A NUMERICAL INDEX OF PODZOL AND PODZOLIC SOIL DEVELOPMENT

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Abstract: A numerical index of soil development, the POD Index, was developed and applied to 723 pedons of United States soils that either exhibit, or are developing, Podzol (Spodosol) morphology. The index is determined solely from morphologic (field) criteria, and provides the first soil development index for Podzol and Podzol-like soils that does not use chemical data. The index assumes that pedogenesis and profile development in these soils produces the following morphologic changes; (1) the E (eluvial) horizon becomes "whiter," (2) the B (illuvial) horizon becomes "redder" and "darker," and (3) the number of B subhorizons increases. Results indicated that the index was useful for differentiating between non-Podzols and Podzols, and between Entic and Typic subgroups of Spodosols. A comparison of POD Indices for Spodosols of differing drainage revealed that maximum development occurred in wet soils (somewhat poorly drained), with minimal development on the driest sites. This finding is consistent with current theory on the effects of drainage/water table relations on Podzol development. Additionally, the index has usefulness in chronosequences of Podzol soil development [Key words: soils, Podzol, Spodosol.]

INTRODUCTION

Podzol soils are primarily sandy and coarse-loamy soils that have a bleached eluvial (E) horizon above a darker, sesquioxide and humus-rich (B) horizon. The taxonomic order "Spodosols" includes most but not all Podzol soils (Buol et al., 1980). Spodosols must, by definition, have a spodic (B) horizon that meets predetermined chemical and morphologic criteria (Soil Survey Staff, 1975).

Although the degree of spodic horizon development is important to use and management of soils, many pedons with Bh, Bhs, or strongly developed Bs horizons do not meet the chemical criteria of the spodic horizon as outlined by the Soil Survey Staff (1975) (Padley et al., 1985; Lietzke and McGuire, 1987). These soils must then be classified as Entisols, producing heterogeneous taxonomic assemblages. Mapping of these soils is also problematic because the morphologic criteria for the spodic horizon, used by the field mapper for soil identification, often do not coincide with chemically-determined class boundaries.

To circumvent this problem, changes in spodic horizon criteria have been suggested, or new classes proposed (McKeague et al., 1983; Mokma, 1983; Evans and Cameron, 1985; Padley et al., 1985; Lietzke and McGuire, 1987). These suggestions have centered on amending the spodic horizon class limits as defined by chemical properties (Bartlett, 1972; Holmgren and Holzhey, 1984; Holmgren and Kimble, 1984). Because it is impractical for a field mapper to collect and analyze soil samples from all questionable pedons, one must ultimately rely on color and other morphological properties that are predictive of class groups and observable in the field. Lietzke and McGuire

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(1987) have suggested that morphologic criteria be given greater weight in classification of Spodosols, and that just revising the chemical criteria may be inappropriate. Indeed, Smith (1979) stated that "the spodic horizon is perhaps normally one of the easiest horizons to identify in the field." We only stress herein that a soil has Podzol morphology, i.e., it is a "Podzol" in the truest sense or is developing toward one.

Existing indices of soil development (Buntley and Westin, 1965; Walker and Green, 1976; Bilzi and Ciolkosz, 1977; Hurst, 1977; Harden, 1982; Birkeland, 1984; Rockwell et al., 1984; Machette, 1985) do not measure important diagnostic properties of Podzol morphology and development vital to chronosequence or hydrosequence studies. One previously reported index of development for these soils, the "podzolization index," is based on chemical data, and cannot be used in the field (Duchaufour and Souchier, 1978). A second index, developed specifically for Podzols and having morphological underpinnings, is a Russian scheme (Tavernier, 1963). Podzols are divided into three classes based on the ratio of A/E horizon thickness; the B horizon is not included. The various ratios are used as indicators of weak, moderate, or strong development (Tavernier, 1963). Clearly, an index of development that is quantitative would have wider applicability in soil geomorphic studies.

The objectives of this study were to (1) develop a color index of soil development that is especially sensitive to features of Podzol morphology, (2) estimate index limits for non-Podzols, Entic subgroups, and Typic subgroups of Spodosols, and (3) test the index for use in studying chronosequences and other developmental studies.

THEORETICAL CONSIDERATIONS IN THE DEVELOPMENT OF THE POD INDEX

A suite of processes called "podzolization" will interact in a freely draining pedon of relatively isotropic, sandy or coarse-loamy texture at time zero, under a cool-temperate climate with forest vegetation, to create a Podzol or Podzol-like profile (Muir, 1961; Franzmeier and Whiteside, 1963). The rates at which pedogenic processes interact to create a Podzol profile are highly dependent upon contrasting rates of regressive soil processes (Johnson and Watson-Stegner, 1987; Johnson et al., 1987). We equate pedogenesis of Podzols with progressive soil development, horizonation, and increased profile anisotropy. Although the importance of regressive soil processes (pedoturbation, erosion, and others) is recognized, we chose to stress the developmental aspects of pedogenesis.

