A Soil Quality Assessment within the Iowa River South Fork Watershed

Diane E. Stott*
USDA-ARS
National Soil Erosion Research Lab.
275 S. Russell St.
West Lafayette, IN 47907-2077

Cynthia A. Cambardella
Mark D. Tomer
Douglas L. Karlen
USDA-ARS
National Lab. for Agric. and the Environ.
2110 University Blvd.
Ames, IA 50011

Roger Wolf
Iowa Soybean Association
1255 SW Prairie Trail Pkwy
Ankeny, IA 50023

Soil quality assessment is a proactive process for understanding the long-term effects of crop and soil management practices within agricultural watersheds. Fields with both well-developed and poor (N-deficient) corn (*Zea mays* L.) canopy growth were identified within the Iowa River's South Fork Watershed. Our objectives were to quantify several soil quality indicators, including the near-surface soil organic carbon (SOC) content, and determine if the Soil Management Assessment Framework (SMAF) could distinguish between the well-developed and poor corn canopy areas. Four sites, three representing the major soil series in the well-developed canopy areas and one in the poor area, were identified and sampled (0–10 cm) within 50 fields. There were no significant differences between performance zones when analyzed collectively. Using SMAF indicator scores, SOC, bulk density (D_b), water-filled pore space (WFPS), electrical conductivity (EC), and microbial biomass carbon (MBC) were significantly lower in the poor canopy areas; however, no single indicator scored significantly less across all 50 fields. When separated by landscape position (hilltop, sideslope, toeslope, or depression), only SOC was significantly different between performance zones across each position. Other indicators that differed in at least one slope position included D_b, WFPS, MBC, EC, P, Fe, Cu, Zn, or potentially mineralizable C. A majority of fields had multiple indicators with SMAF ratings at least 0.10 lower in the poor areas than in the corresponding well-developed canopy areas. Soil quality assessment on a field-by-field basis thus provides an approach for identifying potential specific soil-based causes for the poor canopy development.

Abbreviations: AGS, macroaggregate stability; BG, β-glucosidase; CEAP, Conservation Effects Assessment Project; CRP, Conservation Reserve Program; D_b, bulk density; EC, electrical conductivity; MBC, microbial biomass carbon; N_{min}, potentially mineralizable nitrogen; SMAF, soil management assessment framework; SOC, soil organic carbon; SQI, soil quality index; WFPS, water-filled pore space.

The Conservation Effects Assessment Project (CEAP) was initiated in 2003 to provide a scientific basis for assessing effectiveness of conservation practices by the USDA Natural Resources Conservation Service (NRCS) (Richardson et al., 2008). The initial focus was to assess conservation practice effects on water quality in 15 USDA Agricultural Research Service (ARS) CEAP experimental watersheds. In 2006, a soil quality assessment was initiated, first in the Iowa River South Fork Watershed, and subsequently within all other ARS CEAP watersheds.

The South Fork Watershed consists of about 78,000 ha (Tomer et al., 2008), and includes tributaries of Tipton and Beaver Creeks. The landscape is relatively young and composed of glacial till deposited 10,000 to 15,000 yr ago. It is representative of the Des Moines Lobe, which is the dominant land form of north-central Iowa. The terrain is poorly dissected and internally drained prairie potholes are common in the upper parts of the watershed. The low relief creates poor drainage conditions, and hydric soils occupy 54% of the watershed area. Installation of subsurface tile drains and ditches began more than 100 yr ago. The artificial drainage accelerates transport of excess soil water and with it several dissolved contaminants.

Cropland soil quality at a specific site can be affected by the interaction of many factors including climate, soil type, and management practices such as crop rotation and tillage practice. Assessment tools are needed to evaluate the effects of those factors on critical soil ecoservice functions such as nutrient cycling and water

Soil Sci. Soc. Am. J. 75:2271–2282
Posted online 4 Oct. 2011
doi:10.2136/sssaj2010.0440
Received 30 Nov. 2010.
*Corresponding author (diane.stott@ars.usda.gov).
© Soil Science Society of America, 5585 Guilford Rd., Madison WI 53711 USA
All rights reserved. No part of this periodical may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Permission for printing and for reprinting the material contained herein has been obtained by the publisher.

partitioning. Such tools need to be flexible with regard to selection of soil functions and indicators of those functions to ensure the assessments are meaningful and suitable for the producer's management goals. The assessment tools also need to be sensitive to management changes, preferably within a year or two after implementation. For this study, the Soil Management Assessment Framework (SMAF) (Andrews et al., 2004) was selected for our assessment. A peer-reviewed USDA-NRCS report (Potter et al., 2006) describes the use of the interpretation step of SMAF for the national modeling portion of the overall CEAP project.

The SMAF provides site-specific interpretations for soil quality indicator results. A beta version is available on the web (http://soilquality.org/tools/smaf_intro.html, verified 23 Aug. 2011) and the most recent version is available in Excel format from the authors. 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. 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, and providing a contextual basis for indicator interpretation. Soil quality and its assessment are soil and site specific, and depend on a variety of factors, including inherent soil characteristics, environmental influences such as climate, and human values such as intended land use, management goals, and environmental protection. The SMAF includes soil physical, chemical, and biological indicators that are management-sensitive, and therefore dynamic. Currently, SMAF includes 13 indicators with scoring curves consisting of interpretation algorithms. They are macroaggregate stability (AGS), plant-available water holding capacity, WFPS, D_b, EC, pH, sodium adsorption ratio, extractable P and K, SOC, MBC, potentially mineralizable nitrogen (N_{min}), and β-glucosidase (BG) activity (Andrews et al., 2004; Wienhold et al., 2009; Stott et al., 2010).

A preliminary soil quality assessment along two transects crossing the South Fork watershed (Karlen et al., 2008) used a variety of assessment approaches. The SMAF was used to compute a soil quality index (SQI) using four indicators: pH, EC, SOC, and P. Overall, there were no soil fertility limitation SQIs within the portion of the watershed evaluated based on an average pH of 6.96 and extractable P and K levels of 36 and 162 mg kg^{-1}, respectively. The SMAF analysis indicated soils within the watershed were functioning at 87% of their full potential. The lowest indicator score was associated with SOC (0.60), which averaged only 28.4 g kg^{-1}.

Our primary objective was to quantify several soil quality indicators, including the near-surface carbon content, within a larger portion of the South Fork Watershed, using 11 soil indicators that have scoring curves as well as several other soil indicators for which scoring curves have not yet been developed. The assessment was designed to see if SMAF could identify differences between well- and poorly developed canopy (based on yellowing of the canopy) areas within 50 fields scattered throughout the western two-thirds of the watershed. Two primary strategies have been suggested for assessing soil quality on a watershed scale (Karlen et al., 2008): surveys (e.g., Cambardella et al., 1994) or paired comparisons (e.g., Cambardella et al., 2004; Moorman et al., 2004). We used a combination of these two strategies. Our hypothesis was that a soil quality assessment using the SMAF and surface soil samples would be sensitive enough to separate the field areas with differing performance zones, and would thus identify specific soil quality indicators that co-varied with poor canopy development.

MATERIALS AND METHODS

Watershed Characteristics

The dominant soil association within the South Fork Watershed consists of Clarion (well drained Typic Hapludolls), Nicollet (somewhat poorly drained Aquic Hapludolls), and Webster (poorly drained Typic Haplaquolls) soils (National Cooperative Soil Survey, 1986a, 1986b; Soil Survey Staff, 2004) (Table 1). The prairie potholes are occupied by very poorly drained Okoboji soils (Cumulic Haplaquolls), often with calcareous and poorly drained Harps soils (Typic Calciaquolls) on their margins. About 85% of the watershed is managed in a corn–soybean [*Glycine max* (L.) Merr.] rotation, with pasture or Conservation Reserve Program (CRP) land occupying 6% of the watershed, primarily in riparian valleys where cattle can have free access to streams. Most of the remaining land is developed or devoted to roadways, with only about 1% in forest or wetland. There are about 100 confined swine-feeding operations, most of which are located in Tipton Creek and the upper South Fork watersheds.

Mean annual precipitation is 750 mm with 60% falling during May through August in relatively short, but intense events. Annual baseflow constitutes 60% of the total stream discharge. Rainfall for 2006 was lower than the mean annual precipitation (Fig. 1), however the rain fell at the most opportune times, and crop yields were normal.

Soil Sampling

An aerial survey within the Iowa River's South Fork Watershed was conducted by the Iowa Soybean Association's Environmental Program Team in early August 2006. The survey used aerial visible color and color infrared photography to evaluate crop nutrient status, which has been successfully used to evaluate crop nutrient deficiency and detect N stress in corn (Blackmer et al., 1996). Areas within fields were identified that had a relatively well- or poorly developed crop canopy using the visible and near infrared color images. Since photosynthetically active plant tissue absorbs visible red (600–700 nm) and reflects near infrared (750–1350 nm) light, visible red light is inversely related to chlorophyll concentration and near infrared light is directly related to green leaf density (Knipling, 1970). Poorly developed (stressed) areas were identified as yellowing in the green (visible light) images. If no yellowing was apparent, infrared images were used to identify areas of poor crop canopy development because near infrared sensors are more sensitive to a reduction in green leaf area rather than changes in the reflectance of individual leaves (Knipling, 1970). Both visible and infrared images were collected and subsequently interpreted by a single individual because of the subjectivity associated with such evaluations. Visual assessment was combined with USDA-NRCS Soil Survey information and knowledge provided by local USDA-NRCS soil scientists to ensure proper identification of the soil map units (SMUs) associated with each sampling area.

