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CROP ROTATION IMPACT ON SOIL QUALITY

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Abstract

Management systems influence soil quality over time. A study was carried out on Vanmeter farm of the Ohio State University South Centers at Piketon Ohio, USA to evaluate the impact of crop rotations on soil quality from 2002 to 2007. The crop rotations comprised of continuous corn (CC), corn-soybean (CS) and corn–soybean-wheat-cowpea (CSW). Ten soil cores were collected at 0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm, and sieved. The soils were analyzed for total microbial biomass (C_{mic}), basal respiration (BR) and specific maintenance respiration (qCO_2) rates as biological quality indicators; total organic carbon (TC), active carbon (AC) and total nitrogen (TN) as chemical quality indicators; and aggregate stability (AS), particulate organic matter (POM) and total porosity (ft) as physical quality parameters at different depths of soil. The inductive additive approach based on the concept of "higher value of any soil property except ft, a better indicator of soil quality" was used to calculate the biological (SBQ), chemical (SCQ), physical (SPQ) and composite soil quality (SQI) indices. The results showed that crop rotation had significant impact on C_{mic}, BR, qCO_2, TC, AC, TN, AS and POM except ft at different depths of soil. The CSW had higher soil quality values than CC and CS. The values of selected soil quality properties under the given crop rotation significantly decreased except ft with increasing soil depth. The SBQ (23%), SCQ (16%), SPQ (7%) and SQI (15%) improved under CSW over time. The results imply that multiple cropping systems could be more effective for maintaining and enhancing soil quality than sole-cropping systems.

Introduction

Management practices to sustain crop yields are necessary to conserve or enhance soil quality (Aziz *et al*., 2009; Coulter *et al*., 2009). A difference in management practices often results differences in biological, chemical and physical soils properties which in turn results changes in functional quality of the soil (Islam & Weil, 2000). Soil quality has become a focal point for attempts to quantify modification in soil due to various soil management systems (Islam & Weil 2000; Islam 2008). According to Soil Science Society of America (1995) soil quality is defined as the capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation. These conditions can be accomplished by preserving or improving biological, chemical and physical properties of soil by using crop rotation as component of sustainable agricultural management practices. To develop sustainable agro ecosystem a knowledge about soil quality is essential which gives present and future trends and early warning signs, provide information about the problems of soils and gives a precious base which can be utilized to assess successive and future capacity of soil (McGrath & Zhang, 2003; Aziz *et al*., 2009).

Soil quality is the result of combined activities of biological, chemical and physical properties as a reaction of management operations (Islam, 2006). Numerous studies have revealed that multiple cropping systems had greater C_{mic} and enzyme activities as compared to continuously mono-cropping or with partial crop rotations (Dick, 1984; McGill *et al.*, 1986). Accordingly, crop rotation improves SQ and provides well documented economic and environmental benefits to agricultural producers (Power, 1987). Roberson *et al.*, (1991) reported that cover crops have rapid and significant effects on the stability of soil macroaggregates, even when the total amount of C is apparently unaffected. On fine-textured soils, cover crops have improved physical properties for example aggregation, porosity, bulk density and permeability (Karlen *et al.*, 1992).

In recent years, it was found that biological properties of soil act as early and sensitive indicators in response to alteration in management systems (Kennedy & Papendick, 1995). Biological parameters together with soil chemical and physical properties are recognized to be necessary to assess SQ as affected by changes in management operations (Parkin *et al.*, 1996). Numerous researchers suggested sets of SQ indicators (Doran & Parkin, 1994; Islam & Weil, 2000) and estimated SQ on basses of total data set of selected indicators which they used for study. Moreover, many authors proposed representative indicators, like minimum data set, chosen according to easy to measure and correlation between indicators (Andrews *et al.*, 2002; Govaerts *et al.*, 2006).

The particulate organic matter, active C, total N, C_{mic}, biological activities, enzymes, soil pH, cation exchange capacity, salinity, bulk density and soil aggregation are important indicators of dynamic soil quality because they are responsive to changes in soil management (Wander, 2004). As a dynamic component of the SOM, the microbial life of the soil is often considered as a key indicator of SQ (Islam & Weil, 2000). It is the main mediator of organic matter turnover and responds more quickly than does total organic C to changes in management practices (Powlson *et al.*, 1987). There are certain characteristics, particularly when considered together, are good indicators of SQ. Monitoring of a select set of soil properties that can serve as indicators of change in SQ is possible and can yield useful information on trends in SQ (Dumanski & Pieri, 2000). SQ indicators must be the integration of biological, chemical, and physical properties that are sensitive to management practices (Islam & Weil, 2000; Aparicio & Costa, 2007). The objectives of the study were to evaluate the impact of crop rotation on selected biological, chemical and physical properties as a minimum data-set of soil quality indicators and the sensitivity of various soil quality indices to determine soil's overall functional capacity in agro-ecosystems.

