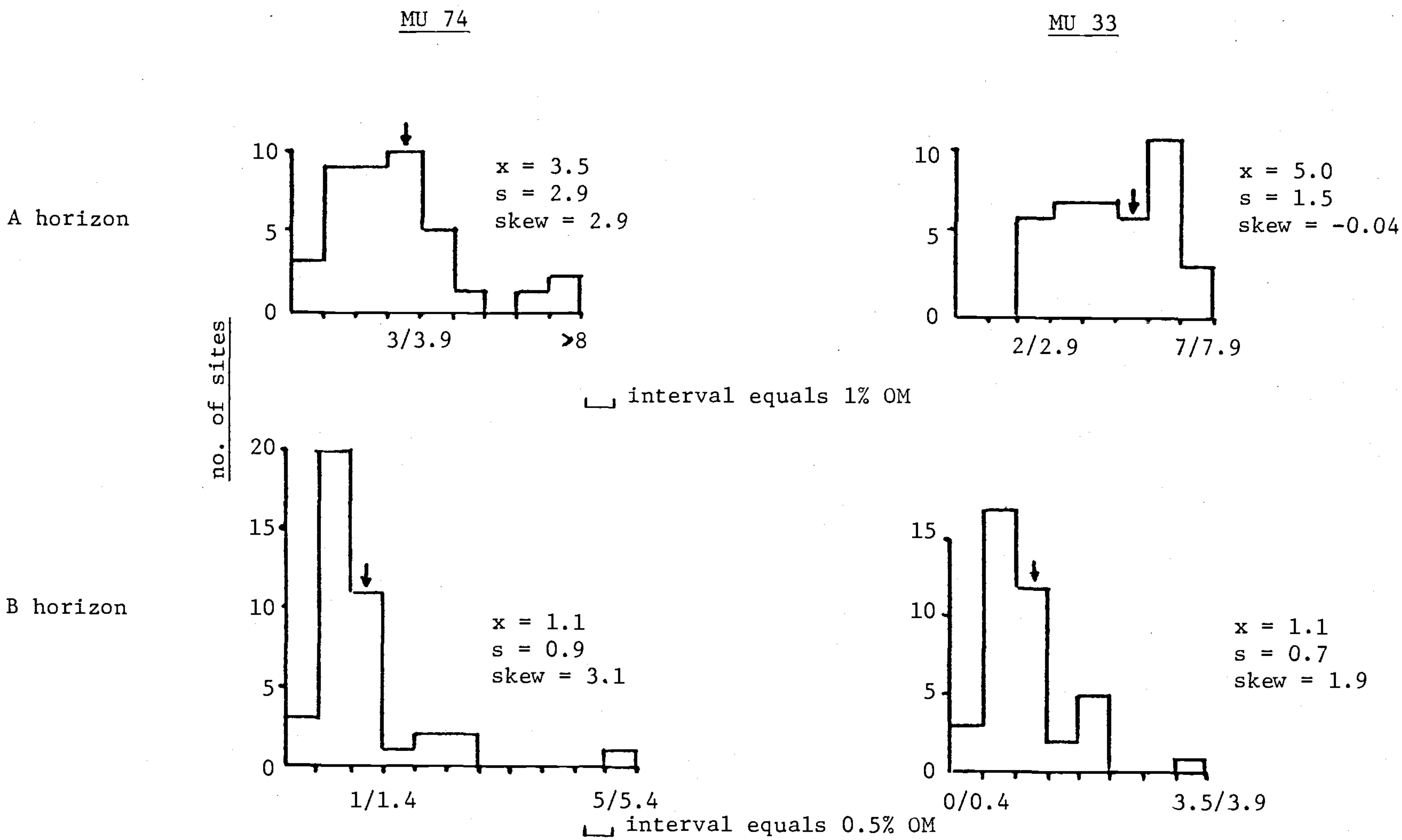


Figure 11. Frequency distributions of % organic matter in the A and B horizons of both MU.

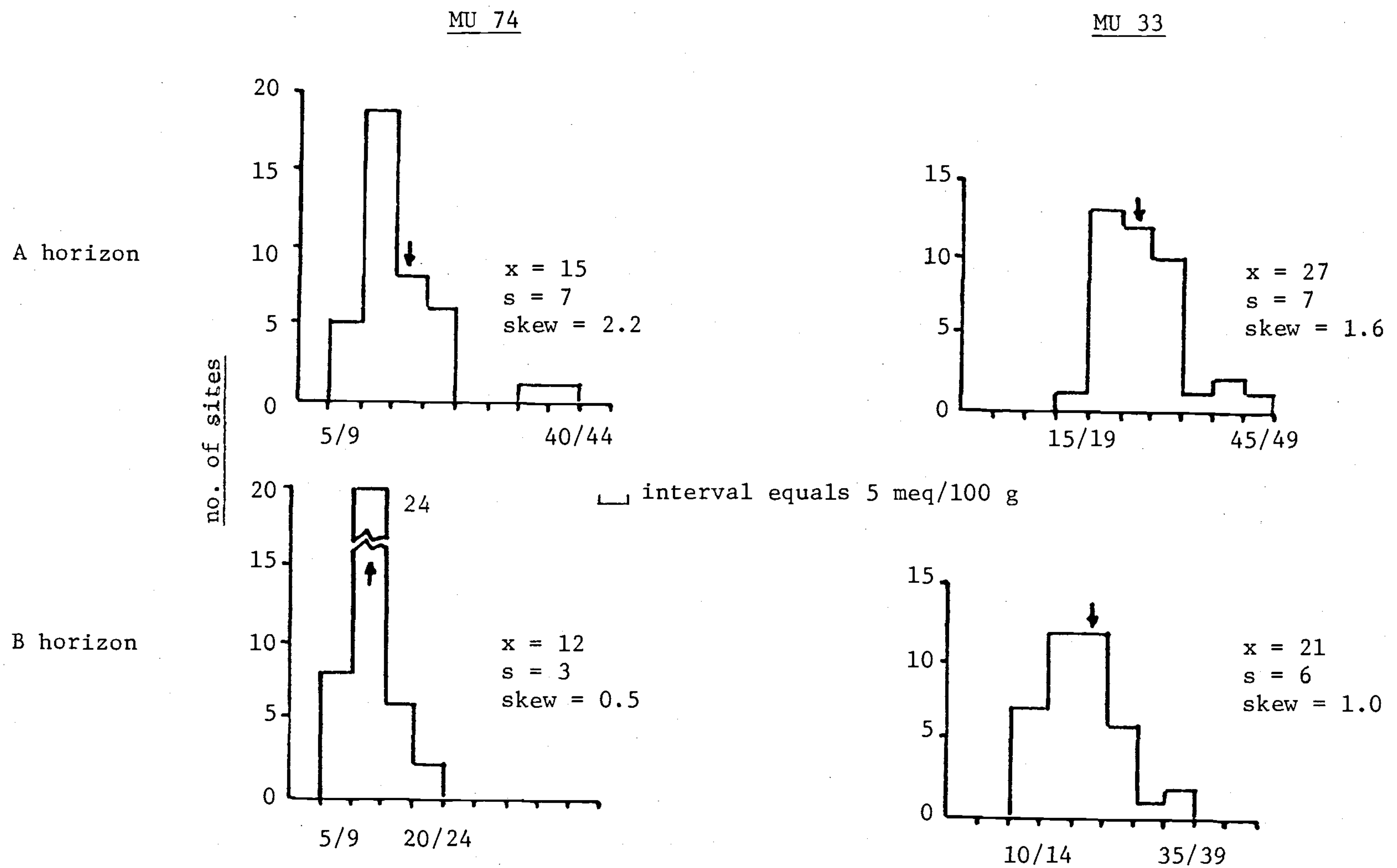


Figure 12. Frequency distributions of cation exchange capacity in the A and B horizons of both MU.

TABLE 7. Descriptive Statistics for Selected Chemical Properties in MU74 and MU33.

	Horizon	$\bar{X}$	S	SE	CV	Skew	Kurt	Range
				MU 74				
pH	A	6.2	.3	.05	5	.3	.7	5.4 - 7.0
	B	6.1	.3	.04	5	-.4	2.1	5.2 - 6.8
K (meq/100 g)	A	0.5	.2	.03	40	.8	.6	0.2 - 1.0
	B	0.3	.2	.03	51	.4	-.8	.06 - .70
Ca (meq/100 g)	A	8.0	5.0	0.8	63	2.0	5.5	2.2 - 27.7
	B	8.0	4.2	0.7	52	1.0	2.3	1.1 - 22.5
Mg (meq/100 g)	A	1.5	0.8	0.1	56	2.1	7.7	0.4 - 5.1
	B	3.1	2.4	0.4	78	1.6	2.4	.3 - 10.0
OM (%)	A	3.5	2.9	.5	84	2.9	9.7	0.6 - 15.5
	B	1.1	0.9	.1	79	3.1	12.4	0.3 - 5.3
CEC (meq/100 g)	A	15	7	1	45	2.2	6.0	8 - 40
	B	12	3	0.5	27	0.5	0.1	7 - 21
KV (g/1)	A	.19	.09	.01	47	.5	-.3	.05 - .4
	B	.25	.26	.04	102	2.1	4.0	.03 - 1.1
CaV (g/1)	A	1.7	1.0	.2	56	.7	.1	.3 - 4.1
	B	2.1	1.3	.2	64	.2	-.9	.01 - 4.7

TABLE 7. Continued.

	Horizon	$\bar{X}$	S	SE	CV	Skew	Kurt	Range
MgV (g/1)	A	.21	.15	.02	70	1.6	4.9	.02 - .8
	B	.52	.51	.08	99	2.1	4.4	.01 - 1.2
OMV (g/1)	A	35	22	3	62	1.3	1.4	7 - 95
	B	13	7	1	51	1.6	2.5	4 - 33
CEV (meq/1)	A	.16	.06	.01	37	.3	-.8	.06 - .28
	B	.16	.07	.01	42	1.0	.9	.04 - .34
				MU 33				
pH	A	6.2	.2	.03	4	.3	-.4	5.7 - 6.5
	B	6.0	.3	.04	4	-.5	.3	5.3 - 6.5
K (meq/100 g)	A	1.0	.4	.1	38	1.1	.4	.5 - 1.9
	B	0.8	.4	.07	52	0.5	-.9	.2 - 1.7
Ca (meq/100 g)	A	9.2	5.0	.8	53	.8	1.5	2.0 - 24.6
	B	7.9	4.4	.7	56	1.1	0.1	2.7 - 18.5
Mg (meq/100 g)	A	1.4	1.0	.2	70	1.9	4.9	.3 - 5.1
	B	2.7	2.3	.4	84	2.4	6.1	.6 - 11
OM (%)	A	5.0	1.5	.2	30	-.04	-1.2	2.6 - 7.7
	B	1.1	.7	.1	64	1.9	4.4	.4 - 3.8

TABLE 7. Continued.

	Horizon	$\bar{X}$	S	SE	CV	Skew	Kurt	Range
CEC (meq/100 g)	A	27	7	1	24	1.6	3.1	19 - 49
	B	21	6	1	31	1.0	1.2	10 - 39
KV (g/1)	A	.23	.15	.02	67	1.8	4.3	.05 - 0.8
	B	.34	.26	.04	75	0.9	-.4	.05 - 0.9
CaV (g/1)	A	1.2	0.9	.2	80	2.4	9.1	0.1 - 5.3
	B	1.7	1.3	.2	77	1.5	2.4	0.2 - 6.0
MgV (g/1)	A	.12	.12	.01	105	2.5	7.4	.01 - 0.6
	B	.38	0.42	.07	110	2.6	7.4	.02 - 2.0
OMV (g/1)	A	30	14	2	46	.8	.2	8 - 64
	B	10	5	.8	50	1.3	2.5	3 - 27
CEV (meq/1)	A	.17	.08	.01	24	1.6	3.1	.06 - 0.43
	B	.21	.12	.02	56	1.3	2.6	.06 - 0.61

(V): Chemical concentrations expressed on a volumetric basis

OM: Organic matter

CEV: Cation exchange capacity expressed volumetrically and slope in these landscapes produce dramatic differences in moisture availability, temperature, litter production, and decomposition, with resultant wide ranges in organic matter contents (Table 7). Mg concentration in MU33 was also highly variable, possibly a result of variations in the composition and type of parent material over the geographic extent of the map unit. Lava flows of different ages and with different sources vary in the occurrence and abundance of mafic phenocrysts such as olivine and pyroxene with the result being a range in MgO content from less than 3.5 to 7.5% (Maynard, 1974). pH varied least among chemical properties, but its CV of 4 or 5 masks a greater degree of variability. In 3 of 4 pH-horizon combinations, the range was 1 pH unit or greater. In MU74, 67 percent of the observations occur between 5.9 and 6.5. If the logarithmic scale of measurement of pH were converted to that of hydrogen-ion concentration the variability which would be measured would probably be much greater than is apparent from using the logarithmic scale. Heilman (1979) feels that, given the numerous confounding factors affecting the determination of pH, it's measurement to the nearest 0.2 unit is adequate.

Interpretations of Single-Property Variability

Effect of Transformation on Statistical Estimates

In Figures 13-16 are shown the effect of plotting the cumulative frequency of observations for selected, badly skewed chemical properties on log-normal probability paper. Approximately straight lines in these graphs indicate that these variables seem to follow log-normal distributions.