Table 1. The soil series represented in this study by slope position. The classification, texture, and drainage class are from the published soils surveys (Soil Survey Staff, 2004), and the soil organic carbon (SOC), bulk density (D_b, whole soil, moist, clod method), and pH data (1:1 suspension) are from summary reports generated from the National Cooperative Soil Survey (1986a, 1986b) characterization database. Not all the soil series represented in the study were found in this online database.

Soil series	Taxonomic classification	Texture	Drainage	SOC		D_b		pH	
				Range	Mean	Range	Mean	Range	Mean
				—— g kg^{-1}——		—— g cm^{-3}——			
			Hilltop						
Clarion	Fine-loamy, mixed, superactive, mesic Typic Hapludolls	loam	moderately well	6.2–31.2	16.6	1.66–1.99	1.79	5.0–7.7	6.2
Muscatine	Fine-silty, mixed, superactive, mesic Aquic Hapludolls	silty clay loam	somewhat poorly	13.8–34.6	25.1	1.25–1.38	1.32	5.4–6.3	5.8
Storden	Fine-loamy, mixed, superactive, mesic Typic Hapludolls	loam	moderately well	1.8–20.1	1.05	–	1.8	7.6–8.2	7.9
			Sideslope						
Lester	Fine-loamy, mixed, superactive, mesic Mollic Hapludalfs	loam	well	0.5–23.7	5.1	1.70–2.13	1.97	6.8–8.3	7.8
Nicollet	Fine-loamy, mixed, superactive, mesic Aquic Hapludolls	clay loam	somewhat poorly	5.7–64.2	27.4	1.22–1.86	1.65	5.9–7.5	6.5
Saude	Coarse-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludolls	loam	well	16.0–22.2	1.91	1.77–1.79	1.78	5.8–6.2	6.0
Tama	Fine-silty, mixed, superactive, mesic Typic Argiudolls	silty clay loam	well	10.2–41.8	19.1	1.37–1.86	1.68	4.4–7.3	6.0
Terril	Fine-loamy, mixed, superactive, mesic Cumulic Hapludolls	loam	moderately well	12.5–19.3	15.5	1.6–1.87	1.75	5.7–6.9	6.4
			Toeslope						
Brownton	Fine, smectitic, calcareous, mesic Vertic Endoaquolls	silty clay loam	poorly	NA†	NA	NA	NA	NA	NA
Canisteo	Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls	clay loam	very poorly	6.2–25.7	16.4	1.73–1.97	1.82	5.7–7.0	6.4
Coland	Fine-loamy, mixed, superactive, mesic Cumulic Endoaquolls	silty clay loam	poorly	NA	NA	NA	NA	NA	NA
Garwin	Fine-silty, mixed, superactive, mesic Typic Endoaquolls	silty clay loam	poorly	NA	NA	NA	NA	NA	NA
Harpster	Fine-silty, mixed, superactive, mesic Typic Calciaquolls	silty clay loam	poorly	SP‡	36.0	SP	1.62	7.8–8.6	8.2
Webster	Fine-loamy, mixed, superactive, mesic Typic Endoaquolls	silty clay loam	poorly	12.8–44.5	30.1	1.53–1.78	1.67	5.6–7.7	6.6
			Depression						
Harps	Fine-loamy, mixed, superactive, mesic Typic Calciaquolls	clay loam	poorly	12.8–34.8	25.5	1.73–1.80	1.76	7.7	8.0
Okoboji	Fine, smectitic, mesic Cumulic Vertic Endoaquolls	silty clay loam	very poorly	14.1–64.3	46.0	1.56–1.66	1.59	6.8–7.3	7.0
Palms	Loamy, mixed, euic, mesic Terric Haplosaprists	muck	very poorly	6.9–16.3	10.2	NA	NA	7.3–8.0	7.7
Wacousta	Fine-silty, mixed, superactive, mesic Typic Endoaquolls	silty clay loam	very poorly	NA	NA	NA	NA	NA	NA

† NA, data not available in the database.

‡ SP, characterization of a single pedon was reported in the database.

In each of 50 fields, sampling sites were selected to include the three well-developed and one poorly developed (stressed) areas. Points were selected from areas where the imagery was relatively homogeneous across 20 m^2. There were specific management differences from field to field because they were owned and operated independently from one another, but overall, they were managed similarly with respect to tillage, planting density, fertilizer rates, manure use, and herbicide applications. Following harvest in October 2006, soil samples were collected from four areas within each field. Twenty cores (3.2-cm diam.) were taken from the 0- to 10-cm depth and composited for each sampling site. The cores were sampled proportionately, by area, from the within and between row positions. Any surface residue was cleared from the sampling area so that all samples started at the soil surface. Samples were placed in plastic bags, sealed, and transported back to the lab.

Samples were weighed for bulk density (Grossman and Reinsch, 2002) 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, removing rocks and

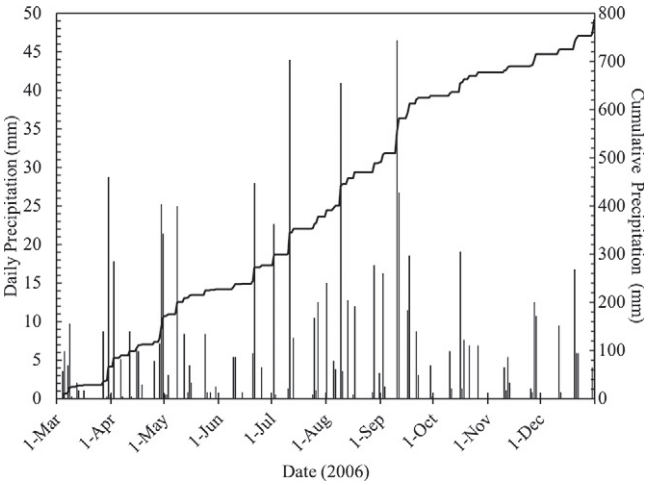

Fig. 1. Daily and cumulative precipitation during the 2004 growing season in Iowa River's South Fork watershed.

plant material larger than the mesh openings. The weight of removed material was recorded. A representative 150-g subsample was removed, placed in a plastic bag, and stored at 4°C for soil microbial biomass carbon determination. Another representative portion was hand-sieved to pass a 2-mm sieve, air-dried, and stored at 4°C until used for determining potentially mineralizable C and N assays (C_{min} and N_{min}, respectively). The remainder of the sample was air-dried, ground to pass a 2-mm sieve, bagged, and stored at 4°C until used.

Soil Assay

Macroaggregate stability was determined using a modified Yoder (Holland, OH)[1] sieving machine, set to 30 strokes per minute for 5 min (Kemper and Roseneau, 1986). Twenty-five grams of 8-mm sieved, air-dried soil was placed on top of a nest of four sieves with openings of 2.0, 1.0, 0.5, and 0.25 mm (sieve numbers 10, 18, 35, and 60, respectively) and physical disruption of the aggregates was performed in deionized water to limit chemical dispersion of the aggregates. Soil texture was determined using the hydrometer procedure of Gee and Or (2002). The readings were corrected for temperature. Percentage silt was calculated as the difference between 100 and (%sand + %clay).

Using 20 g of air dry, 2-mm sieved soil, electrical conductivity (EC) (Whitney, 1998a) and pH (Watson and Brown, 1998) were determined using a 1:1 soil/water ratio and standard EC and pH meters. Mehlich III extractable (Mehlich, 1984) P, K, Ca, and Mg concentrations were determined using an inductively coupled plasma–atomic emission spectrograph (ICP–OES) (Optima 5300 DV, PerkinElmer, Shelton, CT).

A 10-g subsample of field moist, 8-mm-sieved soil was extracted with 50 mL of 2 *M* KCl, and inorganic N [$(NO_2+NO_3) + NH_4$] in the filtrate was quantified using flow injection technology (Lachat Instruments, Milwaukee, WI). Concentrations of Cu, Fe, Mn, and Zn were measured using ICP–OES after extracting another 20-g subsample with diethylenetriamine-pentaacetic acid (DTPA) as described by Whitney (1998b).

