# CORRELATION STUDY OF ENGINEERING AND SOIL CHARACTERISTICS IN SELECTED MOLLISOLS

By

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CORRELATION STUDY OF ENGINEERING

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IN SELECTED MOLLISOLS

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# CHAPTER I

# INTRODUCTION

Soil properties measured in the field and in the laboratory are used by soil scientists to interpret soil usage for agricultural and non-agricultural purposes. Engineering properties are measured in the laboratory by engineers for highway construction purposes. Only a very few engineering properties are used by soil scientists, and a few of soil properties are used by engineers. These two kinds of properties may have some usefulness for soil scientists and engineers if they try to use both sets of properties. Knowledge of soils is increasing rapidly and has an important role in economics and planning. Good interpretation of soil properties needs a large amount of information about the soils. Engineering properties may be one type of information that will be needed by the soil scientists for interpreting soil properties. Soil properties such as types of clay and kinds of salt may also be useful for engineers in constructing the highway.

The purpose of this study is to find the similarity among soils by using engineering and soil properties. It is hoped to encourage soil scientists to use more engineering properties and to encourage engineers to use more soil properties.

# CHAPTER II

## REVIEW OF LITERATURE

Taxonomy has been done in many fields of science such as botony, biology, paleontology, and later on, in soil science.

Aristotle was one of the first who tried to classify organisms. He tried to change the old idea that was taught by Plato, his teacher, toward a more absorbing one in both study and recording of natural phenomena (3).

It is very difficult for different scientists to give descriptions exactly alike for the same thing. Pythagorus (582-507 B. C.) attempted to measure and to express the quality of things in numerical terms (3).

Numerical taxonomy, according to Sneath (24) is "the numerical evaluation of the affinity or similarity between taxonomic units and the ordering of these units and into taxa on the basis of their affinity."

It was a worthy attempt to classify things by what they "really are," and to avoid being misled by mere superficial resemblance. Being essentially deductive, however, the attempt failed because it was applied indiscriminately to situations where only inductive treatment was possible. The attempt never predicted adequate criteria for deciding the meaning of the phrase "what things really are" (3).

Taxonomy classification was divided into two groups: natural and artificial classifications. Gilmour (7) attempted to distinguish the two. He stated, "A natural classification of living things is one which groups together individuals having a large number of attributes in common; whereas an artificial classification is composed of groups having only a small number of common attributes. A natural classification can be used for a wide range of purposes, whereas an artificial classification is useful only for the limited purposes for which it was constructed."

According to Heslop and Harrison (9), "a natural classification in the general of taxonomy is something quite different; it is one based upon overall resemblance, the maximum correlation attribute."

Sneath (3) described the principle of natural groups as follows:

1. The ideal "natural" taxonomy is that in which the taxa have the greatest content of information and which are based on as many features as possible.

2. Every feature is of equal weight in constructing "natural" taxa.

3. Overall similarity (affinity) is a function of the proportion of features in common.

4. Affinity is treated as independent of phylogeny.

Bidwell (3) stated that "classification is necessary; but unless you can progress from classification to mathematics, your reasoning will not take you very far."

The chief advantage of numerical taxonomy, according to Sneath and Sokal (24) are repeatability and objectivity. In conventional taxonomy, they felt that these two features leave much to be desired. They believed that identical estimates of the affinity between two organisms on the basis of the same data can be obtained by means of numerical taxonomy. Wide use of quantitative measures of relationship should greatly increase the accuracy and precision of taxonomy.

Cain (4) stated that the development of precise procedures and the employment of non-human computers allow us to hope, at last, for a taxonomic hierarchy having a quantitative basis.

Selecting properties for numerical classification is still an important problem. Then consideration of many characteristics must be evaluated in constructing a classification. This is much harder than the job of considering one, or perhaps two, properties at a time. Marbut (11) said, "It would be unsafe to predict that no other features, not now known, would ever become important as a basis of differentiation." Michener and Sokal (13) concluded that there is no rational way of allocating the weight of features. The significance of the genetic units depends upon their environment, which is always changing.

Seven headings for the arguments of equal weighting follow (24):

1. If it cannot be decided how to weight the features, give them equal weight.

2. To create taxonomy groups, one must decide how to weight the features which are to be employed for classification. No one can make prior judgments on the importance of characteristics.

3. The concept of taxonomic importance has no exact meaning.

4. Differential weighting, if we admit it, must have exact rules for estimation.

5. The nature of taxonomy depends upon its purpose. Natural, or orthodox, taxonomy is a general arrangement.

6. The property of "naturalness" is due to the high content of implied information which is possessed by a natural group.

7. In practice, equal weight methods are used.

They also concluded that equal weighting is the only practical solution which will give a natural taxonomy, and it appears during the mathematical manipulation.

As the knowledge of soil science increases, so will soil classification change. This is accomplished through shifts in the selection and weighting of criteria of differentiating classes and categories. Simonson (18) stated that "the construction of a classification is circumscribed by the knowledge of soils and their genesis held by soil scientists responsible for the scheme." Arkley (2) also stated that "the properties and the weights given to those properties in defining classes change with time. These changes come about for two reasons: first, more information about soils gradually is accumulated; second, more is learned about the significance of the properties and their interaction to soil genesis and utilization."

The various techniques for quantifying similarities or differences among taxa that have been employed by different workers have been grouped by Sokal and Sneath (24) into three types of coefficients: coefficient of association, correlation coefficient, and taxonomic distance. These have been referred to as coefficient of resemblance or similarity.

Jocquard (19) used coefficient of association in ecology. Sneath (19) applied this method to find the similarities in bacteria. The coefficient which Sneath called similarities is the ratio of those features possessed by both individuals being compared to those features possessed by at least one of them. The correlation coefficient was introduced to numerical taxonomy by Michener and Sokal (13) and Sokal and Michener (23) for the study of bees. They adopted the Pearson product-moment correlation. The method was then applied by Morrishima and Oka (15) to the study of rice species.

"When the data are arbitrarily coded and the number of states varies for different characters, the correlation cannot meet the basic assumption of the bivariate normal frequency distribution." To remedy this situation in numerical taxonomy, Sokal (24) proposed the standardization of the characters which means that all characters will now have a mean of zero and a variance of unity. Rohlf and Sokal (16) determined the effect of standardization of characters on coefficient of correlation and distance. They obtained slight differences between standardized and understandardized distances and markedly reduced average correlation for each matrix of coefficients based on standardized characters.

Cluster analysis is to assemble the operational taxonomic units into groups of higher rank using the similarity coefficients (20). There are several methods referred to as cluster analysis. The average linkage was considered as the most satisfactory for clustering (24). They used Spearman's formula for finding the average between the linkage and considered 0.03 as a criteria.

Spearman's formula:

$$r_{qQ} = \frac{\square qQ}{\sqrt{q+2\ q\quad Q+2\ Q}}$$

where $\square qQ$ is the sum of all correlations between members of one group with the other group

$\triangle q$ is the sum of all correlations between the members of the first group

$\triangle Q$ is a similar sum between members of the second group

q is the number of characters in Group 1

Q is the number of characters in Group 2

Cipra, Unger and Bidwell (5) tried to classify soils into nine orders of new classification system. They applied Dixon's decision table technique (6) to the program and used the seventh approximation (21) as a key. They set 23 rules for the classification. All characters were used. A computer program classified these soils into orders, and when the program listed one soil in two orders, the first order that the program gave was used. They concluded that in one order, only a few characters were needed.

Bidwell and Hole (3) set the steps for improving the conventional classification by:

1. using an unprecedented variety of field and laboratory data

2. defining diagnostic soil characteristics with a new level of precision

3. developing an entirely new system of nomenclature for the categories

It is difficult to determine how many characters should be used in numerical taxonomy. Arkley (1) said, "the differentiating characteristics should carry as many as possible for the objective."

Sarkar and Bidwell (14) stated that two closely related characters might exert a double emphasis on a certain property and thus unduly influence a classification. They calculated the correlation among 61 characters for 26 soils of nine orders, and in a series of steps, reduced the level of correlation among the characters by eliminating one of each pair of the most highly correlated characters. They constructed dendrograms based on the resulting groups of characters and eventually reduced the number of characters to 22. From the dendrogram they concluded that many unselected characters may not be superior to fewer, selected through the correlation criterion.

McKeague (12) used correlation coefficient to find the similarities among every pair of 23 characters. He said that among the high correlation pair, one character could be used to estimate the value of another character. He also used the regression equation to estimate the value of C.E.C. from other properties which had high correlation with the C.E.C.

R. J. Arkley (2) used multivariate factor analysis to classify 34 soil properties for 220 Californian soils by using six factors which were selected on the basis of high correlation coefficient. These factors were soil reaction, hue and chroma, texture value and consistency, depth, and mottling. He concluded that the study had shown the feasibility of using the computer to analyze relations between soil properties and selected properties important for a morphological soil classification. He also said that the bias properties could be reduced to a minimum by including as many soil properties as possible in initial analysis of variables, and allowing the computer to select the factor variables.

"Ordination" as defined by Goodall (8) is "an arrangement of units in a uni- or multi-dimensional order." Hole and Hironaka (10) applied ordination techniques to arrange the soils of the Miami family and of 25 representative soils of as many great soil groups of the world. They used 25 soil properties in their classification procedure and presented indices of similarities relating each soil with every other soil. He concluded that ordination could be used to measure quantitatively the interrelationships between great soil groups, and it will hold promise (a) as a means of recording judgments and insights of soil classificationists and geneticists, and (b) as a means of testing those judgments and insights.

# CHAPTER III

## MATERIALS AND METHODS

The physical and chemical properties of some of the soils of Oklahoma studied by soil scientists, published and unpublished, were collected. The engineering properties of these soils were analyzed by the Oklahoma Highway Department and were published in eight divisions. Forty-one soil characteristics were measured in the field and laboratory, and 36 engineering characteristics of 20 soils of order Millisol were used in this study.

Horizon A includes horizon Ap and A1. Horizon A2 is excluded from the calculation because most of the soils lack this horizon. Horizon B includes horizon B1, B2, and B3.

