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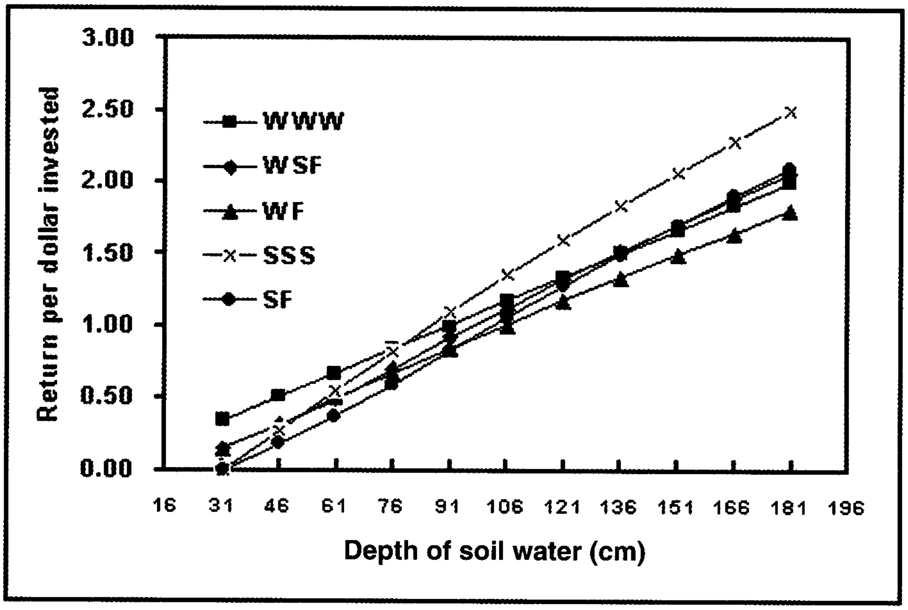

Figure 13. Return per dollar invested for five RT cropping systems as a function of soil water depth at planting based on average predicted yields from 1976 to 1999.

Coupling Use-Dependent and Use-Invariant Data for Soil Quality Evaluation in the United States

R.B. Grossman, D.S. Harms, C.A. Seybold, and J.E. Herrick

ABSTRACT: The estimated properties for soil survey map units typically are only for major soil use. Users are provided only one set of soil properties. We consider the combination of use-invariant and use-dependent databases to produce composite records. The use-invariant data is determined by soil origin and genesis and is at most only slightly subject to change with use. The use-dependent data is readily subject to change by use. Near-surface properties are particularly subject to change with use. Each use-invariant property is assigned a surficial exclusion zone within which the property is considered use-dependent and hence the standard interpretive record is not applicable. Both use-dependent and use-invariant properties are placed in one of five classes. Numerical rankings for quality evaluation are obtained by combining the placements for the several properties concerned.

Keywords: Near-surface, quality class placements, soil interpretations, soil properties, soil quality, soil survey, use-dependency, use-invariance

The soil survey interpretive database contains perhaps five million property estimates by soil layer. The values can be utilized for soil quality evaluation. There is, however, an important limitation. The interpretive database commonly contains only one dataset; land use differences are not considered. Usually the data are based on a single dominant land use. Differences in properties among uses are not part of the interpretive record. An important aspect of soil quality is change in soil function due to soil management and use. For the evaluation of this aspect, the applicable database must contain use-dependent data, which requires change in data collection and storage in the soil survey.

We use the term "use-invariant" for properties such as texture, depth to bedrock, etc. that change little if at all among different uses. Properties that do

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change with use but are not recognized as doing so are not use-invariant. Rather, they are use-dependent but not so recognized. Thus, there are two kinds of "use-dependent" properties: those recognized and those that are not.

There is a further consideration. The present database of use-invariant properties is useful in defining the potential range of values for use-dependent properties and the susceptibility of those properties to change with use. In short, the use-invariant information is necessary but not sufficient by itself to predict the use-dependent properties for soil quality evaluation.