A soil can develop Podzol or Podzol-like morphology in a relatively short period of time. This is often due to coarse parent materials that (1) permit rapid translocation of mineral and organic colloids, (2) have relatively low surface areas that permit small amounts of iron compounds to redden the soil, and (3) release sesquioxides into solution at sufficiently slow rates for translocation to keep pace (Duchaufour and Souchier, 1978; Buol et al., 1980; Evans and Cameron, 1985). As one example, Franzmeier and Whiteside (1963) and Franzmeier et al. (1963), studied Podzol profiles in Michigan and concluded that the processes involved in their formation were not synchronous, but sequential, reaching maximum intensities at different times.

Primary among the morphologic changes that occur in a pedon undergoing podzolization is the development of eluvial (E) and illuvial (Bs or Bh) horizons. With time, the E horizon will both thicken and whiten (i.e., attain less red hues and higher color values) as iron and organic carbon are eluviated. Simultaneously, the B Horizon will: (1) develop redder hues due to additions of iron compounds, (2) become darker in color value as organic carbon illuviates into the horizon and coats the soil particles, and (3) develop subhorizons as the profile thickens (e.g., Bhs, Bs1, Bs2). These assumptions are consistent with the findings of Evans and Cameron (1985), who determined that as the B horizon color of 171 podzolic soils in Canada became redder in hue and lower in value, carbon, iron, and aluminum contents increased. They also found that hue and value were more strongly related to iron, aluminum, and organic carbon than was chroma. Based upon these assumptions and conceptual assertions, we developed the mathematical formulation of an index of Podzol development.

The POD Index was formulated to quantify development in soils with "Podzol" morphology. By doing this, we avoid tailoring the POD Index to one system of taxonomy over another, and widen its applicability. We chose the name "POD Index" for the numerical index of Podzol development primarily because these three letters are found in the original Russian Podzol soil concept and are used in the names of similar soils in all modern classification systems (e.g., Spodosol, Humo-ferric Podzol, Stagnopodzol, Peaty Podzol). Soil names containing the "POD" root usually refer to pedons in which eluviation of Fe, Al, and organic carbon from the E to the B horizon is a dominant process, generally being more important than clay movement (lessivage). Thus, the POD nomenclature and concept spans both linguistic and taxonomic barriers.

MATERIALS AND METHODS

Calculation of the POD Index

The POD Index can be determined for soils for which the following information is available: (1) field morphology or horizonation from the surface to the lowermost B horizon (not including BC transition horizons or the lower sequum of bisequal soils), and (2) color hue and value for E and B horizons of the upper sequum. Determination of the POD Index for a pedon involves initial calculations performed for each B subhorizon (Fig. 1). The results of these calculations are summed for the profile, to arrive at the POD Index:

$$\text{POD Index} = \Sigma \ \Delta V \cdot 2^{\Delta H}$$

where ΔV = value difference between the E and B subhorizon, ΔH = the number of Munsell pages different in hue, and the summation occurs over all B subhorizons. Initial calculations involve: (1) subtraction of the B subhorizon color value (moist) from the E horizon color value (moist), and (2) multiplication of the difference by 1 (if there is no hue change between the horizons of comparison), by 2 (if the horizons differ by one Munsell hue page; e.g., 10YR vs. 7.5YR), by 4 (if horizons are two hues different), by 8 (if three hue pages different; e.g., 2.5YR vs. 5YR), and continued doubling of the multiplicand as increased hue differences occur. Multiplication factors for Munsell pages of intermediate hue (e.g., 6YR) are simply the weighted mean of the two neighboring hue pages. In the event of E horizons that have two or more subhorizons (e.g., E1, E2), the subhorizon with the highest value is used in the calculations. Transitional