The engineering terms used in this study:

1. Oklahoma Subgrade Index (O.S.I.) - This is a modification of the AASHO group index number which is a relative support value determined by using the percent of soil material passing the No. 200 sieve, liquid limit, and plasticity index in an empirical mathematical formula. This index is used to determine base thickness requirements for roadways.

2. Liquid Limit (LL) - The moisture content,

expressed as a percent of oven dry soil, at which a soil passes from a plastic to a liquid state.

3. Plastic Index (PI) - The numerical difference between liquid limit and plastic limit (LL - PL)

4. Shrinkage Limit - The moisture content, expressed as a percent of oven dry soil, at which a wet soil stops shrinking.

5. Shrinkage Ratio - The volume change, expressed as a percent of the volume of the dried soil pat, divided by the moisture loss above the shrinkage limit, expressed as a percentage of the weight of the dried soil pat.

6. Sieve Analysis - Percent by weight of materials (soils) passing through the sieve openings; sieve numbers represent the number of openings per linear inch.

7. AASHO - American Association of State Highway Officials. A performance value determined by using the percent of soil material passing certain specific sieve sizes, liquid limit, and plasticity index in an empirical mathematical formula. Indicates the suitability of the soil as construction material.

8. Volumetric Change - The change in volume for a given moisture content (expressed as a percentage of the dry volume) of the soil mass when the moisture content is reduced from the stipulated percentage to the shrinkage limit.

TABLE I

ENGINEERING CHARACTERISTICS USED IN THIS STUDY

| No. | Characteristics | Horizon |
|---|---|---|
| 1 | OSI | A |
| 2 | OSI | B |
| 3 | OSI | C |
| 4 | No. 10 sieve* | A |
| 5 | No. 10 sieve | B |
| 6 | No. 10 sieve | C |
| 7 | No. 40 sieve | A |
| 8 | No. 40 sieve | B |
| 9 | No. 40 sieve | C |
| 10 | No. 60 sieve | A |
| 11 | No. 60 sieve | B |
| 12 | No. 60 sieve | C |
| 13 | No. 200 sieve | A |
| 14 | No. 200 sieve | B |
| 15 | No. 200 sieve | C |
| 16 | LL | A |
| 17 | LL | B |
| 18 | LL | C |
| 19 | PI | A |
| 20 | PI | B |
| 21 | PI | C |
| 22 | Shrinkage Limit | A |
| 23 | Shrinkage Limit | B |
| 24 | Shrinkage Limit | C |
| 25 | Shrinkage Ratio | A |
| 26 | Shrinkage Ratio | B |
| 27 | Shrinkage Ratio | C |
| 28 | Volumetric Change | A |
| 29 | Volumetric Change | B |
| 30 | Volumetric Change | C |
| 31 | Stabilization: % Cement | A |
| 32 | Stabilization: % Cement | B |
| 33 | Stabilization: % Cement | C |
| 34 | AASHO** | A |
| 35 | AASHO** | B |
| 36 | AASHO** | C |

* Property No. 4 is excluded from the analysis because no difference in each soil

** The units in AASHO were coded: A-2 = 5; A-4 = 10; A-5 = 15; A-6 = 20; A-7 = 25

TABLE II

SOIL CHARACTERISTICS USED IN THIS STUDY

| No. | Characteristics | Horizon |
|---|---|---|
| 37 | C.E.C. | A |
| 38 | C.E.C. | B |
| 39 | C.E.C. | C |
| 40 | Exchangeable Ca | A |
| 41 | Exchangeable Ca | B |
| 42 | Exchangeable Ca | C |
| 43 | Exchangeable Mg | A |
| 44 | Exchangeable Mg | B |
| 45 | Exchangeable Mg | C |
| 46 | Exchangeable K | A |
| 47 | Exchangeable K | B |
| 48 | Exchangeable K | C |
| 49 | Exchangeable Na | A |
| 50 | Exchangeable Na | B |
| 51 | Exchangeable Na | C |
| 52 | Value | A |
| 53 | Value | B |
| 54 | Value | C |
| 55 | Hue* | A |
| 56 | Hue* | B |
| 57 | Hue* | C |
| 58 | Chroma | A |
| 59 | Chroma | B |
| 60 | Chroma | C |
| 61 | % Sand | A |
| 62 | % Sand | B |
| 63 | % Sand | C |
| 64 | % Silt | A |
| 65 | % Silt | B |
| 66 | % Silt | C |
| 67 | % Clay | A |
| 68 | % Clay | B |
| 69 | % Clay | C |
| 70 | Thickness | A |
| 71 | Thickness | B |
| 72 | O.M. | A |
| 73 | O.M. | B |
| 74 | O.M. | C |
| 75 | pH | A |
| 76 | pH | B |
| 77 | pH | C |

* Hue was code as 5Y = 1, 10 YR = 4, 7.5 YR = 8, 5 YR = 16, 2.5 YR = 32

TABLE III

SOIL SERIES USED IN THIS STUDY

| No. | Soil Series | | |
|---|---|---|---|
| 1 | Okemah[1] | Fine, mixed, thermic | Aquic Paleudolls |
| 2 | Foard[1] | Fine, montomorillonitic, thermic | Typic Natrustolls |
| 3 | Verdigris[1] | Fine-silty, mixed, thermic | Cumulic Hapludolls |
| 4 | Summit[1] | Fine, montmorillonitic thermic | Vertic Argiudolls |
| 5 | Waurika[2] | Fine, montmorillonitic, thermic | Aeric Argialbolls |
| 6 | Bates[1] | Fine-loamy, mixed, thermic | Udic Argiustolls |
| 7 | Shellaberger[1] | Fine-loamy, mixed, thermic | Udic Argiustolls |
| 8 | Newtonia[1] | Fine-silty, mixed, thermic | Typic Paleudolls |
| 9 | Vanoss[3] | Fine-silty, mixed, thermic | Udic Argiustolls |
| 10 | Bethany[4] | Fine, mixed, thermic | Typic Paleustolls |
| 11 | Kingfisher[5] | Fine-silty, mixed, thermic | Udic Argiustolls |
| 12 | Brewer[6] | Fine, mixed, thermic | Pachic Argiustolls |
| 13 | Norge[7] | Fine-silty, mixed thermic | Udic Paleustolls |
| 14 | Zaneis[5] | Fine-loamy, mixed, thermic | Udic Argiustolls |
| 15 | Port[8] | Fine-silty, mixed thermic | Cumulic Haplustolls |
| 16 | Grant[1] | Fine-silty, mixed thermic | Udic Argiustolls |
| 17 | Dennis[1] | Fine, mixed, thermic | Aquic Paleudolls |
| 18 | Renfrow[1] | Fine, mixed, thermic | Udertic Paleudolls |
| 19 | Choteau[1] | Fine, mixed, thermic | Aquic Paleudolls |
| 20 | Kirkland[1] | Fine, mixed, thermic | Abruptic Pachic Paleustolls |

The superscripts are shown in the appendix

## Computing Procedures

The association of soils of order Mollisol were studied in six different ways:

1. all standardized engineering characteristics
2. all standardized soil characteristics
3. all standardized engineering and soil characteristics together
4. some selected standardized soil characteristics that had high correlation to soil characteristics
5. some selected standardized soil characteristics that had high correlation to engineering characteristics
6. the selected standardized engineering and soil characteristics together

The association of soils were computed as shown by the following example using three soil characteristics and three engineering characteristics for five soil series.

Original values of each characteristics were arranged to get a mean and standard deviation as shown by an example in Table A-1.

TABLE A-1

ORIGINAL DATA MATRIX

| Characteristics | Soil Series or Taxonomic Units | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | $\bar{X}_i$ | $S_{xi}$ |
| % Sand | 21.90 | 29.00 | 38.70 | 27.00 | 12.60 | 25.84 | 9.58 |
| % Silt | 62.50 | 57.60 | 43.70 | 49.60 | 64.90 | 55.66 | 8.88 |
| % Clay | 15.60 | 12.40 | 17.60 | 23.40 | 22.50 | 18.50 | 4.33 |
| Liquid Limit | 24.00 | 42.00 | 36.00 | 36.00 | 35.00 | 34.00 | 6.54 |
| Plastic Index | 5.00 | 23.00 | 12.00 | 12.00 | 14.00 | 13.20 | 6.45 |
| Shrinkage Limit | 17.00 | 10.00 | 17.00 | 21.00 | 16.00 | 16.20 | 3.96 |

The standardized values of the characteristics in the taxonomic units were obtained by:

$$Z_{ij} = \frac{X_{ij} - \overline{X}_i}{S_{x_i}}$$

where $Z_{ij}$ is the standardized value of the $i^{th}$ characteristic in the $j^{th}$ taxonomic unit

$X_{ij}$ is the original value of the $i^{th}$ characteristic in the $j^{th}$ taxonomic unit

$\overline{X}_i$ is the mean of the $i^{th}$ characteristic

$S_{x_i}$ is the standard deviation of the $i^{th}$ characteristic

The standardized values of each characteristic are shown in Table A-2.

TABLE A-2

THE STANDARDIZED VALUES OF THE CHARACTERISTICS

| | A | B | C | D | E |
|---|---|---|---|---|---|
| % Sand | - .411 | .329 | 1.342 | .121 | -1.382 |
| % Silt | .770 | .218 | -1.346 | - .682 | -1.040 |
| % Clay | - .669 | -1.177 | .207 | 1.131 | .923 |
| Liquid Limit | -1.620 | 1.131 | .214 | .214 | .061 |
| Plastic Index | -1.271 | 1.519 | - .186 | - .186 | .124 |
| Shrinkage Limit | .202 | -1.565 | .202 | 1.212 | - .050 |

## Clustering Methods

Numerous clustering methods have been applied in numerical taxonomy. In this study the unweight variable-group method was used (24). The first step requires the matrix of correlations using the standardized taxonomic units. These are the correlations between soil series, not the correlations between the characteristics. These correlations are exhibited in Table A-3. The next step in clustering is to find the mutually highest correlations as central points of the clusters to be formed. The mutually highest correlation is the correlation among any two taxonomic units which is higher than the correlation of these taxonomic units with any other taxonomic unit. It is convenient to represent the matrix of correlations in symmetrical form as shown in Table A-3. Next, the highest correlation in the column of each soil series is underlined.

