Watershed-scale soil quality assessment: Assessing reasons for poor canopy development in corn

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Abstract
Soil quality assessment is a critical component in understanding the long-term effects of soil and crop management practices within agricultural watersheds. Additionally, simple, robust assessment methodologies are needed for policy planning and implementation. In the South Fork of the Iowa River Watershed, an aerial survey was conducted during the summer of 2006, and fields that were planted to corn and appeared to have sections with underdeveloped canopy were marked. Our objective was to determine if a soil quality assessment could suggest the reasons for the poor canopy development. Fifty-one marked fields were assessed in autumn of 2006. Four composite samples were taken at the 0-10 cm depth in each field, three from the dominant soil types in the field and the fourth from the area with poor canopy. Bulk density (BD), aggregate stability, texture, pH, extractable P, K, Ca, Mg, NO_3, Cu, Fe, Mn and Zn, electrical conductivity (EC), soil organic carbon (SOC), total N, microbial biomass C (MBC), potentially mineralizable C (C_{min})and N (N_{min}), and β-glucosidase (BG) activity were measured. The Soil Management Assessment Framework (SMAF) was used to assess soil quality. There was no single cause for poor canopy across in all fields. Overall, the SOC, MBC, C_{min}, N_{min}, and BG activity were lower in the areas with poor canopy development. SMAF indicator scores for carbon, which compensate for differing soil types, were significantly lower for the poor canopy areas. When the data means were analysed, SOC, MBC, BD and EC, as well as the soil quality index (SQI, mean of the 11 scored indicators) were significantly different between the normal and poor canopy areas. On a field to field basis, there were specific problems such as low SOC and other indications of poor nutrient cycling: low extractable P, high BD, and low water-filled pore space at time of sampling. When the fields were separated by slope position, most indicators and indicator scores were significantly lower in the poor canopy areas. Using SMAF to determine specific problems will help land managers develop management practices to ameliorate poor performing field areas. Policy makers can use information like this to assess overall effectiveness of management systems on ecosystem functions.

Key Words
Soil quality, SQI, β-glucosidase, carbon, pothole topography, maize.

Introduction
While the concept of a performance-based rating for soil is not new, it has most often been related to crop productivity. The soil quality concept has been broadened to include the soil's impact on the environment. It has been suggested that enhancing soil quality is critical for maintaining and improving water quality (Kennedy and Papendick 1995). There continues to be a number of soil quality issues in the United States, including continued high rates of erosion, reductions in soil fertility and production, and exposure to chemical and heavy metal pollution (Karlen and Stott 1994; Andrews *et al.* 2004). A robust method is needed for soil quality assessment to provide information on management impacts on soil functions for both landowners and policy makers. In 2003, the Conservation Effects Assessment Project (CEAP) was initiated to provide a scientific basis for a national assessment of conservation practices by the USDA Natural Resources Conservation Service (Richardson *et al.* 2008). Initially, the primary thrust of CEAP was to assess the impact of implementing conservation practices within agricultural watersheds on water quality. In 2006, a study was initiated to assess the effects of these same conservation practices on soil quality within the USDA Agricultural Research Service's (ARS) fourteen CEAP experimental watersheds. As part of this study, the soil quality of the Iowa River's South Fork Watershed consisting of about 78,000 ha (Tomer *et al.* 2008), was assessed.

For cropland, soil quality for a specific site can be affected by the interaction of many factors including climate, soil type, crop rotation, tillage, and other management factors. Assessment tools are needed to evaluate the impact of management systems on critical soil functions related to soil quality, including nutrient cycling and water partitioning. For CEAP, the tool selected to help assess impacts of management on soil was the Soil Management Assessment Framework (SMAF) (Andrews *et al.* 2004). The SMAF provides site-specific interpretations for soil quality indicator results, with the most recent version is available from us. The SMAF uses measured soil indicator data to assess management effects on soil functions using a three step process that includes indicator selection, indicator interpretation, and integration into an index (SQI). The SMAF uses soil taxonomy as a foundation for assessment, allowing for the modification of many of the scoring indicator values to be based on soil suborder characteristics. Currently, SMAF includes thirteen management-sensitive indicators with scoring curves consisting of interpretation algorithms. They are water stable aggregation (WAS), plant-available water holding capacity, water-filled pore space (WFPS), bulk density (BD), electrical conductivity (EC), pH, sodium adsorption ratio, extractable P and K, soil organic carbon (SOC), microbial biomass C (MBC), potentially mineralizable N (N_{min}), and β-glucosidase (BG) activity (Andrews *et al.* 2004; Stott *et al.* 2010; Wienhold *et al.* 2009).