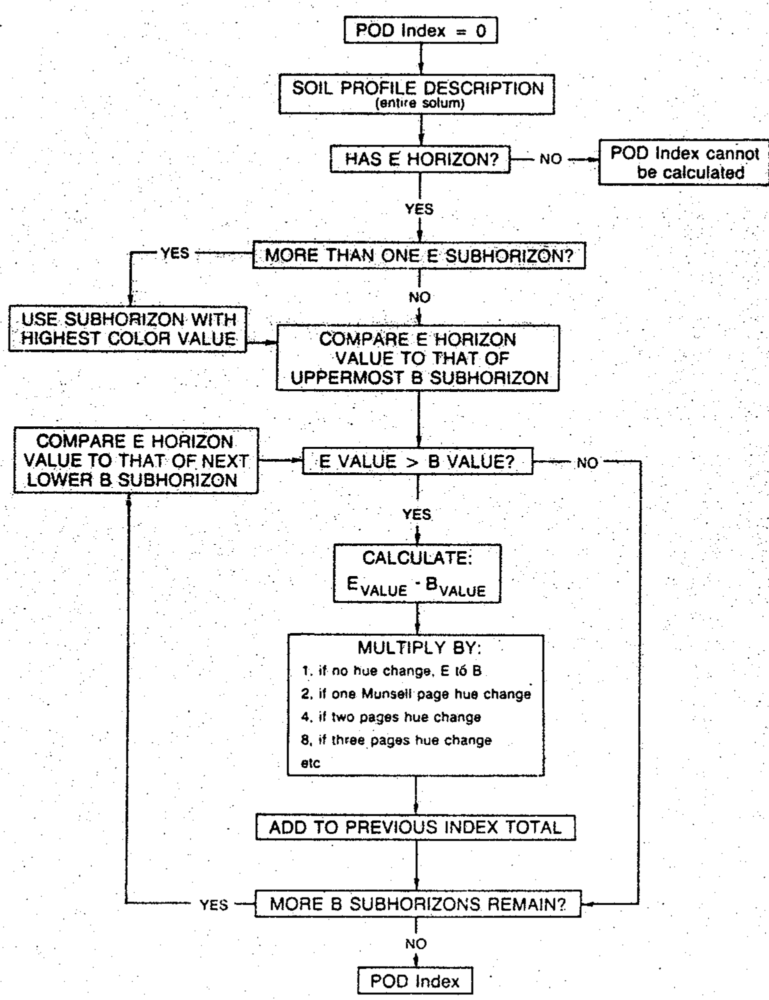

Fig. 1. Flow diagram for use in the derivation of a POD Index for a soil.

horizons such as BC, B/C, or CB are not used in the calculations. For Inceptisols and Entisols, however, BE, EB, and other transitional horizons of the upper solum are used; they are viewed as incipient spodic horizons and may eventually develop into Bs or Bhs horizons. Finally, if the B subhorizon color value is greater than that of the E, the calculation is not performed on that subhorizon (Fig. 1).

Pedons that contain Ap horizons cannot be used in this analysis unless a remnant of the E horizon remains below the Ap, or the color hue and value for the E are known or inferred. Likewise, the POD Index cannot be calculated for soils that lack an E horizon. Although an E horizon is not required for a soil to classify as a Spodosol (Soil Survey Staff, 1975), its presence facilitates the identification of a spodic horizon. In soils that lack an E horizon, other methods must be utilized to determine strength of spodic development, classification, and genesis (Soil Survey Staff, 1975, 1981; Mokma, 1983; Holmgren and Holzhey, 1984; Holmgren and Kimble, 1984), both in our system and in others. Much the same type of problem occurs in the identification of an argillic horizon in soils without an overlying eluvial zone (due to erosion, plow-

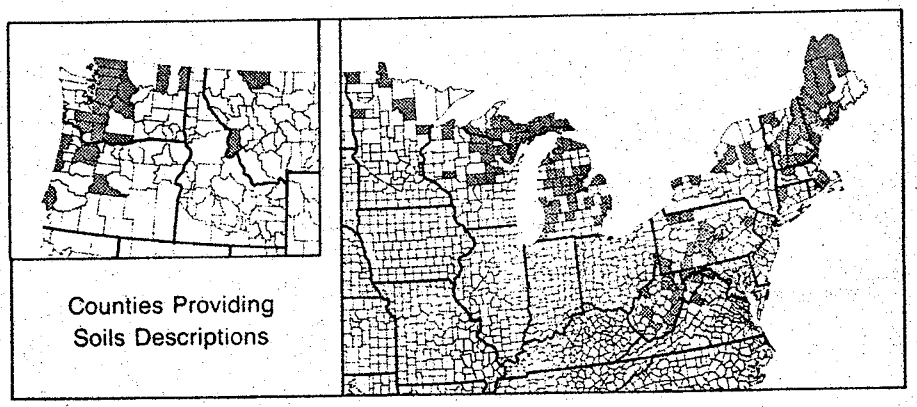

Fig. 2. United States counties from which official pedon descriptions, or representative pedons from county soil surveys, were acquired (first data set). Pedon locations in Alaska (66 total) have been omitted from the map.

ing, etc.). In this case, the presence of clay skins in the Bt is sufficient evidence of clay illuviation (Soil Survey Staff, 1975).

Data Sources

Pedon descriptions used in the development of the POD Index were official soil series descriptions ("blue sheets") obtained from the Soil Conservation Service (SCS), and "representative pedon" descriptions from published National Cooperative Soil Survey (SCS) county soil survey reports. To avoid regional or methodological bias, we endeavored to acquire all appropriate pedon descriptions from both SCS state offices and all published county soil surveys. We included in the data set all Spodosols, Inceptisols, Entisols, and sandy Alfisols that have E horizons (Table 1). In any soil, the lack of an E horizon results in a POD Index of zero. Because we chose to include only those non-Spodosol pedons developing Podzol morphology, pedons lacking an E horizon were not examined.

The application of the Index to soils with a thermic temperature regime (Soil Survey Staff, 1975) was abandoned after initial attempts revealed that profile descriptions of thermic Spodosols seldom include all the B subhorizons. Therefore, only soils with mesic or colder temperature regimes were used in the calculation of the POD Index. Approximately 48% of the 723 pedon descriptions employed were official SCS pedon descriptions. Locations of pedons used in the data set are shown, by county, in Figure 2.