TABLE A-3

THE CORRELATION COEFFICIENTS AMONG TAXONOMIC UNITS FROM IN FULL SYMMETRIC MATRIX (THE HIGHEST COEFFICIENT FOR EACH COLUMN HAS BEEN UNDERLINED)

| | | | | | |
|---|---|---|---|---|---|
| A | X | - .552 | - .389 | - .088 | <u>.217</u> |
| B | - .552 | X | .006 | - .769 | - .193 |
| C | - .389 | <u>.006</u> | X | <u>.361</u> | - .037 |
| D | - .088 | - .769 | <u>.361</u> | X | - .037 |
| E | <u>.217</u> | - .193 | - .918 | - .037 | X |

It was found that A was correlated at 0.217 with E, and the highest correlation of E was also with A. Thus the correlation bwtween A and E was a mutually highest correlation, and A and E would therefore form a cluster. The highest correlation of C was with D, and also D had the highest correlation with C (0.361). Thus C and D formed a cluster.

B had the highest correlation with C (0.006) but C had the highest correlation with C. Therefore C and B was not a mutually highest correlation, and B did not initiate a cluster. Thus at the conclusion of the first clustering cycle, the following clustering was found:

A+E, C+D, B

During one cycle, more than two members are permitted to join the cluster. In unweight variable-group method, a criterion for cluster formation has to be furnished. If adding a new member to a cluster would produce an average correlation between the newcomer and the established cluster lower than the previous level of junction by more than the criterion (in this case 0.060 was used), the prospective member is not admitted. Soil series B was highly correlated with C and it therefore appeared to be a likely candidate for the already established cluster C+D.

$$\text{The average of B with C+D} = \tfrac{1}{2}\,[0.006+(-0.769)] = -0.763$$

The difference from the correlation $r_{CD} = 0.361$ and the average of B with C+D = -0.763 was $r_{CD} - r_{(C+D)B} =$

$$= 0.361-(-0.763) = 1.124$$

This change was greater than 0.060, the established criterion. Thus, during the first clustering cycle, B did not join C + D.

The next clustering cycle, all clusters and unclustered soil series had to be recalculated among themselves. For this, Spearman's sum of variables formula (24) was used.

This formula is:

$$r_{qQ} = \frac{\Box qQ}{q+2\triangle q \quad Q+2\triangle Q}$$

where $\Box qQ$ is the sum of all original correlations between members of one group with the other group

$\triangle q$ is the sum of all correlations between members of the first group

$\triangle Q$ is a similar sum between members of the second group

$q$ is the number of soil series in group 1

$Q$ is the number of soil series in group 2

The computational steps were as follows: considered (A+E) with (C+D).

$$\Box qQ = r_{AC} + r_{AD} + r_{CE} + r_{DE} = -0.389-0.088-0.918-0.037$$

$$= -1.432$$

$$\sqrt{q+2\triangle q} = \sqrt{2+2r_{AE}} = \sqrt{2+2(0.217)} = 1.560$$

$$\sqrt{Q+2\triangle Q} = \sqrt{2+2r_{CD}} = \sqrt{2+2(0.361)} = 1.622$$

$$r_{(A+E)(C+D)} = r_{A'C'} = \frac{-1.432}{1.560 \times 1.622} = -0.565$$

This value was shown in matrix II.

Whenever a cluster and a single soil series is considered, Spearman's formula reduces to:

$$r_{xq} = \frac{\Box xq}{\sqrt{q+2\triangle q}}$$

where the numerator refers to the sum of all correlations of the single soil series, x, with the members of the cluster.

$$r_{(A+E)B} = r_{A'B} = \frac{r_{AB} + r_{BE}}{\sqrt{2+2r_{AE}}} = \frac{-.552 - .193}{1.560}$$

$$= - .477$$

Similarly: $r_{(C+D)B} = -0.470$

These results are exhibited in Matrix II below.

Matrix II

| | A' | B | C' |
|---|---|---|---|
| A' | X | -.477 | -.565 |
| B | -.477 | X | -.470 |
| C | -.565 | -.470 | X |

$$r_{(A+E)(B+C+D)} = r_{A'C'} = \frac{r_{AB} + r_{AC} + r_{AD} + r_{BE} + r_{CE} + r_{DE}}{\sqrt{2+2r_{AE}} \quad \sqrt{3+2(r_{BC}+r_{BD}+r_{CD})}}$$

$$= \frac{-.552 -.389 -.088 -.193 -.918 -.037}{\sqrt{2+2(.217)} \times \sqrt{3+2(.006+(-.769)+.361)}}$$

$$= - \frac{2.177}{1.481}$$

$$= - 1.469$$

This value is shown in Matrix III below.

Matrix III

| | C'' |
|---|---|
| A' | -1.469 |

A' = A+E

C'' = B+C+D

The results of this process could be represented in the Sketch of a Dendrogram, page 24.

## Selecting Characteristics

Each of the characteristics was computed to get a standardized value by using the same procedure as shown before. Then the correlations among the characteristics were computed. Engineering that had correlations 0.50 or higher (as shown in Table IV) to soil characteristics were selected (as shown in Table V). Soil characteristics that had correlations 0.50 or higher to engineering characteristics were selected (as shown in Table VI). The correlations among soil series were obtained. The soils were grouped together by using the same procedure as shown before.

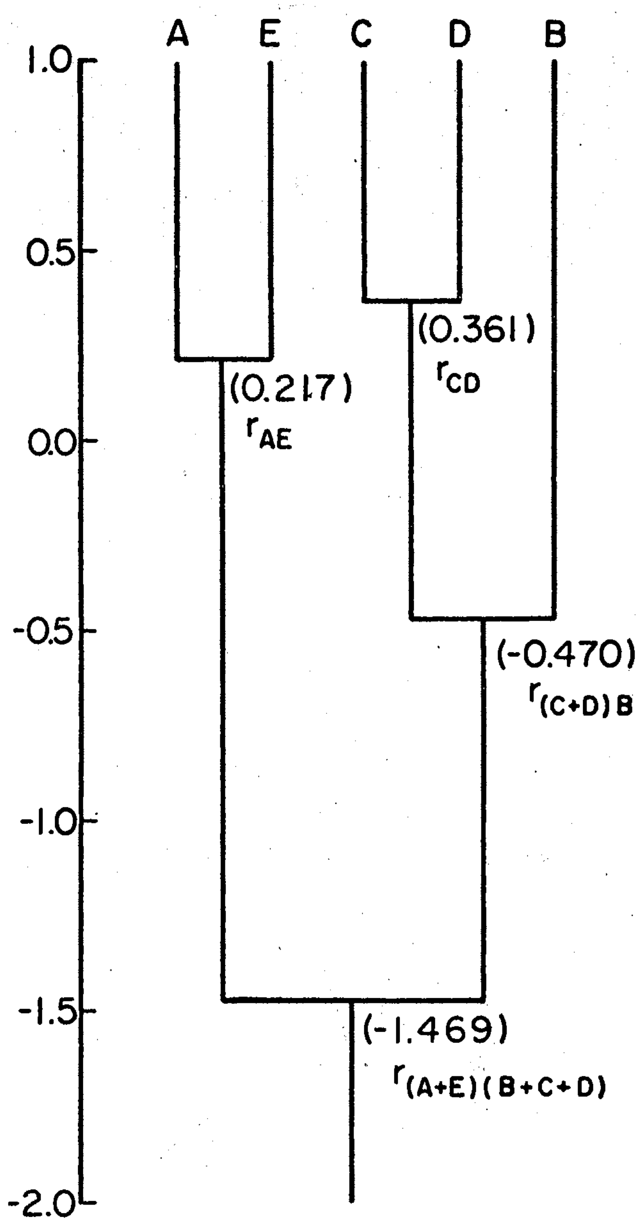
A
E
C
D
B
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
(0.217)
$r_{AE}$
(0.361)
$r_{CD}$
(-0.470)
$r_{(C+D)B}$
(-1.469)
$r_{(A+E)(B+C+D)}$

Figure A-1.

TABLE IV

SOME CORRELATION COEFFICIENTS OF ENGINEERING AND SOIL CHARACTERISTICS THAT HAD HIGH CORRELATION TO EACH OTHER

| | Soil Characteristics | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 48 | 50 |
| 1 | .55 | .49 | .48 | .55 | .61 | .62 | .46 | .32 | .41 | .43 | .09 |
| 2 | .40 | .71 | .62 | .16 | .62 | .61 | .56 | .72 | .71 | .35 | .52 |
| 13 | .31 | .32 | .42 | .33 | .34 | .34 | .31 | .26 | .39 | .18 | .18 |
| 14 | .30 | .36 | .42 | .27 | .31 | .30 | .38 | .33 | .45 | .10 | .23 |
| 15 | .22 | .23 | .32 | .14 | .18 | .22 | .27 | .20 | .34 | .26 | .19 |
| 16 | .66 | .43 | .49 | .65 | .59 | .62 | .34 | .08 | .25 | .48 | -.06 |
| 17 | .45 | .70 | .67 | .20 | .68 | .62 | .49 | .64 | .67 | .44 | .54 |
| 18 | .44 | .47 | .52 | .27 | .51 | .59 | .40 | .38 | .44 | .45 | .20 |
| 19 | .48 | .43 | .35 | .54 | .58 | .53 | .40 | .29 | .29 | .33 | .02 |
| 20 | .29 | .67 | .52 | .08 | .57 | .57 | .51 | .75 | .66 | .26 | .52 |
| 21 | .47 | .60 | .64 | .32 | .59 | .71 | .46 | .52 | .55 | .36 | .35 |
| 22 | .06 | -.28 | -.12 | .18 | -.14 | -.14 | -.21 | -.52 | -.35 | -.19 | -.19 |
| 24 | -.52 | -.59 | -.59 | -.50 | -.74 | -.68 | -.43 | -.43 | -.45 | -.53 | -.44 |
| 26 | .32 | .66 | .53 | .07 | .51 | .54 | .38 | .69 | .60 | .21 | .43 |
| 27 | .49 | .58 | .51 | .43 | .64 | .71 | .36 | .41 | .33 | .37 | .33 |
| 29 | .31 | .59 | .59 | .08 | .57 | .47 | .41 | .59 | .63 | .35 | .51 |
| 30 | .48 | .52 | .67 | .43 | .70 | .66 | .24 | .26 | .38 | .55 | -.17 |
| 31 | .51 | .42 | .35 | .61 | .60 | .49 | .38 | .25 | .26 | .36 | .09 |
| 32 | .44 | .80 | .64 | .16 | .62 | .68 | .64 | .80 | .78 | .35 | .52 |
| 33 | .53 | .60 | .67 | .37 | .56 | .72 | .44 | .42 | .51 | .44 | .23 |
| 34 | .54 | .40 | .30 | .63 | .58 | .53 | .47 | .24 | .21 | .43 | -.06 |
| 35 | .50 | .71 | .62 | .21 | .60 | .57 | .58 | .59 | .67 | .43 | .35 |