Materials and Methods

Study site: The study was conducted at Vanmeter farm of the Ohio State University South Centers at Piketon (39°02′30''N, 83°02′00''W), South-central Ohio, USA. The area is under temperate climate with air temperature ranged between 0-24°C, relative humidity ranged between 79-93%, soil temperature at 15 cm deep ranged between 3-30°C; solar radiation ranged between 9981-43037 KW/m, and wind velocity ranged between 5-9 km/hr. Mean annual rainfall is 96±20 cm with more than 50% of the rainfall falls during April to September.

Major soils at the farm are Huntington silt loam (fine-clay, mixed, mesic Fluventic Hapludoll), Landes loam (coarse-loamy, mixed, mesic Fluventic Hapludoll), Rossburg silt loam (fine-loamy, mixed, mesic Fluventic Hapludoll), and Stonelick sandy loam (coarse-loamy, mixed, mesic Typic Udifluvent). Among the soils, Huntington silt loam is covering more than 90% of the experimental site. The soil has pH 6.2, electrical conductivity 206.4 µS/cm, total porosity 44.6%, antecedent soil moisture content 19%, and contains 21, 55, and 24% sand, silt and clay, respectively.

Field experiment and cultural practices: A field experiment with three crop rotations (continuous corn, CC; corn-soybean, CS; and corn-soybean-wheat, CSW) in factorial arrangement of randomized complete block (RCBD) design was established in 2002. Each treatment was replicated 3 times on 40 x 100 m^2 plots. Corn was planted in all replicated plots at the very beginning of the study. A description of the experimental treatments is as follows:

1. Continuous corn (*Zea Mays*, L.)- The CC plots were fall chisel plowed annually followed by disking in the spring and received 120 kg N/ha from urea-ammonium nitrate (UAN or 28% N) at planting. Corn was planted in the 1st week of May with a seeding rate of 67400 seeds per ha. Phosphorus (P) and potassium (K) fertilizers were applied in the previous fall based on soil tests. Atrazine and acetochlor were applied as pre-emergent herbicides followed by dicamba and nicosulfuron for post-emergent control of weeds.

2. Corn-soybean (*Glycine max* L.) rotation (CS) - The CS plots were fall chisel plowed annually followed by disking in the spring for planting of corn or soybeans. Corn was planted in the 1st week of May with a seeding rate of 67400 seeds per ha, and received 120 kg N/ha from UAN. The P and K fertilizers were applied in the previous fall based on soil test. For soybeans, 75 kg Roundup ready seeds per ha was used. Soybeans were planted in the 1st week of May and received no starter N. The P and K fertilizers were applied to soybeans in the previous fall based on soil tests. Atrazine and acetochlor were applied as pre-emergent herbicides followed by dicamba and nicosulfuron for post-emergent weed control in corn and glyphosate for control of weeds in soybeans.

3. Corn–soybean - wheat (*Tritium aestivum* L.) rotation with cover crop (CSW) - The CSW plots were fall chisel plowed followed by disking in the spring before planting of corn or soybeans. Corn was planted in the 1st week of May with a seeding rate of 67400 seeds per ha. The N fertilizer at 120 kg/ha was applied from UAN. The P and K fertilizers were applied based on soil tests. Atrazine and acetochlor were applied as pre-emergent herbicides followed by dicamba and nicosulfuron for post-emergent control of weeds in corn. After harvesting corn, cereal rye as a cover crop was planted (75 kg/ha) in early November, plowed-down in the 1st week of May followed by planting of soybeans with P and K fertilizers based on soil tests. Roundup ready soybeans was planted @ 75 kg/ha, and received no starter N. Glyphosate was applied for pre- and post-emergent control of weeds in soybeans winter wheat was planted @ 120 kg/ha in late October after harvesting soybeans. The P and K fertilizers based on soil tests and supplemental N (25 kg/ha) were applied to wheat in the spring (N was also provided from soybean residues). Dicamba was applied for post-emergent control of weeds in wheat. After harvesting wheat, Cowpea @ 35 kg/ha was drilled in the 3rd week of July (to utilize residual soil moisture for quick germination) and plowed-down in the fall. Corn was planted in the spring without any chemical N inputs (required amount of N was expected to release from decomposition of Cowpea residues). The crop rotation was repeated.