RESULTS AND DISCUSSION

POD Index vs. Taxonomic Classification

The POD Index was determined for 723 United States pedons, listed by subgroup in Table 1; mean POD Index values with coefficients of variation for selected taxonomic subgroups are graphically provided in Figure 3. Statistical comparison of the POD Index of recognized Soil Taxonomy units was performed as a means of determining whether Index values are correlated to taxonomic classes. Analysis of variance

Table 1. Soil Subgroups Used in Calculation of the POD Index: (United States pedons)

Great group	Subgroup[a]	Official pedons	Representative pedons
	Moist and Dry Soils		
Quartzipsamments	Typic	3	0
Udipsamments	Typic	3	9
	Alfic	0	3
	Spodic	3	9
	Aquic	4	1
Udorthents	Typic	0	1
	Aquic	0	1
Dystrochrepts	Typic	11	36
	Lithic	0	5
	Fluventic	0	1
	Aquic	0	1
Glossoboralfs	Eutric	1	1
Eutroboralfs	Typic	0	1
Hapludalfs	Psammentic	0	4
	Arenic	0	2
Haplorthods	Typic	53	49
	Entic	20	75
	Aquentic	1	1
	Aqualfic	4	10
	Alfic	18	46
	Humic	3	0
	Lithic	4	8
	Aquic	13	5
Fragiorthods	Typic	3	5
	Alfic	11	4
	Aquic	3	1
Cryorthods	Typic	74	2
	Entic	3	0
	Humic	33	2
	Haplic	3	0
	Boralfic	1	0
	Lithic	3	0
	Humic Lithic	9	1
Haplohumods	Typic	2	0
Cryohumods	Typic	3	0
	Haplic	3	0
	Wet and Very Wet Soils		
Haplaquods	Typic	2	7
	Entic	12	43
	Psammentic	1	0
	Alfic	13	30
	Aeric	3	12
	Lithic	0	1
Sideraquods	Typic	5	0
	Alfic	2	0
Fragiaquods	Typic	1	1
	Alfic	2	1
Cryaquods	Typic	4	0
	Sideric	6	0
	Lithic	1	0
Total		344	379

[a]Classification follows *Soil Taxonomy* (Soil Survey Staff, 1975).

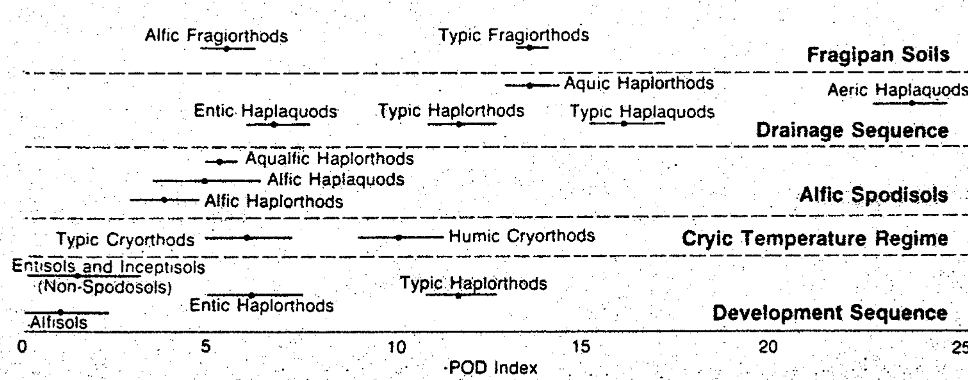

Fig. 3. POD Index values for several selected taxonomic groups, as compiled from the first data set. Dots locate the mean POD Index values for a subgroup; bars represent the range of the coefficient of variation for the subgroup.

tests applied to these taxonomic classes revealed that the POD Indices for non-Spodosols, Entic Haplorthods, and Typic Haplorthods were statistically different ($P = 0.001$). A similar confidence level was achieved when comparing Entic Haplaquods and Typic Haplaquods. Conversely, no statistical difference (at $P = 0.20$) was observed between either Entic Haplaquods and Entic Haplorthods or Typic Haplaquods and Typic Haplorthods. These findings suggested that the POD Index adequately discriminates between soils of similar degree of development in these drainage classes.

The POD Index of non-Spodosols (Inceptisols, Entisols and coarse-textured Alfisols that contained E horizons) was consistently two or less. Although the mean Index for Entic Haplorthods was near six, the majority of these pedons were in the 2-6 range (Fig. 4). Typic Haplorthods had a mean POD Index of 11.6; most exhibited indices equal to or exceeding six (Fig. 4). Most Cryorthods, as well as Cryic and Alfic subgroups of Spodosols, had POD Indices greater than two. Therefore, POD Index limits were determined for the following Soil Taxonomy units: Non-Spodosols (0-2), Entic Haplorthods (2-6), Typic Haplorthods ($\geqslant$6), and Cryorthods and Alfic subgroups ($\geqslant$2). Pedons in the area of overlap often were difficult to classify based on morphology alone, suggesting that they could classify into either the upper or lower group.

The POD Index did not distinguish between coarse-textured Alfisols with Podzol-like features and non-Spodosols falling into the Entisol and Inceptisol orders (Fig. 3). This finding was tested by analysis of variance, which demonstrated the lack of statistical difference between the indices of Alfisols and other non-Spodosols (Inceptisols and Entisols) ($P = 0.52$). Therefore, we suggest that the POD Index is discriminating for Podzol and Podzol-like features, and does not give strong weighting to lessivage and other processes dominant in finer-textured forest soils. It is not sensitive to morphologic features found in soils developing toward other orders (Alfisols, Ultisols, Mollisols, etc.).