There are two primary strategies have been suggested for assessing soil quality on a watershed scale : surveys or paired comparisons (Karlen *et al.* 2008). We used a combination of these two strategies. An aerial survey was conducted in late spring and field sections planted to corn that had poor canopy development compared to the rest of the field were noted. Two transects through the watershed were sampled and included the zones of deficiency. Our hypothesis was that a soil quality assessment of the fields, using the SMAF, would be able to characterize possible reasons for the deficient canopy development.

Materials and methods

Watershed characteristics

The landscape is dominated by the Clarion-Nicollet-Webster soil association, forming a sequence, respectively, of moderately well drained Typic Hapludolls, somewhat poorly drained Aquic Hapludolls, and poorly drained Typic Haplaquolls, with Harps soils (Typic Calciaquolls) occupying glacial potholes with Webster soils (Soil Survey Staff 2004). Most of the soils have a loam texture. About 85% of the watershed is under corn and soybean rotation, and 6% in grass (CRP) and pasture, mostly along riparian valleys in the lower watershed where cattle can then have free access to streams.

Soil sampling

In October 2006, soils were sampled in fields marked during the aerial survey. each of Three samples were taken in within the field under areas with normal canopy development, each sample was taken from a different, dominant soil map unit (SMU); a fourth sample was taken in the area that had poorly developed canopy. A sample consisted of a composite of 20 cores taken at the 0-10 cm depth in a transect across the SMU. The cores were sampled proportionately from the within and between row positions. Any surface residue was cleared from the sampling area so that all samples start at the soil surface. Samples were stored in zip lock plastic bags and transported back to the lab.

Samples were weighed for BD and water content determinations. A 10 g subsample was placed in an oven at 104 °C for 24 h to gravimetrically determine field water content. Soil was passed through an 8-mm sieve. A representative 150 g subsample was removed, placed in a plastic bag and stored at 4 °C for MBC determination. Another representative portion was hand sieved to pass a 2-mm sieve, air-dried and stored at 4°C until used for determining C_{min} and N_{min}. At least 25 g was set aside to air-dry and used for the WSA assay. The remainder of the sample was air-dried, ground to pass a 2-mm sieve, bagged and stored at 4 °C until use.

Soil assays

Water stable aggregation was determined using a 25 g air-dried, 8-mm sieved sample using a modified Yoder sieving machine, set to 30 strokes per minute for 5 minutes. Soil texture was determined using the hydrometer procedure. Using 20 g of air dry, 2 mm sieved soil, EC and pH were determined using a 1:2 soil-to-water ratio. Mehlich III extractable P, K, Ca, and Mg concentrations were determined using an inductively coupled plasma-atomic emission spectrograph (ICP-AES). KCl extracted NO_3-N, and DPTA extracted Cu, Fe, Mn, Zn were also determined using standard methods. Total soil C (TC) and total N were measured by dry combustion and inorganic carbon (SIC) was quantified (Sherrod *et al.* 2002). Soil organic C was calculated as the difference between TC and SIC. The MBC was measured with standard soil fumigation and chemical extractions (Tate *et al*. 1988). Organic C in fumigated and non-fumigated extracts will be determined and biomass C will be calculated using a correction factor (k = 0.33; Sparling and West 1988). An aerobic 28-day incubation method was used to determine C_{min} and N_{min}., with alkali basetraps used to absorb the CO_2. Aliquots of the base trap were acidified and the CO_2 concentration was measured using a gas chromatograph equipped with an autosampler and a thermal conductivity detector. Mineral N ($(NO_2+NO_3) + NH_4$) was determined colorimetrically using a flow injection system. β-glucosidase activity was determined by the method of Eivazi and Tabatabai (1988).

Soil management assessment framework

The soil measurements used to calculate the SQI were: BD, AGS, WFPS, pH, EC, extractable P and K, SOC, MBC, N_{min}, and BG activity. The data were scored and then used to compute the indices for each site (Andrews *et al.* 2004; Stott *et al.* 2010). To score the various indicators, knowledge of the soil taxonomic classification, texture, and general climate was required. Data were examined combined (*n*=203) as well as grouped by normal (*n*=150) vs. poor (*n*=50) canopy development. Data were also further grouped by landscape position. Using least significant difference (LSD, *P*=0.05) calculations, data from the individual fields were examined to explore possible reasons for the poor canopy development.