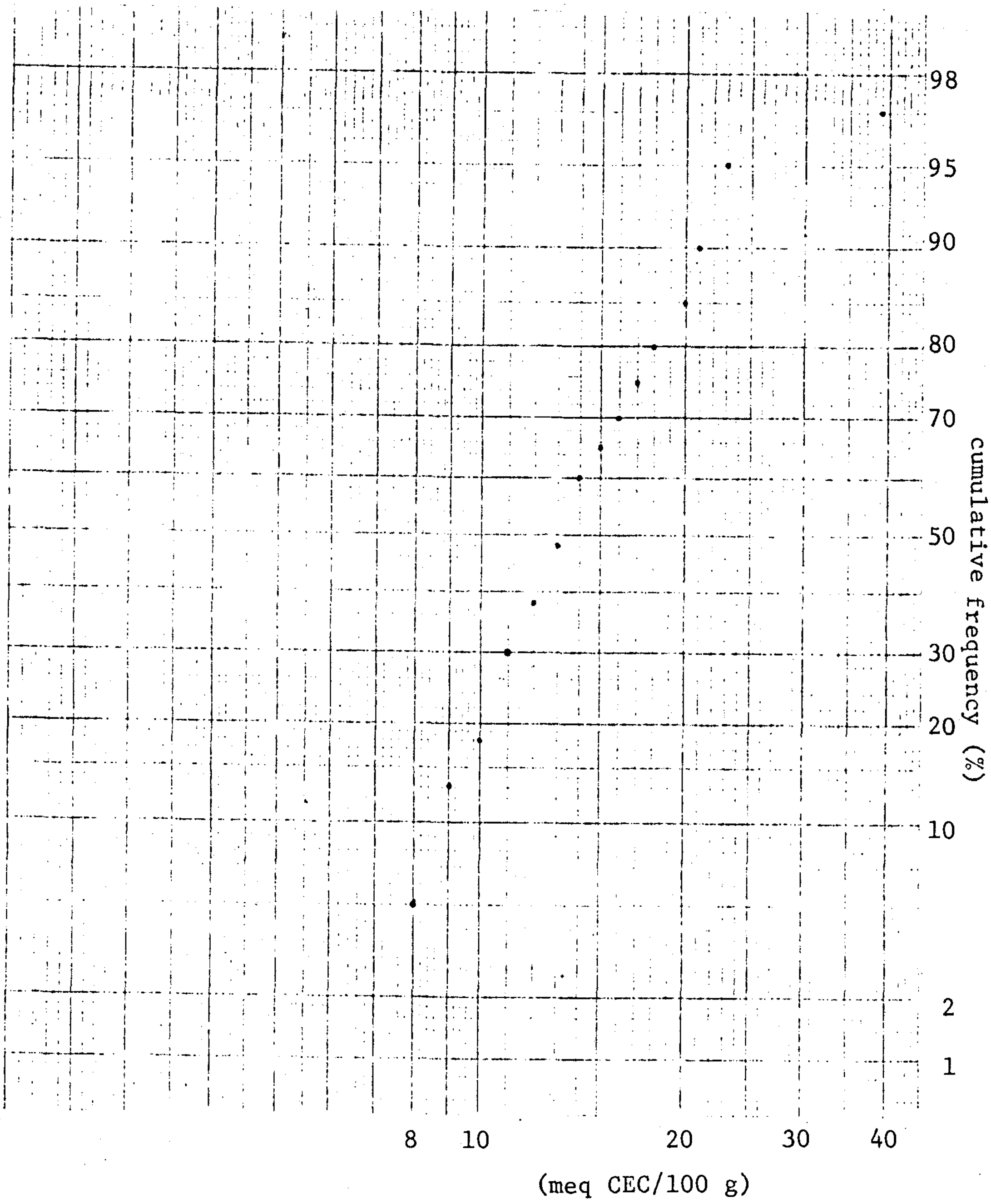


Figure 13. Plot on log-normal probability paper of the cumulative frequency of 40 observations for cation exchange capacity in the A horizon of MU 74.

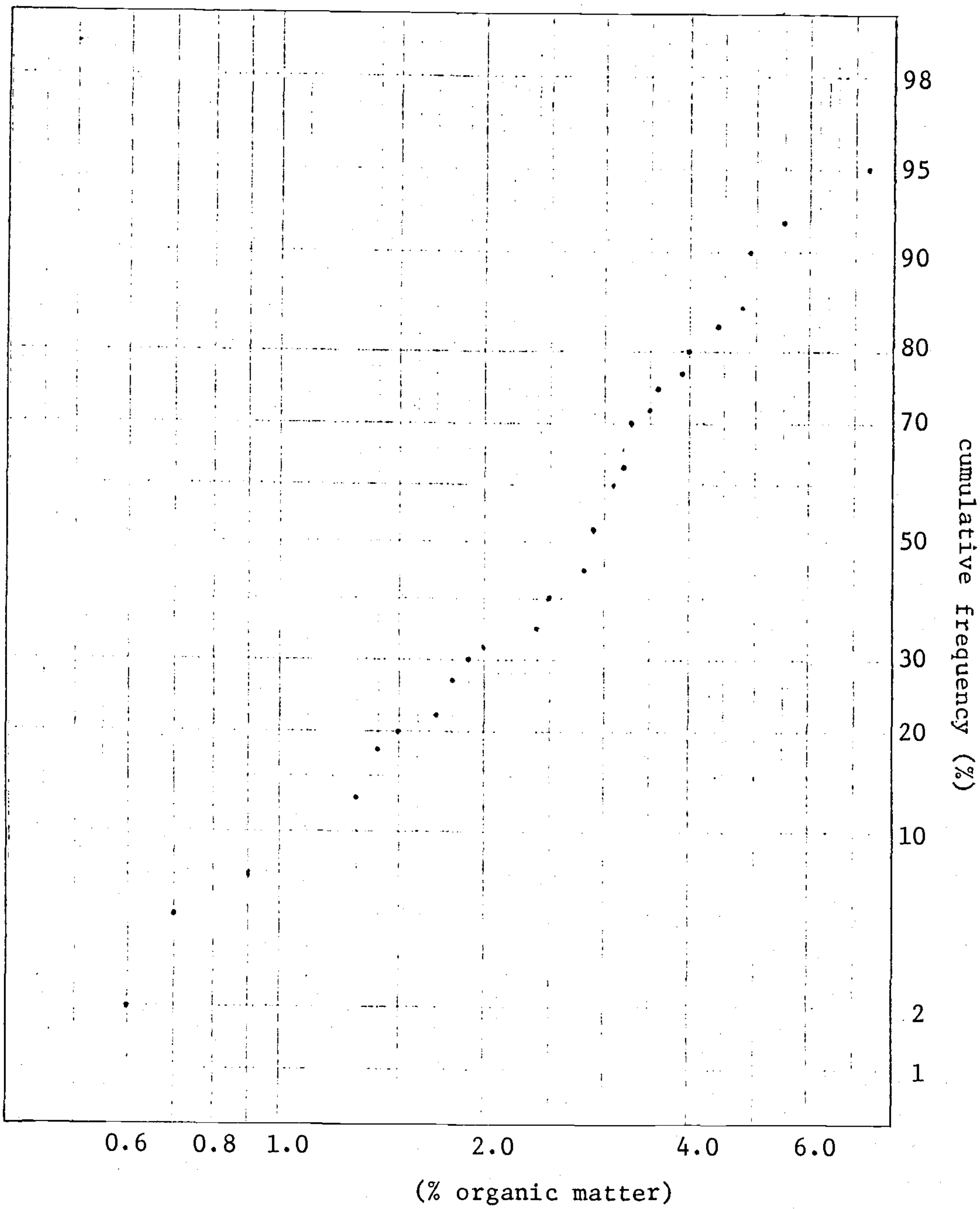


Figure 14. Plot on log-normal probability paper of the cumulative frequency of 40 observations for % organic matter in the A horizon of MU 74.

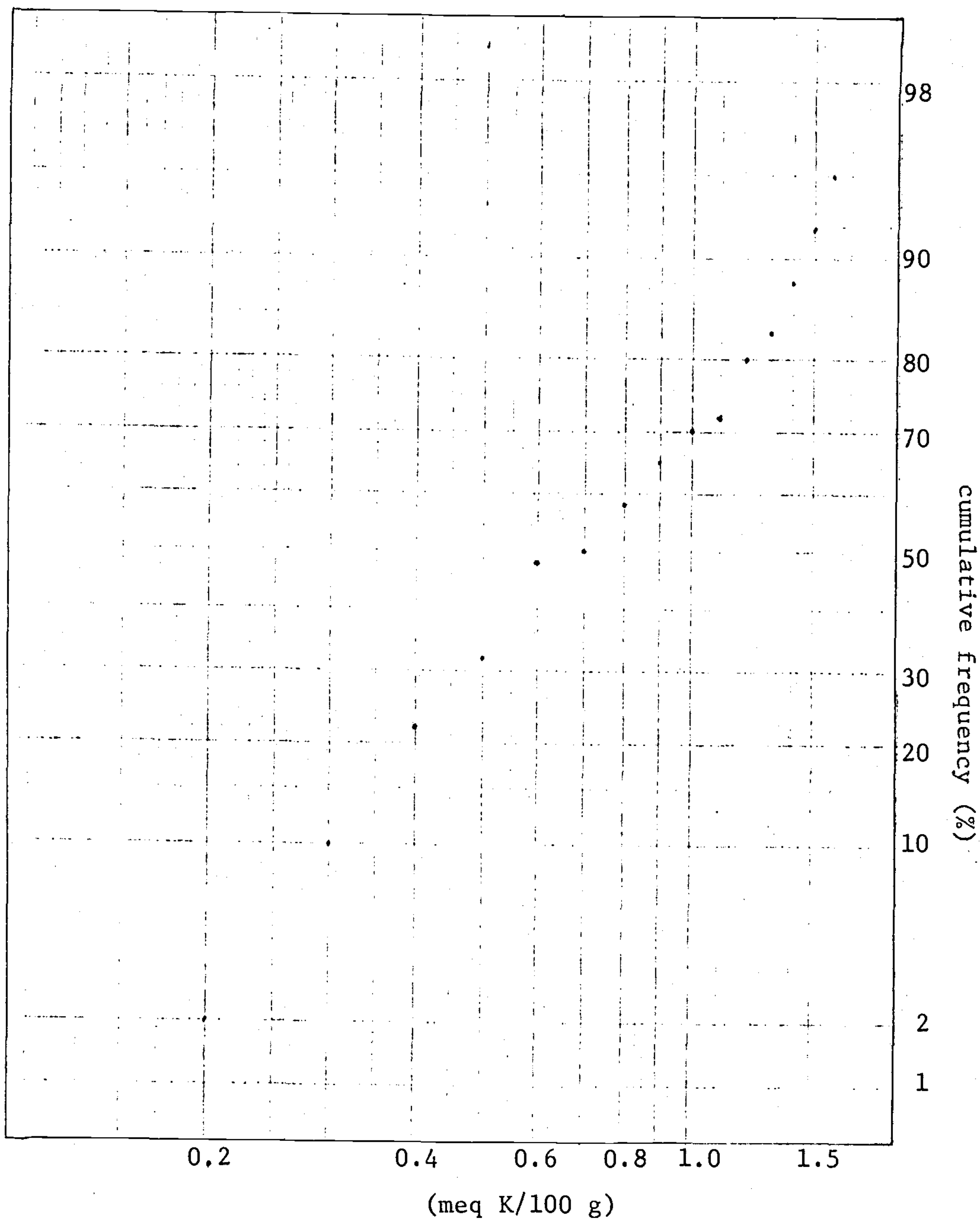


Figure 15. Plot on log-normal probability paper of the cumulative frequency of 40 observations for extractable K in the B horizon of MU 33.

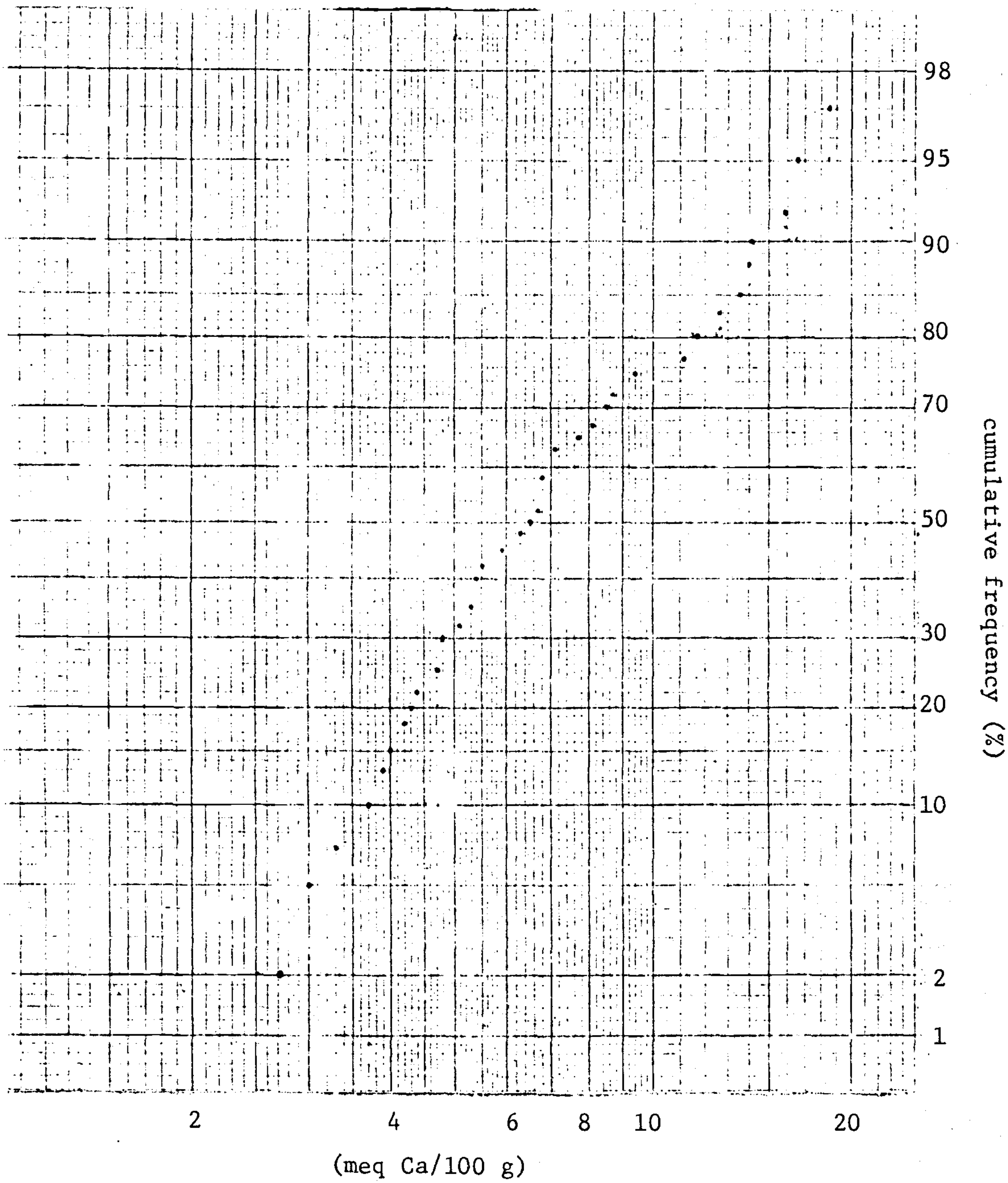


Figure 16. Plot on log-normal probability paper of the cumulative frequency of 40 observations for extractable Ca in the B horizon of MU 33.