TABLE IV (CONTINUED)

| | Soil Characteristics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 51 | 53 | 59 | 64 | 65 | 66 | 67 | 68 | 69 | 77 |
| 1 | .12 | -.30 | -.46 | .37 | .28 | .34 | .56 | .38 | .41 | .38 |
| 2 | .65 | -.37 | -.52 | .37 | .14 | .33 | .36 | .62 | .59 | .47 |
| 13 | .25 | .12 | .02 | .55 | .53 | .52 | .44 | .32 | .40 | .12 |
| 14 | .30 | .10 | -.01 | .61 | .57 | .58 | .40 | .36 | .42 | .13 |
| 15 | .12 | .14 | .13 | .55 | .54 | .44 | .09 | .17 | .20 | -.14 |
| 16 | .02 | -.24 | -.49 | .18 | .15 | .15 | .66 | .34 | .42 | .32 |
| 17 | .68 | -.36 | -.52 | .36 | .14 | .26 | .37 | .64 | .64 | .46 |
| 18 | .27 | -.22 | -.29 | .34 | .23 | .21 | .28 | .40 | .44 | -.02 |
| 19 | .08 | -.42 | -.59 | .18 | .09 | .22 | .58 | .36 | .35 | .51 |
| 20 | .65 | -.41 | -.48 | .23 | -.01 | .23 | .26 | .58 | .52 | .50 |
| 21 | .51 | -.22 | -.39 | .38 | .23 | .30 | .44 | .58 | .67 | .09 |
| 22 | -.15 | .55 | .26 | .13 | .28 | -.00 | .06 | -.26 | -.13 | -.21 |
| 24 | -.51 | .32 | .69 | -.31 | -.18 | -.22 | -.48 | -.46 | -.51 | -.14 |
| 26 | .51 | -.40 | -.55 | .17 | -.06 | .13 | .30 | .65 | .56 | .48 |
| 27 | .41 | -.21 | -.55 | .37 | .21 | .26 | .46 | .54 | .56 | .32 |
| 29 | .66 | -.40 | -.52 | .20 | .01 | .13 | .29 | .54 | .55 | .45 |
| 30 | -.37 | .38 | -.37 | .38 | .22 | .19 | .42 | .54 | .69 | .16 |
| 31 | .05 | -.23 | -.47 | .48 | .39 | .39 | .56 | .35 | .31 | .39 |
| 32 | .62 | -.33 | -.46 | .50 | .26 | .47 | .37 | .74 | .66 | .49 |
| 33 | .41 | -.10 | -.28 | .53 | .41 | .45 | .49 | .65 | .74 | -.08 |
| 34 | -.06 | -.44 | -.59 | .27 | .24 | .24 | .28 | .59 | .29 | .58 |
| 35 | .44 | -.42 | -.54 | .28 | .10 | .32 | .46 | .58 | .55 | .49 |

TABLE V

ENGINEERING CHARACTERISTICS WITH HIGH CORRELATION (0.50 OR HIGHER) TO SOIL CHARACTERISTICS

| No. | Characteristics | Horizons |
|---|---|---|
| 1 | O.S.I. | A |
| 2 | O.S.I. | B |
| 13 | No. 200 sieve | A |
| 14 | No. 200 sieve | B |
| 15 | No. 200 sieve | C |
| 16 | L L | A |
| 17 | L L | B |
| 18 | L L | C |
| 19 | P I | A |
| 20 | P I | B |
| 21 | P I | C |
| 22 | Shrinkage limit | A |
| 24 | Shrinkage limit | C |
| 26 | Shrinkage ratio | B |
| 27 | Shrinkage ratio | C |
| 29 | Volumetric change | B |
| 30 | Volumetric change | C |
| 31 | % Cement | A |
| 32 | % Cement | B |
| 33 | % Cement | C |
| 34 | AASHO | A |
| 35 | AASHO | B |

TABLE VI

SOIL CHARACTERISTICS WITH HIGH CORRELATION (0.50 OR HIGHER) TO ENGINEERING CHARACTERISTICS

| No. | Characteristics | Horizons |
|---|---|---|
| 37 | C.E.C. | A |
| 38 | C.E.C. | B |
| 39 | C.E.C. | C |
| 40 | Exchangeable Ca | A |
| 41 | Exchangeable Ca | B |
| 42 | Exchangeable Ca | C |
| 43 | Exchangeable Mg | A |
| 44 | Exchangeable Mg | B |
| 45 | Exchangeable Mg | C |
| 48 | Exchangeable K | C |
| 50 | Exchangeable Na | B |
| 51 | Exchangeable Na | C |
| 53 | Value | B |
| 59 | Chroma | B |
| 64 | % Silt | A |
| 65 | % Silt | B |
| 66 | % Silt | C |
| 67 | % Clay | A |
| 68 | % Clay | B |
| 69 | % Clay | C |
| 77 | pH | C |

# CHAPTER IV

## RESULTS

The association among twenty soils of order Mollisol by using engineering characteristics, soil characteristics, and engineering and soil characteristics together, were shown in a form of dendrograms by clustering the soils into groups. An unweight variable-group method (24) as described in the example was used.

In every dendrogram, each group of soils was given a grouping number because it would be easier to compare the association of the soils between groups.

The association of soils by using all standardized engineering characteristics were shown in Figure 1. In Group I, Waurika and Renfrow had the highest similarity, which was .672, and then Brewer, Zaneis, Choteau, and Bethany joined the group at .624, .481, .278, and .096 respectively.

In Group II, Okemah and Foard had the highest similarity, which was .723, and were grouped together. Dennis joined this group at .521. Summit and Kirkland joined together at .377 and these two soils joined the first three soils in the same cycle, because the average similarity between three soils with these two soils was .332 which was

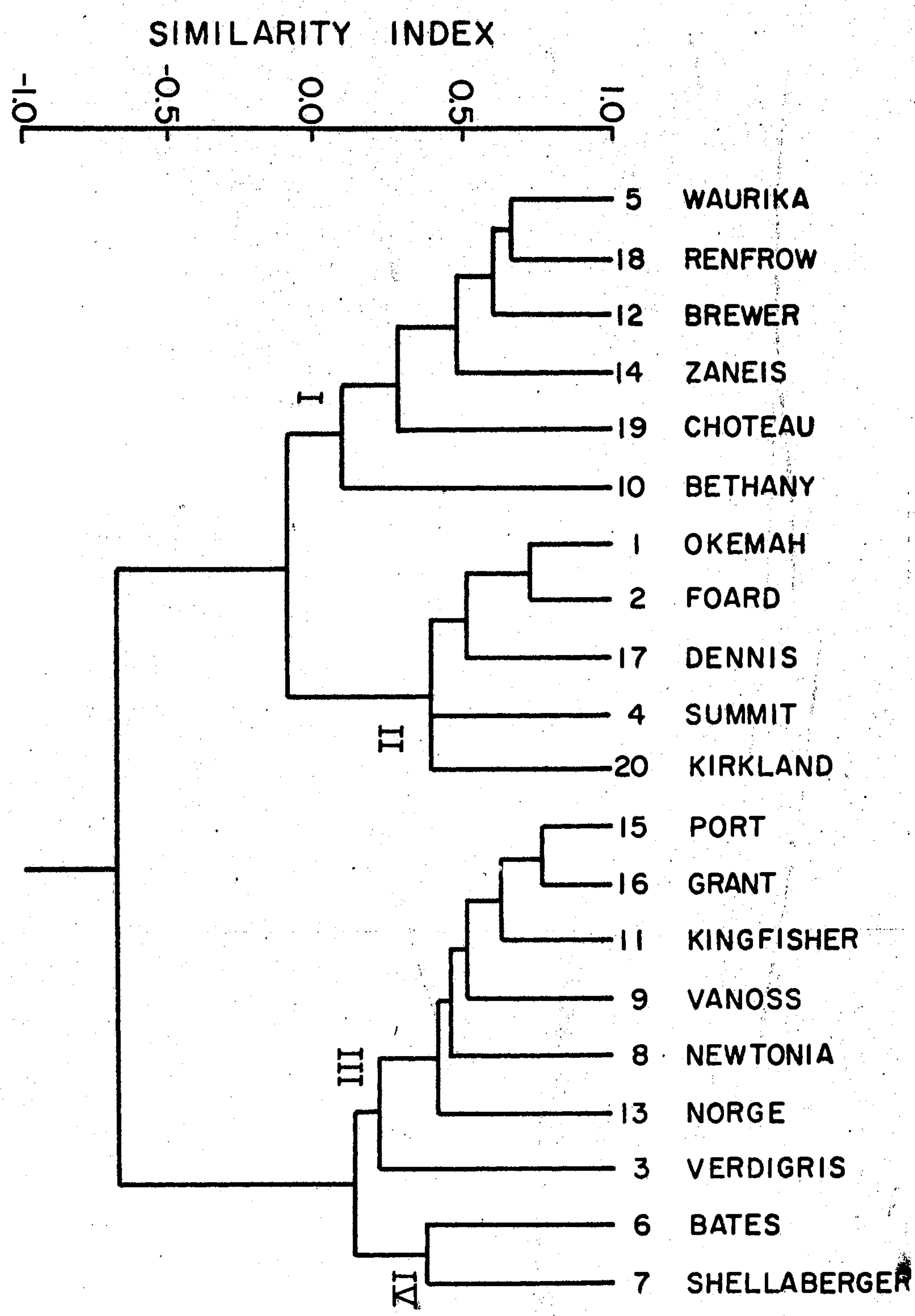


Figure 1. Dendrogram Showing the Association of Soils by Using All Standardized Engineering Characteristics

less than 0.06. Group I and Group II joined together at -,110.