In this study we combine the use-invariant soil survey interpretive database with near-surface use-dependent information to obtain composite records for documentation of soil quality. Figure 1 is a schematic of an interpretation program that includes use-dependence. The figure shows three use-dependent records for a single map unit component and a single use-invariant record. Each use-dependent record would be combined with the use-invariant interpretive record to obtain a composite record that would be used for soil quality evaluation and for interpretations in general.

The use-invariant component of the composite record pertains to "inherent" soil quality, whereas the use-dependent component is used to evaluate "dynamic" soil quality, in other words, as affected by land use and management (Seybold et al. 1998). As previously stated, the use-invariant record may exert a strong influence on the classes of the use-dependent record. The study is directly relevant to characterization of "the capacity of soil to function," which is considered a short definition of soil quality (Karlen et al. 1997, p 6). We address a source of information on soil quality that seems to need more consideration. For example, in their excellent study Karlen et al (1998) present the kinds of indicators and the scales of observation. But they do not explore the soil survey database, which is the largest body of relevant information. The situation would seem a continuation of the long continued disconnection between academic research activities and the operational soil survey.

Composite Property Records

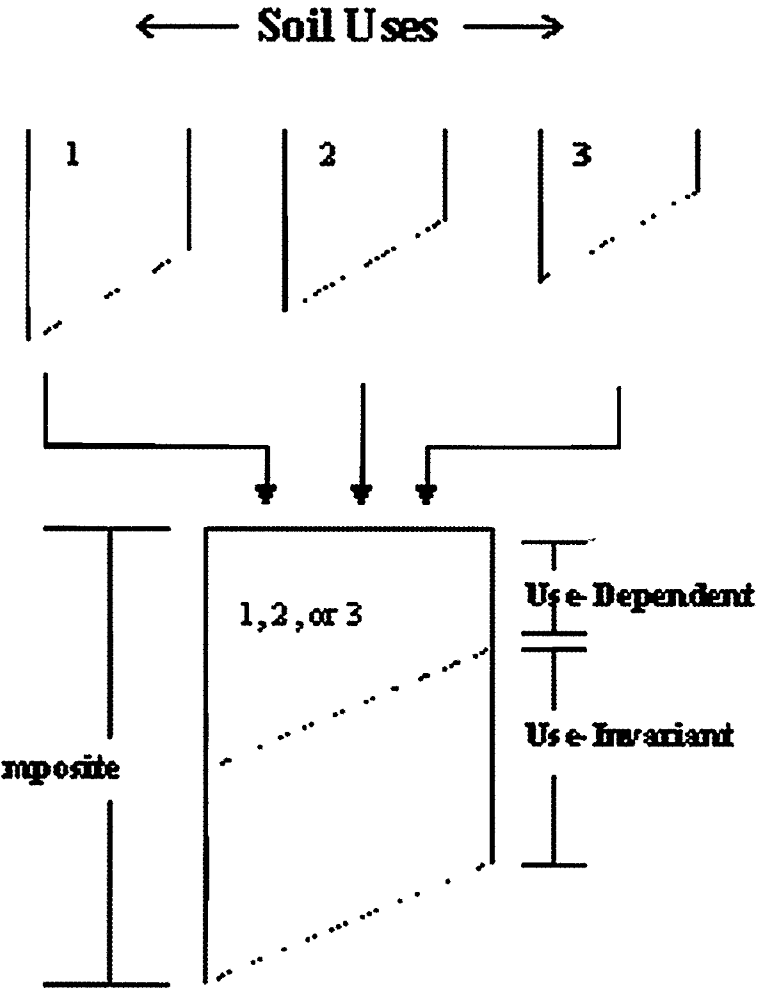

Figure 1. Schematic for the combining of use-dependent and use-invariant records to form a composite record.

Additional remarks may be useful about the distinction between use-dependent and use-invariant soil properties. Certain soil properties are greatly affected by use and management and would be considered use-dependent. Infiltration, for example, is extremely sensitive to change in soil management and use (e.g., cultivated vs. forested). Some soil properties which result from genesis or parent material origin are weakly affected by human activities. These properties would be considered use-invariant and the current interpretive soil survey database provides meaningful values. Particle size distribution (texture), a property that usually changes little with use, is use-invariant.