A graphic example of the effect of the square root and logarithmic transformations on the originally skewed distribution of Ca in the A horizon of MU74 is shown in Figure 17. In Tables 8 and 9 are presented the statistical estimates for selected chemical properties subjected to these transformations. Both transformations tended to normalize the distributions, as indicated by the reduced coefficients of skewness and kurtosis. The transformations also reduced the variance causing much lower CV's. The means of the square root transformations can be converted back to the original scale, and they tend to be slightly lower, because the mean of a set of square roots is less than the square root of the original mean (Snedecor and Cochran, 1967). This return to the original scale could not be done with the variances since they were often less than 1. The variances of the logarithmic transformations can be returned to the original scale. Geometric means were sometimes much lower than arithmetic means (Tables 7-9).

McIntyre and Tanner (1959) suggested that for anormally distributed properties that seem to follow a skewed or log-normal distribution the geometric mean may be more appropriate than the arithmetic mean to describe the central tendency of the distribution. If the observations are left in the transformed state, they are amenable to statistical analysis, since they are normalized. However, interpretation of parameters in terms of logarithmic meq/100 g or (% organic matter)$^{\frac{1}{2}}$ becomes difficult. McIntyre and Tanner (1959) also described a graphical technique for determining a standard deviation for log-normal distributions such that $\pm$ s would include 68 percent of the population. Koch and Link (1970) describe two numerical methods for these determinations. These two methods differ only in their efficiency as estimators of the mean and variance of

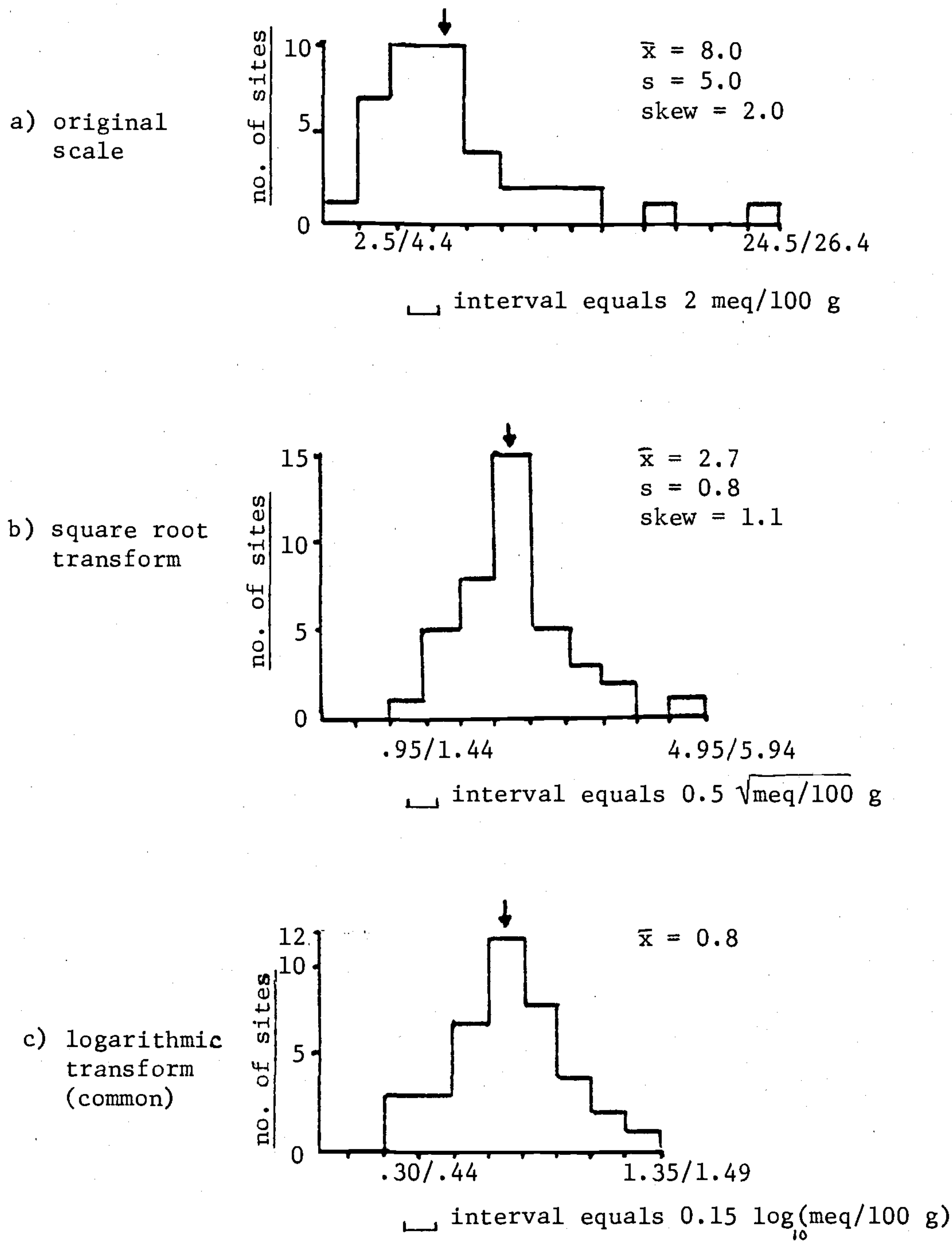


Figure 17. The effect of square root and logarithmic(common) transformations on the frequency distribution of extractable Ca in the A horizon of MU 74.

TABLE 8. Descriptive Statistics for Square Root* Transformations of Selected Chemical Properties in Both MU (weight basis).

	horizon	$\bar{X}$	S	SE	CV	skew	kurtosis
				MU33			
Ca	B	2.7	0.7	.12	27	0.7	-0.5
Mg	A	1.1	0.4	.06	34	0.8	1.3
	B	1.5	0.6	.09	36	1.6	2.6
OM	B	1.0	0.3	.05	29	0.6	1.4
CEC	B	4.5	0.7	.10	15	0.6	0.5
				MU74			
Ca	A	2.7	0.8	.12	29	1.1	1.8
Mg	A	1.2	0.3	.05	27	0.8	2.0
	B	1.6	0.6	.10	39	0.7	0.5
OM	A	1.7	0.6	.10	36	1.6	4.2
	B	1.0	0.3	.05	33	1.9	5.0
CEC	A	3.8	0.8	.12	21	3.3	1.6

*Not transformed back to original scale.

TABLE 9. Geometric Mean ($\bar{X}$), Standard Deviation (S), and Coefficient of Variation (CV) for Chemical Properties in MU33 and 74 after Logarithmic Transformation.

		MU33		MU74	
		A	B	A	B
K (meq/100 g)	$\bar{X}$	1.0	0.8	0.5	0.3
	S	0.2	0.3	0.13	0.2
	CV	20	38	29	50
Ca (meq/100 g)	$\bar{X}$	7.8	6.9	6.8	6.9
	S	1.9	1.7	1.7	1.8
	CV	24	25	25	26
Mg (meq/100 g)	$\bar{X}$	1.3	2.3	1.5	2.6
	S	0.4	0.6	0.4	0.7
	CV	31	26	27	27
OM (%)	$\bar{X}$	4.8	1.0	2.9	1.0
	S	1.4	0.3	0.6	0.4
	CV	34	30	21	40
CEC (meq/100 g)	$\bar{X}$	27	20	13	12
	S	1.2	1.3	0.5	1.3
	CV	4	7	4	11

log-normal distributions. The less efficient method was chosen in this study for the calculations of geometric means and standard deviations because of its simplicity and in order to illustrate how sample size requirements can be modified. Although in general the effect of both types of transformations on variability and normalization of these chemical properties is similar, the logarithmic transformation is preferred because of its greater flexibility in other statistical calculations.

Estimates of Sample Size Requirements

The number of samples required to estimate population means within chosen accuracy limits are given in Table 10. These numbers were calculated from the formula:

$$n = \frac{t^2 s^2}{d^2}$$

where t = 1.96 with $(1 - \alpha) = 0.95$ assuming infinite degrees of freedom, s^2 = estimate of variance of a given property over the entire mapping unit, and d = desired level of accuracy as a portion of the mean (Snedecor and Cochran, 1967). This formula assumes simple random sampling over the geographic extent of the map unit.

For many properties, such as percent coarse fragments and extractable bases, the number of samples required was far more than the 40 samples taken in this study. MU74 had more property-horizon combinations which exceeded the sampling intensity of this study than did MU33 (17 vs. 12). The number of samples required ranged from 1 for pH to 279 for Mg in the B horizon of MU33. The sample size of 1 for pH is unrealistically low due to the scale of measurement, whereby ± 10 percent of the mean

TABLE 10. Number of Samples Required to Estimate Mapping Unit Population Means $\pm$ 10% at 95% Confidence Levels Assuming Simple Random Sampling. (Estimates for Geometric Means)

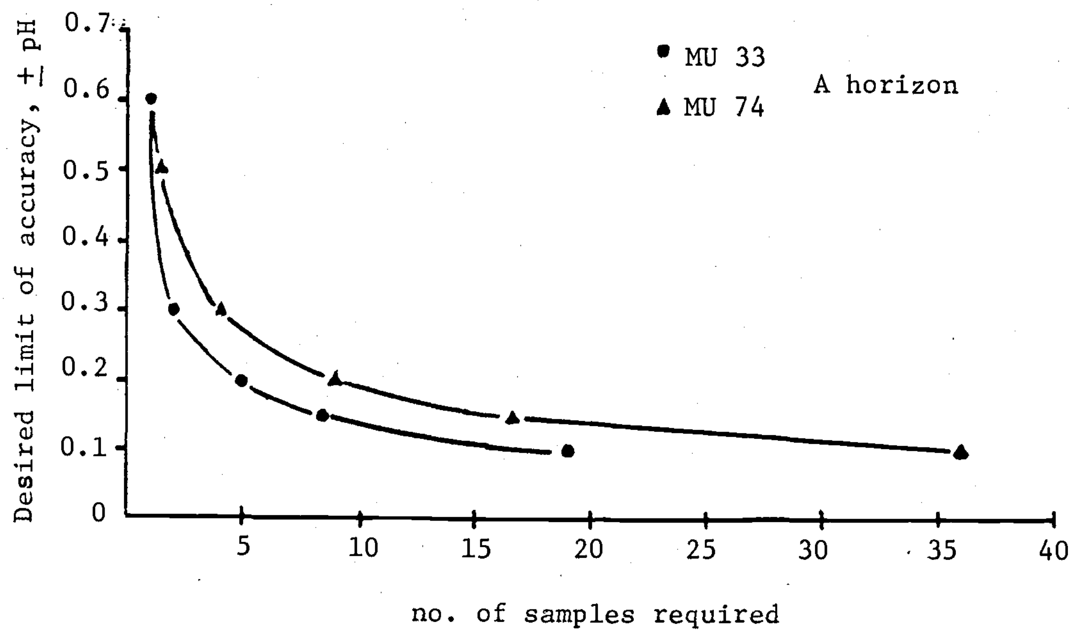
		MU33		MU74	
		A	B	A	B
Thickness O		74	-	246	-
Thickness A		28	-	68	-
Depth of Solum		42	-	41	-
Depth to B2		36	-	91	-
Color Value		4	5	18	11
Chroma		28	19	27	36
% Clay		29	36	52	127
% Silt		5	7	22	20
% > 2 mm		108	217	239	220
Bulk Density		22	11	9	3
pH		1	1	1	1
K	wt.	61 (16)	96 (41)	61 (32)	171 (96)
	vol.	163	225	86	415
Ca	wt.	113 (23)	119 (23)	150 (24)	106 (26)
	vol.	216	225	133	147
Mg	wt.	196 (36)	279 (26)	109 (27)	230 (28)
	vol.	384	469	196	369
OM	wt.	35 (33)	156 (35)	264 (16)	257 (61)
	vol.	84	96	152	111
CEC	wt.	26 (2)	31 (2)	84 (2)	27 (5)
	vol.	85	125	54	74

would permit a range of over 1 pH unit, far too inaccurate to be of any use. These problems are partially solved by developing what Wilding, Jones, and Schafer (1965) termed limit of accuracy curves. As examples, two such curves are illustrated in Figure 18. The use of these allows one to determine the number of observations required for any desired degree of accuracy. In the case of pH, a narrower limit of accuracy should be specified, perhaps as Heilman (1979) suggested, 0.2 pH unit. From the curve it can be determined that for a limit of accuracy of $\pm$ 0.1 pH unit, about 19 and 36 observations are needed for MU33 and MU74, respectively.

