Published July, 1960

An Experiment in Ordination of Some Soil Profiles[1]

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ABSTRACT

"Ordination" as defined by Goodall is "an arrangement of units in a uni- or multidimensional order." The authors have attempted to apply this method of classification to soil profiles.

Data concerning three groups of soil profiles were treated separately in order to show the degrees of similarity and dissimilarity between the profiles. Soils of the Miami family and catena were examined in this manner twice, once on the basis of laboratory data and a second time on the basis of current detailed soil profile descriptions. The two treatments gave some strikingly similar results. The third group of soils consisted of 25 soil profiles considered to be representative of as many great soil groups of the world. A three-dimensional model showing relationships between these profiles illustrates the possibilities of this kind of analysis.

Bray, Brown, and Curtis (2, 4, 5) have applied to the classification of plant communities in Wisconsin an "ordination," which permits the plotting of the communities in two or three dimensions, showing similarities and dissimilarities between the units. The ordination method, defined by Goodall (6) as "an arrangement of units in a uni- or multidimensional order," does not define the causes of the relationships discovered by it, but may lead to a more thorough inquiry into the causes. In an "irregular subject" (8), like soil genesis and classification, explanation of a multifactor dependent (1) relationship may be even more profitable than prediction of it.

[1]Contribution from the Soil Survey Survey Division, Wisconsin Geological and Natural History Survey, and from the Soils Department, College of Agriculture, both of the University of Wisconsin, Madison. Published with the permission of the Director of the Wisconsin Agr. Exp. Sta. Presented before Div. V, Soil Science Society of America, Nov. 19, 1959, at Cincinnati, Ohio. Received Nov. 25, 1959. Approved Feb. 3, 1960.

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Table 1—Matrix of hypothetical exact interpoint distances for soils studied by Brown and Thorp (3).

Soil	Miami	Wooster	Hillsdale	Fox	Crosby	Bethel	Brookston	Clyde
Miami	100	61.1	63.4	49.1	79.1	64.0	65.4	50.5
Wooster	38.9	100	59.0	40.8	56.1	40.1	47.2	39.6
Hillsdale	36.6	41.0	100	50.4	61.6	49.7	46.4	39.4
Fox	50.9	59.2	49.6	100	48.3	43.3	29.0	31.1
Crosby	20.9	43.9	38.4	51.7	100	81.0	76.6	57.9
Bethel	36.0	59.9	50.3	56.7	19.0	100	70.1	56.6
Brookston	34.6	52.8	53.6	71.0	23.4	29.9	100	71.6
Clyde	49.5	60.4	60.6	68.9	42.1	43.4	28.4	100

Note: The upper-right portion of the table shows hypothetical data on point similarity or "indices of similarity." The lower-left portion shows data on similarity which were inverted to show interpoint distances, or "indices of dissimilarity."