In Group III, Port and Grant had the highest similarity at .754 and then Kingfisher, Vanoss, Newtonia, Norge, Verdigris joined the group at .616, .496, .458, .413, and .219 respectively. In Group IV, Bates and Shellaberger joined together at .351 and then joined Group III at .134. Group I and Group II joined Group III and Group IV at -.686.

The association of soils by using all standardized soil characteristics were shown in Figure 2. Okemah and Dennis joined together in Group I at .371 and also Renfrow was admitted to join this group because the average of Okemah and Dennis to Renfrow was .337, which was less than .06. Bethany and Summit joined together at the similarity index .562. Kirkland joined this group at .443. These two clusters joined together at .359 and Brewer joined these two groups at .341.

In Group II, Port and Verdigris at .356 and then Vanoss and Kingfisher joined this group at .205 and .132 respectively. Group III joined Group I and Group II at -.143. In Group III, Foard amd Waurika joined at .618, Choteau joined Newtonia at .425. These two groups joined at .079.

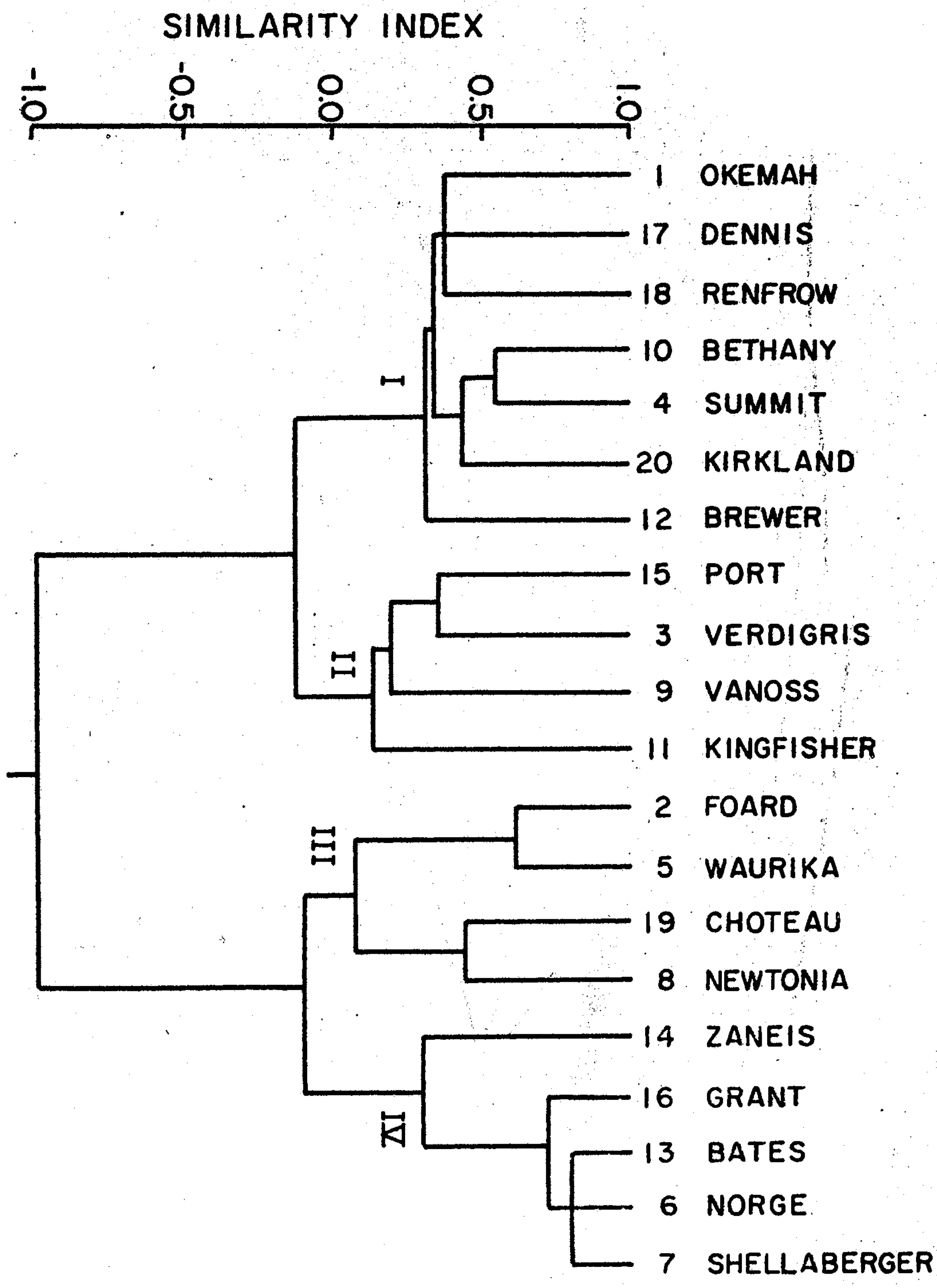


Figure 2. Dendrogram Showing the Association of Soils by Using All Standardized Soil Characteristics

In Group IV, Norge and Shellaberger joined together at .800, and Bates was admitted to join this group in this cycle too, because the average between the similarity of Norge and Shellaberger to Bates was .766, which was less than .06. Grant and Zaneis then joined the group at .735 and .305 respectively. Group III joined Group IV at -.102.

The association of soils by using all standardized engineering and soil characteristics together were shown in Figure 3. In Group I, Brewer and Renfrow joined together at .385 and then Waurika and Zaneis joined this group at .266 and .215 respectively. In Group II, Okemah and Dennis joined together at .435, Foard and Waurika joined together at .355, and then these two groups joined together at .338. Summit and Bethany joined together at .419, and then joined the last two groups at .326. Group I joined Group II at .107.

In Group III, Port and Verdigris joined together at .442, Vanoss and Kingfisher joined together at .204, and then joined the first two soils at .129. Choteau joined this group at -.041.

In Group IV, Grant and Norge joined together at .584, and then Bates, Shellaberger, Newtonia joined this cluster at .526, .454, and .384 respectively. Group III and Group IV joined together at -.050, and then joined Group I and Group II at -.982.

The association of soils by using some selected standardized engineering characteristics that had high correla-

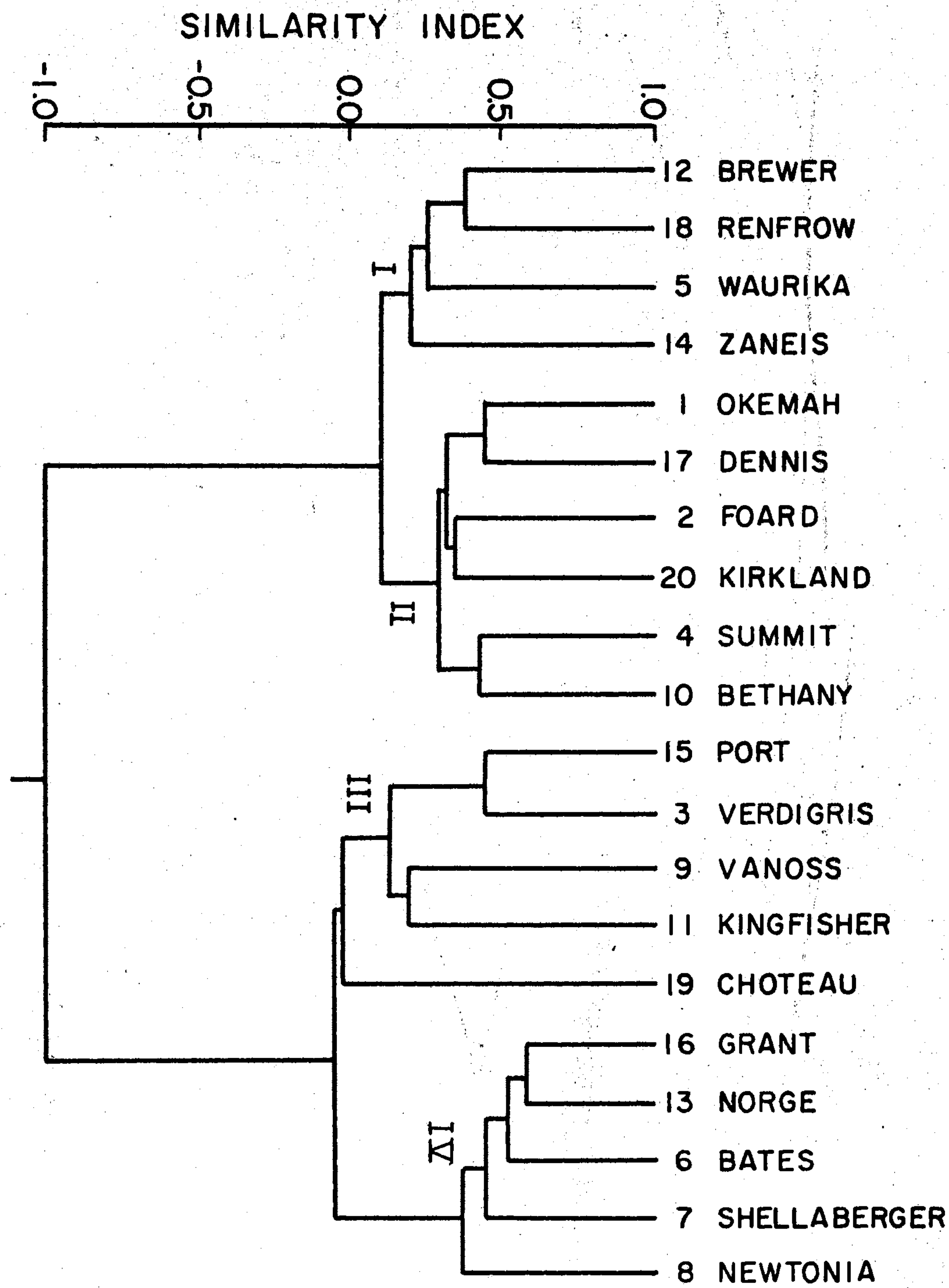


Figure 3. Dendrogram Showing the Association of Soils by Using All Standardized Engineering and Soil Characteristics

tions (0.50 or higher) to soil characteristics were shown in Figure 4. In Group I, Okemah and Foard joined together at .644, and then Kirkland joined this cluster at .575.