An analysis of pedons that fell outside the taxonomic limits provided insight into morphology-classification relationships. For example, all of the 14 non-Spodosol pedons ("outliers") that exceeded the POD Index taxonomic limit of two were described as having albic and Bs horizons, morphologic features often used in the field to map or classify pedons as Entic Haplorthods (assuming laboratory data are not avail-

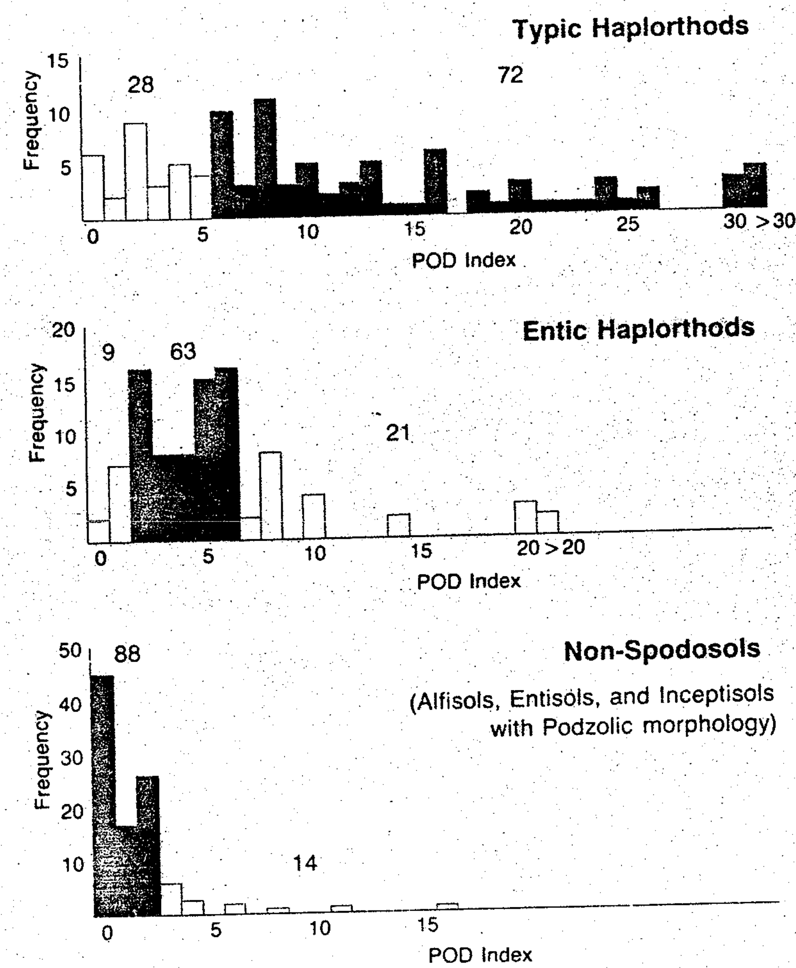

Fig. 4. Histograms showing the range of POD Indices for soils in each of three taxonomic subgroups, United States data set. Black bars indicate the pedons that correctly met the prescribed taxonomic limits of the POD Index. White bars show the number of outlier pedons (those that fell outside the POD taxonomic limits for that subgroup), and their values.

able). Seven of the nine Entic Haplorthods with POD Indices <2 had weak Bs horizons, and the other two pedons had weak or no albic horizons, indicating that these pedons are weakly developed and may, in actuality, classify as non-Spodosols. Seven of the 21 Entic Haplorthods with POD Indices >6 had Bhs horizons and 11 had dark Bs horizons, suggestive of strong development. Nineteen of the 28 Typic Haplorthod pedons with POD Indices <6 lacked Bhs horizons, and probably should be classified as Entic Haplorthods. Of the remaining 9 Typic Haplorthod "outliers," five pedons had weak Bhs horizons and two had weak or no albic horizon, again indicative of weak development for the subgroup.

Testing the Utility of the POD Index

The POD Index was further tested against 344 Podzol-like pedons described in the literature. This second data set focused primarily on soils from outside the United

Table 2. Number of Pedons in Different Taxonomic Groupings, as Determined by the POD Index (literature data set)

Classification	POD Index Values		
	0-2	3-6	7+
	Number of Pedons in Category		
Soil Taxonomy			
Non-Spodosols	62	20[a]	15[a]
Canadian			
Non-Podzolic	4	0	2[a]
Other Systems			
Non-Podzols	14	1[a]	0
Classification	**0-1**	**2-6**	**7+**
	Number of Pedons in Category		
Soil Taxonomy			
Spodosols			
Entic	4[b]	14	6
Other	4[b]	27	34
Classification	**0-1**	**2-5**	**6+**
	Number of Pedons in Category		
Soil Taxonomy			
Spodosols			
Typic	2[b]	12	50
Canadian			
Podzolic	6[b]	5	23
Other systems			
Podzols	5[b]	22	31

[a]All non-Spodosols and non-Podzols with POD Indices greater than 2 had albic and Bhs or Bs horizons.