Texture affects bulk density. But bulk density, because of sensitivity to mechanical pressure is also use-dependent. The influence of mechanical pressure extends to about 30 cm for most situations and to about 50 cm maximum for nearly all agronomic and grazing disturbances. Bulk density at depths greater than 50 cm is usually use-invariant. Soil properties in the surface layer can be strongly affected by management. Therefore, differences between estimated values of use-dependent properties in the use-invariant interpretive database and actual measurements can be very large. Consider a map unit component that encompasses areas of conventional tillage, no-till, and woodland. The minimum near-surface saturated hydraulic conductivity (K-sat) can range 10–100 fold with conventional tillage having the lowest and woodland having the highest values. The present interpretive database for K-sat contains a single property range for all uses and this range usually covers only a 3 fold difference (1.5–5 cm hr^{-1}).

Uncertainty in K-sat assignment has important ramifications for assessment of the Hydrologic Group. For example, the Hydrologic Group reported in the soil survey may be designated a B based on the use-invariant database, but for the areas of conventional tillage it should be a C or D. The Natural Resources Conservation Service employs a protocol to predict relative pesticide movement (in soils) that is dependent on the Hydrologic Group (Goss and Wauchope 1990). The protocol would yield the same result for the three uses above because the Hydrologic Group is designated the same. In reality the applicable Hydrologic Group could be quite different across the uses.

To demonstrate the evaluation of soil quality, we constructed soil quality class sets for use-dependent and use-invariant properties. In practice, the class sets would be developed for groups of similar soils and defined on a regional basis. Each group of soils has a different potential for soil quality. Land-use affects the quality of the soil within the soil groups. The maximum potential for soil quality, in most cases, would occur under native vegetation. The use-dependent and use-invariant class placements can be combined into a quality statement for the soil.

Methodology

A soil concept for a soil or group of similar soils must be defined. The concept would encompass a group of uses that affect the soil similarly. For example, cropping systems that use conventional tillage, cropping systems that use no-till, wheat/fallow rotations with conventional tillage, or native systems are groups of uses. Next, the zone in the soil profile that is affected by soil use and management is determined for each property of concern. This zone is called the exclusion zone. This is where the property is considered use-dependent. Decisions on criteria for the exclusion zones should be made regionally with the 17 NRCS soil management offices and Agricultural Experiment Stations involved. The area below the exclusion zone is where the property is considered use-invariant. The National Soil Information System (NASIS) is the source of information on use-invariant properties (USDA 1998). Class sets for quality placement are developed for each property as applicable to a group of similar soils. Both use-dependent and use-invariant property values are ranked in a five class system, with five the best.

Development of class sets for use-dependent properties. Several class sets for specific use-dependent properties were developed for some soils of the Midwest cornbelt. These selected soils are medium or fine textured, high in silt, dominated by expanding lattice clays, usually moist, and have intermediate (mesic) soil temperature. The first property we considered was permeability or K-sat (Table 1). We assumed that the interpretive permeability range in the database for the near-surface is for natural vegetation, and therefore, the actual permeability for most other uses would be slower. For the western part of the Cornbelt, measurements of near-surface K-sat for long term grass are within or near to the interpretive permeability class and much higher than for cultivated conditions. For class placement, the measured or estimated permeability for a land use (i.e., cultivated agriculture) is compared to the range in the interpretive database. If the measured or estimated permeability is equal to or faster than the estimated value in the database, then the soil quality class is high (classes 4 or 5). If the observed or estimated permeability is considerably lower than the value in the data base, then the quality class is low (classes 1 or 2).

Several important use-dependent properties are not in the current interpretive data base (e.g., aggregate stability). Since the interpretive soil survey data base lacks these kinds of values, the approach used for the development of class sets for permeability is not applicable. Instead, ranges in point measurements or estimates of properties for large areas (i.e., regions) would be developed and placed in sets of ad hoc quality classes (discussed later).