Total soil C and total N were measured by dry combustion (EA1112 Flash NC Elemental analyzer, Thermo Finnegan Scientific, Inc., Waltham, MA) using air-dried, ground soil. For samples with a pH of 7.3 or greater, soil inorganic carbon was quantified according to the method of Sherrod et al. (2002). Soil organic carbon (SOC) was calculated as the difference between total and inorganic C. Microbial biomass was measured on 8-mm sieved field-moist samples with standard soil fumigation and chemical extractions (Brookes et al., 1985; Vance et al., 1987). Potentially mineralizable N was measured using an aerobic 28-d incubation method described by Drinkwater et al. (1996) with mineral N [$(NO_2+NO_3) + NH_4$] determined colorimetrically using a flow injection system (Lachat Instruments, Milwaukee, WI). Mineralizable C was also measured during an aerobic 28-d incubation using KOH basetraps to absorb the CO_2. Aliquots of the base trap were acidified and the CO_2 concentration was measured using a gas chromatograph (Model 3800, Varian, Inc., Walnut Creek, CA) equipped with a CombiPal autosampler (CTC Analytics AG, Zwingen, Switzerland) and a thermal conductivity detector. β-glucosidase activity was determined using the method of Eivazi and Tabatabai (1988) and expressed as mg *p*-nitrophenol released kg^{-1} soil h^{-1} incubation.

Soil Management Assessment Framework

Eleven soil measurements (D_b, AGS, WFPS, pH, EC, extractable P and K, SOC, MBC, N_{min}, and BG activity) were used to calculate a SQI using the SMAF. The data were scored as previously outlined (Andrews et al., 2004; Wienhold et al., 2009; Stott et al., 2010) and used to compute the indices for each site. To score the various indicators, knowledge of the soil taxonomic classification, texture, and general climate is required. Besides obtaining individual indicator scores, a combined SQI was calculated by summing the scores, multiplying by 100, and dividing by the number of measurements, which for this study was 11.

Statistical Analysis

Data were combined (n = 200) and grouped by well-developed (n = 150) and poorly developed canopy (n = 50) areas. Data were further grouped and analyzed by either previous crop (corn, soybean, or unknown) or by landscape position. The Clarion (n = 57), Clarion-Storden complex (8), Muscatine (1) and Storden (1) SMUs were classed as *hilltop* positions. The Lester (n = 1), Nicollet (15), Saude (3), Tama (1), and Terril (1) SMUs occupied the *sideslope* positions. Brownton (n = 1), Canisteo (29), Coland (2), Coland-Terril Complex (2), Garwin (1), Harpster (1), Webster (11) and Webster-Nicollet complex (22) SMUs were considered to be in the *toeslope* position. The Harps (n = 26), Harps-Okoboji complex (3), Okoboji (7), Okoboji-Harps complex (4), Palms (5), and Wacousta (1) soil series were grouped as *depressions*.

Statistics were calculated using SAS version 9.1 (SAS Institute, Cary, NC). Preliminary analysis using a chi-square test indicated that the soil indicator data were, in most cases, nonnormally distributed. Therefore, nonparametric statistics (Wilcoxon analysis with Kruskal-Wallis test) were used to test for significant differences among watersheds or landform elements at $\alpha = 0.05$. Transformations that were tried included log, square, square root, and reciprocal, and the one that led to the most normally distributed transformation was chosen for each indicator. Analysis of variance using parametric methods on the transformed data yielded similar results to the nonparametric analysis. Type III sums of squares were used in the parametric ANOVA. Means were separated using Tukey's range test at $P = 0.05$. For SQI values, means for the watersheds and landscape

1 Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

positions were compared with ANOVA for unbalanced design and the means were separated with the Student's t test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Physical parameters of interest were AGS and D_b for their role in soil structure and water infiltration, as well as WFPS for its role in biogeochemical processes (Table 2). Most soils sampled were well aggregated, and while the mean D_b was typical for the region, there was a wide range in values. At the time of sampling, the mean WFPS was slightly less than the 60% that is considered optimum for maximum biological activity (Linn and Doran, 1984), but this was not considered unusual since sampling occurred in October after grain harvest. The biochemical indicators related to soil organic matter and nutrient cycling processes that were measured included SOC, MBC, C_{min}, and BG activity. The mean SOC was similar to that typically found in north-central Iowa, and about one-half that of the values associated with native Midwestern Mollisols (Karlen, 2008; David et al., 2009). The BG activity was generally quite low as compared with other soils under similar climate, soil type, and management (Stott et al., 2010; Eivazi and Tabatabai, 1988; Dodor and Tabatabai, 2005). For a nutrient management assessment, pH, EC, N, NO_3–N, N_{min}, P, and K were the primary chemical and fertility indicators considered, with additional measurements for Ca, Mg, Cu, Fe, Mn, and Zn contents. The mean numbers were very similar to those found in previous surveys (Karlen et al., 2002; Karlen, 2008), and are typical for north central Iowa. The mean and median values for soil P and K would be classified as very high (Sawyer et al., 2003; Sawyer et al., 2008). Of the micronutrients tested, only Zn had a potential for being low in some soils due to the near-neutral pH values (Vitosh et al., 1995).

When the data were grouped into well- and poorly developed canopy areas, most of the means trended lower in the poorly developed areas, but the differences were not statistically significant (Table 3). A small percentage of the well- (6.5%) and poorly developed (6.0%) canopy areas were rated as very low to low P (<15 mg kg^{-1}) for corn, 14% of the areas were at optimum levels for P (16–20 mg kg^{-1}) and 89.5 of the well-developed and 80.0% of the poorly developed areas had high (21–30 mg kg^{-1}) to very high (>31 mg kg^{-1}) P levels (Sawyer et al., 2003, 2008). For K, 1.5 and 4.0% of the well- and poorly developed canopy sites, respectively, were rated as having low K levels (91–130 mg kg^{-1}), 6.9 and 14% had optimum levels (131–170 mg kg^{-1}), 8.8 and 8.0% had high levels (171–200 mg kg^{-1}), while the remaining 33.8 and 74.0% of the sites had very high levels of extractable K (>201 mg kg^{-1}), respectively. Zinc becomes less available as pH increases, and among the well-developed canopy areas sampled, 33.3% had adequate Zn (<0.9 mg kg^{-1}), while only 24.0% of the poorly developed canopy areas had sufficient amounts.

Indicators were then scored with the SMAF (Andrews et al., 2004; Wienhold et al., 2009; Stott et al., 2010), taking into account differing soil and climatic properties that are known to influence the interpretation of an indicator (Table 4). A SMAF score of 0.8 means that the soil indicator is at 80% of the optimum or maximum value. Currently, only 11 of the indicators measured in this study have scoring functions available in the SMAF. Except for AGS, all the indicator scores exhibited wide ranges. For most of the soils represented in this study, AGS would have to drop below 70% before the score dropped below 1.0, and the lowest measurement was 68.6% (Table 3). The means of five indicator scores were found to be significantly different in the well- vs. poorly developed canopy areas (Table 4): D_b (Fig. 2), EC (Fig. 3), SOC (Fig. 4), MBC (Fig. 5), and P. The SQIs were also significantly different in the well- vs. poorly developed canopy areas, representing 86 and 82% of optimum soil quality, respectively. The minimum SQI score in the poorly developed canopy areas was lower than in well-developed areas, with the maximum SQI scores for both areas being the same. The mean SQI in the Karlen et al. (2008) study was 87, but only included four indicators: SOC, pH, P and EC, two of which were not considered significantly different in our study. Additionally, samples in that study represented a wide range of crop and soil management systems, including some meadows and CRP land.

The scoring curves for D_b are less-is-better sigmoidal shapes, and take soil texture and mineralogy into consideration (Andrews et al., 2004). For a majority of the soils sampled, bulk densities of <1.3 g cm^{-3} are scored at 0.99 or better, and for the sandier soils,

Table 2. Measured soil quality indicators for each composite sample averaged over all fields sampled in 2007 within the South Fork Watershed of the Iowa River in north central Iowa. Fifty fields were sampled (n = 200), with four composites taken from areas in each field (three with well-developed crop canopy and one from the area displaying poor canopy development during the growing season).

Indicator	Mean	Median	Range	Standard deviation
Physical				
% Clay	18.6	18.5	3.3–41.2	6.1
% Sand	40.1	38.6	12.8–77.0	13.0
Bulk density, g cm^{-3}	1.2	1.2	0.17–1.61	0.46
Wet aggregate stability, %	88.0	88.4	49.0–95.2	4.3
Water-filled pore space, %	51	51	19–81	11
Chemical				
pH	7.0	7.3	4.8–7.9	0.8
Electrical conductivity, ds m^{-1}	0.27	0.26	0.08–0.56	0.11
Biochemical				
Soil organic C, g kg^{-1}	30.5	27.0	6.1–221	22.6
Microbial biomass C, mg kg^{-1}	504	456	122–1875	224
Mineralizable C, mg kg^{-1}	329	335	54–1036	132
β-Glucosidase, mg PNP kg^{-1} h^{-1}†	149	146	24–290	49
Nutrients				
Total N, g kg^{-1}	2.7	2.3	0.9–18.7	1.9
Nitrate N, mg kg^{-1}	17.3	15.3	4.1–104.1	10.3
Mineralizable N, mg kg^{-1}	49.5	49.7	5.9–134	16.9
Extractable P, mg kg^{-1}	103	86	8.5–496	83
Extractable K, mg kg^{-1}	303	267	100–1072	151
Extractable Ca, g kg^{-1}	4.4	3.2	0.9–20.2	3.3
Extractable Mg, mg kg^{-1}	433	425	140–941	154
Extractable Fe, mg kg^{-1}	41.6	24.8	0.04–375	43.5
Extractable Mn, mg kg^{-1}	24.9	19.9	0.01–75.5	14.7
Extractable Cu, mg kg^{-1}	6.1	4.5	0.00–35.9	5.1
Extractable Zn, mg kg^{-1}	5.3	4.5	0.03–19.5	3.4

† PNP, *p*-nitrophenol.