[b]All Spodosols and Podzols with POD Indices less than 2 had weak or no albic and/or Bs horizons.

Note. Nineteen pedons were classified in both Soil Taxonomy and the Canadian System of Soil Classification.

Locations of Pedons Described:

United States (States):
Alaska, Colorado, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New York, Oregon, Pennsylvania, Vermont, Washington, Wisconsin

Canada (Provinces):
British Columbia, Newfoundland, New Brunswick, Northwest Territories, Nova Scotia, Ontario, Quebec

Other Countries:
Belgium, England, Finland, France, Ireland, Netherlands, Norway, Scotland, Spain, Sweden, Switzerland, USSR, Wales

States; pedon descriptions were obtained from published articles, books, monographs, and reports (Table 2). The pedons were classified according to Soil Taxonomy (Soil Survey Staff, 1975), to the Canadian system of soil classification (Canadian Soil Survey Comm., 1978), or to other classification systems. In the latter two cases, the pedons were simply grouped as Podzols or non-Podzols.

As in the first data set, application of POD Index taxonomic limits to the "literature" pedon descriptions produced positive results. In all groups, the Index classified over 60% of the pedons correctly; in some groups all or nearly all pedons were correctly classified (Table 2). For example, 14 of 15 non-Podzols had POD Indices less than or equal to 2, thus correctly placing them within the predetermined taxonomic limits. Although 45 of the 107 non-Spodosols and non-Podzols had POD Index values greater than 2 (and thus were incorrectly classified by the Index), all 45 exhibited Podzol morphology, having albic E horizons coupled with Bs and/or Bhs horizons (Table 2). These pedons include soils with Podzol morphology but which failed to meet *chemical* criteria for the spodic horizon. More than 91% of the 245 pedons classified as Spodosols, Podzolic soils, or Podzols had POD Indices of 2 or more. Based on the data presented, we conclude that the success of the POD Index at placing pedons into the appropriate taxonomic group of Soil Taxonomy is acceptable for many field classification purposes. This level of accomplishment is indeed noteworthy when considering that misclassifications by experienced soil scientists can be easily made in the field.

POD Index vs. Time

If the Podzol developmental theory outlined above is valid, then the POD Index should become greater as age and degree of development increase. We calculated POD Indices for five soils in a classic Podzol chronosequence study (Franzmeier and Whiteside, 1963; Franzmeier et al., 1963). The soils studied were located in Michigan, developed in sandy material, and had formed in Holocene beach deposits. Calculation of POD Indices for the five pedons reported in this study was complicated by the description of multiple colors for several horizons. As a compromise, we used mean color values where more than one had been described.

The mathematical relationship between POD Index and time in these soils (Franzmeier and Whiteside, 1963; Franzmeier et al., 1963) is shown in Figure 5. According to these data, Podzol development appears to be increasing at an accelerating, or perhaps steady, rate. Assuming that a POD Index of 2 or more can be used as the Podzol/non-Podzol classification boundary, then the data in Figure 5 suggest that 3000-4000 years are required for soils to develop into Podzols (Entic or Typic Haplorthods) in Michigan. Likewise, approximately 7000 years are required for the formation of a Typic Haplorthod, based on a POD Index of 6 or more. This length of time compares favorably with the 8000-year estimate for Bhs horizon formation in Michigan, as determined by Franzmeier and Whiteside (1963).

POD Index vs. Wetness

Spodosol subgroups of varying degrees of wetness were analyzed to determine if profile development, as indicated by the POD Index, differed significantly as a func-