Morphology of the near-surface should be incorporated in soil quality evaluation (Harms et al. 1995; Grossman et al. 1999). We use five morphological properties discussed in the Soil Survey Manual: soil structure, moist rupture resistance, crust, surface connected macropores and surface connected cracks (Soil Survey Staff 1993). Except for crust, the soil must be moderately moist or very moist. Placement of the morphology into classes as indices of soil quality were based on the assumed ability of the soil to transmit water and/or limit root extension. Table 2 gives the quality classes for structure, Table 3 for moist rupture resistance, and Table 4 for crust. Classes for surface connected macropores and for cracks have been developed, but are not shown. Layers within 0–30 cm are delimited on class changes in structure and/or rupture resistance. The index based on structure and rupture resistance is calculated first and then adjusted down for crust and upward for the surface connected features. Indices for each 10 cm zone are calculated on the assumption of weighting by relative thickness within the zone. The three 10 cm zones are then weighted 4, 2, 1 to calculate an indice 0–30 cm. The procedure assumes that the importance of the morphological properties used decreases within the 30 cm depth.

Table 2. Soil quality classes based on structure, 0-30 cm.

Class	Criteria[†]
1	All structures with *common* or *many* stress surfaces irrespective of other features, *massive*, *platy* with *firm* or stronger horizontal rupture resistance, all *weak* structure except *granular*, *moderate very coarse prismatic, all columnar*.
2	All structures with *few* stress surfaces irrespective of other features, *weak granular, moderate very coarse* and *coarse blocky* and *coarse and medium prismatic, platy* with *friable* horizontal rupture resistance, *strong coarse and very coarse prismatic*.
3	No stress surfaces, *moderate medium blocky* and *very fine and fine prismatic*, *platy* with *very friable* horizontal rupture resistance, *strong coarse* and *very coarse blocky* and *medium* prismatic.
4	No stress surfaces, *moderate granular*, *moderate very fine and fine blocky* and *strong fine prismatic*.
5	No stress surfaces, *strong granular, strong very fine* through *medium blocky* and *very fine prismatic*.

[†] If the structure is described as "parting to" use the stronger of the two structures. If intermediate structure classes are described, use the intermediate classes here.

Some additional remarks about crust are necessary. The concern is with mineral surface crusts caused by raindrop impact (Soil Survey Staff 1993). Classes are based on dry rupture resistance and the thickness of the massive zone that forms through rainfall. This classification does not apply to crusts formed by frost action or those in which the structure has been strongly modified by microbiotic organisms, such as algae, lichens, and cyanobacteria. In many rangeland soils, cyanobacteria are present but not in sufficient densities to have a significant impact on dry rupture resistance, so the test is still valid.

Quality class sets were also developed for soil organic matter content of the 0–5 cm depth (Table 5), maximum bulk density within the 0–20 cm zone, and aggre-

Table 1. Classes for soil quality evaluation of near surface permeability based on comparison of measured values to interpretive estimates that are around for native vegetation.[†]

	Interpretive Permeability Estimates					
Measured K-sat	5–15	1.5–5	0.5–1.5	0.15–0.5	0.004–0.15	< 0.004
			cm hr^{-1}			
			Quality Class			
15–50	5	5	5	5	5	5
5–15	5	5	5	5	5	5
1.5–5	4	5	5	5	5	5
0.5–1.5	3	4	5	5	5	5
0.15–0.5	2	3	4	5	5	5
0.004–0.15	1	2	3	4	5	5
< 0.004	1	1	2	NA	NA	NA

[†] Compare the minimum to the base of the Ap horizon or 0-20 cm if no Ap.
Interpretive classes 15-50, > 50 cm hr-1 are not considered.

Table 3. Soil quality classes based on moist rupture resistance, 0–30 cm.

Texture Class	Moist Rupture Resistance†				
	Loose	Very Friable	Friable	Firm	Very Firm and Stronger
Sandy, loamy sand	2	3	3	2	1
Not above and < 18% clay	3	4	3	2	1
18-40% clay	4	5	3	2	1
≥ 40% clay	5	5	4	1	1

† For 0–5 cm, if very friable and structure classes 1 or 2, place in class 2. This is done because surficial zones that are massive or have weak structure are prone to erosion.

Table 4. Soil quality classes of raindrop impact crust for medium textures.