Table 3. Measured soil quality indicators over fields sampled in 2007 within the South Fork Watershed of the Iowa River in north central Iowa. Fifty fields were sampled, with three composites taken from areas in each field with well-developed crop canopy (*n* = 150), and one from the area displaying poor canopy development during the growing season (*n* = 50). There were no significant differences between the well- and poorly developed canopy areas.

Indicator	Normal canopy				Poor canopy			
	Mean	Median	Range	Standard deviation	Mean	Median	Range	Standard deviation
Physical								
% Clay	19.5	19.8	3.9–41.2	5.9	16.1	14.9	3.3–33.2	6.3
% Sand	37.9	36.4	12.8–68.2	11.6	47.1	49.0	15.8–77.0	14.5
Bulk density, g cm^{-3}	1.2	1.2	0.5–1.6	0.2	1.2	1.3	0.6–1.6	0.2
Wet aggregate stability, %	88.4	88.7	68.6–95.2	3.3	87.9	88.1	81.4–92.4	2.7
Water-filled pore space, %	53.1	52.3	31.7–80.8	10.2	44.8	44.8	18.9–65.1	11.1
Chemical								
pH	6.9	7.2	4.8–7.9	0.8	7.1	7.4	5.0–7.9	0.7
Electrical conductivity, ds m^{-1}	0.29	0.27	0.11–0.56	0.10	0.23	0.19	0.08–0.54	0.11
Biochemical								
Soil organic C, g kg^{-1}	32.1	29.1	221–12.3	22.6	25.6	19.1	154–6.2	22.7
Microbial biomass C, mg kg^{-1}	530	477	122–1875	226	426	365	190–1265	201
Mineralizable C, mg kg^{-1}	333	341	109–748	120	315	334	54–1036	165
β-Glucosidase, mg PNP kg^{-1}†	153	152	24–291	49	132	125	61–265	43
Nutrients								
Total N, g kg^{-1}	2.8	2.5	1.2–18.6	1.9	2.3	1.7	0.9–13.7	2.0
Nitrate N, mg kg^{-1}	17.2	15.3	4.1–104.1	10.3	13.9	11.2	4.3–92.0	12.9
Mineralizable N, mg kg^{-1}	50.7	51.5	13.8–116	15.7	46.3	43.5	19.5–134	19.1
Extractable P, mg kg^{-1}	105.2	87.0	8.5–496	84.9	94.3	76.2	10.9–463	78.5
Extractable K, mg kg^{-1}	311	273	103–965	147	284	241	100–1072	165
Extractable Ca, g kg^{-1}	5.5	4.3	0.8–30.0	4.4	4.4	3.2	0.9–20.2	3.3
Extractable Mg, mg kg^{-1}	444	439	140–941	151	399	373	143–868	158
Extractable Fe, mg kg^{-1}	44.0	28.6	0.04–196	39.5	34.5	17.1	6.4–375	53.7
Extractable Mn, mg kg^{-1}	26.1	20.8	0.01–75.5	15.4	21.4	17.3	7.1–52.5	11.8
Extractable Cu, mg kg^{-1}	6.6	5.1	0.0–35.9	5.42	4.5	3.0	0.8–17.5	3.7
Extractable Zn, mg kg^{-1}	5.6	5.0	0.03–19.5	3.5	4.4	3.6	0.7–13.6	3.0

† PNP, *p*-nitrophenol.

D_b < 1.4 g cm^{-3} are scored at 0.99 or better. Bulk density influences soil functions such as the soil's physical structure, water, and solute movement, and soil aeration. The majority of the well-developed canopy sites had bulk density measurements that were scored at 90% of optimum for their specific soil types (Fig. 2), while less than one-half of the poorly developed canopy sites scored within the same range. It should be noted that even the lowest range of scores, <60% of optimum, still included a well-developed canopy site, thus emphasizing that no single indicator is likely to account for canopy development differences in all fields.

Most sites had EC scores > 0.99 (99% of optimum), but the sites that scored 0.99 or less were dominantly in the poorly developed canopy areas (Fig. 3). The mean scores for well- vs. poorly developed canopy areas (Table 4) are in line with the mean score of 0.96 from the preliminary survey (Karlen et al., 2008), but the range in values was wider in this study. The EC indicator scoring curves have a parabolic shape denoting an optimum range, with too little or too much resulting in lower scores (Karlen and Stott, 1994). The scoring curves account for crop type, method of measurement (a constant in this study) and soil texture class. For most soils in this study, EC measurements between 0.17 and 0.72 ds m^{-1} would result in a score of 1.0, and values between 0.72 and 0.82 ds m^{-1} would have scores ≥ 0.90 (Andrews et al., 2004).

The SMAF SOC indicator scoring curves are the more-is-better sigmoidal shaped curves (Karlen and Stott, 1994), taking into consideration soil taxonomic class, soil texture, and climate (which was the same for the entire watershed). For a majority of the soils in this study, a score of 1.0 would be equivalent to about 50 g C kg^{-1} soil, and would represent values found in soils under native vegetation (Andrews et al., 2004). Total SOC was one of the lowest scoring indicators (Table 4), with the sample scores ranging from 1.00–0.06, and mean scores of 0.71 and 0.50 in the well-developed and poorly developed canopy areas, respectively. The data indicate that there is a potential for these soils to sequester C, providing that the appropriate management schemes are put into place. These scores are in line with those previously found in the area, with a mean SOC score of 0.6 from 220 samples and a standard deviation of 0.26 (Karlen et al., 2008) When viewing the distribution of the SOC scores (Fig. 4), it is evident that samples from the poorly developed canopy areas dominated the lowest scoring categories, but there were some well-developed canopy areas that also fell into the lower categories.

The MBC scoring curves, like SOC, were s-shaped representing a more-is-better situation, that considered soil taxonomic class, soil texture, climate, and season of sampling (Andrews et al., 2004), with the latter two factors being the same for all our samples. An MBC score of about 0.9 would be assigned to MBC read-

Table 4. Scored soil quality indicators calculated using the Soil Management Assessment Framework (SMAF) and field data (measured data shown in Table 3) collected within the South Fork Watershed of the Iowa River in north central Iowa in 2007. Fifty fields were sampled, with three composites taken from areas in each field with well-developed crop canopy (*n* = 150), and one from the area displaying poor canopy development during the growing season (*n* = 50).

Soil quality indicator	Normal canopy		Poor canopy	
	Mean	Range	Mean	Range
Physical				
Bulk density	0.96 a†	0.42–0.99	0.91 b	0.40–0.99
Wet aggregate stability	1.00	0.98–1.00	1.00	–
Water-filled pore space	0.92	0.59–0.98	0.87	0.36–0.98
Chemical				
pH	0.88	0.72–1.00	0.86	0.72–1.00
Electrical conductivity	0.98 a	0.62–1.00	0.93 b	0.49–1.00
Biochemical				
Soil organic C	0.71 a	0.09–1.00	0.50 b	0.06–1.00
Microbial biomass C	0.94 a	0.17–1.00	0.87 b	0.40–1.00
β-Glucosidase activity	0.18 a	0.02–0.87	0.15 b	0.05–0.69
Nutrients				
Extractable P	0.90 a	0.00–1.00	0.94 b	0.00–1.00
Extractable K	0.97	0.67–1.00	0.95	0.66–1.00
Mineralizable N	0.98	0.04–1.00	0.98	0.68–1.00
Standard soil quality index	85.7 a	70.5–94.0	81.5 b	63.6–94.2

† Different letters for an indicator indicates significant difference as determined by Tukey's range test (P = 0.05) on transformed data; no letters indicate no significant difference in a paired comparison. The means presented in the table are for untransformed data.

ings of about 490 mg kg^{-1} and a score of 0.99 would be assigned to values of about 640 mg kg^{-1} (Andrews et al., 2004). Microbial biomass C would indicate the size of the soil microbial population, and by implication the ability of the soil to cycle nutrients and degrade organic pollutants. The mean MBC scores were relatively high, at 0.94 and 0.87 in the well-developed vs. poorly developed canopy areas respectively (Table 4), with almost 80% of the well-developed canopy sites scoring 0.9 or better, and about 56% of the poorly developed canopy sites scoring in the same range.

The score distributions for D_b, EC, SOC, and MBC (Fig. 2–5) emphasized that there was no single cause for poor canopy development across all 50 fields and therefore an individual field assessment would be more useful for developing amelioration plans.