In the case of Mg, as well as other chemical variables with skewed distributions, normalizing the distribution via logarithmic transformations reduced the sample requirements for estimation of the geometric mean drastically (Table 10).

Some of the wide range in sample requirements for different properties may be more apparent than real, a result of different scales of measurement, magnitude of mean values, and the type of frequency distribution, as mentioned above. The fact remains, however, that in many cases sample sizes will be prohibitively large, and all properties which may be of importance will not be estimated with the same level of accuracy from a sample of the same, limited size. In soil-site studies variables must be ranked according to their perceived importance, along with the desired level of accuracy for each variable.

Compromises in accuracy will necessarily be made, but consideration of the variability of properties before sampling may allow the best compromise to be made. This point has been emphasized in forest soil sampling for quite some time (Mader, 1963; Ike and Clutter, 1968). Blyth



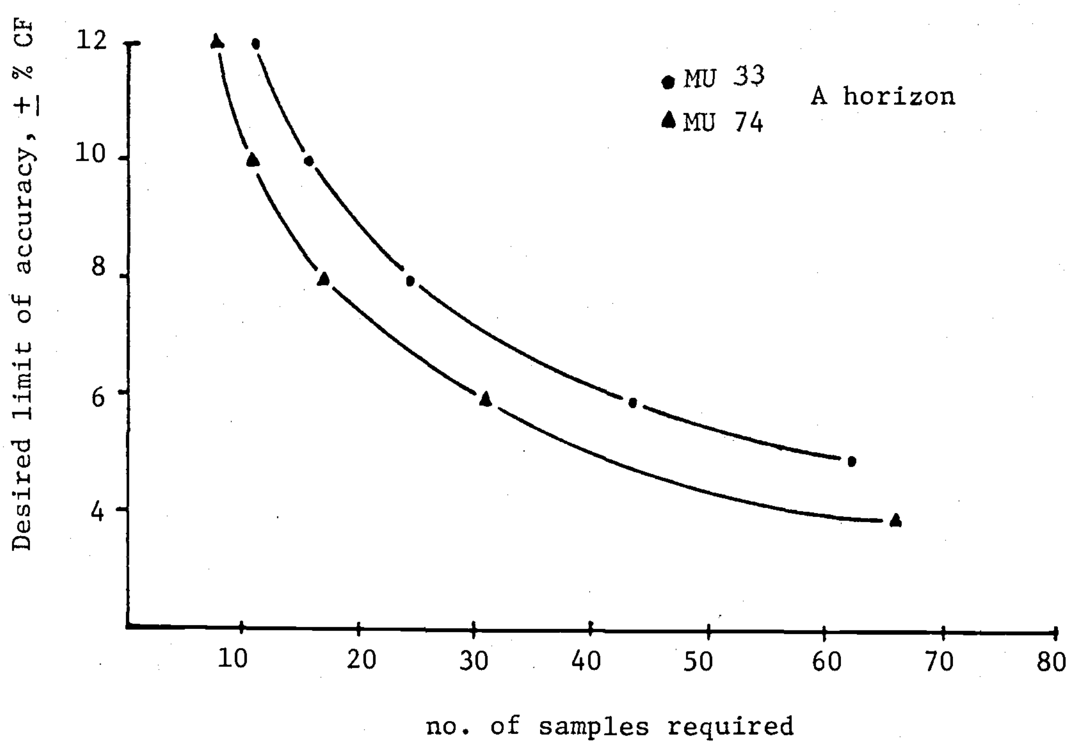


Figure 18. Limit of accuracy curves for pH and % coarse fragments in the A horizon of both MU.

and MacLeod (1978) found that the most variable properties (exchangeable bases) provided little utility in correlating soil properties to tree growth. Estimates of sample requirements can be used as best first estimates until additional variability information is available which may allow more efficient stratification in the sampling plan. Basic variability information can also be used to estimate how many samples would be required to detect a given amount of change in a property as a result of a particular management activity (Larson and Wooldridge, 1977), or to detect differences between mapping units for selected properties.

Weight vs. Volume Expression of Chemical Properties

Several authors have noted that expressing chemical properties volumetrically is a more realistic way of representing their importance to plant growth (Mehlich, 1980; Mollitor, Leaf, and Morris, 1980). It is also useful in studying soil genesis (Brown, 1975). In forest soils, where large variations of coarse fragments are common and nutrient pools are concentrated in the upper portion of the solum, the amounts of nutrients in a volume of whole soil may be a more sensitive indicator of fertility (Geist and Strickler, 1978). The amounts of coarse fragments, on a volume basis, and bulk densities in a given profile, were used to convert to volumetric quantities, according to the method used by Brown (1975) for some forest soils in reference stands of the H. J. Andrews Forest in the Western Cascades, Oregon.

Volumetric chemical properties (Table 7) were, with certain exceptions, more variable than if expressed on a weight basis. This may be due to three factors. First, and most important, is the independent variation of the chemical quantities and the distributions of coarse fragments and bulk density, which were used to calculate the volumetric quantities. This independent variation causes greater variability than for any of these variables measured separately. Large amounts of coarse fragments and low bulk densities in effect dilutes concentrations of chemical elements present on a total-soil-volume basis. There is also an opposing tendency to concentrate bases in the smaller soil volume of fine earth available in soils of high gravel content (McNabb et al., 1978). The interaction of these opposing forces will influence the variability measured.

Secondly, since coarse fragments and bulk density are included in the calculations, their sampling errors are also included so that a multiplicative error results, which constitutes a portion of the variability measured. A third, less important source of additional variation may be due to the smaller values resulting from the volumetric calculations. A standard deviation in a property of 0.2 g/l, for example, will cause an extremely high CV in relation to means of the size encountered here.

Organic matter and CEC were the only two properties which were the same or lower in variability, when expressed volumetrically (Table 7). OM in the A and B horizons of MU74 and in the B horizon of MU33 was lower. A horizon CEC in both MU was lower or the same. Expressing chemical properties volumetrically also altered the trends between surface and subsoil levels. In several cases, concentrations were higher in the subsoil whereas when measured on a weight basis they were lower.

Concentrations of chemical properties, expressed on a volumetric basis, were generally larger in MU74 than in MU33 (Table 7). This is surprising since the concentrations of most properties, except Mg, when expressed on a weight basis, were lower in MU74. This reversal is primarily due to the lower bulk densities and higher amounts of coarse fragments in MU33. This also illustrates how weight measures provide only one perspective on fertility levels of soils. In reality the soils of MU33 probably have larger total quantities of nutrients available to plants than does MU74, as a result of their generally deeper solum and thicker A horizons, which contain a significant portion of the nutrient pool.

Comparison of MU74 with MU33

MU74. Means of morphologic properties measured in MU74 were similar to those reported in the range of profile characteristics in the SRI. The ranges found in this study however, were generally greater than in the SRI (Table 2). The primary cause of this is alteration of surface characteristics by management, usually logging, resulting in removal of litter and/or erosion of mineral surface soils. The range in thicknesses of the O and A horizons were 0-9 and 5-40 cm, respectively. The depth to the B2 horizon corresponds to the thickness of the surface layers described in the SRI and includes A1 and A3 or B1 horizons. The mean depth to B2 (39 cm) falls within the range for the landtype (25-40 cm) but towards the deeper end. The greater range in depth of solum (0.3 - 1.4 m) as compared to the range in the SRI was due to several shallow profiles located near outcrops of metavolcanic rock. The high end of the true range for solum depth may be much deeper than reported. Although bedrock or saprolite was encountered in most sites, several profiles were found that contained thick deposits of colluvium in draws and incipient drainageways or massive deposits of clay high in coarse fragments. These latter deposits may have been from old earthflows or remnants of older, buried soils. They were generally free of any roots and appeared to form an effective lower boundary in terms of their extremely reduced permeability to water and root penetration. Atzet (1979) found that depths of soils developed on Applegate metasediments and metavolcanics overlap extensively with means of 100 and 93 cm and standard deviations of 25 and 36 cm, for the two rock types. This is quite similar to the mean and standard deviation of 85 and 28 cm found in this study (Table 6). Values of several properties differed appreciably from those expected from the SRI. Mean amounts of coarse fragements were lower (21 vs. $35\text{-}50^{+}$%) and were extremely variable. Amounts of clay were lower, and dominant soil textures (silt loam) were different from the loams and clay loams reported in the SRI (Figure 19, Table 2). Atzet (1979) also found silt loams to be the dominant texture for soils developed from Applegate metamorphic rocks. Mean bulk densities of these soils were also relatively high (1.36 g/cc in surface). This may be the result of low amounts of organic matter, extreme drying conditions during the summer months, and compaction from logging activities.

Levels of chemical properties generally differed appreciably from those reported in the SRI. Soils sampled in this study were generally less acid, had higher amounts of extractable bases, and lower amounts of organic matter and CEC. These results agree well, however, with those reported for some forest soils in Southern Oregon (Heilman, 1979) and soils formed under mixed conifer vegetation types in northeast Oregon (Geist and Strickler, 1978).

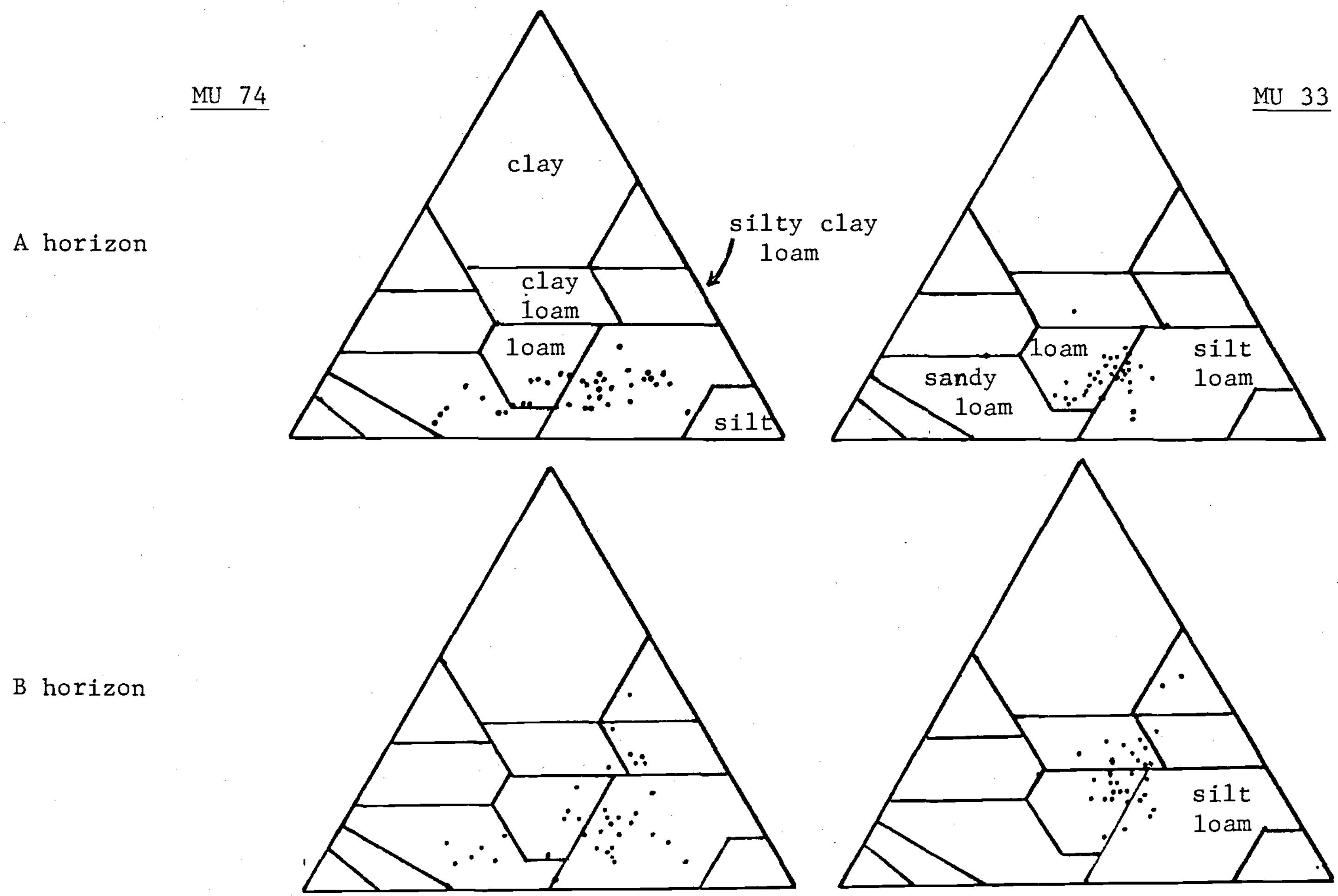


Figure 19. Plot of the textural classification of samples from the A and B horizons of both MU.

MU33. Soils in MU33 were generally deeper, redder, higher in clay and corase fragments, lower in bulk density, and more fertile, on a weight basis, than those of MU74 (Tables 6 and 7). As in MU74, mean horizon thicknesses fell within the SRI ranges, but ranges in this study were usually greater. The mean depth of solum (134 cm) was less than in the SRI, but the maximum and minimum depths observed were, respectively, deeper and shallower than reported. The deepest soils found were formed from highly weathered tuffs; the shallowest profiles were associated either with younger, weakly developed, extremely stony andesitic soils or with hard tuffs.

