CORRELATION OF ENGINEERING AND SOIL CHARACTERISTICS IN SELECTED MOLLISOLS

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Thirty-six standardized engineering and 41 standardized soil characteristics of 20 Oklahoma soils of the order Mollisol were used in a study of the numerical classification of the soils. Soil quality and management groups were compared as to the agreement or disagreement of these soil groups with those in the dendrograms. It was found that regardless of whether all the engineering characteristics or only certain selected engineering characteristics were used, there was little difference in the resulting weighted number of disagreements. Application of some selected soil characteristics gave better agreement with the reference groups than did use of all soil characteristics. Combined use of all engineering and soil characteristics gave the best agreement.

The number and kind of soil characteristics used in the numerical classification of soils are still an important problem for soil scientists. Sokal and Sneath (1) stated that, in numerical taxonomy, the characteristics used should be as numerous as possible, free of interinfluences, and treated as equally important. Arkley (2) said that bias properties could be reduced to a minimum by including as many soil properties as possible in initial analysis of variables and by allowing the computer to select the factor variables.

Soil characteristics, but not engineering characteristics, have been used by several workers (2-6) in numerical classification of soils. Engineering characteristics may include information that will be valuable in the numerical classification if it is to be interpreted for better soil usage and management. The purpose of this study was to introduce engineering characteristics into the numerical classification of soils for such interpretational purposes.

MATERIALS AND METHODS

Thirty-six engineering characteristics (Table 1) analyzed by the Oklahoma Highway Department and 41 soil characteristics (Table 2) of 20 Mollisols (Table 3) in Oklahoma were used in this study. Horizon A includes A1 and A2. Horizon A2 is excluded from the analysis because most of the soils lack this horizon. Horizon B includes B1, B2, and B3.

All 77 characteristics were standardized which made them have a mean of zero and standard deviation as a unity.

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

$$Z_{ij} = \frac{X_{ij} - \bar{X}_i}{S_{X_i}} \qquad \text{Eq. 1}$$

where

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

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

$\bar{X}_i$ = the mean of the i^{th} characteristic

S_{X_i} = the standard deviation of the i^{th} characteristic

Then the correlation coefficients among soil series were computed. The soils were grouped together by their numerical relationships. For this Spearman's sum of variables formula (Equation 2 below) was used (1).

Eq. 2

$$r_{qQ} = \frac{\Sigma qQ}{\sqrt{a+2\Delta p}\,\sqrt{Q+2\Delta Q}}$$

where

ΣqQ = the sum of original correlations between members of one group with the other group

Δq = the sum of correlations between members of the first group

ΔQ = a similar sum between members of the second group

q = the number of soil series in group 1

Q = the number of soil series in group 2

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

Eq. 3

$$r_{xq} = \frac{\Sigma xq}{\sqrt{q+2\Delta q}}$$

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

Selecting characteristics

Each of the characteristics was computed to get a standardized value. Then the correlations among the characteristics were computed. Engineering properties with high correlation (0.50 or higher) to soil characteristics were selected, as shown in Table 4. Soil characteristics that correlated well with engineering characteristics were selected, as shown in Table 5. The correlations among soil series were obtained, and soils were grouped according to the same procedure as described above.

RESULTS AND DISCUSSION

Soil qualities and managements in Table 6 are divided into four groups by their similarities. Here the groups based on soil quality and management are compared, as