Thickness Massive Zone	Dry Rupture Resistance Classes†		
	Weak	Moderate, Moderately Strong, Strong	Very Strong, Extremely Strong
mm			
< 1	5	5	3
1–2	5	4	2
2–4	5	3	2
4–8	5	3	1
8–20	5	3	1
≥ 20	4	2	1

† Class placement for other textures are available.

Table 5. Soil quality classes based on evaluation of organic carbon, 0–5 cm.

Quality Class	Criteria†	
	Organic Carbon Pctct	Organic Carbon/ Clay Ratio
1	< 0.5	< 0.02
2	0.5–1	0.05–0.02
3	1–2	0.05–0.1
4	2–4	0.1–0.2
5	≥ 4	≥ 0.2

† The lower placement for each of the two criteria determines the class.

Table 6. Soil quality classes based on maximum bulk density stratified by texture class. Exclusion: 0–30 cm.

Quality Class	Criteria		
	S, LS, SL	C, SC, SiC, SiCl	Other
	Mg m^{-3}		
1	≥ 1.75	≥ 1.50	≥ 1.65
2	1.70–1.75	1.45–1.50	1.60–1.65
3	1.60–1.70	1.35–1.45	1.50–1.60
4	1.50–1.60	1.25–1.35	1.40–1.50
5	< 1.50	< 1.25	< 1.40

Table 7. Soil quality classes based on maximum salinity 0–25 cm.

Quality Class	Criteria dS m^{-1}
1	≥ 16
2	8–16
3	4–8
4	2–4
5	< 2

Explanation: Assumes that condition 0-25 cm is indicative for soil as a whole.
Exclusion: 0 horizons.

gate stability 0–5 cm depth. Class sets for maximum bulk density and aggregate stability are not shown. The bulk density class set is essentially the same as shown in Table 6 for evaluation of use-invariant bulk density.

Development of class sets for use-invariant properties. Classes are shown for a few of the numerous use-invariant interpretive properties in the database applicable to soil quality evaluation. As discussed previously, these properties are evaluated for the soil beneath an "exclusion" zone. Tables 6 through 10 contain the quality class sets for maximum bulk density to 1 m, salinity, permeability, root restriction, and available water capacity, respectively. The selection of the class limits was strongly determined by limits of classes used in the interpretation program of the National Cooperative Soil Survey (Soil Survey Staff 1993). For example, the class limits for salinity (shown in Table 7) are the same as in U.S. Department of Agriculture Handbook 60 (1954), which, in turn, has been widely used in the soil survey. The bulk density class limits follow, in part, those determined by Pierce et al (1983).

Composite Records

Composite soil property records combine use-dependent and use-invariant values. To illustrate, two map unit components were evaluated: Aksarben, fine, smectitic, mesic Typic Argiudolls from Lancaster County, Nebraska, map unit ShC (Brown et al. 1980); and Harrisburg, coarse-loamy, mixed, superactive, thermic Typic Petrocalcids from Doña County, New Mexico, map unit SH (Bullock and Neher 1980). Aksarben is Sharpsburg in the cited soil survey. For the Aksarben soil, cropland and pasture uses were evaluated. For the Harrisburg soil only grazing use was evaluated. Use-dependent properties were measured or estimated and use-invariant information was obtained from the interpretive data base. Quality class values were assigned to each property (Tables 11 and 12). The kinds and numbers of properties employed differ between the two soils and the number of use-dependent and use-invariant properties are not the same. Class sets are not provided for pH and wind erosion resistance for Aksarben.

It is desirable to combine the various class placements for each use-dependent and use-invariant record into single index numbers (Tables 11 and 12). In the approach used, the sum of the class placements is divided by the total number of properties to obtain a mean of the quality or index. Alternatively, the number of class placements for various properties of ≤ 2 may be employed (shown in parenthesis in Tables 11 and 12). Aksarben has no properties of two or less, whereas Harrisburg has three. In some cases it may be desirable to weight the properties differently before calculating the mean.

Discussion

How may such an approach be applied in the National Cooperative Soil Survey? The current National Soil Survey database (NASIS) permits the inclusion of use-dependent data. However, a use-dependent database has not been created.

Table 8. Soil quality classes based on permeability.