Impact of Landscape Position

When considering landscape positions, 25% of the well-developed and 32% of the poorly developed canopy areas were on hilltops, 7.5 and 12% were on sideslopes, 25.5 and 34% were from toeslopes, and 17 and 22% were in depression areas, respectively. When separated by hillslope position, most measured indicators were not significantly different between the two canopy types (Table 5), with the following exceptions: On hilltops, D_b and WFPS were significantly higher, and extractable P was significantly lower in the well-developed canopy when compared with the poorly developed canopy areas. Extractable P may be lower in the well-developed canopy areas because the crop growth is better, thus utilizing higher concentrations of applied P. At the sideslope position, only C_{min}

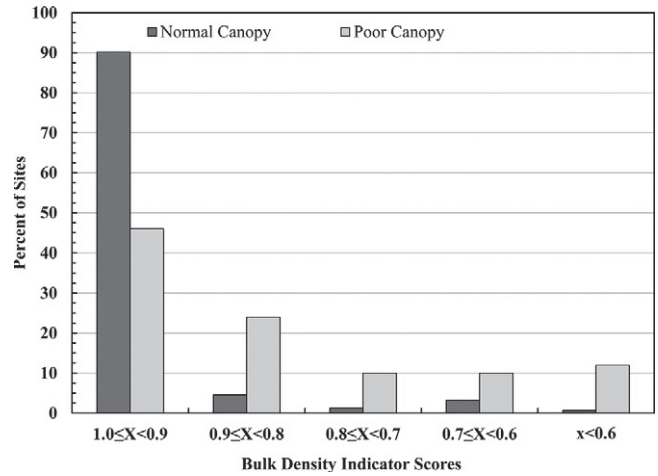

Fig. 2. Percentage of sites within five ranges for the bulk density (D_b) indicator as scored with the Soil Management Assessment Framework comparing the areas with well-developed corn canopy to those with poorly developed corn canopy. A score of 1.0 represents an optimal value given soil texture and mineralogy combination. No D_b measurement was scored below 0.60.

was significantly higher under the well-developed canopy. On the toeslopes, WFPS, SOC, BG, Fe, Cu, and Zn are significantly higher in the well-developed canopy areas and pH was significantly lower in the well-developed canopy areas. In the depression areas, EC, SOC, Ca, and Mg were significantly higher in the well-developed canopy areas. Most other indicators, although not significantly different, trended higher in the well-developed canopy areas at all slope positions, except D_b and pH, which trended lower, and in the depression areas, P, K, and Fe trended higher. Only SOC was significantly higher in the well-developed canopy areas across all slope positions. Indicators such as SOC, WFPS, MBC, and C_{min} reflect the soil's biological resilience and its ability to cycle and store nutrients, highlighting the importance of maintaining or increasing the C content of the soils in the South Fork of the Iowa River Watershed. In contrast to our findings, a study in three Iowa watersheds (Cambardella et al., 2004) showed no significant differences

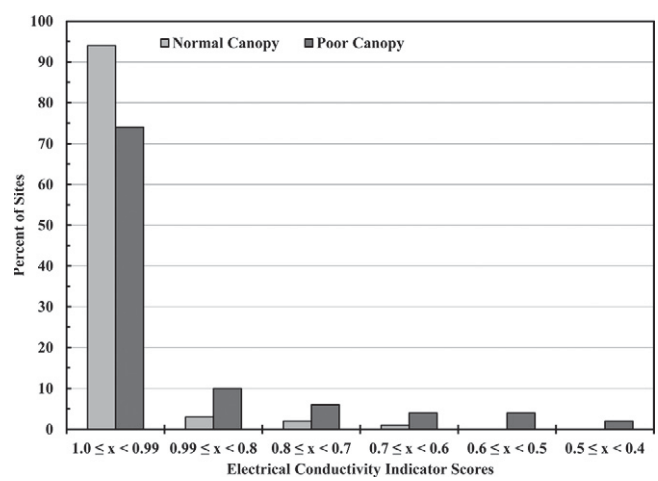

Fig. 3. Percentage of sites falling within six ranges of electrical conductivity (EC) indicator scores as determined using the Soil Management Assessment Framework, comparing areas with well-developed corn canopy to those with poorly developed canopy. A score of 1.0 represents an optimal value for a given crop. No EC score measured below 0.40.

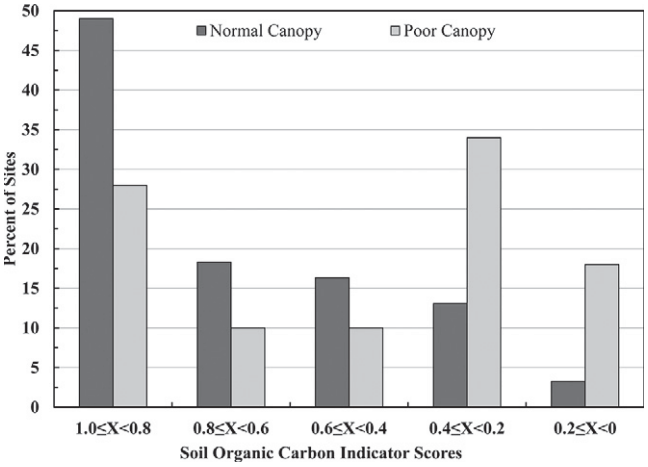

Fig. 4. Percentage of sites falling within five ranges of soil organic carbon indicator scores as determined using the Soil Management Assessment Framework, comparing the areas with well-developed vs. poorly developed corn canopy. A score of 1.0 represents an optimal value given soil texture, soil type, and climate.

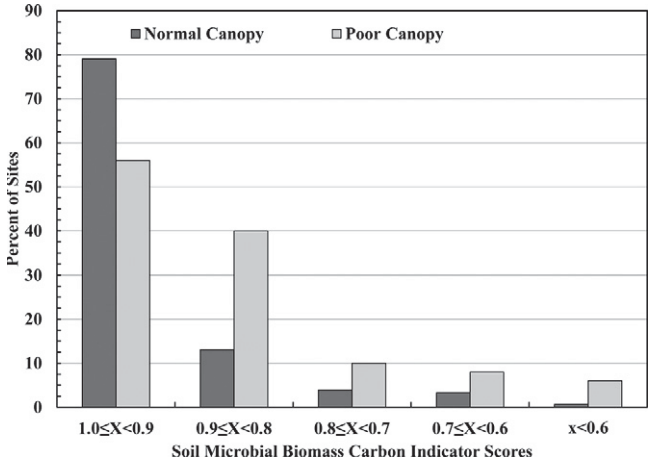

Fig. 5. Percentage of sites falling within five ranges for the soil microbial biomass carbon (MBC) indicator as scored by the Soil Management Assessment Framework, comparing areas with well-developed corn canopy to those with poorly developed corn canopy. A score of 1.0 represents an optimal soil microbial biomass carbon content based on soil texture, soil type, climate, and season of sampling. No site was scored below 0.60 for MBC.

Table 5. Means of measured soil quality indicators in the South Fork of the Iowa River watershed as affected by landscape position. Fifty fields were sampled, with three composites, usually from different soil series, taken from areas in each field with well-developed crop canopy, and one from the area displaying poor canopy development during the growing season.

Indicator	Slope position							
	Hilltop		Sideslope		Toeslope		Depression	
	Canopy development							
	Normal	Poor	Normal	Poor	Normal	Poor	Normal	Poor
n =	30	15	60	6	18	3	42	26
Physical								
Bulk Density, g cm^{-3}	1.23 a†	1.17 b	1.19	1.24	1.21	1.26	1.05	1.23
Wet Aggregate Stability, %	88.7	88.1	88.9	86.9	87.2	88.1	87.4	87.6
Water-filled Pore Space, %	0.55 a	0.40 b	0.52	0.46	0.51 a	0.45 b	0.53	0.46
Chemical								
pH	6.89	6.91	6.89	7.42	6.86 a	7.18 b	7.15	7.09
Electrical Conductivity, ds m^{-1}	0.28	0.19	0.29	0.29	0.26	0.23	0.35 a	0.23 b
Biochemical								
Soil Organic C, g kg^{-1}	27.3	22.3	29.8	25.0	27.8 a	23.0 b	49.1 a	31.6 b
Microbial Biomass C, mg kg^{-1}	493	386	521	438	490	399	662	487
β-Glucosidase, mg PNP kg^{-1} h^{-1}‡	160	137	158	116	152 a	124 b	143	148
Mineralizable C, mg kg^{-1}	334	280	346 a	191 b	308	341	358	311
Nutrients								
Total N, g kg^{-1}	2.4	2.0	2.7	2.2	2.4	2.1	4.4 a	2.9 b
Nitrate N, mg kg^{-1}	17.3 a	12.7 b	14.8	10.6	15.8	11.8	20.3	18.7
Mineralizable N, mg kg^{-1}	50.1	45.4	51.3	34.2	47.1	44.3	55.8	52.6
Extractable P, mg kg^{-1}	119 a	173 b	104	54	97	78	91	98
Extractable K, mg kg^{-1}	305	218	327	238	279	262	351	359
Extractable Ca, g kg^{-1}	4856	3591	7386	5146	4629	4627	6949 a	4110 b
Extractable Mg, mg kg^{-1}	413	333	499	473	431	429	493 a	357 b
Extractable Fe, mg kg^{-1}	45.3	33.3	44.7	13.9	45.0 a	28.6 b	39.4	49.3
Extractable Mn, mg kg^{-1}	26.6	24.0	30.8	14.2	27.6	21.8	20.2	21.1
Extractable Cu, mg kg^{-1}	6.4	5.8	5.3	2.6	7.1 a	3.8 b	7.1	5.6
Extractable Zn, mg kg^{-1}	5.8	4.7	5.4	2.7	5.7 a	3.8 b	5.3	5.6

† Different lowercase letters for an indicator within a given landscape position, normal vs. poor canopy development, indicates significant difference as determined by Tukey's test on transformed data; no letters indicate no significant difference in a paired comparison. The means presented in the table used untransformed data.