TABLE 1. *Engineering characteristics used in the study.*

Computer No.	Characteristics	Soil Horizons[f]	Computer No.	Characteristics	Soil Horizons[f]
1	OSI[a]	(A)	19	PI[d]	(A)
2	OSI	(B)	20	PI	(B)
3	OSI	(C)	21	PI	(C)
4	No. 10 sieve[b]	(A)	22	Shrinkage Limit	(A)
5	No. 10 sieve	(B)	23	Shrinkage Limit	(B)
6	No. 10 sieve	(C)	24	Shrinkage Limit	(C)
7	No. 40 sieve	(A)	25	Shrinkage Ratio	(A)
8	No. 40 sieve	(B)	26	Shrinkage Ratio	(B)
9	No. 40 sieve	(C)	27	Shrinkage Ratio	(C)
10	No. 60 sieve	(A)	28	Volumetric Change	(A)
11	No. 60 sieve	(B)	29	Volumetric Change	(B)
12	No. 60 sieve	(C)	30	Volumetric Change	(C)
13	No. 200 sieve	(A)	31	Stabilization: % cement	(A)
14	No. 200 sieve	(B)	32	Stabilization: % cement	(B)
15	No. 200 sieve	(C)	33	Stabilization: % cement	(C)
16	LL[c]	(A)	34	AASHO[e]	(A)
17	LL	(B)	35	AASHO	(B)
18	LL	(C)	36	AASHO	(C)

[a] OSI is the Oklahoma Subgrade Index number.
[b] Property No. 4 is excluded from the analysis bcause Sieve No. 10 retained little gravel for each A horizon of every soil.
[c] LL is the liquid limit.
[d] PI refers to the plasticity index.
[e] The units in the classification by American Association of State Highway Officials were coded: A-2 = 5; A-4 = 10; A-5 = 15; A-6 = 20; A-7 = 25.
[f] A usually is the topsoil layer; B the subsoil; C refers to parent material.

to agreement or disagreement, with the soils in the groups of the dendrograms. Each soil group in the dendrogram is assigned a number, I through IV. Deviation of soils in the groups in the dendrograms is measured. Total deviation, or total number of weighted disagreements of the soils in each dendrogram with the soils in the reference groups, is used to compare the association of the soils between the dendrograms.

TABLE 2. *Soil characteristics used in the study.*

Computer No	Characteristics	Soil Horizons
37	CEC[a]	(A)
38	CEC	(B)
39	CEC	(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[b]	(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	OM[c]	(A)
73	OM	(B)
74	OM	(C)
75	pH	(A)
76	pH	(B)
77	pH	(C)

[a] CEC is cation exchange capacity.
[b] Hue, one of three color variables, was coded as 5Y = 1, 10YR = 4, 7.5YR = 8, 5YR = 16, 2.5YR = 32. The others, Chroma and Value, have numbers for measurements.
[c] OM refers to percentage of organic matter.

TABLE 3. *Soil series used in this study.*

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

TABLE 4. *Engineering characteristics with high correlation to soil characteristics.*

Computer No.	Characteristics	Soil Horizons
1	OSI[a]	(A)
2	OSI	(B)
13	No. 200 sieve	(A)
14	No. 200 sieve	(B)
15	No. 200 sieve	(C)
16	LL[b]	(A)
17	LL	(B)
18	LL	(C)
19	PI[c]	(A)
20	PI	(B)
21	PI	(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[d]	(A)
35	AASHO	(B)

[a] OSI is the Oklahoma Subgrade Index number.
[b] LL is the liquid limit.
[c] PI refers to plasticity index.
[d] AASHO is the classification by American Association of State Highway Officials.

The weighted number of disagreements in dendrogram I, *i.e.*, the one showing association of the soils by using all engineering characteristics, was found to be 9. The weighted number of disagreements in dendrogram IV, based on use of some selected engineering characteristics, was 10. Soils in the groups in both dendrograms show consistent agreement with soils in the reference groups. In dendrogram I, only one soil, Choteau, deviated from the reference groups by more than one group. Also in

TABLE 5. *Soil characteristics with high correlation to engineering characteristics.*

Computer No.	Characteristics	Soil Horizons
37	CEC[a]	(A)
38	CEC	(B)
39	CEC	(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]	(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)

[a] CEC is cation exchange capacity.
[b] Hue, Value, and Chroma are three variables used to describe soil colors.