Dominant textures of loams and clay loams (Figure 19) agreed with those reported in the SRI. Because the mean volume of coarse fragments in the MU is between 15 and 35%, use of the very gravelly adjective is appropriate in the soil description. Coarse fragments were not separated into classes of gravel, cobbles, stones, etc. because sampling of the extremely large size fractions was not feasible, although they were observed to be quite common during field sampling. Mean levels of chemical properties agreed quite well with those reported in the SRI, with the exception of slightly lower OM and CEC values.

It is difficult, as well as unrealistic, to make statments about and contrast the general nature of the variability of the two mapping units, looking at only one property at a time. However, on the basis of three criteria, the coefficient of variation (CV), the range and the number of samples required to estimate the means within a $\pm$ 10 percent limit of accuracy, over all properties measured, MU74 is generally more variable than MU33. Of the 28 property and property-horizon combinations measured in both MU, 17 had larger CV's and required more samples in

MU74 than in MU33. Six properties had lower CV's and sample sizes in MU74, and five were the same for both. These trends for CV and sample requirements might be expected since both these measures of variability use the standard deviation and the mean in their calculation. Examination of the range, however, yields essentially the same result: 14 wider ranges, 6 narrower, and 8 identical ones for MU74 as compared to MU33. In both the A and B horizons, MU74 was more variable, requiring larger numbers of samples for 7 of 12 properties. Although MU74 overall was generally more variable than MU33, the subsoil of MU33 was commonly more variable, when compared to the surface horizon, than the subsoil of MU74 (9 of 12 properties vs. 4 of 12 in MU74). MU74 was distinctly more variable in physical and morphological properties (6 of 8 property-horizon combinations in each of these groups of properties required more samples) than MU33, with the exception of bulk density. The two mapping units were equally variable in terms of chemical properties. This should not be unusual since mapping is not done and mapping units are not defined on the basis of chemical properties. The physical and morphological properties are more readily measured in the field and are correlated to a greater extent with features on air photos (Webster and Beckett, 1968). For this reason, their variability, relative to each other, can be estimated more readily. That MU74 is more variable than MU33 is not surprising, considering that the two units were chosen to represent extremes in their internal uniformity. Although 17 property-horizon combinations in MU74 had larger CV's than in MU33, 12 of these differences were 15 percentage points of less (the largest differences for CV being 35 and 54 percentage points for thickness of the A and A horizon OM). This indicates that the differences in variability of the two mapping units is not great.

Spatial Distribution of Variability

Mapping units, with defined ranges in key characteristics, are composed of delineations, scattered geographically, each of which more or less conforms to the concept of the map unit. A common misconception among map users, however, is that all delineations of a map unit are exactly the same. Delineations are also the functional on-the-ground land units upon which management activities take place. It is imperative, therefore, that land managers recognize the existence of geographic variation from delineation to delineation. This in turn should lead to a realization of the importance of more detailed information, including a knowledge of just how variable selected properties may be within any one delineation of a map unit. In this section patterns of variation both within and between delineations will be explained in greater detail.

Statistical Techniques

One-way analysis of variance (ANOVA) tests were performed on individual soil properties to evaluate whether the majority of the variation of a property occurs within or between delineations and whether delineations were significantly different in their means for that property. The proportions of total variance were derived by calculating the variance components estimates for the between and within delineation components and equating them to the expected mean squares developed assuming a random effects model (Webster, 1977a). The setup for the ANOVA table is presented in Table 11. Tables 12 and 13 present selected results from

TABLE 11. Analysis of Variance Table Used for Within/Between Delineation Variance Component Calculation.

Source of Variation	d.f.		Sum of Squares	Mean Square	Expected Mean Square
Between Delineations	$(a-1)=8-1$	$= 7$	SS_B	$MS_B = SS_B/(a-1)$	$\sigma^2 + 5\,\sigma_b^2$
Within Delineations	$a(n-1)=8(5-1)=$	32	SS_w	$MS_w = SS_w/a(n-1)$	σ^2
	Total (N-1)	39	SS_T		

F-ratio calculated as MS_B/MS_w

with 7 and 32 d.f.

$F_{critical}$ $(1-x) = 0.95 \quad = \quad 2.32$

$(1-x) = 0.99 \quad = \quad 3.25$

a: number of delineations

n: number of sites within a delineation

N: total number of sites

σ_b^2: variance component due to differences between delineations

TABLE 12. One-Way ANOVA F-Ratio and Proportion of Variance for Surface Horizon Properties in Both MU.

	% of Total Variance					
	MU33			MU74		
	BD	WD	F-Ratio	BD	WD	F-Ratio
Thickness O	9	91	1.56	11	89	Δ 3.47**
Thickness A	5	95	Δ 1.34	4	96	Δ 1.29
Depth of Solum	22	78	Δ 2.68*	30	70	Δ 3.63**
Depth to B2	0	100	Δ 0.61	20	80	Δ 2.53*
Color Value	34	66	Δ 4.15**	15	85	Δ 2.06
Chroma	43	57	Δ 5.48**	38	62	Δ 4.80**
% Clay	36	64	Δ 4.43**	71	29	Δ16.03**
% Silt	28	72	3.34**	76	24	Δ21.11**
% > 2 mm	13	87	Δ 1.85	43	57	Δ 5.64**

BD: Between Delineation

WD: Within Delineation

Δ Hartley's maximum/minimum test of homogeneity of group variances showed no significant differences at 5% level.

* F-Ratio significant at 5% level. Critical Level with 7 and 32 d.f. = 2.32

** 1% Level = 3.25

TABLE 12. Continued.

		% of Total Variance					
		MU33			MU74		
		BD	WD	F-Ratio	BD	WD	F-Ratio
pH		38	62	Δ 4.71**	49	51	Δ 6.90**
K	wt.	62	38	Δ10.83**	55	45	Δ 8.51**
	vol.	32	68	3.80**	58	42	Δ 9.61**
Ca	wt.	71	29	Δ15.49**	46	54	6.29**
	sqr.	--	--	--	59	41	10.14**
	vol.	33	67	4.02**	71	29	16.21**
Mg	wt.	38	62	4.62**	45	55	6.05**
	sqr.	43	57	6.80**	61	39	10.61**
	vol.	17	83	2.23	44	56	5.90**
OM	wt.	0	100	Δ 0.30	17	83	2.25
	sqr.	--	--	--	23	77	2.83*
	vol.	13	87	Δ 1.89	34	66	4.15**
CEC	wt.	19	81	Δ 2.40*	31	69	3.85**
	sqr.	--	--	--	38	62	4.90**
	vol.	18	82	2.40*	68	32	Δ15.33**

sqr.: Square Root Transformation

TABLE 13. One-Way ANOVA F-Ratio and Proportion of Variance for B-Horizon Properties in Both MU.

	% of Total Variance					
	MU33			MU74		
	BD	WD	F-Ratio	BD	WD	F-Ratio
Color Value	33	67	Δ 3.94**	25	75	Δ 3.12*
Chroma	37	63	Δ 4.60**	0	100	Δ 0.93
% Clay	18	82	Δ 2.28	54	46	8.23**
% Silt	2	98	Δ 1.14	53	47	8.11**
% 2 mm	44 $\bar{x}=21$	56	Δ 5.79**	12 $\bar{x}=40$	88	Δ 1.86

BD: Between Delineation

WD: Within Delineation

Δ Hartley's Maximum/Minimum Test of Homogeneity of Group Variances showed no significant differences at 5% level.

* F-Ratio significant at 5% level. Critical Level (7,32) d.f. = 2.32

** 1% Level = 3.25

TABLE 13. Continued

		% of Total Variance					
		MU33			MU74		
		BD	WD	F-Ratio	BD	WD	F-Ratio
pH		30	70	Δ 3.64**	12	88	Δ 1.88
K	wt.	47	53	6.28**	37	63	Δ 4.66**
	vol.	54	46	7.99**	44	56	5.96**
Ca	wt.	64	36	11.54**	39	61	Δ 5.06**
	sqr.	66	34	Δ12.77**	--	--	--
	vol.	59	41	9.79**	46	54	Δ 6.36**
Mg	wt.	34	66	4.07**	25	75	3.06*
	sqr.	40	60	5.08**	29	71	Δ 3.53**
	vol.	34	66	4.03**	25	75	3.08*
OM	wt.	39	61	4.89**	3	97	1.20
	sqr.	35	65	4.24**	9	91	Δ 1.62
	vol.	39	61	Δ 4.82**	13	87	Δ 1.95
CEC	wt.	44	56	5.73**	36	64	4.47**
	sqr.	47	53	6.29**	41	59	5.40**
	vol.	43	57	4.39**	19	81	2.43*

sqr.: Square Root Transformation

analyses. The F-ratio tests the null hypothesis, Ho, that all eight delineation means are equal, for a given property. The assumption of random effects was based on the fact that delineations and sites within delineations were randomly selected, though not without some bias due to other study requirements such as the desirability of undisturbed sites and accessibility. In addition, since the number of delineations sampled comprised a significant portion (greater than five percent) of the total population of mapped delineations, a fixed population correction (f.p.c.) was applied to the between-delineation variance component. The f.p.c., in effect, reduces this variance estimate due to the more complete sampling of the entire population.

Proportion of Variance

In general, the higher the F-ratio the greater the proportion of total variance that is accounted for by between-delineation differences. An F-ratio of about 7 indicates approximately equal contributions from the two sources of variation. The amount of total variance due to differences between delineations ranged widely (Tables 12 and 13). Lowest values were obtained for organic matter in the surface of MU33 and chroma in subsoil of MU74. With respect to these properties, the delineations are essentially uniform, and all of the variance occurs within delineations. At the other extreme are properties such as clay and silt in MU74 and Ca in MU33 where over 70 percent of the variance is between delineations. With respect to these properties, delineations are not the same, and to assume so is wrong.

The amounts of the total variance of a property which are found within and between delineations can be interpreted in terms of the scale and source of the variation, the similarities of delineations, and the efficiency of the classification for these mapping units. Having large proportions of within-delineation variance reduces the scale of variability to one of hundreds of feet and indicates rather local sources of variation. This situation was found for the morphological properties measured in both MU. On the average, 84 and 91 percent of the total variance occurred within delineations of MU74 and 33 (Tables 12 and 13). Small scale differences in topographic features such as aspect, slope shape, gradient, position and dissection influence the soil microclimate and the production/decomposition of vegetation. When combined with the different spatial distributions of litterfall caused by the type and pattern of vegetation present (Zinke, 1962; Zinke and Crocker, 1962) as well as the effects of tree throw and mass movement phenomena (Armson and Fessenden, 1973; Troedsson and Lyford, 1973; Hack and Goodlett, 1960), significant small-scale variability of soil horizon thicknesses should be expected. McFee and Stone (1965) found this to be the case when they noted the inadequacy of single soil pit descriptions in characterizing horizon thicknesses in plots only 0.1 acre in size. In addition, the scale of the survey (1:60,000) as well as the definition of the map units themselves, which allow inclusions of several distinctive types of soils, will add significantly to the within-delineation variation.

Several properties (particularly Ca in the A and B horizons, and K in B horizon of MU33, and clay and silt in the surface of MU74) had 60 to 70 percent of their total variance accounted for by differences between delineations (Tables 12 and 13). Large proportions of between-delineation variance for certain properties point to the influence of large scale geographic variation due to gross differences in climate (rainfall/temperature), parent material, vegetation, or geomorphic processes. Delineations in MU74 were separated by distances of 1 to 26 mi. (Figure 1). The largest separation distances were parallel to the drier and warmer climatic gradient occurring from West to East. Differences in precipitation and temperature along this gradient might be expected to cause major differences in degree and type of profile development, particularly in terms of depth of leaching, organic matter and base content, profile acidity and morphological properties.

Except for the morphological properties, which had uniformly large amounts of within-delineation variance, the proportions of variance for physical and chemical properties exhibited no trends, either for particular properties, between map units, or between surface and subsoil horizons (Tables 12 and 13).

The fact that, over most properties, within-delineation variance was larger indicates good map unit design. For broad planning and management purposes the map units can be treated as being uniform, within the limitations imposed by those properties which contain large proportions of between-delineation variance.

Differences Between Delineations

In the A horizon all properties except thickness of A, percent coarse fragments and organic matter in MU33, and color value and organic matter in MU74 had significant F-ratios and different delineation means. In the B horizon, all properties except clay and silt in MU33, and chroma, percent coarse fragments, pH, and organic matter in MU74 had significantly different delineation means (Tables 12 and 13). An F-ratio which is significant indicates that at the minimum, only one of the delineations needs to be significantly different from all the rest, for that property. Thus, in both mapping units there was at least one delineation which differed significantly from the map unit concept in one or more key features. In the sampling of a map unit, delineations were not deleted from selection even if it was apparent from field examination that they differed from the map unit concept. One of the intentions of the study was to measure soil variability of map units as mapped. In MU74 one delineation, located along the margins of a granitic pluton, had soils developed from hornblende diorite and metamorphic colluvium over diorite instead of from Applegate metamorphics. In MU33, one delineation located along the High Cascade-Western Cascade margin had pinkish-gray colored soils developed from welded tuffs, which greatly contrasted from the typical reddish-brown soils derived from basaltic and andesitic flow rocks. These particular delineations possessed the most obvious departures from the map unit concept. However, considering the wide geographical area over which the delineations were located (Figure 1), the variations in climate and topography, and the complex history of soil formation in these landscapes, it seems reasonable to expect differences between delineations. Furthermore, differences that are significant statistically may be of little or no practical significance for management. For example, delineation means for A horizon extractable K in MU33 were found to be significantly different at the 1% level (Table 12). The range in delineation means was from 0.7 to 1.7 meq/100 g, all well above possible deficiency levels that have been suggested for tree growth (Heilman, 1979). In other cases, such as with A horizon CF in MU33, large variation within delineations becomes equally as important as differences between delineation means. Since coarse fragment content strongly influences soil-water storage capacity, variations of the magnitude found here between delineations (24-55 percentage points) could mean significant differences in interpretation of seedling regeneration success from one site to another. It is up to the land manager to decide which may be more important, large variations within shorter distances at one site, major mean differences between sites that are supposed to be similar for management, or both.