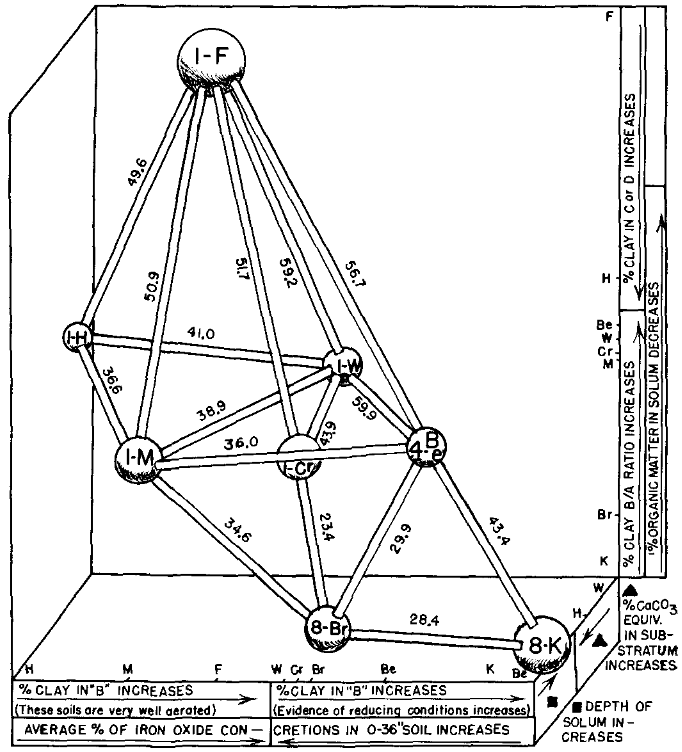

Figure 1—Perspective projection of a model showing indices of dissimilarity (given along the rays of the figure) from matrix table 1, based on laboratory data (3). The Miami catena (Miami, 1-M; Crosby, 1-Cr; Bethel, 4-Be; Brookston, 8-Br; Clyde, 8-K) lies in a vertical slice parallel to the front of the diagram. The Planosol, Bethel silt loam (4-Be) lies foremost (toward the observer). Wooster, 1-W; Fox, 1-F; and Hillsdale, 1-H are Gray-Brown Podzolic soils in the Miami family.

Soil scientists refer to a continuum (9), and therefore it seems appropriate that ordination be applied to soils. In this study the formulae of Bray, Brown, Burgess, and Curtis were not challenged. Certain ratios were used as items of data simply because they are useful in characterizing soils. Because adequate information on soil "communities" or soil associations seems to be less accessible at present than on soil profiles, the writers undertook to produce an ordination of three sets of soil profile data: (*a*) some of the laboratory data reported by Brown and Thorp, (3) for the Miami family and catena, (*b*) some data from mimeographed detailed soil profile descriptions of these soils, as supplied by O. C. Rogers and others of the U. S. Soil Conservation Service, and (*c*) some data from unpublished and published detailed field descriptions and laboratory analyses of selected soil profiles considered to be representative of 25 great soil groups of the world.

METHODS AND PROCEDURES

A table (of which table 2 is an example) was constructed listing data, such as minimum pH in the B horizon, under each soil type name. A second table was derived from the first, in which a value from 0 to 100 was assigned proportionately to figures in a given line of data, in such a manner that the maximum figure for the soils being studied was assigned "100" and the minimum figure, "0." No two kinds of data were found to consistently reinforce or contradict each other. The sum of the entire column of figures listed under a soil type in the second table was called "A." The corresponding sum for a second soil type was called "B." The two columns were compared and a third column was made of the lesser figure of each pair of figures. The sum of this third column was called "w." By means of the formula, $2w/(A + B)$ = index of similarity, a value less than 1 was obtained and was multiplied by 100 to express the theoretical similarity between the two soils. The index of dissimilarity was obtained by subtracting this index of similarity from 100. Three matrix tables (of which table 1 is an example) were constructed, giving the indices of similarity and dissimilarity between the soils. Twenty to twenty-five pieces of information were used in each of the three ordinations.

A definition of the index of similarity and a brief history of the method described above are reported by Curtis (5). The index has been found to be a valid correlation coefficient by

Table 2—Soil properties and proportional values from which table 1 and figure 1 were derived.