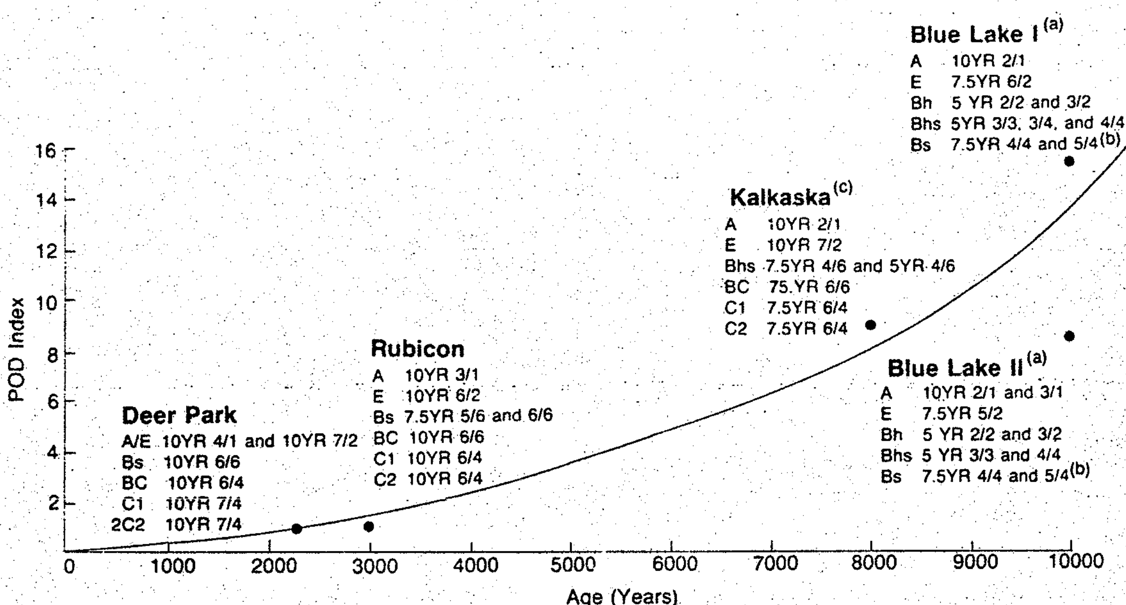

Fig. 5. POD Index vs. age for five soils of a Michigan chronosequence. Soil descriptions and ages are modified from Franzmeier and Whiteside (1963). Notes: (a) The described horizons of the lower (alfic) sequum for Blue Lake I and II have been omitted. (b) Although Franzmeier and Whiteside describe this horizon as a "B3," morphologic evidence and recent changes in horizon nomenclature would identify this horizon as a "Bs." Therefore, we have renamed the horizon and included it in the calculation of the POD Index for the Blue Lake soils I and II. (c) Franzmeier and Whiteside describe a Bh horizon for the Kalkaska soil, stating that it "occurs scattered throughout the Bhir (Bhs) horizon" (p. 30). The Bh, existing only as scattered fragments, is essentially disregarded by Franzmeier and Whiteside; neither is it used in the POD Index calculations.

tion of wetness. The four subgroups tested (Fig. 6) conform roughly to the following natural drainage classes: Typic Haplorthods (well and moderately well drained): Aquic Haplorthods (moderately well and somewhat poorly drained): Aeric Haplaquods (somewhat poorly drained): Typic Haplaquods somewhat poorly and poorly drained). Because there is overlap between Soil Taxonomy (Soil Survey Staff, 1975) and drainage class, we used the modifiers very wet, wet, moist, and dry when describing the wetness characteristics of the subgroups.

Mean POD Index values for the four major wetness classes are shown in Figure 6. An analysis of variance test revealed that the class means are significantly different ($P = 0.009$). Based on the POD Index, therefore, the degree of profile development in these soils is: wet > very wet > moist > dry.

This relationship between soil development and wetness is commonly observed in the field; Aquods exhibit darker Bhs horizons than the drier Haplorthods, especially in the upper B horizon (Table 3). Previous research has suggested that wider fluctuations of soil moisture in mid- and lower-catena soils, as compared to freely draining counterparts, may lead to stronger morphologic expression and development (McKeague, 1965; Macyk et al., 1978). Additionally, redox cycles are more frequent in the Aeric Haplaquods than in the Typic Haplaquods, the latter being in the reduced state for longer periods of time. Greater redox cycle frequency in the Aeric Haplaquods will

Table 3. Horizonation and Horizon Colors of Four Spodosols of Varying Wetness

SOIL SERIES: Berkshire fine sandy loam, very stony
CLASSIFICATION: Coarse-loamy, mixed, frigid, Typic Haplorthods
DRAINAGE CLASS: Well drained
LOCATION: Franklin County, Massachusetts
POD INDEX: 10

Horizon	Depth (in)	Matrix color (moist)
Oi	3-1	
Oe	1-0	
Ap	0-6	7.5YR 3/2 (dark brown)
E	6-8	5YR 6/1 (light gray)
Bhs	8-9	2.5YR 2/4 (dark reddish brown)
Bs	9-13	5YR 4/6 (yellowish red)
Bw	13-22	10YR 5/4 (yellowish brown)
C	22-65	2.5YR 5/5 (light olive brown)

SOIL SERIES: Madawaska fine sandy loam
CLASSIFICATION: Coarse-loamy over sandy or sandy-skeletal, mixed, frigid, Aquic Haplorthods
DRAINAGE CLASS: Moderately well drained
LOCATION: York County, Maine
POD INDEX: 13

Horizon	Depth (in)	Matrix color (moist)
Ap	0-9	10YR 3/2 (very dark grayish brown)
E	9-10	7.5YR 6/2 (pinkish gray)
Bh	10-12	5YR 3/4 (dark reddish brown)
Bs	12-17	5YR 4/6 (yellowish red)
Bwl	17-19	7.5YR 5/6 (strong brown)
Bw2	19-23	10YR 5/6 (yellowish brown)
2Cl	23-48	5YR 6/3 (pale olive)
2C2	48-60	2.5YR 6/2 (light brownish gray)

SOIL SERIES: Saugatuck sand
CLASSIFICATION: Sandy, mixed, frigid, ortstein, Aeric Haplaquods
DRAINAGE CLASS: Somewhat poorly drained
LOCATION: Gladwin County, Michigan
POD INDEX: 22

Horizon	Depth (in)	Matrix color (moist)
A	0-2	10YR 2/1 (black)
E	2-12	10YR 6/2 (light brownish gray)
Bhsm1	12-17	5YR 2/2 (dark reddish brown)
Bhsm2	17-28	7.5YR 3/2 (dark brown)
BC	28-34	10YR 4/3 (dark brown)
C	34-48	10YR 6/3 (pale brown)