TABLE 6. *Soil quality and soil management groups for the selected Mollisols.*

Soil Series	Range Site	Permeability	Land Capability Class	Wheat Productivity Bu/A	Similar Management Groups
Foard	Claypan prairie	very slow	IIs	20	I
Waurika	Claypan prairie	very slow	IIs	23	I
Renfrow	Claypan prairie	very slow	IIs	26	I
Kirkland	Claypan prairie	very slow	IIs	27	I
Brewer	Claypan prairie	very slow	IIs	23	I
Bethany	Loamy prairie	slow	I	33	II
Summit	Loamy prairie	slow	IIw	34	II
Dennis	Loamy prairie	slow	I	32	II
Okemah	Loamy prairie	slow	I	34	II
Zaneis	Loamy prairie	slow	I	26	II
Choteau	Loamy prairie	moderately slow	I	30	III
Vanoss	Loamy prairie	moderately slow	I	31	III
Norge	Loamy prairie	moderately slow	I	27	III
Kingfisher	Loamy prairie	moderately slow	I	31	III
Newtonia	Loamy prairie	moderately slow	I	34	III
Bates	Loamy prairie	moderate	I	24	IV
Grant	Loamy prairie	moderate	I	30	IV
Shellaberger	Deep sand prairie	moderate	IIe	22	IV
Verdigris	Loamy bottom land	moderate	I	33	IV
Port	Loamy bottom land	moderate	I	33	IV

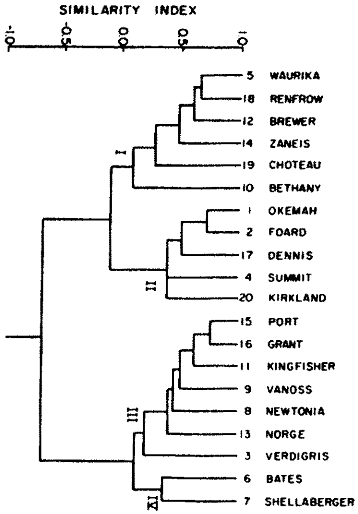

FIGURE 1. Dendrogram I shows the association of soils by using all standardized engineering characteristics.

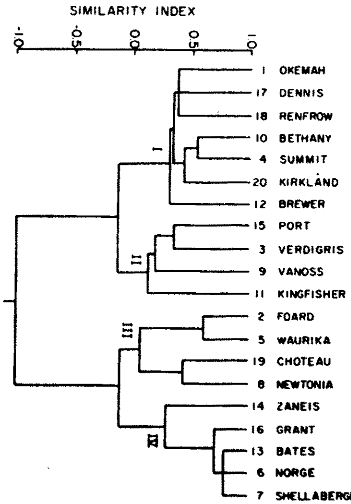

FIGURE 2. Dendrogram II shows the association of soils by using all standardized soil characteristics.

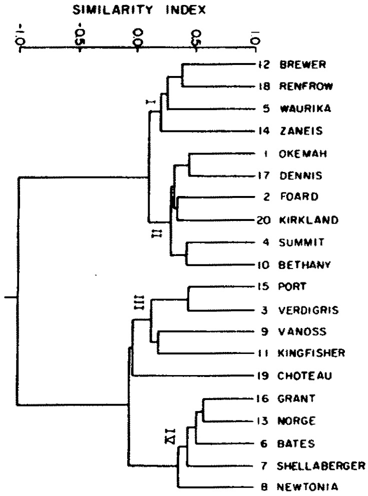

FIGURE 3. Dendrogram III shows the association of soils by using all standardized engineering and soil characteristics.

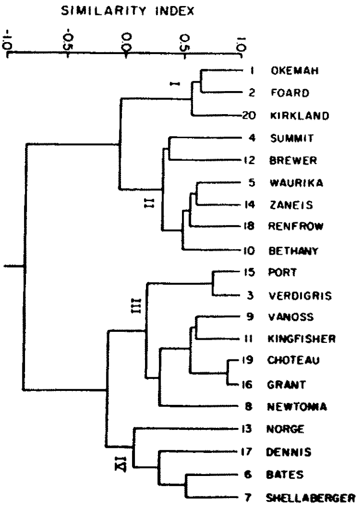

FIGURE 4. Dendrogram IV shows the association of soils by using some selected standardized engineering characteristics.