Results

When the data means were analysed, SOC, MBC, BD and EC, as well as the SQI (mean of the 11 scored indicators) were significantly different between the normal and poor canopy areas (Table 1). SMAF assessment takes into account differing soil taxonomic classes and textures. A score of 0.8 means that the soil indicator is at 80% of the optimum for that soil type. There was no single indicator that scored significantly less in the poor canopy areas as compared to normal canopy areas across all fifty fields. When considering landscape positions (Table 2), 52% of the normal and 18% of the poor canopy sections were on hilltop and sideslope positions, while 20 and 30% were in depression areas, respectively.

Table 1. Soil quality indicator measurements from fields sampled in the South Fork Watershed, Samples were taken from sections that had normal canopy development (*n*=153), and one from the section displaying poor canopy development during the growing season (*n*=50).

Soil Quality Indicator	Normal Canopy		Poor Canopy	
	Mean	S.D.	Mean	S.D.
Soil organic C (g/kg)	32.1	22.6	25.6	22.7
Microbial biomass C (mg/kg)	530	226	426	201
Total N (g/kg)	28.3	19.1	23.3	20.2
Nitrate N (mg/kg)	17.2	10.3	13.9	12.9
Mineralizable N (mg/kg)	50.7	15.7	46.3	19.1
β-Glucosidase (mg p-nitrophenol/kg)	153	49	132	43
Bulk Density (g/cm^3)	1.2	0.2	1.2	0.2
Water-filled Pore Space (%)	53.1	10.2	44.8	11.1
Wet Aggregate Stability (%)	88.4	3.3	87.9	3.3
pH	6.9	0.8	7.1	0.8
Electrical Conductivity (ds)	0.29	0.10	0.23	0.10

Table 2. Mean soil quality indicator scores, calculated using the Soil Management Assessment Framework (SMAF), as affected by slope position and canopy development in the South Fork Watershed.

Slope Position	Hilltop		Sideslope		Toeslope		Depression		
Canopy Development	Normal	Poor	Normal	Poor	Normal	Poor	Normal	Poor	LSD†
Indicator Score *n*=	31	15	61	5	18	4	43	26	
Total Organic C	0.69	0.44	0.75	0.71	0.68	0.50	0.76	0.47	0.02
Microbial Biomass C	0.94	0.89	0.95	0.93	0.92	0.85	0.95	0.90	0.01
Potentially Mineralizable N	0.97	0.98	1.00	0.91	0.97	0.98	0.99	1.00	0.01
β-Glucosidase Activity	0.20	0.14	0.25	0.19	0.18	0.12	0.15	0.17	0.01
Bulk Density	0.95	0.99	0.95	0.98	0.97	0.91	0.98	0.87	0.01
Water-filled Pore Space	0.92	0.81	0.94	0.91	0.92	0.87	0.91	0.89	0.01
Wet Aggregate Stability	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
pH	0.88	0.87	0.91	0.86	0.90	0.85	0.85	0.88	0.01
Electrical Conductivity	0.99	0.87	0.97	1.00	0.96	0.94	1.00	0.92	0.01
Extractable P	0.86	0.60	0.89	1.00	0.95	0.99	0.94	0.94	0.02
Extractable K	0.97	0.93	0.96	0.87	0.96	0.95	0.98	0.97	0.01
Standard SQI‡	0.85	0.78	0.87	0.85	0.86	0.81	0.87	0.82	0.04

†Least Significant Difference, *P*=0.05

‡The Soil Quality Index (SQI) is a simple mean of the 11 scored indicators.

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In three of the landscape positions (hilltop, sideslope, and depression), the mean SQI scored significantly lower (LSD, P=0.05) in the areas of poor canopy development vs. the normal canopy areas. The fourth landscape position (toeslope) trended less, but did meet the statistical requirement. All indicator scores, except PMN, WAS, BD and pH, were lower in the poor canopy areas within a given slope position. Many fields had multiple indicators that were scored at least 10% (0.1) less in the poor vs. normal canopy areas. The 3 the soil organic matter indicators, SOC, MBC, and β-Glucosidase activity, scored at least 10% lower in 54% of the poor canopy areas, while 22% of the fields showed no differences between the poor and normal canopy areas. Seventy percent of the fields had at least one soil fertility indicator (P, K, or N_{min}), that scored 10% lower in the poor canopy areas, and 78% of the fields had one or both of the soil chemical reaction indicators (pH, EC) that scored 10% less.

Conclusion

SMAF was able to pinpoint specific problems in fields where canopy development was poor. Using SMAF to determine specific problems will help land managers develop management schemes ameliorate the poor performing areas of the fields. Policy makers can use information like this, on a watershed basis to assess overall effectiveness of management systems on soil ecosystem functions.

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