In Group II, Waurika and Zaneis joined together at .624 and then Renfrow and Bethany joined these two soils at .589 and .512 respectively. Summit and Brewer joined together at .391 and then joined the group at .333. Group I and Group II joined at -.036.

In Group III, Choteau and Grant joined together at .900 and Vanoss joined Kingfisher at .646. These two clusters joined together at .597, and then joined with Newtonia at .335. Port and Verdigris joined together at .782 and joined the group at .216.

In Group IV, Bates and Shellaberger joined together at .563, and then Dennis and Norge joined the cluster at .332 and .122 respectively. Group III and Group IV joined together at -.116 and then joined Group I and Group II at -.836.

The association of soils by using some selected standardized soil characteristics that had high correlations (0.50 or higher) to engineering characteristics were shown in Figure 5. In Group I, Foard and Waurika joined together at .843. Zaneis and Renfrow joined together at .437, and Kirkland joined this cluster at .417, and then this group joined the first at .219. In Group II, Summit and Bethany joined together at .833 and then Verdigris and Brewer joined this cluster at .354 and .316 respectively. Okemah and

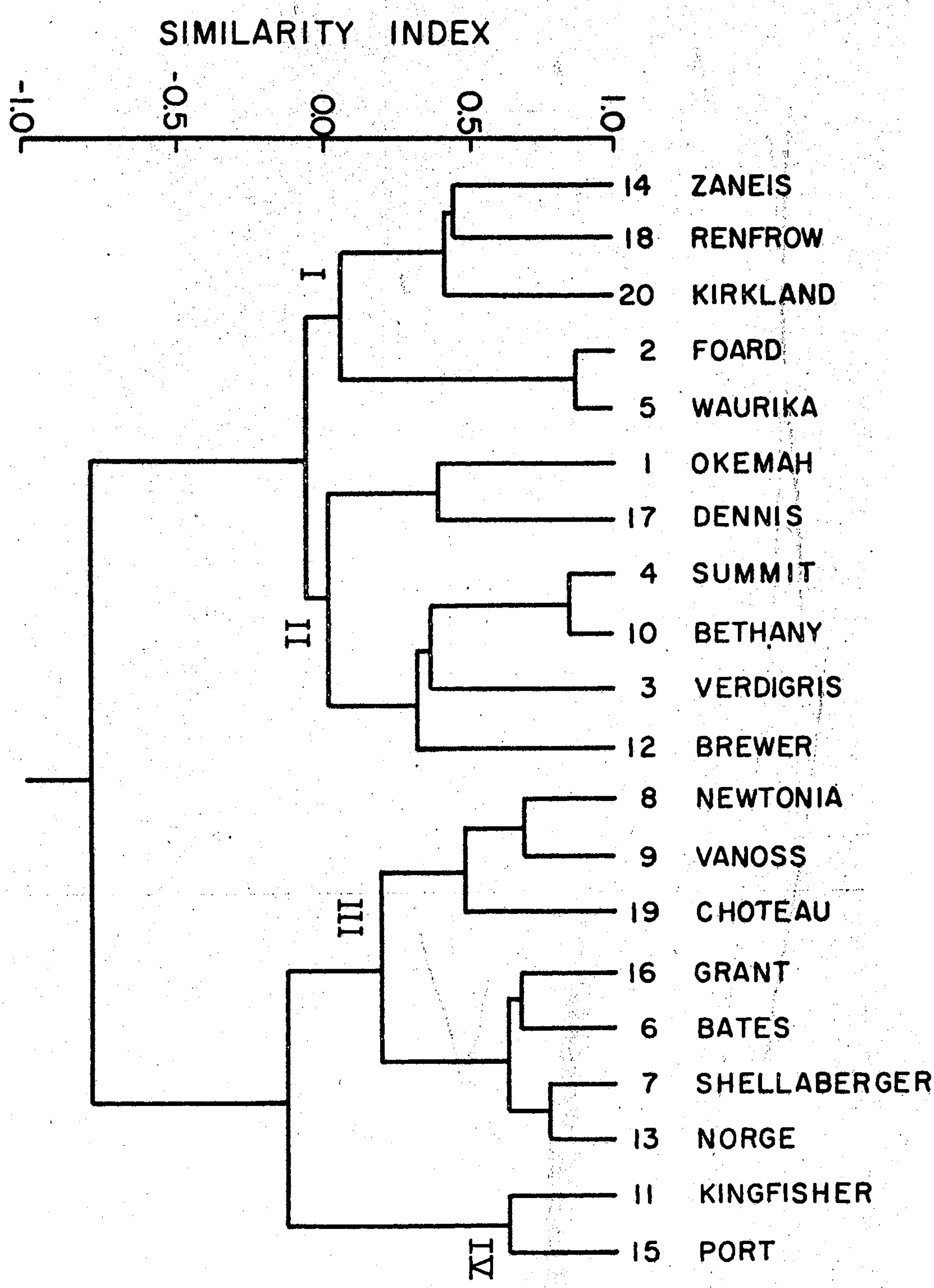


Figure 4. Dendrogram Showing the Association of Soils by Using Some Selected Standardized Engineering Characteristics that had High Correlations to Soil Characteristics

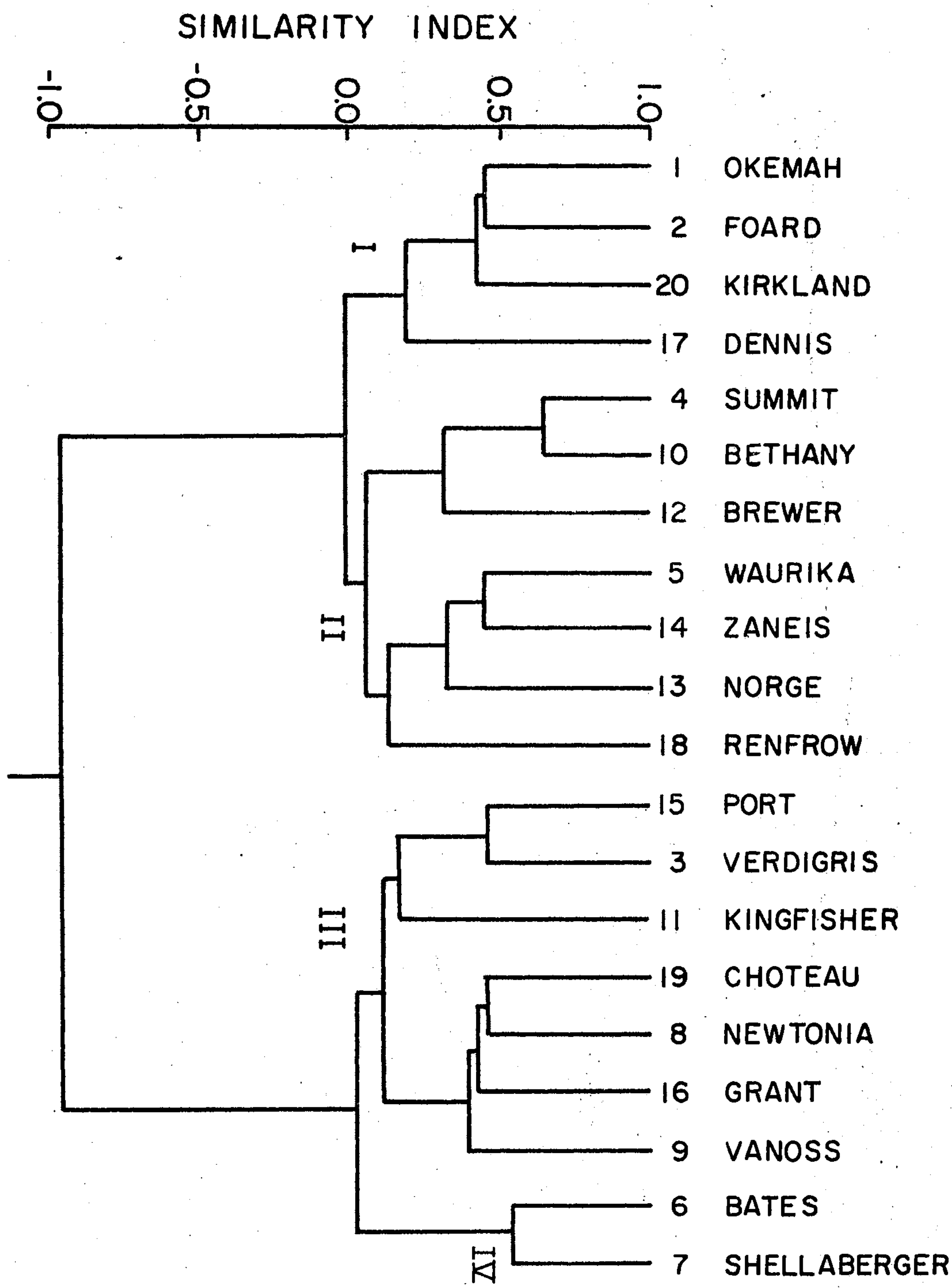


Figure 5. Dendrogram Showing the Association of Soils by Using Some Selected Standardized Soil Characteristics that had High Correlation to Engineering Characteristics.

Dennis joined together at .396 and then joined the group at .040. Group I and Group II joined together at -.063.