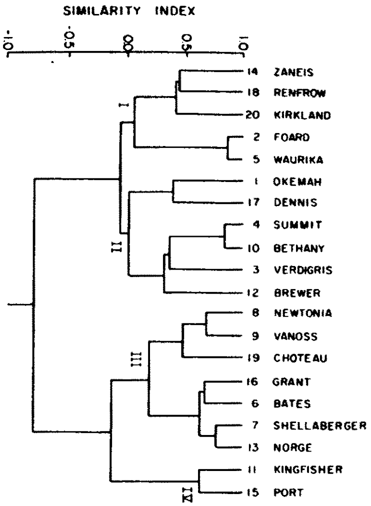

Figure 5. Dendrogram I shows the association of soils by using some selected standardized soil characteristics.

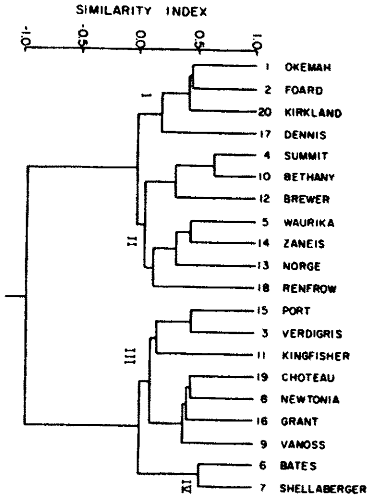

Figure 6. Dendrogram VI shows the association of soils by using selected engineering and soil characteristics.

Table 7. *Classification by groups of the soils in each dendrogram by soil quality and management groups.*

Soil series	Table VI	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	-	9	17	7	10	8	9

dendrogram II, one soil, Dennis, deviated from the reference group by more than one group. The weighted number of disagreements of the soils in dendrogram II, *i.e.*, by using all standardized soil characteristics, was found to be 17. Five soils in this dendrogram deviated from the reference groups by more than one group. The highest total deviation was between the soils in dendrogram II and the reference groups. This result may be influenced by closely related characters which might exert a double emphasis on a certain property (5). The weighted number of disagreements in dendrogram V, association of soils by certain standardized soil characteristics, with the reference groups proved to be 8. Only one soil, Verdigris, deviated from the reference by more than one group. The weighted number of disagreements of the soils in dendrogram III, the association of soils by considering all standardized engineering and soil characteristics, with the reference was found to be 7. The weighted number of disagreements in dendrogram VI, based on certain selected standardized engineering and soil characteristics, with the reference was shown to be 9. Dendrograms III and VI agreed most closely with the soils in the reference groups; no soils deviated from the reference by more than one group (Table 7).

CONCLUSIONS

The combined use of all engineering and soil characteristics gave the best agreement between the dendrogram groups and those in the reference groups. Large numbers of soils, covering a wider range within the Mollisol order and of other orders, *e.g.*, Inceptisol and Alfisol, should be studied to confirm this result.

REFERENCES

1. R. R. SOKAL and P. H. A. SNEATH, *Principles of Numerical Taxonomy*, W. H. Freeman, San Francisco, 1963, p. 359.
2. R. J. ARKLEY, Soil Sci. Soc. Amer. Proc. 35: 312-315 (1971).
3. O. W. BIDWELL and F. D. HOLE, Soil Sci. 97: 58-62 (1964).
4. J. E. CIPRA, B. UNGER, and O. W. BIDWELL, Soil Sci. 108: 153-159 (1968).
5. C. D. MICHENER and R. R. SOKAL, Evolution 11: 130-162 (1957).
6. P. K. SARKAR, O. W. BIDWELL, and L. F. MARCUS, Soil Sci. Soc. Amer. Proc. 30: 269-272 (1966).