‡ PNP, *p*-nitrophenol.

Table 6. Means of scored soil quality indicators, calculated using the Soil Management Assessment Framework (SMAF), as affected by slope position and canopy development in the South Fork Watershed.

Indicator score	Slope position							
	Hilltop		Sideslope		Toeslope		Depression	
	Canopy development							
	Normal	Poor	Normal	Poor	Normal	Poor	Normal	Poor
n =	30	15	60	6	18	3	42	26
Physical								
Bulk density	0.95	0.99	0.95	0.98	0.97 a	0.91 b	0.98 a	0.87 b
Wet aggregate stability	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Water-filled pore space	0.92 a	0.81 b	0.94	0.91	0.92	0.87	0.91	0.89
Chemical								
pH	0.88	0.87	0.91 a	0.86 b	0.90 a	0.85 b	0.85	0.88
Electrical conductivity	0.99 a	0.87 b	0.97	1.00	0.96	0.94	1.00 a	0.92 b
Biochemical								
Soil organic C	0.69 a	0.44 b	0.75	0.71	0.68 a	0.50 b	0.76 a	0.47 b
Microbial biomass C	0.94 a	0.88 b	0.96	0.97	0.92 a	0.84 b	0.95 a	0.89 b
β-Glucosidase activity	0.20	0.14	0.19	0.25	0.18	0.12	0.15	0.17
Nutrients								
Extractable P	0.86 a	0.60 b	0.88 a	1.00 b	0.95	0.99	0.94	0.94
Extractable K	0.97	0.93	0.96	0.87	0.96	0.95	0.98	0.97
Mineralizable N	0.97	0.98	1.00 a	0.91 b	0.97	0.98	0.99	1.00
Standard soil quality index	85.2 a	77.6 b	86.4	85.7	85.6 a	81.4 b	86.5 a	81.9 b

† Different lowercase letters for an indicator within a given landscape position, normal vs. poor canopy development, indicates significant difference as determined by Tukey's test on transformed data; no letters indicate no significant difference in a paired comparison. The means presented in the table used untransformed data.

across five landscape positions for AGS, D_b, SOC, total N, nitrate N, MBC, and P. They reported that pH was significantly higher in the toe and footslope positions as compared with the summit. Only the backslope position had a significantly lower N_{min} relative to the toeslope and summit, with no difference when compared with the footslope and shoulder positions.

Once scored, SOC was significantly lower in the poorly developed canopy areas when compared with the well-developed areas at all but the sideslope position (Table 6). The higher SOC indicator scores probably reflect the observation that the well-developed areas produced more biomass and roots than the poorly developed areas leading to more C retained in the soil. The advantage of separating the samples by slope position is that it highlights the impact of erosion and deposition on the various indicators and their scores. This was evident in the earlier study in this watershed (Karlen et al., 2008) where the mean SOC scores were lowest on the hilltops (0.40) and greatest in the depression areas (0.93). That pattern remained the same in our study, but our means were comparatively lower in the depression areas and higher on the hilltops as compared with the earlier study. The MBC indicator scores were significantly higher in the well-developed areas for all but the sideslope position. The BG indicator scores were uniformly low for both canopy areas at all hillslope positions. Water-filled pore space was scored using the set of scoring curves based on the importance of WFPS to biological activity (Wienhold et al., 2009). Alternatively, it could have been scored based on its importance in environmental protection. The WFPS indicator scores were significantly higher in the well-developed areas for the hilltop position only. These soils tended to be well-drained and the scores were probably indicative of the role of SOC in retaining water. These indicators, when grouped together, represent the soil organic matter or biological indicators. Higher scores reflect the level of carbon sequestration, which in turn impacts microbial populations (MBC) and metabolic activity (BG). However the SOC scores in this study were relatively low, with the well-developed canopy areas having mean scores from 68 to 76% of maximum sequestration possible for the various soil types, and the poorly developed areas with mean scores of 44–71%. The mean BG scores were <20% of the maximum activity expected in these soil types (Stott et al., 2010) for both canopy areas and all landscape positions. Season of sampling generally does not impact BG activity levels. Interestingly, the MBC scores were relatively high, with the mean scores > 85%. This may be an indication of increasing microbial populations in response to the postharvest availability of dead roots and plant biomass.

For P, the scoring curve is an optimal type curve, with the below optimum P concentrations resulting in low indicator scores could be due either to insufficient P for plant growth, which was generally not the case in this study (Table 2), or to environmental risk of P in runoff. The differences in the scoring curves are based on crop type, taxonomic suborder (or SOC content), soil texture, and slope class. The curves are also adjusted based on method used, but that was a constant in this study. In this study (Table 6), the low P indicator scores resulted from a combination of high P and risk of P-laden runoff. The P indicator scores were significantly better in the well-developed areas on the hilltops with low slopes, worse on the side-slopes and about equal in the toeslope and depression areas. The high scores for samples from hilltop positions in well-developed canopy areas is probably due to the better plant growth resulting in higher P usage, as the well-developed areas had smaller concentrations of P (Table

Table 7. Means of measured soil quality indicators in the South Fork watershed as affected by previous crop. The previous crop was known for 39 fields, 21 with corn the previous year, and 18 with soybean. Three composites were taken from areas, usually from three different soil series, in each field with well-developed crop canopy, and one from the area displaying poor canopy development during the growing season.

	Previous crop			
	Corn		Soybean	
	Canopy development			
Indicator	Normal	Poor	Normal	Poor
n =	63	21	57	20
Physical				
Bulk density, g cm^{-3}	1.17	1.19	1.20	1.24
Wet aggregate stability, %	88.5	87.8	87.5	88.1
Water-filled pore space, %	0.55 a†	0.45 b	0.52 a	0.47 b
Chemical				
pH	7.0	7.2	6.8 a	7.3 b
Electrical conductivity, ds m^{-1}	0.29 a	0.24 b	0.29	0.25
Biochemical				
Soil organic C, g kg^{-1}	35.8 a	30.3 b	30.3 a	25.0 b
Microbial biomass C, mg kg^{-1}	540	457	515	439
β-Glucosidase, mg PNP kg^{-1} h^{-1}‡	158	139	151	140
Mineralizable C, mg kg^{-1}	365	365	324	314
Nutrients				
Total N, g kg^{-1}	3.1	2.7	2.6	2.2
Nitrate N, mg kg^{-1}	13.3	17.1	15.8	11.5
Mineralizable N, mg kg^{-1}	52.7	49.4	48.6	47.4
Extractable P, mg kg^{-1}	127	123	81	74
Extractable K, mg kg^{-1}	344	347	273	239
Extractable Ca, g kg^{-1}	5111	4143	6062	4837
Extractable Mg, mg kg^{-1}	453	382	453	448
Extractable Fe, mg kg^{-1}	45.2	43.7	42.3 a	23.5 b
Extractable Mn, mg kg^{-1}	25.5	21.3	25.8	19.5
Extractable Cu, mg kg^{-1}	7.8	6.0	5.6 a	3.9 b
Extractable Zn, mg kg^{-1}	6.57	5.64	4.62 a	3.36 b

† Different lowercase letters for an indicator within a given previous crop indicates significant differences as determined by Tukey's test on transformed data; no letters indicate no significant difference in a paired comparison. The means presented in the table used untransformed data.

‡ PNP, *p*-nitrophenol.

5), and where low slopes reduced the risk of runoff. The lower scores on the sideslopes was probably a reflection of too much P (Table 5) and a higher risk of erosion and runoff. The lower risk of runoff in the toeslope and depressional areas resulted in near equal scores, with mean scores > 90% of the optimum score.