In Group III, Newtonia and Vanoss joined together at .688 and Choteau joined this cluster at .465. Norge and Shellaberger joined together at .783, Bates joined Grant at .680. These two clusters met at .644, and then joined the first cluster at .172. In Group IV, Kingfisher and Port joined together at .613 and joined Group III at -.139. Group I and Group II joined Group III and Group IV at -.791.

The association of soils by using those selected standardized engineering characteristics and selected standardized soil characteristics were shown in Figure 6. In Group I, Okemah and Foard joined together at .463 and then Kirkland and Dennis joined this cluster at .457 and .207 respectively.

In Group II, Summit and Bethany joined together at .652 and Brewer joined this cluster at .314. Waurika joined together with Zaneis at .463 and then Norge and Renfrow joined this cluster at .320 and .151 respectively. These two clusters met at .076. Group I and Group II met at -.031.

In Group III, Port and Verdigris joined together at .471 and then Kingfisher joined this cluster at .197. Newtonia joined Choteau at .475, Grant and Vanoss joined this cluster at .431 and .412 respectively. These two clusters joined together at .227.

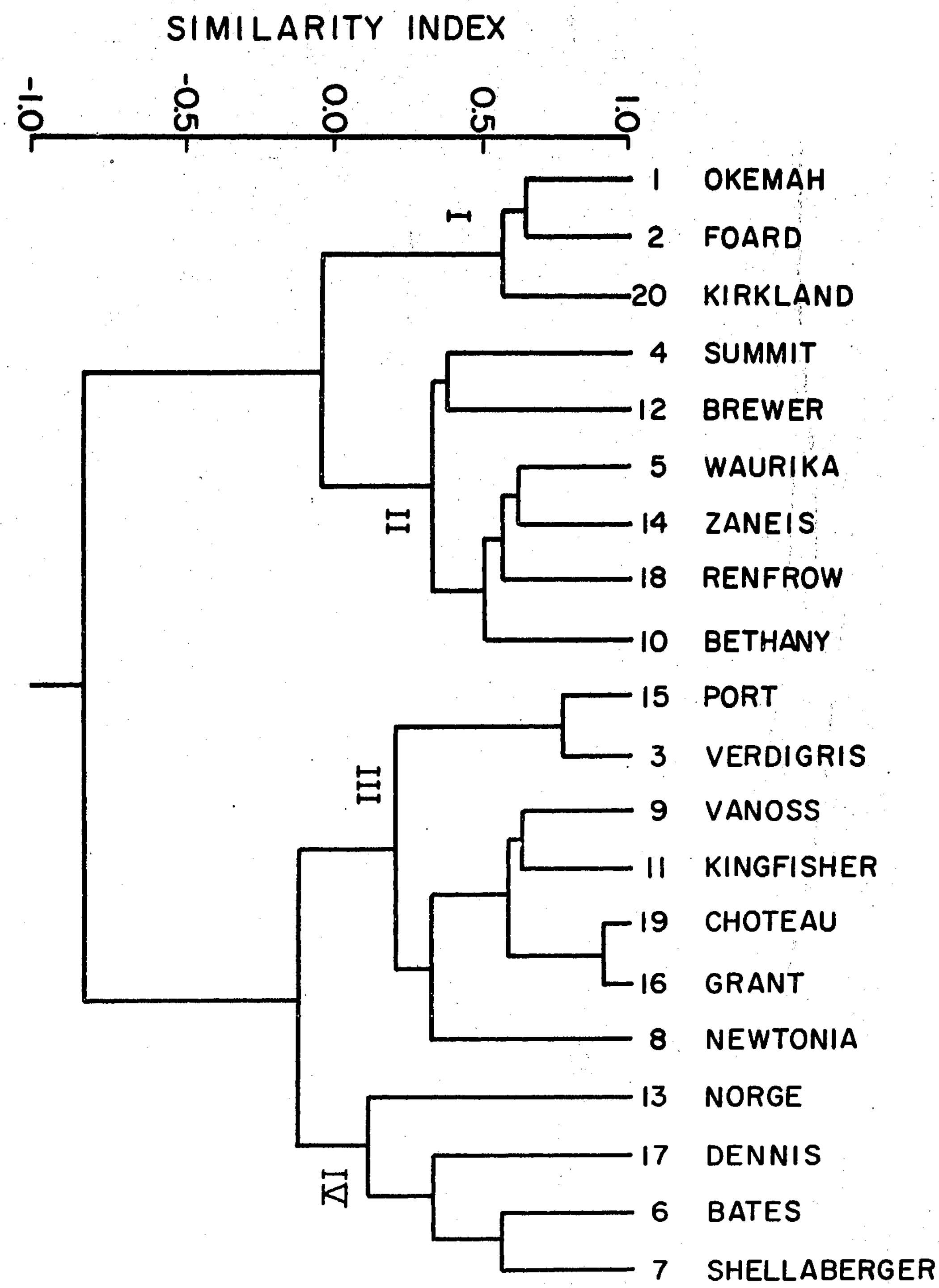


Figure 6. Dendrogram Showing the Association of Soils by Using Selected Engineering and Soil Characteristics that had High Correlations to Each Other

In Group IV, Bates and Shellaberger joined together at .566. Group III met Group IV at .072, and then these two groups joined Group I and Group II at -.937.

# CHAPTER V

## DISCUSSION AND CONCLUSIONS

Soil quality and management groups of the soils (as shown in Table VII) and are divided into four groups by their similarities in qualities and managements. The groups of soil quality and management are used as reference to find the agreement, or disagreement, of these groups with the groupings in the dendrograms. Each group of the soils is denoted by giving it a number, I to IV. The deviation of the soil in the group of the dendrogram from the group in the reference is measured. For an example, Dennis is in Group II of the reference, and is in Group III of Dendrogram I. The deviation of Dennis soil between the group in the reference and the group in the dendrogram equals 1. If Dennis is in Group IV in Dendrogram II, the deviation of Dennis between the group in the reference and the group in Dendrogram II is 2. Total deviations or disagreements of the soils in every group of each dendrogram (as shown in Table VIII) are used to compare the agreement and disagreement between the groups of the soils in one dendrogram with that of the reference groups.

TABLE VII

SOIL QUALITY AND SOIL MANAGEMENT GROUPS
FOR THE SELECTED MOLLISOLS

| Soil Series | Range Site | Permeability | Land Capability Class |
|---|---|---|---|
| Foard | Claypan prairie | Very slow | IIs |
| Waurika | Claypan prairie | Very slow | IIs |
| Renfrow | Claypan prairie | Very slow | IIs |
| Kirkland | Claypan prairie | Very slow | IIs |
| Brewer | Claypan prairie | Very slow | IIs |
| Bethany | Loamy prairie | Slow | I |
| Summit | Loamy prairie | Slow | IIw |
| Dennis | Loamy prairie | Slow | I |
| Okemah | Loamy prairie | Slow | I |
| Zaneis | Loamy prairie | Slow | I |
| Choteau | Loamy prairie | Moderately slow | I |
| Vanoss | Loamy prairie | Moderately slow | I |
| Norge | Loamy prairie | Moderately slow | I |
| Kingfisher | Loamy prairie | Moderately slow | I |
| Newtonia | Loamy prairie | Moderately slow | I |
| Bates | Loamy prairie | Moderate | I |
| Grant | Loamy prairie | Moderate | IIe |
| Verdigris | Loamy bottom land | Moderate | I |
| Port | Loamy bottom land | Moderate | I |

TABLE VII (CONTINUED)

| Soil Series | Wheat Productivity (Bu/A) | Similar Management Groups |
|---|---|---|
| Foard | 20 | I |
| Waurika | 23 | I |
| Renfrow | 26 | I |
| Kirkland | 27 | I |
| Brewer | 23 | I |
| Bethany | 33 | II |
| Summit | 34 | II |
| Dennis | 32 | II |
| Okemah | 34 | II |
| Zaneis | 26 | II |
| Choteau | 30 | III |
| Vanoss | 31 | III |
| Norge | 27 | III |
| Kingfisher | 31 | III |
| Newtonia | 34 | III |
| Bates | 24 | IV |
| Grant | 30 | IV |
| Shellaberger | 22 | IV |
| Verdigris | 38 | IV |
| Port | 33 | IV |

A range site is an area of rangeland sufficiently uniform in climax, soils, and topography to produce a particular climax, or original, vegetation.

Permeability is the quality of soil that enables to transmit water or air. It can be measured quantitatively in terms of rate of flow of water through a unit cross section of saturated soil in unit time, under specified temperature and hydraulic conditions. In this study the least permeable layer was used.

The capability classification is one of interpretive groupings made primarily for agricultural purposes. The soils are grouped according to their potentialities and limitations for sustained production of the common cultivated crops that do not require specilized site and conditioning or site treatment.

Subclasses:

e - erosion hazard

w - wetness

s - root zone limitations

Yields are taken from "Productivity of Key Soils in Oklahoma" by Fenton Gray, Department of Agronomy, Bulletin B-650, October 1966, 30 p.