Soil property	Range in values of properties for each soil							
	1-M	1-W	1-H	1-F	1-Cr	4-Be	8-Br	8-K
Max. % particles more than 2 mm. in diameter in C or D horizon	10	10	0*	70†	10	36	10	25
Max. % clay in B horizon	37.4	24.1	19.0*	47.1†	35.7	39.4	36.5	46.2
Ratio max. % clay in B to min. % clay in A horizon	2.41	2.43	2.71	3.71†	2.18	2.94	1.50	1.12*
Ratio of max. % clay in B to % clay in C or D horizon	1.76	1.31	1.76	16.24†	1.43	2.42	1.28*	2.00
Min. % clay in C or D horizon	21.3	18.4	10.8	2.9*	25.0	16.3	28.6†	23.0
Ratio of % clay in upper B to that in lower A horizons	1.38	1.52	1.99†	1.90	1.97	1.99†	1.25	1.12*
Average % organic matter in 0- to 36-inch profile	1.72	1.66	0.72*	1.68	1.67	1.30	3.41	5.04†
Ratio of % organic matter in the A_1 to that in the B horizon	4.43*	24.29†	14.3	11.18	13.0	6.97	5.78	10.75
% of the 36 inches of the soil profile which contains mottles	0*	0*	0*	0*	100†	100†	100†	100†
% of the 36 inches of the soil profile which is gleyed	0*	0*	0*	0*	0*	0*	6	44†
Min. pH in the B horizon	5.2	4.4*	5.0	4.6	5.3	5.9	6.8	6.9†
Ratio of the max. pH in the A to the min. pH in the B horizons	1.2	1.4†	1.1	1.4†	1.2	0.9*	1.0	0.9*
Ratio of the max. pH below the B horizon to the min. pH in the B	1.5	1.1*	1.6	1.8†	1.5	1.3	1.1*	1.2
Average pH in 0- to 36-inch soil profile	5.6	4.3*	5.4	5.1	6.1	6.4	6.7	6.9†
Average % iron oxide concretions of sand and gravel sizes in the 36-inch soil profile	2.3	3.9	1.0*	2.5	21.4	24.7†	18.6	6.4
Thickness in inches of A_2 or G horizon	3*	9	6	8	9	6	10	40†
Thickness in inches of solum	36	38	54	38	36	30*	44	66†
Ba_1 value (see Jenny, reference 7) of max. textural B horizon	0.29	0.34	0.47†	0.21*	0.30	0.21*	0.30	0.25
Ratio of the ba_1 value for B horizon to that for C or D horizon	0.85	0.92	0.94†	0.28*	0.83	0.78	0.81	0.71
Ba_2 value (see Jenny) of max. B horizon	0.43	0.60†	0.46	0.43	0.38	0.34*	0.40	0.42
Ratio of the ba_2 value of the B horizon to that of the C horizon	0.14	0.90†	0.26	0.04*	0.09	0.06	0.17	0.08
SiO_2/R_2O_3 ratio of the max. B horizon	6.52	7.27	10.66†	4.98*	6.46	6.55	6.98	5.73
Ratio of the SiO_2/R_2O_3 ratio of the max. B to that of the C or D horizons	0.92	0.86	0.83	0.43*	0.97	1.00	1.09†	0.87
Ratio of the SiO_2/R_2O_3 ratio of the A horizon to that of the C or D horizon	1.69	0.50*	1.27	1.05	1.69	2.00†	1.24	0.88
SiO_2/R_2O_3 ratio of the C or D horizon	7.10	8.41	12.92†	11.50	6.67	6.57	6.43*	6.60

* Corresponds to the proportional value of 0 for this soil property. † Corresponds to the proportional value of 100 for this soil property.

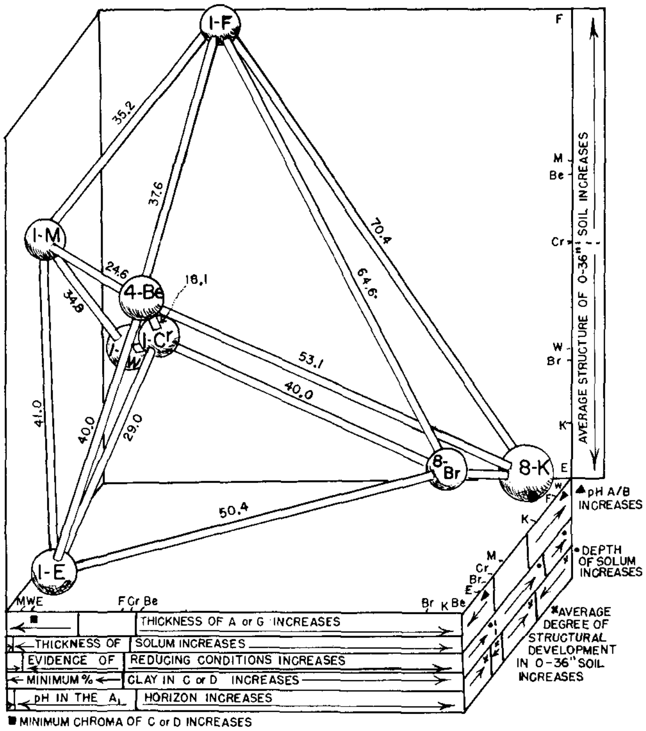

Figure 2—Perspective projection of a model based on detailed soil profile descriptions. The Elmdale series, 1-E, is substituted for Hillsdale, 1-H, for lack of a suitable description of the latter. The eccentricity of the Humic-Gley soils, 8-Br, 8-K, has been increased, and that of the Gray-Brown Podzolic soils other than Miami, 1-M, has been decreased by this ordination, as compared with that shown in figure 1.