Soil collection and processing: Prior to establish the experiment, 18 composite soil samples were randomly collected from the entire field for baseline data using GPS guided systematic sampling in early spring May 2002. Ten soil cores were collected at a depth of 30 cm in plastic tubes for each composite sample using an environmental soil probe (1.9 cm internal diameter). The soil cores were segmented at 0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm, respectively in the laboratory. The segmented soils at each depth were mixed to obtain composite samples followed by gentle sieving to pass through a 4-mm mesh to remove stones, roots, and large organic residues. After sieving, the composite field-moist soil was divided into two equal parts and each sub-sample was placed in a separate Ziplock plastic bag. The soil from one sub-sample bag was passed through a 2-mm sieve and homogenized to measure antecedent soil moisture content and incubated for 7 d at room temperature ($25^{o}C$) to stabilize microbial activity. After stabilization, the field-moist soil samples were used to measure microbial biomass and/or incubated for biological properties. Soil from the second bag was spread on a polyethylene sheet and air-dried for 72 h with a fan at room temperature and analyzed for selected chemical and physical properties.

In early spring (May) of 2007, a total of 18 composite soil samples were resampled (using GPS) from the same locations, depth, processed and analyzed as described elsewhere to evaluate the temporal (2002 vs. 2007) effects of crop rotation on soil properties.

Analytical Methods

Determination of soil biological quality indicators: Soil microbial biomass (C_{mic}), basal respiration (BR) and specific maintenance respiration (qCO_2) rates were measured and/or calculated as soil biological quality indicators. The C_{mic} was measured by following rapid microwave irradiation and extraction method (Islam & Weil (1998a). The C_{mic} was calculated according to the formula given below:

$$C_{mic}\ (\text{mg C/kg soil}) = (MWC_{ext} - UMWC_{ext})/K_{ext}$$

The MWC_{ext} is the extractable C in microwaved soil, the Cext is the extractable C in field-moist soil, and K_{ext} is the fraction (0.241) of the C_{mic} extracted by 0.5M K_2SO_4 (Islam & Weil, 1998b).

Basal respiration (BR), as a measure of biological activity was determined using *In vitro* static incubation of untreated field-moist soil. About 20 g ODE of 2-mm sieved field-moist homogenized soil adjusted at 70% WFP was taken in 25 ml glass beaker. Each soil sample was placed in a 1L mason jar along with a glass vial containing 10 mL of distilled water to maintain humidity and a plastic vial containing 10 mL of 0.5 M NaOH to trap evolved CO_2 from the incubated soil. The mason jars were sealed airtight and incubated in the dark at $25\pm1^{o}C$ for 20 d. The CO_2 evolved over time from the incubated soil was absorbed in the 0.5 M NaOH followed by precipitation as $BaCO_3$ by the addition of excess 1 M $BaCl_2$. The remaining NaOH in each vial was titrated to the phenolphthalein endpoint with a standardized 0.5 M HCl solution. The BR rate was calculated as below:

$$\text{BR rates (mg } CO_2\text{/kg soil)} = (CO_2\text{soil} - CO_2\text{ air})/20\ \text{d}$$

where CO_2soil is the evolution of CO_2 during 20 d incubation of non-amended homogenized soil and CO_2 air is the ambient air CO_2 in a blank mason jar.

The qCO_2 i.e., catabolism of C per unit C_{mic} per day was calculated by following Anderson and Gray, (1991).

$$qCO_2\ (\mu g\ CO_2/mg\ C_{mic}/d) = (BR\ rates)/\ C_{mic}.$$

Determination of soil chemical quality indicators: Soil total organic C (TC), active carbon (AC) and total nitrogen (TN) were determined as soil chemical quality indicators. The TC and TN were measured on finely ground (200 µm) ODE soil samples by dry combustion method using Elementar CNS analyzer. Since the pH of the collected soils was < 6.5 the total C content of the soil was considered as TC content. Active carbon (AC) based on $KMnO_4$ oxidation was measured on air-dried soil (Weil *et al*., 2003).