TABLE VIII

CLASSIFICATION BY GROUPS OF THE SOILS IN EACH DENDROGRAM WITH THE SOIL QUALITY AND MANAGEMENT GROUPS

| Soil Series | Table VII | Fig. 1 | Fig. 2 | Fig. 3 | Fig. 4 | Fig. 5 | Fig. 6 |
|---|---|---|---|---|---|---|---|
| Foard | I | II | III | II | I | I | I |
| Waurika | I | I | III | I | II | I | II |
| Renfrow | I | I | I | I | II | I | II |
| Kirkland | I | II | I | II | I | I | I |
| Brewer | I | I | I | I | II | II | II |
| Bethany | II | I | I | II | II | II | II |
| Summit | II | II | I | II | I | II | II |
| Dennis | II | II | I | II | IV | II | I |
| Okemah | II | II | I | II | II | II | I |
| Zaneis | II | I | IV | I | II | I | II |
| Choteau | III | I | III | III | III | III | III |
| Vanoss | III | III | II | III | III | III | III |
| Norge | III | III | IV | IV | IV | III | II |
| Kingfisher | III | III | II | III | III | IV | III |
| Newtonia | III | III | III | IV | III | III | III |
| Bates | IV | IV | IV | IV | IV | III | IV |
| Grant | IV | III | IV | IV | III | III | III |
| Shellaberger | IV | IV | IV | IV | IV | III | IV |
| Verdigris | IV | III | II | III | III | II | III |
| Port | IV | III | II | III | III | IV | III |
| Weighted Number of Disagreements with Reference Groupings | 0 | 9 | 17 | 7 | 10 | 8 | 9 |

In Figure 1, the association of soils by using all standardized engineering characteristics is shown. In Group I, Waurika, Renfrow, and Brewer are also in Group I of the reference, so there is no deviation of these soils between the reference and the dendrogram. Zaneis and Bethany are in Group II of the reference, the deviations of each soil equal to 1. Choteau is in Group III of the reference, so its deviation between the dendrogram and the reference is 2. The total deviation of the soils in Group I of Dendrogram I from the reference is 4. In Group II, Okemah, Dennis, and Summit are also in Group II of the reference and the dendrogram. Foard and Kirkland are in Group I in the reference, the deviation of each soil equals 1. Total deviation of the soils in Group II is 2. In Group III, there is no deviation of Kingfisher, Vanoss, and Norge from the groups in the reference. Port, Grant, and Verdigris are in Group IV in the reference, the deviation of each soil equals to 1. The total deviation of the soils in this group is 3. In Group IV, there is no deviation of the soils in this group, because Bates and Shellaberger are in Group IV in the reference. The total deviation or disagreement of the soils in Figure 1 is found to be 9.

In Figure 2, the association of soils by using all standardized soil characteristics is shown. In Group I, Renfrow, Kirkland, and Brewer are also in Group I in the reference, so there is no deviation of these soils. Okemah, Dennis, Bethany, and Summit are in Group II in the reference, the deviation of each of these soils equals to 1. Total of the deviation of the soils in Group I is 4. In Group II, Port and Verdigris are in Group IV in the reference, so their deviations of each equal to 2. Vanoss and Kingfisher are in Group III in the reference, the deviations of each soil equal to 1. Total of the deviation of the soils in this group is 6. In Group III, Foard and Waurika are in Group I in the reference, so the deviation of each of these two soils equals to 2. There is no deviation of Choteau and Newtonia, because they are also in Group III in the reference. Total of the deviations of the soils in Group III is 4. In Group IV, Zaneis is in Group II in the reference, so the deviation of this soil equals to 2. Norge is in Group III in the reference; its deviation is 1. There is no deviation of Grant, Bates, and Shellaberger from the reference. Total deviations of the soils in Group IV is 3. When comparing the disagreement in Figure 2 with the reference, it is seen that the total of the weighted deviations is 17.

In Figure 3, the association of soils by using all standardized engineering and soil characteristics together is shown. In Group I, there is no deviation of Brewer, Renfrow, and Waurika from the reference. Zaneis is in Group II in the reference, so its deviation is 1. Total deviation of the soils in Group I equals to 1. In Group II, there is no deviation of Okemah, Dennis, Summit, and Bethany, because they are also in Group II in the reference.

Foard and Kirkland are in Group I in the reference, so the deviation of each soil equals to 1. Total of the deviation of the soils in Group II is 2. In Group III, Port and Verdigris are in Group IV in the reference, so the deviation of each soil equals to 1. There is no deviation of Vanoss, Kingfisher, and Choteau, because they are also in Group III in the reference. Total of the deviation of the soils in Group III is 2. In Group IV, Norge and Newtonia are in Group III in the reference, so the deviation of each soil is 1. There is no deviation of Grant, Bates, and Shellaberger from the reference. Total of the deviation of the soils in Group IV is 2. The total of these deviations in Figure 3 is found to be 7.

In Figure 4, the association of soils by using some selected standardized engineering characteristics is shown. In Group I, the deviation of Okemah is 1, because Okemah is in Group II in the reference. There is no deviation of Foard and Kirkland, because they are also in Group I in the reference. Total of the deviation of the soils in Group I is 1. In Group II, there is no deviation of Summit, Zaneis, and Bethany because they are also in Group II in the reference. Brewer, Waurika, and Renfrow are in Group I in the reference, so the deviation of each soil is 1. Total of the deviation of the soils in Group II is 3. In Group III, there is no deviation of Vanoss, Kingfisher, and Choteau from the reference. Port, Verdigris, and Grant are in Group IV in the reference, the deviation of each soil is 1.

Total deviation of the soils in Group III is 3. In Group IV, there is no deviation of Bates and Shellaberger from the reference. Norge is in Group III in the reference, so its deviation is 1. Dennis is in Group II in the reference, so its deviation is 2. Total deviation of the soils in Group IV is 3. The total deviation or disagreement of the soils in the groups of Figure 4 is found to be 10.

In Figure 5, the association of soils by using some selected standardized soil characteristics is shown. In Group I, there is no deviation of Renfrow, Kirkland, Foard, and Waurika. Zaneis is in Group II in the reference, so its deviation is 1. Total of the deviation of the soils in Group I is 1. Group II, there is no deviation of Okemah, Dennis, Summit, and Bethany from the reference. Verdigris is in Group IV in the reference, so its deviation is 2. Brewer is in Group I in the reference, so its deviation is 1. Total of the deviation of the soils in Group II is 3. In Group III, there is no deviation of Newtonia, Vanoss, Choteau, and Norge from the reference. Grant, Bates, and Shellaberger are in Group IV in the reference, so the deviation of each soil is 1. Total of the deviation of the soils in Group III is 3. In Group IV, there is no deviation of Port from the reference. Kingfisher is in Group III in the reference, so its deviation is 1. Total deviation of the soils in Group IV is 1. The total deviation or disagreements of the soils in the groups in Figure 5 is found to be 8.

In Figure 6, the association of soils by using selected standardized engineering and soil characteristics is shown. In Group I, there is no deviation of Foard and Kirkland from the reference. Okemah and Dennis are in Group II in the reference, so the deviation of each soil is 1. Total of the deviation of the soils in Group I is 2. In Group II, there is no deviation of Summit, Bethany, and Zaneis from the reference. Brewer, Waurika, and Renfrow are in Group I in the reference, so the deviation of each soil is 1. Norge is in Group III in the reference; the deviation of Norge is 1. Total of the deviation of the soils in Group II is 4. In Group III, there is no deviation of Kingfisher, Choteau, Newtonia, and Vanoss. Port, Verdigris, and Grant are in Group IV in the reference, so the deviation of each soil is 1. Total of the deviation of the soils in Group III is 3. There is no deviation of the soils in Group IV. The total deviation or disagreement of the soils in the grups in Figure 6 is found to be 9.

The weighted number of disagreements in Figure 1, that showing the association of the soils by using all standardized engineering characteristics, is found to be 9. The weighted number of disagreements in Figure 5, that using some selected standardized engineering characteristics, is found to be 10. The soils in the groups in both dendrograms show a consistence of the soils in the groups. In Figure 1, only one soil, Choteau, deviates from the reference groups more than one group. Also in Figure 2, one soil, Dennis, deviates from the reference group more than one group. The weighted number of disagreements of the soils in Figure 2, that the association of the soils by using all standardized soil characteristics, with the reference groups is found to be 17. Five soils in this dendrogram deviate from the reference groups more than one group. Total deviation of the soils in this dendrogram from the reference is found to be the highest. This result may be influenced by closely related characters that might exert a double emphasis on a certain property and thus influence the classification (17). The weighted number of disagreements in Figure 5, that the association of soils by using some selected standardized soil characteristics, with the reference groups is found to be 8. Only one soil, Verdigris, deviates from the reference more than one group. The weighted number of disagreements of the soils in Figure 3, that the association of soils by using all standardized engineering and soil characteristics together, with the reference is found to be 7. The weighted number of disagreements in Figure 6, that the association of soils by using some selected standardized engineering and soil characteristics, with the reference is found to be 9. These two dendrograms show the most consistence of the soils in the groups. No soils deviate from the reference more than one group.

This study shows that using both engineering and soil characteristics gave the most consistence in grouping the soils when comparing the soils in the groups in the dendrograms with the groups of the soils in the reference. Using all engineering and soil characteristics together gave the best agreement between the soils in the groups in the dendrogram and the soils in the reference groups. Large numbers of soils, covering a wider range of the soils of Mollisol order and from the other order such as Inceptisol, Alfisol, are needed for further study to confirm this result.

This study is only a preliminary study of engineering and soil characteristics in interpretation of the soils. It cannot confirm what set of the characteristics will give results in grouping the soils for interpretational purposes. And it cannot really confirm that this result will give an accurate conclusion until more samples, covering a wider range of the soils in order Mollisol, and from the others such as Inceptisol, Alfisol. Soil scientists and engineers should collect their samples from the same sites, typical for the soils being studied and perhaps at the same time. Results should go to the computer for storage for future use both by engineers and agronomists for predicting better use of the soils.

# CHAPTER VI

## SUMMARY

The association of 20 soils of order Mollisol in Oklahoma were made using six different sets of characteristics: all standardized engineering characteristics, all standardized soil characteristics, all standardized engineering and soil characteristics together, some selected standardized engineering characteristics that had high correlations (0.50 or higher) to soil characteristics, some selected standardized soil characteristics that had high correlations (0.50 or higher) to engineering characteristics, and some selected standardized engineering and soil characteristics together. The results of the association of the soils were shown in dendrograms.

The similarities of soil quality and management groupings were used to find the number of disagreements of the soils in the groups in the dendrograms. Using all standardized engineering characteristics gave less number of disagreements of the soils than those that used some selected standardized engineering characteristics. Using some selected standardized soil characteristics gave less number of disagreement of the soils, which was about half of that by using all standardized soil characteristics. The number of disagreements of the soils in dendrogram that using some selected standardized soil characteristics was less than those when using all standardized engineering characteristics. Using all standardized engineering and soil characteristics together gave the best agreement of the soil grouping with the soil quality and management groups.

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# APPENDIX

## SOURCES OF SOIL CHARACTERISTICS


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