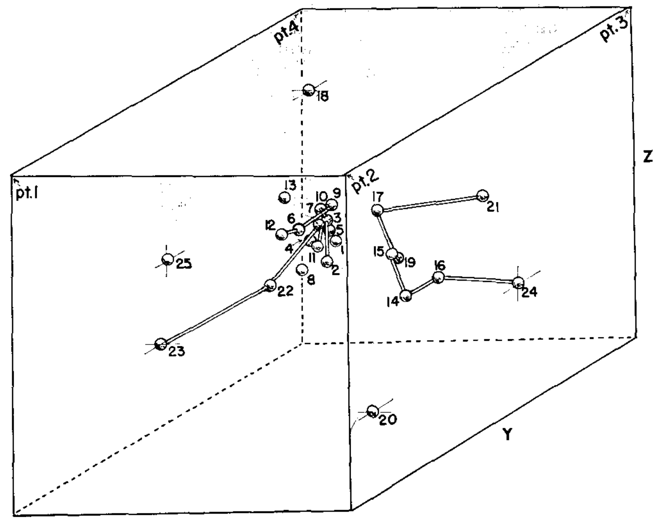

Figure 3—Model based on both laboratory and field data. Apparent trends are shown by connecting relevant spheres: 21, Ground-Water Podzol; 17, Podzol; 19, Yellow Podzolic; 15, Red Podzolic; 14, Reddish Brown Latosol; 16, Hydrol Humic Latosol; 24, Humic Ferruginous Latosol; 23, Subarctic Brown; 22, Alpine Turf; 7, Rendzina; 11, Terra Rossa; 12, Gray Desert; 6, Sierozem; 9, Solodized Solonetz; 10, Brown; 3, Chernozem; 2, Brunizem. An orthographic projection of the spheres on the top of the figure would show the Ando soil, 20, midway between the first and last-named sequences. Figure 4 gives the key to the numbers on the spheres in the other figures. The four numbered points are referred to in the text.

ecologists in comparing two entities by means of quantitative expressions of a number of attributes.

Table 2 lists the soil properties and kinds of data from which table 1 and figure 1 were derived. In each line of table 2, minimum and maximum figures are marked as corresponding, respectively, to proportional values of 0 and 100. Soil symbols, such as 1-M, in this table are explained in the captions of the figures illustrating this paper.

Two and three-dimensional models can be constructed from a matrix table by mathematical, descriptive geometrical, or "carpentry" techniques. The latter consists of cutting rods in lengths proportional to the dissimilarity indices, and connecting them. This method was used by the authors in constructing the models from which figures 1 and 2 in this paper were projected. The orientation of each of these models represents a preference of the authors. Personal judgment was used in selecting data, in orienting a model derived from the matrix table, and in interpreting the table and the model. The properties listed on the margins of figures 1 and 2 are only those which showed trends along the axes of the figures. The sizes of spheres in figures 1 and 2 indicate the "error of triangulation" which is apparently inherent in the multidimensional indices given in the tables.

Figure 3 was prepared as follows. All of the indices of similarity listed in a matrix table were totaled by soils. The soil with the least sum was placed at point 1 in an orthographic projection of the top of figure 3. The soil with the next smallest sum was placed at point 2, 100 units away from point 1. The positions of the other soils were determined by the formula[3], $q = L - x^{+}y/2$ in which q is the distance of another soil from point 1, L is length of axis (here called 100 because most indices are high), x is the index of similarity between

[3]This formula was given to the authors by Mr. Robert Burgess, Research Assistant, Department of Botany, University of Wiconsin.