Class	Criteria†	
	Low	High
	cm hr^{-1}	
1	< 0.004 within I m	≥ 15 continuous to 1.5 m
2	0.004–0.15 within 1 m and no < 0.004	≥ 15 continuous 0.6–1.5 m and not continuous above 0.6 m
3	0.15–0.5 within 1 m and no < 0.004	≥ 15 continuous 1–1.5 m or some part 0–1 m above 15
4	0.5–1.5 or 5–15 continuous to 1 m	≥ 15 absent 1–1.5 m and some part 0–1 m above 15
5	1.5–5 continuous to 1.5 m	≥ 15 continuous to 1.5 m

† The lower of the two placements determines the class. 'Not continuous'means the presence of ≥15cm thick zones that differ by one or more permeability classes from each other.

Table 9. Soil quality classes based on physical root restriction.

Quality Class	Criteria Depth cm
1	≤ 25
2	25–50
3	50–100
4	100–150
5	≥ 150

Explanation: Definition of physical root restriction described in Soil Survey Staff (1993 p 135). Exclusion: Ap; 0–20 cm below O if no Ap.

Table 10. Soil quality classes based on available water capacity (AWC).

Quality Class	Criteria Average AWC 0–150cm
1	< 0.5
2	0.05–0.10
3	0.10–0.15
4	0.15–0.20
5	≥ 0.20

Explanation: Weighted averages. Exclusion: O horizon.

An important reason is the lack of measurements that have been made on a use-dependent basis. Properties and class set limits should be defined regionally because of soil complexity, particularly those properties that are closely related to plant-soil interactions. It follows that people with national or regional experience should make the decisions about criteria and class limits.

The exclusion zones must be specific for the land use under consideration and may change with soil property. Depth of the exclusion zone of a use-dependent soil property may vary considerably. For example, the exclusion zone for maximum density may extend to 50 cm where compaction by heavy agricultural equipment is likely, but perhaps to 20 cm for rangeland or woodland. Decisions on depths of the exclusion zone may be based on variance from properties in the use-invariant database.

Integration of the properties to produce a single number requires much consideration. We recognize that properties are correlated or linked. Therefore, it is not advisable to weight all properties equally. For example, aggregate stability is strongly controlled by the type and amount of soil organic matter. Therefore, it would seem reasonable that organic matter should be assigned more weight than aggregate stability. Similarly, rupture resistance and bulk density should receive less weight if the structure were strongly expressed and the units were small than if the structure were weak and the units were large. The reason is that despite unfavorable rupture resistance, and/or bulk density, roots could grow and free water move in the spaces among the structural units. A short numerical statement may be constructed to describe the quality of a soil-use concept. For example, for Aksarben pasture (Table 11) the statement might be "use-dependent 4.5/6" and use-invariant 4.0/8" where mean quality placement is first and the number of properties is second.

Class limits follow the literature in some instances and in other cases they are based on our best judgment for separating levels of soil function that will affect use and management of the soil. Classes would be adjusted regionally as knowledge is gained. In order to develop improved class sets it is necessary to provide initial limits. More generally we need a language to exchange information. We do not have a language for use in the National Cooperative Soil Survey. Class limits need not be permanent to initiate a language.

Conclusion

The approach does not require modification in how soils are mapped. We would not map soil use. The change would be in documentation of the map unit component properties. Separate records would be available for the same soil under major uses. The use-dependent database would have application not only to soil quality but to soil behavior prediction for a wide range of considerations. We do not provide an operational proposal. Our intent is to provide enough specifics to illustrate the general concept and direction. The next step would be to make some near-surface measurements in different regions and then have people with broad experience construct composite records. There is no lack of use-invariant interpretive data. Such records are available for much of the private land of the U.S. The limitation is the use-dependent database.

Finally, the present soil survey interpretive database, by itself, cannot be used to evaluate soil quality. Equally important, use-invariant soil properties are essential because they affect the range of values for use-dependent properties and the susceptibility of these properties to change with use. We have to obtain use-dependent data and combine them with our present use-invariant data into composite records.