If the differences indicated by a significant F-ratio are not of practical importance or are within the designated limits for the MU, they should be ignored, and attention should be focused on the amount of the total variance which may be found within delineations. In addition to the real differences between delineations which may be present, significant F-ratios might have been caused by major departures of delineations from the ANOVA model assumptions of normality and equality of group variances (Snedecor and Cochran, 1967). Most chemical properties had significantly skewed distributions and consistently unequal group (delineation) variances (Tables 12 and 13). Square root transformations normalized the distributions and lowered the variance, but rarely reduced it below levels significant for Hartley's maximum/minimum variance test (3 of 12 transformation succeeded) (Neter and Wasserman, 1974). In the three cases where the variance ratio was reduced below critical levels, no differences in the outcome of ANOVA analyses were apparent, indicating that the differences between delineations were real.

New Estimates of Required Sample Sizes

Once estimates of variance components for properties of a mapping unit have been obtained, they can be used to more effectively stratify the sampling plan and reduce sampling effort. Two different estimates of sample size requirements can be made, depending on the sampling objectives. First, if estimates of the mean of a property or set of properties at a particular site; i.e. within a particular delineation, are desired, then knowing the within-delineation variance component and the desired level of accuracy will allow calculation of the required sample size. These estimates are shown in Table 14. In most cases the sampling requirements for individual delineations will be much less, depending on the proportion of within-class variance, than for estimation of mapping unit means. If estimation of map unit means is desired, both the between and within delineation variance components, along with the desired level of accuracy, and estimates of the costs of sampling delineations and sites within delineations can be used to optimally allocate sampling effort (Wilding, Jones, and Schafer, 1965). An example of this type of analysis is shown in Figure 20. First an attempt of the number of sites per delineation is made, followed by an estimate of the number of delineations to sample. Although the particular constraints for the example of this sampling problem were desired levels of accuracy, the equations can be modified to alternatively deal with cost constraints.

Another use of variance components is in site classification and soil-site studies. The soil and site properties which are the most useful in studies relating to tree growth are those whose variability remains low over fairly extensive areas (Blyth and MacLeod, 1978). The

TABLE 14. Number of Samples Required to Estimate Population Means with ± 10% Accuracy at 95% Confidence Levels Using Within Delineation Variance.

	MU33		MU74	
Thickness of O	67		164	
Thickness of A	28		67	
Depth of Solum	33		30	
Depth to B2	36		73	
	A	B	A	B
Color value	3	4	17	8
chroma	16	11	24	36
% clay	20	32	15	59
% silt	3	9	8	9
% > 2 mm	94	120	137	195
K	22	54	25	61
Ca	32	41	79	62
Mg	112	173	65	171
OM	42	93	214	232
CEC	20	20	56	20

The initial calculation estimates the required number of sites per delineation:

(1) $Nw = Sw/Sb\sqrt{Cb/Cw} = 2.61/1.31\sqrt{25/2} = 7$

where:

Nw = number of sites per delineation

Sw = within delineation variance =2.61

Sb = between delineation variance = 1.31

Cw = cost of sampling each additional site within a delineation = $2

Cb = cost of sampling a delineation = $25

The number of required delineations is then calculated:

(2) $Nd = (Sb/V)*((Sw\sqrt{Cw} + Sb\sqrt{Cb})/\sqrt{Cb})$

$= (1.31/0.35)*((2.61\sqrt{2} + 1.31\sqrt{25})/\sqrt{25} = 8$

where:

Nd = number of delineations

V = desired level of accuracy, in this case ± 10% of the mean for % organic matter in the A horizon of MU 74, 3.45, or 0.35.

Therefore the total number of samples required is 7*8 = 56, which compares with 264, the number required assuming simple random sampling and no partitioning of the map unit variance. Costs and equations were taken from Wilding, Jones, and Schafer (1965).

Figure 20. Example of optimal allocation of samples for % OM in MU 74.

term "fairly extensive" can be taken to mean approximately the size of plots used in site studies, or for forest management activities which in the latter case equates fairly well with the size of a single delineation. This would imply having large proportions of between delineation variance, thereby minimizing within-delineation variance. In this way correlations based on the range of a given property would be more reliable since there would be more confidence in the uniformity of the plots sampled. In most cases however, for the properties which are often found to be of importance, such as morphological properties, high variability within sites is the norm (Carmean, 1975), and sampling is often not sufficiently intensive to accurately determine mean levels.

Variation of Properties with Distance

Considering the fact that most properties which were measured had most of their variability occurring within delineations rather than as a result of differences between delineations, an attempt was made to more narrowly define the bounds of the spatial variation which was occurring and to identify specific trends of variation with distance.

Statistical Techniques

Effects of separation distances between sampling sites within delineations were also evaluated with an analysis of variance technique. Because consecutive sites in each delineation were located as specified distances from each other, the change in the value of any given property from one site to the next could be calculated. These differences were used as an index of the tendency of a property to vary as a function of distance. The sign of the differences between sites was ignored, since only absolute changes were of concern. A two-way classification was developed for analysis of the variance of each of several properties. The four separation distances (660, 200, 60, 15 ft) were used as the treatments, and the eight delineations sampled from each mapping unit were used as replications (Snedecor and Cochran, 1967).

Results of ANOVA calculations on the data generated by calculating changes in the values of selected properties from site to site are presented in Tables 15 and 16. For 18 properties measured in both MU, the effect of distance was significant at the 5% level only for percent slope in both MU, percent coarse fragments in the A and B horizons of MU74, and percent organic matter in the A horizon of MU33. Slope gradient would be expected to change more at larger distances rather than smaller ones, especially in the steep, highly dissected topography found in MU74. Variations of coarse fragments with distance in MU74 parallel the trends for slope, the largest differences occurring most often at 660 ft. (Table 17). In the steep, mountainous terrain of MU74, colluvial movement is quite common, as indicated by the frequent observations of abrupt changes of coarse fragment distributions within profiles, a diagnostic feature of lithologic discontinuities (Parsons and Herriman, 1975). Over a given distance along a slope, the greater the change in slope gradient the more likely deposition of colluvial material will occur, if the gradient becomes gentler. If the slope gradient becomes steeper then movement of colluvial material is more likely. For organic matter in MU33, maximum changes were found most often at separation distance of 200 and 660 ft. (Table 17).

TABLE 15. Two-way Analysis of Variance of the Changes in Selected Properties Between Sites at Four Separation Distances in MU33.

Source	df	SS	MS	F	SS	MS	F
			% slope			thickness of A	
Distance	3	77	25.8	4.52*	102	34.1	0.50
Delineation	7	96	13.6	2.39Δ	637	90.9	1.34
Error	21	119	5.7		1425	67.9	
			CF - A			CF - B	
Distance	3	236	78.7	0.33	965	322	1.46
Delineation	7	1551	221.6	0.84	2287	327	1.48
Error	21	5526	263.1		4631	221	
			% clay - A			% clay - B	
Distance	3	15.6	5.2	0.83	57.9	19.3	0.50
Delineation	7	89.9	12.8	2.03Δ	95.8	13.7	0.35
Error	21	133.0	6.3		815.9	38.9	

* Significant at 5% level

Δ Significant at 10% level

** Significant at 1% level

TABLE 15. Continued.

Source	df	SS	MS	F	SS	MS	F
			pH - A			pH - B	
Distance	3	.03	.01	0.25	0.15	0.05	0.83
Delineation	7	.25	.04	1.33	0.00	0.00	0
Error	21	.61	.03		1.25	0.06	
			KWT - A			KWT - B	
Distance	3	0.02	.007	0.23	0.23	0.08	1.14
Delineation	7	0.40	.06	2.00	0.41	0.06	0.86
Error	21	0.60	.03		1.48	0.07	
			CAWT - A			CAWT - B	
Distance	3	14.8	4.9	0.89	8.4	2.8	0.88
Delineation	7	61.6	8.8	1.60	37.3	5.3	1.66
Error	21	114.7	5.5		67.1	3.2	

TABLE 15. Continued.

Source	df	SS	MS	F	SS	MS	F
			MGWT - A			MGWT - B	
Distance	3	2.4	0.8	1.14	8.0	2.7	2.45$^{\Delta}$
Delineation	7	9.1	1.3	1.86	43.5	6.2	5.64**
Error	21	15.2	0.7		23.5	1.1	
			OMWT - A			OMWT - B	
Distance	3	11.7	3.9	3.17*	0.3	0.1	0.50
Delineation	7	15.8	2.3	1.92	2.2	0.3	1.50
Error	21	25.9	1.2		3.4	0.2	
			CEWT - A			CEWT - B	
Distance	3	87	29	1.32	17	5.5	0.89
Delineation	7	80	11	0.50	140	2.0	3.22
Error	21	460	22		130	6.2	

TABLE 16. Two-way Analysis of Variance of the Changes in Selected Properties Between Sites at Four Separation Distances in MU74.

Source	df	SS	MS	F	SS	MS	F
			CF - A			CF - B	
Distance	3	1346.6	448.9	4.02*	896.3	298.8	3.47*
Delineation	7	999.3	142.8	1.27	985.5	140.8	1.64
Error	21	2345.9	111.7		1807.2	86.1	
			% clay - A			% clay - B	
Distance	3	24.0	8.0	0.54	59.4	19.8	0.44
Delineation	7	104.1	14.9	3.92**	318.1	45.4	1.00
Error	21	80.5	3.8		952.5	45.4	
			% slope			Thickness of A	
Distance	3	961	320	5.9**	213	71	1.16
Delineation	7	851	122	2.26^Δ	424	61	1.30
Error	21	1130	54		986	47	
			pH - A			pH - B	
Distance	3	0.11	0.04	1.00	0.05	.02	0.25
Delineation	7	0.28	0.04	1.33	0.58	.08	2.00
Error	21	0.66	0.03		0.85	.04	

*Significant at 5% level   ^ΔSignificant at 10% level

**Significant at 1% level

TABLE 16. Continued

Source	df	SS	MS	F	SS	MS	F
			KWT - A			KWT - B	
Distance	3	.03	.01	0.71	0	0	0
Delineation	7	.10	.014	1.16	.22	.03	5.0**
Error	21	.26	.012		.13	.006	
			CAWT - A			CAWT - B	
Distance	3	60.4	20.1	2.42$^{\Delta}$	37.5	12.5	2.45$^{\Delta}$
Delineation	7	89.9	12.8	1.54	126.5	18.1	3.54*
Error	21	174.2	8.3		108.0	5.1	
			MGWT - A			MGWT - B	
Distance	3	3.0	1.0	1.00	10.6	3.5	1.48
Delineation	7	9.1	1.3	1.30	108.3	15.5	6.46**
Error	21	21.4	1.0		50.2	2.4	
			OMWT - A			OMWT - B	
Distance	3	21.6	7.2	1.60	0.7	0.2	0.33
Delineation	7	61.3	8.8	1.96	4.1	0.6	1.00
Error	21	95.1	4.5		13.1	0.6	
			CEWT - A			CEWT - B	
Distance	3	185	61.7	1.42	1.2	0.4	0.09
Delineation	7	137	19.6	0.45	111.9	16.0	3.47*
Error	21	916	43.6		95.8	4.6	

TABLE 17. The Number of Delineations, at Four Separation Distances, in Which the Maximum Change for Selected Properties Occurred (A Horizon)
8 Delineations/MU

Separation Distance (ft)	MU33				MU74			
	660	200	60	15	660	200	60	15
% Slope	* 3	3	1	1	* 4	4	0	0
Thickness A	4	0	2.5	1.5	2	2	3	1
% Coarse fragments	2	1	4	1	5	2	1	0
% Clay	0	3	5	0	2	3	3	0
pH	1	2	1	4	1.5	3.5	2	1
K	2	0.5	3	2.5	4	2	1	1
Ca	4	1	0	3	4	3.5	0	0.5
Mg	4	1	1	2	1.5	5	1.5	0
OM	* 3	4	1	0	2	3	3	0
CEC	4	0	1	3	3.5	2.5	0.5	1.5

*Distances were significantly different (5% level) in 2-way ANOVA.

TABLE 18. The Number of Delineations, at Four Separation Distances, in which the Maximum Change for Selected Properties Occurred (B horizon).

Separation Distance (ft)	MU33				MU74			
	660	200	60	15	660	200	60	15
% Coarse fragments	1	4.5	1.5	1	* 4	2	1	1
% Clay	2	2	3	1	4	1	2	1
pH	3.5	2	1	1.5	1	2	2	3
K	1	3	0.5	2.5	1.8	3.1	2.5	0.6
Ca	2	2	2	2	2.5	2.5	1	2
Mg	3	3	1	1	1	2	3	2
OM	2.5	2.5	1	2	1.2	1.7	3.4	1.7
CEC	0	3	0.5	4.5	3	1.5	2	1.5

*Distances were significantly different (5% level) in 2-way ANOVA.

Most of the properties analyzed had the occurrence of their maximum change distributed over all distances in no apparent pattern (Tables 17 and 18). The maximum change, or the minimum, in most properties was as likely to occur at 660 ft as it was at 15 ft. This lack of any trend may be interpreted as indicating a random distribution of changes in properties over the distances chosen. The transects were not placed in any specified direction, such as toeslope to ridgetop, perpendicular to the slope, etc., which might have resulted in clear but biased trends in variation. This procedure was not taken because the study was attempting to analyze variability of soil properties regardless of their direction. These landscapes are such that variation along the slope is often as great or greater than that found in a perpendicular direction.