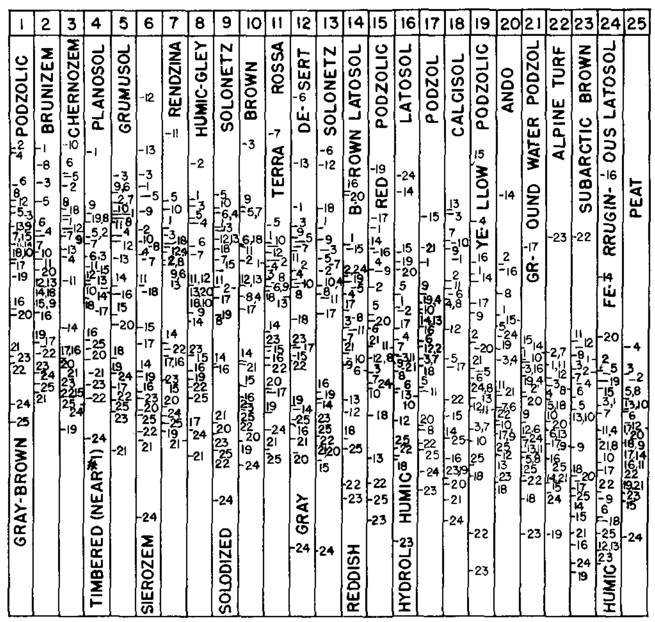

Figure 4—Graphic portrayal of degrees of similarity between soils as determined by an ordination. Numbers correspond to the great soil group soil profiles named. Distances of numbers from the head of a column are proportional to the indices of dissimilarity. Thus, the Gray-Brown Podzolic soil is seen to be most closely related to the Brunizem and least to the Peat. The columns, from left to right, are in order of increasing sums of indices of dissimilarity, expressing eccentricity.

the soil at point 1 and another soil being placed, and y is the index of similarity between the soil being placed and the soil at point 2. Two soils with low sums of indices of similarity were selected from near the middle of the resulting array of points along line 1-2, and the soil with the lower sum was placed at point 1, and the other soil was placed at point 4. The same formula was used to arrange the remaining soils between points 1 and 4. The two arrays of points permitted a two-dimensional plotting of the points on the top face of figure 3, and by a similar procedure, orthographic projections on the front and side of the figure were obtained, as was the three-dimensional version shown. Figure 4 shows graphically the indices of dissimilarity between the 25 representative great soil group soil profiles.

DISCUSSION

The indices of similarity and dissimilarity in the matrix tables can be used directly to indicate relationships between the soils under consideration. Because these indices express all the data introduced into the equation, the three axes of figures 1, 2, and 3 are multifactor ones. The closest approach to one continuous trend occurs along the vertical axis of figure 1; the percent of organic matter in the 0- to 36-inch profile decreases upward to, but not including, the Fox silt loam.

The changes in relative positions from figure 1 to figure 2 of soils common to both figures is a reflection of the differences in arrays of data used. This indicates the need for further study by the ordination method of the significance of the various soil properties and forms of data used in soil classification. The validity of giving each piece of data equal weight in an ordination should be tested.

In the first three figures some soils cluster near the center, while other soils lie at the periphery. These two habits can be labeled "centripetency," and "eccentricity," and can be expressed in a continuum as in figure 4. Relationships between soils can be demonstrated further by (*a*) connecting apparent sequences, as in figure 3, and by (*b*) plotting and "contouring" data (1, 2) on orthographic projections of the points onto the faces in figure 3. By cutting figure 3 into vertical slices and placing included soil points on as many pages, the investigator can incorporate this ordination into the form of a book, reminiscent of the Munsell color chart.

CONCLUSIONS

Certain concepts of soil scientists experienced in soil classification and genesis are substantiated by this experiment in ordination. For example, the Crosby silt loam (figures 1 and 2) has been considered to be an imperfectly drained Gray-Brown Podzolic soil, rather than an imperfectly drained relative of the Humic-Gley soil. This ordination study supports this judgment. Another example is provided by the occurrence in figures 1 and 2 of the Miami- Kokomo (Clyde) catena as a sequence separate and distinct from the other members of the Miami family. Also, certain geographic great soil group sequences appear in this ordination (figure 3), which is based on soil profile characteristics alone.

This study indicates the importance of measuring quantitatively the interrelationships between great soil groups. For example, figures 1 and 2 show that the Planosol great soil group includes at least one soil (the Bethel), which is more similar to Gray-Brown Podzolic soils of its catena than to Gray-Brown Podzolic soils in other related catenas. This indicates that the representative soil profile data used in this experiment emphasized geologic attributes more than pedologic attributes. The ordination method is a useful tool for evaluating the significance of great soil groupings and the significance of the various soil properties on which soil classification is based.

Although it may be argued that ordination of soil profiles yields conclusions predetermined by the selection of data by the soil scientist, and his interpretation of the results, nevertheless this method holds 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.

If a standard ordination procedure for soils were widely accepted, it is possible that a three-dimensional classification of soil profiles could be constructed by means of which each soil would be labeled with a tri-part notation as well as with a name.

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