Table 11. Class placements for selected use-dependent and use-invariant properties of Aksarben soil.†

Property	Cropland‡	Pasture‡
Use dependent	Quality Class	Quality Class
Aggregate Stability	2	5
Bulk Density	3	4
Crust	5	5
Morphology	4	5
Organic Matter	3	4
Permeability	2	4
Quality Index	3.2 (2)	4.5 (0)
Use-Invariant		
AWC	4	4
Bulk Density	3	3
CEC	5	5
Organic Matter	4	4
Permeability	4	4
pH	3	3
Root Limiting Depth	5	5
Wind Erosion Resistance	4	4
Quality Index	4.0 (0)	4.0 (0)

†Cropland, March; Pasture, May.

‡The index here is the average of the properties. Alternatively, it could focus on the low values, perhaps the sum of placements 1 and 2 (in parenthesis).

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Table 12. Calculated soil quality index for selected use-dependent and use-invariant properties of Harrisburg soil.

Property	
Use-dependent	Quality Class
Aggregate Stability	1
Bulk Density	3
Crust	3
Morphology	1.9
Infiltration	3
Quality Index‡	2.4 (2)
Use-Invariant	
AWC	4†
Bulk Density	3
CEC	5
Organic Matter	4
Permeability	4†
pH	3
Wind Erosion	1
Quality Index‡	3.6 (1)

† Uncertainty about values below petrocalcic upper boundary

‡ The Index here is the average of the properties. Alternatively, it could focus on the low values, perhaps the sum of placements of 1 and 2 (sums are in parenthesis).

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Organizational Factors Affecting the Strength of Missouri's Soil and Water Conservation Districts

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ABSTRACT: In this study we develop an index to measure "district strength" in Missouri. By district strength we refer to the ability or capacity of districts to promote and meet their conservation goals. Using data from a statewide mail survey of SWCD supervisors and SWCD employees, we examine how various organizational factors influence district strength, including such internal variables as supervisor leadership and perceptions of the adequacy of employee salaries, and external variables, including district relations with the Missouri Soil and Water Districts Commission, and Natural Resources Conservation Service. Our findings reveal that supervisor leadership, districts linkages to the state Commission, and, to a lesser extent, external relations with NRCS, influence district strength.

Keywords: Conservation, organizations, organizational effectiveness, soil and water conservation districts

An increasing amount of conservation policy discourse centers on how to increase local capacity to solve local problems. This focal point is evident in mandates to increase local involvement and public participation as well as in the formation of partnerships between local, state, and federal organizations to solve environmental problems (Armstrong and Jacobs 1996; Arts 1984; Endicott 1993; Harless 1991; Nelson et al. 1993). Soil and Water Conservation Districts (SWCDs) represent perhaps the most longstanding and widespread form of local governance designed to empower local citizens to protect the environment.

Initially conceived in the 1930s, legislation such as the Soil Conservation Act (1935) and Model State Soil Conservation Districts Law (1937) enabled the formation of SWCDs in most counties of the United States. Although the structure of districts and their powers vary between states, in general these groups are structured as local governmental units and are typically governed by a board of local citizens (Steiner 1990). Because SWCDs are found in most counties throughout the United States and are designed to provide the infrastructure for local entities to solve local problems, they make an ideal case to identify and assess the factors associated with the ability of local organizations to solve local conservation problems.

Although SWCDs, and other local governmental and nongovernmental organizations, play an important role in protecting the nation's natural resources, most researchers have not focused on why some groups are more successful than others in solving conservation problems. Instead, most studies have emphasized the "end users" of best management practices and conservation programs. Extensive research, for example, has attempted to identify and demonstrate how personal characteristics, farm characteristics, and conservation attitudes relate to farmers' acceptance and use of a variety of best management practices (Gould 1989; Lockeretz 1990; Rikoon et al. 1996). While this research has improved our understanding of individual behavior, it overlooks the importance and impacts of organizations and institutions that implement and control conservation programs. Effective organizations may facilitate conservation activities while ineffective organizations may hinder these activities (Cernea 1987; Franklin 1976; Nowak 1992).

In this study, we address the relative importance of organizational factors that might influence district strength among Missouri Soil and Water Conservation Districts. Because SWCDs are local units of government, their organizational struc-

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