The soil chemical reaction indicators, pH and EC, had somewhat opposite results. The pH scoring curves differ by crop, and have no other contributing factors, thus a single curve was used. The pH indicators scores were significantly lower in the poorly developed areas at the side- and toe-slope positions, reflecting the higher pH values found in those areas that are above the optima for the corn crop. The EC scoring curves are differentiated on the basis of crop (corn) and soil texture. The EC scores were higher for the well-developed areas at the hilltop and depression areas. In the Karlen et al. (2008) study, mean pH scores from the four landscape positions were generally slightly higher than in this study, 0.89–0.95, while the EC scores, which ranged from 0.91 on the sideslopes to 0.99 on toeslopes and in depressions, were about the same as we found.

The N_{min} indicator scores were relatively high overall, with mean scores of 91 to 100% of the optimum concentrations for these soil types (Table 6). Only on the sideslope positions were the mean scores significantly higher in the well-developed canopy areas as compared with the poorly developed areas. There were wide ranges in all the N (total, nitrate, N_{min}) indicators (Table 3), but little differentiation by landscape position, with the exception of total N in the depressional areas, that might reflect N gain through deposition. Extractable K scores were high, with means ranging from 0.87 to 0.98, and no significant differences were seen based on landscape position.

The physical indicators, D_b and AGS, scored quite high. There were no significant differences in AGS, as all areas sampled scored from 99 to 100% of optimum, regardless of performance zones. The mean D_b scores were also high, 0.87 to 0.99, and were significantly higher in the well-developed canopy areas for the toeslope and depression landscape positions. This may be due to compaction from carrying out management operations when the soil was too wet, with other parts of the field being at optimal moisture conditions for the operations.

The integrative SQI consistently detected significant differences in the well- vs. poorly developed canopy areas at every slope position (Table 6). This was despite the P indicators being higher for the poorly developed field areas.

Impact of Previous Crop

The previous crop was known for 41 out of the 50 fields, with about one-half each in corn or soybean during the previous year (Table 7). In fields where corn followed corn, WFPS, EC, and SOC were significantly higher in the well- vs. the poorly developed areas. Once scored (Table 8), D_b, EC, SOC, and MBC were significantly higher in the well- vs. poorly developed canopy areas, as was the SQI. For fields previously in soybean, WFPS, pH, SOC, FE, Cu, and Zn were significantly higher in the well- vs. poorly developed canopy areas. The only micronutrient that had levels low enough to compromise crop growth was Zn. When indicators were scored, none of the 11 indicators were significantly different between performance zones. The SOC and BG scores were low compared with the other scores.

Our measurements for SOC, pH, EC, P, K Ca, Mg, and scores for SOC, pH, P, and EC within the well-developed canopy areas were similar to those previously published by Karlen et al. (2008), while those in the poorly developed canopy areas tended to be lower. This was not unexpected since the preliminary survey (Karlen et al., 2008) focused on sampling representative major SMUs outside of the growing season with no regard to canopy condition. Agreement between the two studies is also important, as it emphasizes that soil quality assessment using the SMAF protocol is consistent and reproducible. This means that long-term soil and crop management effects on soil resources within a watershed can indeed be assessed and compared over

time using an SQI or individual scores as hypothesized in the soil quality development literature (e.g., Karlen and Stott, 1994; Andrews et al., 2004; Wienhold et al., 2006).

Analysis of Individual Fields

Despite the mean differences that were identified, no single indicator scored significantly less in the poorly developed canopy areas as compared to the well-developed areas across all 50 fields. When looking at fields on an individual basis, most had multiple indicators that scored at least 0.10 less in the poorly developed areas than in the well-developed areas. For example, in a majority of soils tested, a 0.10 change in the SMAF SOC score corresponded to a 2 to 3 g kg^{-1} shift in SOC content when scores range from 0.3 to 0.7 and are within the linear portion of the sigmoidal scoring curve, which is the general borderline for being able to accurately measure significant SOC changes in the field. For scores > 0.7, larger shifts in SOC content are required to change the scored value. In some of the depressional areas, soil type and texture required use of different SOC scoring curves, where a score change of 0.10 corresponded to a SOC content change of 20 to 30 g kg^{-1}. Soils such as these would also have a greater capacity to sequester C (Andrews et al., 2004).

Out of 50 fields evaluated, 21 had bulk densities that scored at least 0.10 lower in the poorly developed canopy areas; however, every field had sufficient wet-aggregate stability to support ecosystem services (AGS scores ranged between 0.98–1.00). The WFPS, which is a physical measurement that contributes to the biological activity, varied widely, however, on a field-by-field basis, was not markedly different between well- and poorly developed canopy areas. All three of the biochemical indicators (SOC, MBC, and β-glucosidase activity) were scored at least 0.10 lower in 54% of the poorly vs. well-developed areas in a given field, yet 22% of the fields showed no differences (<0.1). Seventy-two percent of the fields had at least one nutrient indicator (P, K, or mineralizable N) scoring 0.10 lower in the poorly developed canopy areas, while 34% of the fields had at least two indicators that were 0.10 lower. The P indicator often scored higher in poorly developed canopy areas, but usually not by more than 0.10. For the soil chemical indicators (pH, EC), at least one was lower in the poorly developed canopy areas in 78% of the fields. A field-by field analysis is valuable for the land manager, and SMAF can be useful tool for accomplishing the assessment.

CONCLUSIONS

While there was no single cause for poor canopy development in the corn fields that were assessed, there was a pattern of lower SOC and plant available nutrients and/or higher bulk densities in the poorly developed areas, although when all samples were grouped together, there were no statistically significant differences. When the sample pool was divided by landscape position, several indicators became significantly different on at least one slope position between the well- vs. poorly developed areas: D_b, WFPS, EC, pH, SOC, BG, C_{min}, Total N, NO_3–N, Ca, Mg, Fe, Cu, and Zn. When the indicators were scored using SMAF, a different pattern of significance emerged, with the biochemical indicators, SOC and BG having the lowest overall scores. The pattern showed that while soil quality overall was maintained though effective soil and nutrient management, the organic matter and metabolic indicators were low, often <50% of maximum for the SOC and <20% for BG, suggesting that the soils' biological capacity has been compromised. The MBC had scores in the 80s and 90s, reflecting response of the microbial population to the abundance of dead and dying roots and biomass, but this may not result in additional C sequestration. When the sample pool was divided by cropping history, significant differences between canopy development areas was seen only in the corn on corn rotation. The soil quality assessment did not pinpoint differences in the canopy development areas when soybean was the previous crop. This may indicate that canopy development issues reside with the corn management, or other factors not measured were in play.

Table 8. Means of scored soil quality indicators, calculated using the Soil Management Assessment Framework (SMAF), as affected by previous crop and canopy development in the South Fork Watershed.

Indicator score	Previous crop			
	Corn		Soybean	
	Canopy development			
	Normal	Poor	Normal	Poor
n =	63	21	60	20
Physical				
Bulk density	0.97 a†	0.92 b	0.95	0.91
Wet aggregate stability	1.00	1.00	1.00	1.00
Water-filled pore space	0.91	0.88	0.94	0.88
Chemical				
pH	0.88	0.86	0.88	0.86
Electrical conductivity	0.99 a	0.95 b	0.98	0.96
Biochemical				
Soil organic C	0.70 a	0.52 b	0.69	0.57
Microbial biomass C	0.94 a	0.88 b	0.93	0.90
β-Glucosidase activity	0.20	0.16	0.17	0.17
Nutrients				
Mineralizable N	0.99	0.98	0.96	0.98
Extractable P	0.87	0.86	0.94	0.99
Extractable K	0.98	0.96	0.96	0.94
Standard soil quality index	85.7 a	81.6 b	85.5	83.2

† Different lowercase letters for an indicator within a given previous crop indicates significant differences as determined by Tukey's test on transformed data; no letters indicate no significant difference in a paired comparison. The means presented in the table used untransformed data.

Our study supports previous conclusions that the SMAF methodology provides a tool for answering resource management questions where soil parameters play a key role. Scoring indicators using the SMAF allows shifts in interpretation due to soil and climatic factors. The primary effect of texture was seen in a few of the wetter depression areas, classified as Haplosaprists. For the year sampled, these areas all exhibited well-developed canopies and with the appropriate scoring curve could be readily compared with other soil types.

On a more practical level, using SMAF for a field-by-field assessment of the impacts of management practices on soil pa-

rameters allowed for pinpointing possible specific soil-based causes for the poor canopy development in each area.

ACKNOWLEDGMENTS

We thank Rhonda Graef, Larry Pelleck, and Jody Omacht for their technical assistance, Brent Schleck for aid in the SMAF analysis, and Dennis Bucholtz for aid with the statistical analysis. This publication is based on work supported by the USDA Agricultural Research Service under the ARS Cropland CEAP Project. The USDA is an equal opportunity provider and employer.