Determination soil physical quality indicators: Total porosity (ft), aggregate stability (AS) and particulate organic matter (POM) were measured as soil physical quality indicators. The POM was collected by taking a 10 g oven-dried equivalent (ODE) sample of 2 mm sieved field-moist soil at 80% water-filled porosity in 50 mL screw-top polypropylene tubes. The tubes containing soils used for microwave eradiation (MW) were covered with punctured caps to regulate pressure buildup. After initial MW heating (400 J g^{-1}) the soils in the tube were tapped few times on the bench to mix followed by an additional MW heating at the same rate. The MW soil samples were allowed to cool down for 30 min at room temperature. The soils were shaken with 20 mL of 0.5M K_2SO_4 (pH 7.0) at 250 rpm for 60 min. After shaking, the soil suspensions were centrifuged at 3000 rpm for 5 min and filtered to collect disperse and floated organic residues on filter paper as particulate organic matter (POM). The POM was then transferred from the filter paper to a 53 µm sieve, washed under running water and oven-dried at 105^{o}C for 15 min by using a forced-air oven. A sample of POM was burned at 480^{o}C for 4 hr in a muffle furnace to calculate POM by loss on ignition and the results were expressed as sand-free basis.

An aggregate stability index (AS) was determined using wet sieving with vertical oscillation (Gardi *et al*., 2002). The aggregates were oven-dried at 105^{0}C for 24 hr in a forced-air oven until a constant was obtained, weighted and calculated for aggregate stability as follows:

$$AS\ (\%) = (X/Y)*100$$

where X is the amount of soil aggregates retained on 250 µm sieve after treatment and shaking, and Y is the total amount of soil aggregates taken for aggregate analysis.

Total porosity (ft) was calculated from the measured values of bulk density (ρb) and standard soil particle density (ρp) of 2.65 g/cm^3 and was expressed as percent as follows:

$$ft\ (\%) = (1 - (\rho b/\rho p)) * 100$$

The ρb was determined by using the core method (Blake & Hartge, 1986) from the relationship of oven-dried mass of a known volume of soil as:

$$\rho b\ (g/cm^3) = (\pi * r^2 * L)/w$$

where r is the internal radius of a soil core sampler, L is the length of soil core, and w is the total weight (g) of ODE of soil.

Soil pH was determined in 1:2 soil-distilled deionized water slurries using a combination glass electrode. The electrical conductivity was determined in 1:1 soil-distilled deionized water using a standard conductivity meter.

Calculation of soil quality index: The group of biological, biochemical/chemical and biophysical/physical properties of soil were selected to use in the study as core indicators of SQ are C_{mic}, BR, qCO_2, TC, AC, TN, *ƒ*t, AS and POM.

An integrated measure of soil quality will be produced using the inductive additive approach based on normalization, summation and average of selected core biological, chemical and physical properties into a single integrator of soil quality (Islam, 2006; Stunner & Islam, 2008; Aziz *et al*., 2009). This approach will allow datum for each individual soil property (X0) measured or calculated to be transformed on a scale [>0, <1] relative to the maximum value (Xmax) of that X0 (Xi = X0/Xmax) in the data set. Transformations of pi will be done to normalize the data sets for reducing heterogeneous variances of the errors and to simplify the relationship between random errors influenced variables. Equal weight will be assigned to each Xi such that each Xi is in [>0, <1] scale and the mean summation of the weight for soil quality will be [>0, <1].

Statistical analysis: Significant differences in selected soil quality indicator properties such as C_{mic}, BR, qCO_2, *ƒ*t, AS, and POM, and C_{index} attributed to the simple and interactive effects of crop rotation, soil depth and their interaction were analyzed by using a PROC ANOVA procedure of the SAS (Anon., 2008). Treatment means were separated by using an F-protected least significant difference (LSD) test with $p \leq 0.05$.

Results and Discussion

Crop rotation impact on selected soil quality indicator properties: Soil quality indicators varied significantly in response to crop rotation over time (Tables 1-3). The C_{mic} concentration in continuous corn (CC), corn-soybean (CS) and corn-soybean-wheat rotation (CSW) increased by 14, 17 and 34%, respectively over time (Table 1). On average, the C_{mic} in CSW was 21-23% higher than CS and CC, respectively. The BR increased by 15% in CSW and 4% in CC and CS. Soils under CSW had a higher BR (12%) compared with CC and CS, respectively. However, the qCO_2 did not respond significantly to the long-term effects of crop rotation (Table 1). The SBQ in CSW was 16% higher than CS and CC, respectively (Table 1). The ΔSBQ was also significantly higher under CSW than CC and CS, respectively. The values of soil biological quality indicators decreased except qCO2 with an increase in soil depth. The SBQ followed a similar pattern.