This apparently random distribution of variation of most properties is probably due to a combination of three factors. The first is the possibility that any more subtle effects due to distance were masked by large scale geographic variation between delineations. For example in MU33, most delineations were similar in terms of having soils derived from similar rocks, namely basaltic andesites. However, the same types of rocks were deposited over different areas at different times in a series of flows. Flows were often separated by sufficient time to allow extensive weathering and erosion, which makes mapping of geology in this area especially difficult (Maynard, 1974). Therefore, in the eight delineations sampled, there may be represented soils derived from similar rocks, but in three different stages of weathering. The confounding effect of variation between delineations can be seen in Table 19. Even in MU74, where about 12 of 18 properties, on the average, find their

TABLE 19. The Variability of the Numbers of Properties, at Four Separation Distances, where the Maximum and Minimum Change Occurred (18 properties in total).

	Separation Distance (ft.)			
	660	200	60	15
		MU33		
Maximum change				
Mean	5.3	4.7	3.8	4.2
Standard Deviation	2.6	1.8	2.7	3.3
Range	2.5 - 10.0	2.5 - 8.0	0 - 8.0	0 - 9.0
Minimum change				
Mean	3.5	4.3	4.8	5.4
Standard Deviation	1.7	2.0	1.7	1.5
Range	1.0 - 6.3	1.5 - 7.7	2.2 - 8.0	2.8 - 7.0
		MU74		
Maximum change				
Mean	5.9	5.8	4.0	2.3
Standard Deviation	2.9	3.8	1.9	2.1
Range	3 - 11.2	2.7 - 11.3	1.3 - 7.0	0.3 - 4.8
Minimum change				
Mean	2.7	3.6	3.9	7.8
Standard Deviation	1.3	2.1	2.5	2.0
Range	1 - 4.5	0.8 - 6.6	0.3 - 7.0	6 - 10.8

maximum change at 200-660 ft and their minimum change at 15-60 ft, the range of variation in number of properties that achieve maximum change at any given distance is quite large. This trend is also apparent in the relatively large delineation mean squares found for many properties in the analysis of variance (Tables 15 to 16).

A second cause of random variation may be attributed to the sampling plan. Had it been possible to replicate distances within delineations, the effect of the differences between delineations could possibly have been reduced or eliminated entirely. Constraints on the number of possible sites required a compromise between the number of delineations sampled as opposed to the number of sites within a delineation, with the final choice being more delineations. Further refinement of the evaluation of distance would require a study set up specifically to meet that objective with a sampling plan designed to avoid the compromises mentioned above. In addition, the method of calculating differences between sites tended to weight the values obtained in the middle of the transect more than the ends, since they were used more frequently (Beckett and Bie, 1976).

The third reason for random variation may be due to the interaction of soil-forming factors and processes. These processes operate at different spatial scales and with different intensities, such that over any given distance no one process or factor may dominate in determining the level or "state" of a given soil property (Jenny, 1941). The result may be apparent randomization of variation or just the inability to separate and identify individual processes and their effect on properties.

The effect on management of random distribution of variation with distance or direction may be to cause evaluation of sites in terms of the prevalence of the most limiting conditions or properties. If variation could be assumed to be dominantly systematic or directional then the most variable areas might be identified and avoided or managed differently. This would not be the case if random variation were dominant.

Total Variation Within the Soil-Landscape System

Since a mapping unit is defined on the basis of many attributes, some of which are more diagnostic than others, examination of the variation of individual properties or groups of properties is quite useful. Unfortunately, in examining properties singly, relationships between variables are obscured or overlooked, contributions of individual sites or delineations are masked, and trends of variation may not be evident. To better evaluate the "big picture," each mapping unit was analyzed using the multivariate statistical technique of principal components analysis (PCA). The purpose was to look at the variation of the entire system so that the similarities of the 40 soil individuals sampled in each MU could be evaluated and the results of other portions of the study confirmed.

Principal Components Analysis

Explanations of the statistical techniques of PCA are quite intricate. Clear presentations of this and other multivariate methodology, however, as well as its use and applicability in describing soil systems, is given by Webster (1977a) and Norris (1970). In essence, PCA uses the multiple correlations between single variables to create new variables which are linear combinations of the original ones and which are also uncorrelated with each other. Each linear combination consists of the original variables, each with a unique coefficient that represents the amount of that variable's contribution to the overall combination. Since these new variables are uncorrelated, the amount of the total variation in the system that is accounted for by each linear combination can be calculated. Usually the number of new variables, or factors, that are created is much less than the original number, yet the reduced set of factors still accounts for most of the total variation in the system. In addition scores for individuals, which in this study are the 40 soil profiles of each map unit, for each of the factors, can be computed. These scores are based on the values for the original variables found in each profile and the coefficients for these variables in each linear combination. These scores, can then be plotted graphically to show the similarities of the individuals. They can also be used as new observations for the individuals in further analyses.

Twenty-four variables, representing both site properties and soil properties from either or both the A and B horizons, were used for each MU. These variables were chosen after initial PCA runs using all variables indicated that many had little or no correlation with other variables and could be removed from the analysis. The variables used are listed in Tables 20 and 21 along with their coefficients, or loadings, on the first three newly created variables or factors. Variables with loadings greater than $\pm$ 0.40 were arbitrarily chosen as being significant in terms of their contribution to a factor. The PCA analysis used was that offered in the Statistical Package for the Social Sciences (Nie

TABLE 20. Varimax Rotated Factor Loading Pattern for MU74 (% of total variance). * indicates "significant" variables.

Property	Factor 1 (16.4)	Factor 2 (16.3)	Factor 3 (12.2)
Slope	-.12	-.19	*.56
Aspect	.24	-.14	*-.61
Solum Depth	-.07	-.11	*.90
Thickness O	.05	* .52	*.43
Depth to B2	-.11	-.13	*.78
A Horizon			
Clay	*.53	* .46	-.26
Silt	.18	-.16	-.09
Hue	-.24	.36	-.00
Ca	.32	* .81	.29
Mg	*.75	.19	*-.41
OM	-.06	* .88	-.02
CEC	.18	* .91	-.09
Coarse Fragments	-.10	.33	.13
B Horizon			
Clay	*.48	.13	.11
Silt	.06	-.16	-.17
pH	.29	.08	-.20
Hue	.36	.06	.22
Value	.07	.13	-.24
Chroma	.15	-.14	.11
K	.08	* .75	-.05
Ca	*.88	.20	-.21
Mg	*.87	-.20	.02
OM	-.08	.12	-.18
CEC	*.86	.21	.03

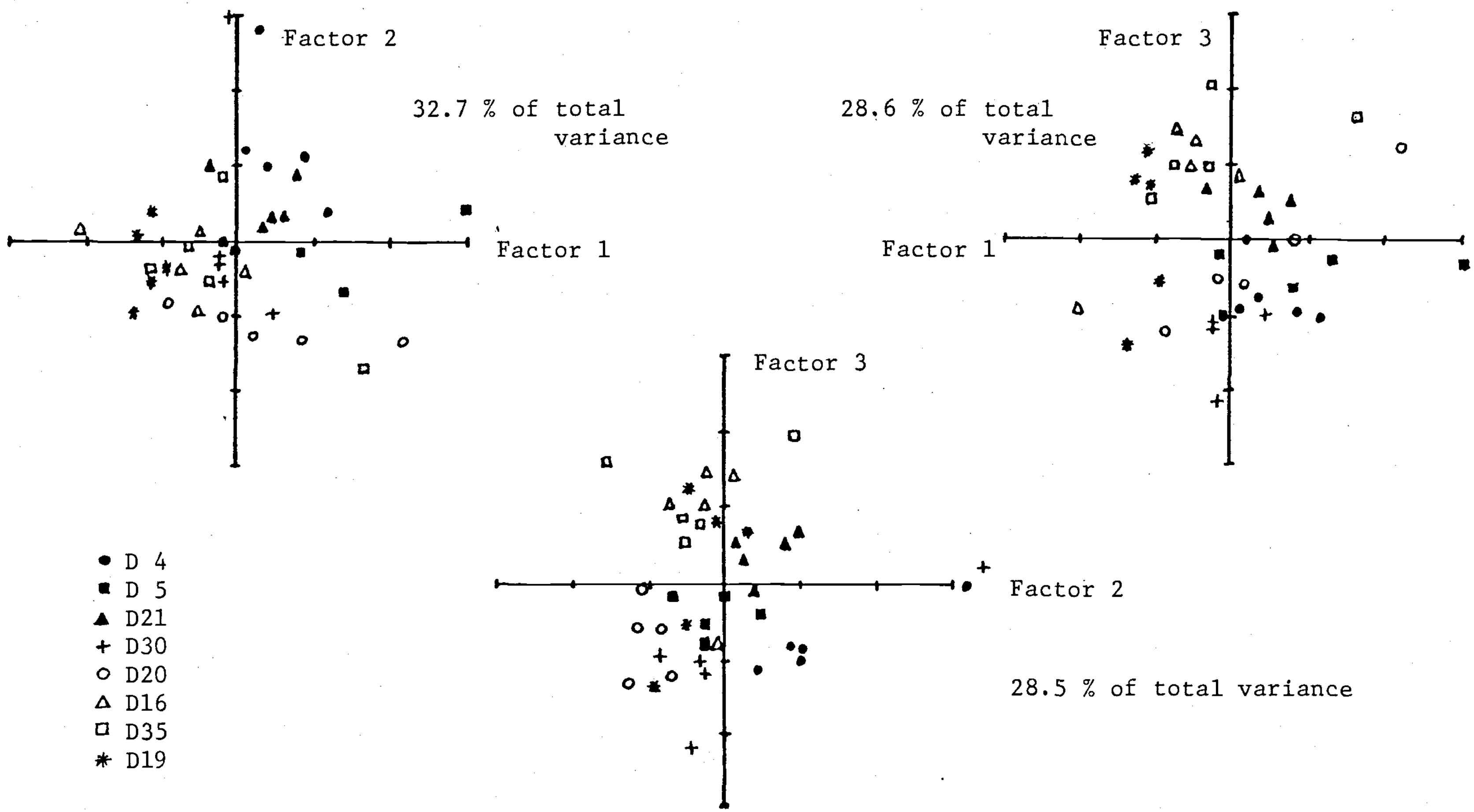


Figure 21. Factor scores for sampling sites in MU 74 plotted on axes of factors 1, 2, and 3.

TABLE 21. Varimax Rotated Factor Loading Patterns for MU33 (% of total variance). *indicates "significant" variables

Property	Factor 1 (23.7)	Factor 2 (13.5)	Factor 3 (11.8)
Slope	*.72	-.36	.13
Aspect	*.63	-.38	.04
Solum Depth	.39	-.03	-.03
A Horizon			
Clay	.39	-.38	*-.68
Hue	-.28	.33	*-.67
Value	-.22	* .70	-.22
Chroma	*-.59	* .42	.14
Coarse Fragments	.01	.10	.17
pH	* .48	-.07	.28
K	* .77	.29	.09
Ca	* .94	.05	-.00
Mg	* .85	.03	-.07
OM	-.03	* .52	.19
CEC	* .61	* .59	-.06
B Horizon			
Clay	.17	.13	*-.68
Value	.17	*-.63	.35
Chroma	*-.52	.25	.25
Coarse Fragments	*-.47	.08	* .69
pH	.14	.32	-.07
K	.23	* .48	-.27
Ca	* .88	.23	.23
Mg	* .81	.22	.14
OM	-.15	.34	* .46
CEC	* .68	* .46	.34

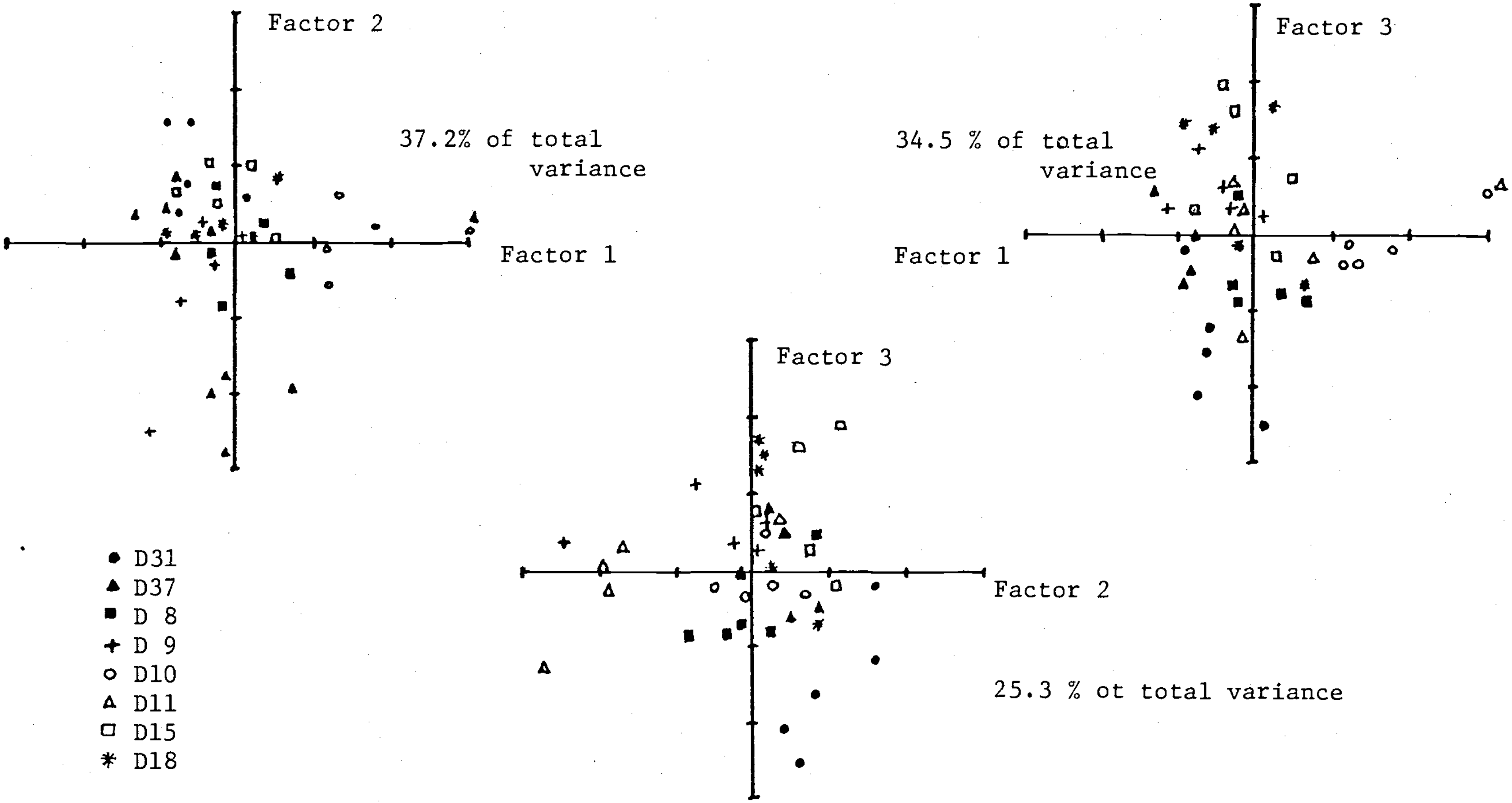


Figure 22. Factor scores for sampling sites in MU 33 plotted on axes of factors 1, 2, and 3.

et al., 1975) and was run on the OSU Cyber 70 model 73 computer. A Varimax method of rotation was employed which modifies the new variables so that correlations between a few original variables are emphasized, and interpretability of the new variables is enhanced.