SOIL SERIES: Kinross mucky sand
CLASSIFICATION: Sandy, mixed, frigid, Typic Haplaquods
DRAINAGE CLASS: Poorly drained
LOCATION: Delta County, Michigan
POD INDEX: 16

Horizon	Depth (in)	Matrix color (moist)
Oa	6-0	5YR 2/1 (black)
Eg	0-4	10YR 5/2 (grayish brown)
Bhs	4-6	5YR 3/2 (dark reddish brown)
Bs	6-18	5YR 3/4 (dark reddish brown)
BC	18-36	7.5YR 4/4 (dark brown)
C	36-60	7.5YR 5/4 (brown)

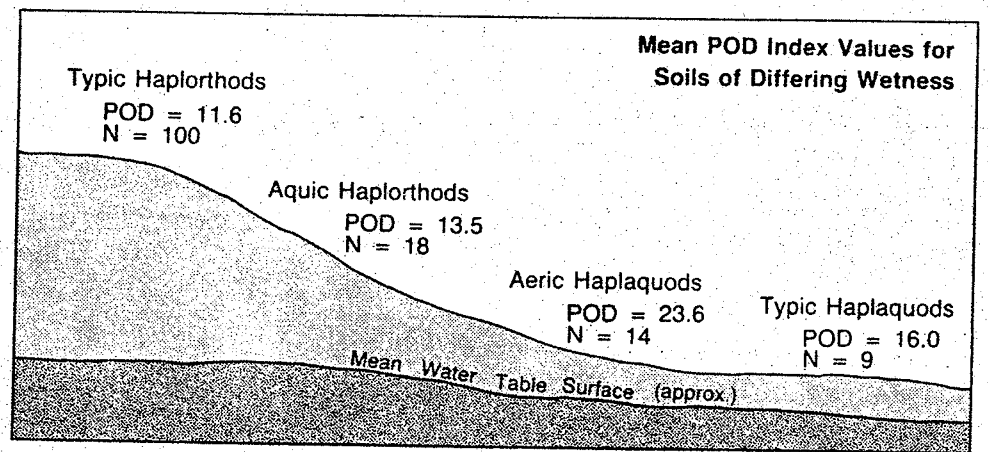

Fig. 6. Mean POD Index values for soils of differing wetness, first data set.

tend to accelerate weathering of ferromagnesian minerals, leading to spodic horizons with higher Fe content.

Inhibition of vertical throughflow by high water tables in the wet Spodosols may account for the greater concentrations of humus-sesquioxide complexes near the upper boundary of the B horizon. Thus, wet soils often exhibit ortstein (Bsm or Bhsm horizons) and exceptionally dark Bhs horizons. Conversely, in the freely leaching environment of drier Orthods, organic carbon-sesquioxide complexes are often distributed through a thicker spodic horizon, ortstein is less common, and colors are not as dark. As a result, the degree of profile anisotropy with regard to color (the main developmental criterion of the POD Index) is better expressed in the wet soils.

Typic Haplaquods have lower POD Index values than Aeric Haplaquods because eluviation-illuviation processes are more often inhibited in the former soils by a high water table, at times saturating the entire solum. Likewise, E horizon colors in the very wet soils may not be as "bright" (i.e., high value) due to gleying, which produces duller, grayish colors (Table 3).

Mean values of Alfic subgroups of Spodosols in varying drainage classes were: Alfic Haplorthods: 3.7, Aqualfic Haplorthods: 5.2, Alfic Haplaquods: 4.8 (Fig. 3). The group means are not statistically different ($P = 0.407$). These data, first, confirm field observations that spodic horizons are not strongly developed in soils with underlying argillic horizons. Lack of strong spodic expression in such soils is generally ascribed to finer-textured parent materials, greater incidence of broadleaf (as compared to coniferous) forest vegetation, and a limited thickness of material in which a spodic sequum can develop. Second, the data suggest that in weakly-developed Podzols, other factors appear to be more important than wetness in determining strength of development. Nonetheless, slightly higher POD Index values were observed in mid-catena positions than on uplands. This trend was also observed in Spodosols without Bt horizons.

CONCLUSIONS

This study provides a development index for Podzols, Spodosols, and soils that are developing Podzol morphology. As such, it fills a methodological gap in the literature that other indices have failed to address. We have demonstrated that the POD Index has utility in three fields: (1) classification, (2) chronosequence studies, and (3) hydrosequence studies. The index differentiated between non-Spodosols, Entic Haplorthods, and Typic Haplorthods with 65-75% reliability. Likewise, more than 90% of pedons classified as Podzols met predetermined POD Index class limits for such soils. Many of the pedons for which the POD Index did not correctly predict the classification appeared to have been misclassified, based on morphologic characteristics. Application of the Index to soils of a Podzol chronosequence resulted in a good relationship between POD Index and time. Finally, the POD Index mirrored field observations of spodic horizon development in hydrosequences, where wet and very wet pedons typically show the strongest development.

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