REFERENCES

Andrews, S.S., D.L. Karlen, and C.A. Cambardella. 2004. The soil management assessment framework: A quantitative soil quality evaluation method. Soil Sci. Soc. Am. J. 68:1945–1962. doi:10.2136/sssaj2004.1945

Blackmer, T.M., J.S. Schepers, G.E. Varvel, and G.E. Meyer. 1996. Analysis of aerial photography for nitrogen stress within corn fields. Agron. J. 88:729–733. doi:10.2134/agronj1996.00021962008800050008x

Brookes, P.C., A. Landman, G. Pruden, and D.S. Jenkinson. 1985. Chloroform fumigation and the release of soil nitrogen: A rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biol. Biochem. 17:837–842. doi:10.1016/0038-0717(85)90144-0

Cambardella, C.A., T.B. Moorman, S.S. Andrews, and D.L. Karlen. 2004. Watershed-scale assessment of soil quality in the loess hills of southwest Iowa. Soil Tillage Res. 78:237–247. doi:10.1016/j.still.2004.02.015

Cambardella, C.A., T.B. Moorman, T.B. Parkin, D.L. Karlen, J.M. Novak, R.F. Turco, A.E. Konopka. 1994. Field-scale variability of soil properties in Central Iowa Soils. Soil Sci. Soc. Am. J. 58:1501-1511.

David, M.B., G.F. McIsaac, R.G. Darmody, and R.A. Omonode. 2009. Long-term changes in Mollisol organic carbon and nitrogen. J. Environ. Qual. 38:200–211. doi:10.2134/jeq2008.0132

Dodor, D.E., and M.A. Tabatabai. 2005. Glycosidases in soils as affected by cropping systems. J. Plant Nutr. Soil Sci. 168:749–758. doi:10.1002/jpln.200521761

Drinkwater, L.E., C.A. Cambardella, J.D. Reeder, and C.W. Rice. 1996. Potentially mineralizable nitrogen as an indicator of biologically active soil nitrogen. p. 217–229. *In* J.W. Doran and A.J. Jones (ed.) Methods for assessing soil quality. SSSA, Madison, WI.

Eivazi, F., and M.A. Tabatabai. 1988. Glucosidases and galactosidases in soils. Soil Biol. Biochem. 20:601–606. doi:10.1016/0038-0717(88)90141-1

Gee, G.W., and D. Or. 2002. Particle-size analysis. p. 255–293. *In* J.H. Dane and G.C. Topp (ed.) Methods of soil analysis. Part 4. Physical methods. SSSA, Madison, WI.

Grossman, R.B., T.G. Reinsch. 2002. Bulk density and linear extensibility. p. 201-228. *In* J.H. Dane and G.C. Topp. (ed.) Methods of soil analysis. Part 4. Physical methods. 2nd ed. SSSA Book Series No. 5. SSSA, Madison, WI.

Karlen, D.L. 2008. A new paradigm for natural resources research: The Conservation Effects Assessment Project. J. Soil Water Conserv. 63:220A. doi:10.2489/jswc.63.6.220A

Karlen, D.L., K.A. Kohler, D.A. Laird, R.L. Thompson, and D.D. Buhler. 2002. Soil-test dynamics throughout a five-year Thompson Farm rotation in Iowa. Am. J. Alternative Agric. 17:9–17.

Karlen, D.L., and D.E. Stott. 1994. A framework for evaluation physical and chemical indicators of soil quality. p. 53–72. *In* J.W. Doran (ed.) Defining soil quality for a sustainable environment. SSSA, Madison, WI.

Karlen, D.L., M.D. Tomer, J. Neppel, and C.A. Cambardella. 2008. A preliminary watershed scale soil quality assessment in north central Iowa, USA. Soil Tillage Res. 99:291–299. doi:10.1016/j.still.2008.03.002

Kemper, W.D., and R.C. Roseneau. 1986. Aggregate stability and size distribution. p. 425-442. *In* A. Klute (ed.) Methods of soil analysis. Part 1. Physical and mineralogical methods. 2nd ed. SSSA, Madison, WI.

Knipling, E.B. 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Remote Sens. Environ. 1:155–159. doi:10.1016/S0034-4257(70)80021-9

Linn, D.M., and J.W. Doran. 1984. Effect of water-filled pore space on carbon dioxide and nitrous oxide production in till and nontilled soils. Soil Sci. Soc. Am. J. 48:1267–1272. doi:10.2136/sssaj1984.03615995004800060013x

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun. Soil Sci. Plant Anal. 15:1409–1416. doi:10.1080/00103628409367568

Moorman, T.B., C.A. Cambardella, D.E. James, D.L. Karlen, and L.A. Kramer. 2004. Quantification of tillage and landscape effects on soil carbon in small Iowa watersheds. Soil Tillage Res. 78:225-236.

National Cooperative Soil Survey. 1986a. Soil Survey of Hamilton County, Iowa. Available at http://soils.usda.gov/survey/online_surveys/iowa/ [verified 7 Sept. 2011]. USDA-NRCS, Washington, DC.

National Cooperative Soil Survey. 1986b. Soil Survey of Hardin County, Iowa. Available at http://soils.usda.gov/survey/online_surveys/iowa/ [verified 7 Sept. 2011]. USDA-NRCS, Washington, DC.

Potter, S.R., S.S. Andrews, J.D. Atwood, R.L. Kellogg, J. Lemunyon, M.L. Norfleet, and D. Oman. 2006. Model simulation of soil loss, nutrient loss, and change in soil organic carbon associated with crop production. Available at http://www.nrcs.usda.gov/wps/portal/nrcs/home [cited 25 Mar. 2011; verified 12 Aug. 2011]. USDA-NRCS, Washington, DC.

Richardson, C.W., D.A. Bucks, and E.J. Sadler. 2008. The Conservation Effects Assessment Project benchmark watersheds: Synthesis of preliminary findings. J. Soil Water Conserv. 63:590–604. doi:10.2489/jswc.63.6.590

Sawyer, J.E., A.P. Mallarino, and R. Killorn. 2003. Interpretation of soil test results. Iowa State Univ. Ext., Ames.

Sawyer, J.E., A.P. Mallarino, R. Killorn, and S.K. Barnhart. 2008. A general guide for crop nutrient and limestone recommendations in Iowa. Iowa State Univ. Ext., Ames.

Sherrod, L.A., G. Dunn, G.A. Peterson, and R.L. Kolberg. 2002. Inorganic carbon analysis by modified pressure-calcimeter method. Soil Sci. Soc. Am. J. 66:299–305. doi:10.2136/sssaj2002.0299

Soil Survey Staff. 2004. Official soil series descriptions. Release 1.1. USDA-NRCS, Washington, DC.

Stott, D.E., S.S. Andrews, M.A. Liebig, B.J. Wienhold, and D.L. Karlen. 2010. Evaluation of β-glucosidase activity as a soil quality indicator for the Soil Management Assessment Framework (SMAF). Soil Sci. Soc. Am. J. 74:107–119. doi:10.2136/sssaj2009.0029

Tomer, M.D., T.B. Moorman, and C.G. Rossi. 2008. Assessment of the Iowa River's South Fork watershed: Part 1. Water quality. J. Soil Water Conserv. 63:360-370. doi:10.2489/jswc.63.6.360

Vance, E.D., P.C. Brookes, and D.S. Jenkinson. 1987. Microbial biomass measurements in forest soils: Determination of k_C values and tests of hypotheses to explain the failure of the chloroform fumigation-incubation method in acid soils. Soil Biol. Biochem. 19:689–696. doi:10.1016/0038-0717(87)90050-2

Vitosh, M.L., J.W. Johnson, and D.B. Mengel. 1995. Tri-state fertilizer recommendations for corn, soybeans, wheat and alfalfa. Univ. Ext. Bull. E-2567. Available at http://www.ces.purdue.edu/extmedia/AY/AY-9-32.pdf [cited 13 July 2010; verified 12 Aug. 2011]. Michigan State Univ., East Lansing.

Watson, M.E., and J.R. Brown. 1998. pH and lime requirement. p. 13–16. *In* J.R. Brown (ed.) Recommended chemical soil test procedures for the North Central Region. NCR Publ. 221 (revised). Bull. SB1001. Missouri Agric. Exp. Stn., Columbia, MO.

Whitney, D.A. 1998a. Soil salinity. p. 59–60. *In* J.R. Brown (ed.) Recommended chemical soil test procedures for the North Central Region. NCR Publ. 221 (revised). Bull. SB1001. Missouri Agric. Exp. Stn., Columbia, MO.

Whitney, D.A. 1998b. Micronutrients: Zinc, iron manganese and copper. p. 13–16. *In* J.R. Brown (ed.) Recommended chemical soil test procedures for the North Central Region. NCR Publ. 221 (revised). Bull. SB1001. Missouri Agric. Exp. Stn., Columbia, MO.

Wienhold, B.J., D.L. Karlen, S.S. Andrews, and D.E. Stott. 2009. Protocol for Soil Management Assessment Framework (SMAF) soil indicator scoring curve development. Renew. Agric. Food Syst. 24:260–266. doi:10.1017/S1742170509990093

Wienhold, B.J., J.L. Pikul, M.A. Liebig, M.M. Mikha, G.E. Varvel, J.W. Doran, and S.S. Andrews. 2006. Cropping system effects on soil quality in the Great Plains: Synthesis from a regional project. Renew. Agric. Food Syst. 21:49–59. doi:10.1079/RAF2005125