The first seven new variables created for each MU accounted for 78.5 and 80.7 percent of the total variance of MU33 and 74, respectively, with the first three accounting for 49 and 44.9 percent. This is similar to that reported in other soils studies (Courtney, 1973; Barkham and Norris, 1970) but is not extremely high.

Pedogenic Significance of Factor Loadings

The first factor of MU74 accounted for 16.4% of the total variance, and had high loadings for CEC and extractable Ca and Mg in the B horizons, and Mg in the A horizon. This factor can be interpreted as emphasizing subsoil fertility and the influence of parent material and rock weathering. Mg, which loaded highly in both horizons, suggest the influence of the abundance of base-rich primary minerals such as the amphiboles. In the landscapes of MU74, Mg-rich minerals are lowest in the diorites, intermediate in the metasediments, and high to very high in the metavolcanics and serpentines. Weathering of these rocks releases the Mg to the exchange complex in amounts proportional to the relative abundance in the parent rocks. Sites from delineation 19 (D19), found over hornblende diorite, are clustered around negative values on component 1 (Figure 21), indicating base-poor, less weathered soils. Base-rich, sites from D5, formed from metasediments, possess the most positive values.

Factor 2 strongly emphasizes the base status and fertility of the surface horizon and clearly suggests the influence of vegetation, both on the accumulation of OM on the surface and within the A, and on Ca being recycled and retained more strongly in the upper portions of the profile. K is also recycled through the vegetation, but being more mobile, moves more readily into the B (Lousier and Parkinson, 1979). The plot of factors 1 and 2 (Figure 21) tends to separate the profiles into two groups representing the base-rich, fertile sites in the upper right and the base-poor, less fertile sites in the lower left. This separation tends to correspond to those sites in lower slope positions and bench areas which may receive base-rich water from upslope versus upper slope and ridgetop sites which are more highly leached. Alternatively these lower positions may reflect more effective moisture conditions which allow more vigorous plant growth, greater OM accumulation and base recycling, while the ridgetops are drier and less productive. The separation of the fertility of the subsoil and surface horizons by two factors may indicate a distinction between the soil forming processes responsible for the fertility of the A and B horizons.

Factor 3 loads highly on slope gradient, aspect, solum depth, and the depth to the B2 horizon, and may be interpreted as a landscape factor. When factor 3 is plotted with factor 2 little variation in surface horizon fertility is seen, but two distinct clusters separating the shallower, southerly aspect sites and the depper, northerly aspect sites is evident.

Factor 1 of MU33, accounting for 24% of the total variance (Table 21), emphasized the base status and fertility of the entire solum. This is in contrast to MU74 where subsoil and surface fertility were separated on individual variables. This tends to emphasize the greater uniformity of the parent materials in this mapping unit, at least in terms of their weathering products and composition. Chroma can be correlated with the weathering of the andesitic parent materials. The influence of landscape is also found in this factor through the high loading of slope and aspect. This interpretation is confirmed by the clustering of sites along the axes of factor 1, except for sites from D10 which are distinctly separate and may represent an older, more highly weathered remnant of an earlier period of soil formation (Figure 22). Factor 2, as in MU74, can be interpreted as a vegetation factor, though not as strongly expressed. Organic matter and CEC in the A and subsoil K again suggest the influence of OM on CEC and recycling. Color value is influenced by OM but also by parent material. Delineation 11 stands apart and represents the grayer soils, previously mentioned, which were formed from welded tuffs of the Western Cascades. Factor 3 shows the greatest dispersion among sites. Loading highly on clay in both horizons and coarse fragments and organic matter in the subsoil, this factor may be loosely interpreted as a combination of soil age and physical properties inherited from the parent material in the subsoil.

The sites which are clay-rich and lower in coarse fragments and organic matter in the subsoil (indicated by the negative sign in front of the loading) generally were weathering from tuffs in the subsoil (D15 and 18). Those lower in clay and high in CF were forming in residuum of andesitic gravels and cobbles (MU31). The tuffs may represent an older previous period of deposition and landscape development in that andesitic coarse fragments were rather common in surface horizons but were much more variable in their occurrence in the subsoil.

The plot of factors 2 and 3 is interesting in that the similarities of sites due to fertility have, in effect, been removed, and four somewhat distinct clusters appear which may most clearly portray the differences between delineations due to soil age and parent material (Figure 22). The cluster representing D11 has been previously discussed. The elongate cluster of D31 represents soils formed from the youngest flows in the study area (Maynard, 1974). Profiles in the central cluster, which represent 60% of the sites, are probably forming in two distinct parent materials.

Uniformity of the Map Units

In general, both map units appear to be relatively uniform, for the sites sampled and properties measured. This is indicated by the hyperspherical clustering of sample sites around the origin, when individuals are mapped on the axes of the first two factors. These two factors account for almost 40% of the total variance in both MU (Figures 21 and 22). Courtney (1973) found similar relationships for a mapping unit studied in England. If the classes which were sampled were different mapping units instead of delineations within mapping units, or if delineations did not truly fit the mapping unit concept, separate clusters might be expected. It must be remembered, however, that the relationships pictured on these graphs represent only a portion of the total variance of the system and only for certain properties. If another factor were added and individuals were plotted in three dimensions, the relationships between individuals might be completely different.

The diversity of parent materials, both between and within delineations in MU74, differences in age, stability, and type of surfaces, and climatic variations due to elevational and geographic differences interact to give a picture of a map unit which is uniform only in the sense that it is uniformly variable. Although plots of individuals on axes which represent about 33% of the total variance measured indicate a general uniformity of the mapping unit in terms of fertility (Figure 21), the properties which may more clearly discriminate between delineations and which are important to productivity and management may not have been measured. Waring and Youngberg (1972) have suggested that nutrient status of soils is not as important as moisture and temperature regimes for tree growth in these landscapes. That the morphological and site characteristics, which may indirectly reflect moisture and temperature conditions, produced the most clustering of sites would tend to support their suggestion.

That the landscapes, parent materials, and vegetation of MU33 are generally more uniform than in MU74 is seen in the tighter central clustering of sites around the origin on the plot of Factors 1 and 2 (Figure 21). The sites in MU74 tended to be more scattered with more apparent outliers or unusual profiles. This reinforces the results presented in earlier sections as to the wider range in aspect, greater diversity of type of material and vegetation, and generally greater variability of MU74 as compared to MU33.

Summary

PCA, when applied to 24 variables in the two mapping units under study, extracted factors which were generally interpretable in terms of the factors and processes responsible for soil development in these landscapes. The three interpretable factors for each MU accounted for about 50% of the total variance in the soil properties analyzed, and accurately portrayed the relationships among individuals and delineations within the mapping units. Chemical properties accounted for most of the variation in both MU. Sites in MU74 exhibited greater variability than in MU33 based on greater dispersion among sites ordinated along axes representing chemical properties. Physical and morphological properties tended to produce clustering of sites which indicated differences between delineations for both MU. This supports the conclusions found in other aspects of the study regarding the general variability of properties and the differences between the two mapping units.

SUMMARY AND CONCLUSIONS

The major results and conclusions found as a result of this study of the variability of soil properties of two SRI mapping units are:

A. Individual soil properties exhibited several different types of distributions. Approximately normal and positively skew types were most common. Chemical properties in particular tended to have skewed distributions. The distributions of properties in the subsoil were not always similar to or predictable from those of the surface. Determination of the form of frequency distributions of properties is important in studies of variability as a preliminary means of evaluating the variation of the population and to identify those properties which may require special treatment in order to yield valid results. Assumptions of normality for distributions that are clearly non-normal may lead to substantial errors in estimates of central tendency and variability.

B. Several different statistical descriptions of variability seemed to indicate that, over most properties measured, MU74, located in the Siskyou Mountains, is generally more variable than MU33, located in the Southern Cascade Mountains. This was the original assumption made at the beginning of the study, but the differences in variability between the map units in terms of CV were often less than 15 percentage points. Variability was quantified in terms of the estimates of required sample sizes, ranges and CV. Chemical properties were generally more variable than physical or morphological properties, which were about equal. The most variable chemical properties were extractable bases and organic matter. Coarse fragments and thickness of O horizon were the most variable physical and morphological properties. Least variable were pH, CEC, bulk density, texture, and color.

C. The number of samples needed to estimate the property means for each MU varied considerably depending on the property considered, whether mapping unit means or delineation means are desired, the accuracy required, cost constraints, previous estimates of variability, and the structure of the sampling plan used. In many cases, the number of samples required to estimate means was prohibitively large (e.g. 264 for coarse fragment in surface of MU74). Substantial reduction was achieved by using estimates of within and between delineation components of variance. It is important to rank properties according to their potential significance before sampling, have an idea as to the degree of accuracy that is desirable, and be willing to accept some compromises in the accuracy of highly variable properties.

D. Between 50 and 75% of the total variation in most chemical, physical, and morphological properties of both mapping units occurs within delineations. This result tends to support the validity of the mapping units since the delineations can be considered to be adequately uniform for management purposes, for most of the properties measured in this study.

E. In MU33 depth of solum, percent clay and silt in the A horizon, percent coarse fragments, and OM in the B horizon, and pH, K, Ca, Mg and CEC, value, and chroma in both the A and B had statistically significant differences between delineation means. In MU74 the thickness of the O horizon, depth of solum, depth to the B2, chroma, percent coarse fragments, and pH in the A, value in the B, and percent clay, silt, K, Ca, Mg, and CEC in both horizon had significant F-ratios. In many cases the significant results could be traced to one unusual delineation and the differences were sometimes not of practical significance.

F. An analysis of variance of the changes in the values of selected soil properties as a function of distance within delineations revealed that:

1. large or small changes in the values of most properties were as likely to occur at spacings of 15 ft as at 660 ft.

2. significant differences with distance occurred only for percent slope in both MU, coarse fragments in the A and B horizons of MU74, and organic matter in the A for MU33.

These results are probably due to a combination of three factors.

1. Masking of distance effects by large-scale geographic variation between delineations.

2. The interaction of soil-forming processes over different spatial scales and with varying intensities causing a random distribution of properties, as measured.

3. Use of a sampling plan which was not ideally suited to the identification of distance effects.

G. Soil chemical properties were converted to concentrations on a whole soil basis, taking into account bulk density and percent coarse fragments. Comparison of weight and volume expressions shows that:

1. Chemical concentrations on a volumetric basis are generally greater in MU74 than in MU33. Higher bulk densities and lower amounts of coarse fragments in MU74 account for the difference. However, MU33 would probably have more total nutrients available to plants because of the greater depth of solum.

2. With certain exceptions, these properties are more variable when expressed on a volumetric basis.

3. In MU74, a larger portion of total variation was found between delineations, when chemical properties were expressed volumetrically.

H. The use of Principal Components Analysis (PCA) appeared to effectively group variables in meaningful sets which could be interpreted in terms of soil forming processes. Major sources of variation paralleled that found in other portions of the study. In addition, the relationships between sample profiles and delineations could be accurately represented graphically on axes which represented up to 38 percent of the total variation measured.

I. Specifically identifying sources of variation in both MU was difficult, and especially so in MU74. Possible major sources of variation in MU74 are the sudden changes in the character of parent material over short distances and the variety of geomorphic surfaces of varying age and stability present within the unit as mapped. In MU33 changes in the parent material, especially in the subsoil, and the influence of microrelief may be important sources of variation.

J. In general, although the information derived from this study pertains to more site-specific uses than the mapping units were designed for, this variability information can be useful at both broad planning and site-specific levels:

1. At broad planning levels, land managers, by knowing the range and geographic variation of properties, can make better predictions about the response of mapping units to management.

2. At site-specific levels variability information can be used:

i) to develop more efficient sampling programs

ii) to develop more accurate map unit descriptions

iii) aid in interpretation development

iv) in soil-site studies.

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