The TC in CSW was significantly higher by 14-15% than CS and CC, respectively (Table 2). Crop rotation and soil depth had a significant interaction on TC content. The AC under all crop rotations increased over time; however, the AC under CSW was 7-9% higher than CS and CC, respectively. The TN content significantly increased (5-19%) under all crop rotation over time. The difference in TN content (15%) between CSW vs. CC and CS was highly significant. The SCQ in CSW was 13% higher than CS and CC, respectively. (Table 2). Irrespective crop rotations, the TC, AC, TN and SCQ significantly decreased with increasing soil depth.

Table 1. Crop rotation impacts on soil biological quality indicators at different depths (Averaged across tillage).

Crop rotation	Depth of soil (cm)	C_{mic} (mg/kg)	BR (mg/kg/d)	QCO_2 (μg/mg/d)	SBQ (%)	ΔSBQ (%/yr)
Initial$_{(2002)}$		103.7Y*	8.1Y	73.0X	43.8Y	0 Y
CC$_{2007}$		121.2Yb+	8.4Xb	78.0Xa	47.6Yb	0.7Yb
CS$_{2007}$		124.2Yb	8.4Xb	77.0Xa	48.1Yb	0.8Yb
CSW$_{2007}$		158.2Xa	9.5Xa	66.0Xa	56.9Xa	2.6Xa
		Crop rotation and soil depth interaction				
Initial$_{(2002)}$	0-7.5	185.7ns	10.7ns	58.0ns	58.5ns	0
	7.5-15	103.8	6.9	68.0	45.8	0
	15-22.5	75.2	5.6	76.0	38.7	0
	22.5-30	50.2	4.2	88.0	32.1	0
CC$_{2007}$	0-7.5	192.9	11.8	66.0	60.9	0.5ns
	7.5-15	120.2	8.9	77.0	48.3	0.5
	15.22.5	97.5	7.4	84.0	42.8	0.8
	22.5-30	74.0	5.7	85.0	38.2	1.2
CS$_{2007}$	0-7.5	180.2	11.3	66.0	59.1	0.1
	7.5-15	127.2	9.0	76.0	49.6	0.7
	15.22.5	102.6	7.1	83.0	42.5	0.7
	22.5-30	86.6	6.2	81.0	41.1	1.8
CSW$_{2007}$	0-7.5	247.8	14.0	60.0	71.8	2.7
	7.5-15	177.5	10.6	66.0	62.3	3.3
	15.22.5	116.4	7.4	66.0	49.0	2.1
	22.5-30	91.1	6.1	70.0	44.4	2.5

Initial=Data collected from conventionally tilled (CT) continuous corn (CC) plots in 2002, CC$_{2007}$=Data collected from continuous corn plots in 2007, CS$_{2007}$=Data collected from corn-soybean rotation plots in 2007, CSW$_{2007}$=Data collected from corn-soybean-wheat rotation plots in 2007, C_{mic}=Microbial biomass carbon, BR=Bas respiration rates, qCO_2=Specific maintenance respiration rates, SBQ=Soil biologic quality, ΔSBQ=Rate of change in soil biologic quality and ns=Non-significant.

*Means followed by same upper case (X to Z) letter in the column were not significantly different at $p \leq 0.05$ over time (2002 vs. 2007). +Means followed by same lower case (a to c) letters in the column were not significantly different at $p \leq 0.05$ among crop rotation treatments in 2007. # indicates significant crop rotation and soil depth interaction.

Crop rotation did not exert any significant effect on *f*t over time (Table 3). However, AS and POM varied significantly in response to crop rotation treatments. Soils under CSW had a higher AS by 16-24% compared with CC and CS, respectively. The AS decreased under CS over time. The POM concentration in CC and CSW rotations had increased by 8%; however, decreased under CS over time. The SPQ under CSW increased (7%) over time. The SPQ under CSW was 4-8% higher than CC and CS, respectively (Table 3). The *f*t, AS and POM significantly influenced by crop rotation and soil depth interaction; however, they decreased with increasing soil depth.

Crop rotation had a significant impact on composite soil quality index (SQI) calculated based on biological, chemical and physical quality indices (Table 4). The increase in SQI under CSW was significantly higher (11-12%) than CC and CS, respectively. Irrespective of crop rotations, the SQI decreased with increasing soil depth. The increase in SQI was highest with CSW.

Table 2. Crop rotation impacts on soil chemical quality indicators at different depths (Averaged across crop rotation).

Crop rotation	Depth of soil (cm)	TC (g/kg)	AC (mg/kg)	TN (g/kg)	SCQ (%)	ΔSBQ (%/yr)
Initial$_{(2002)}$		13.2Y*	622.9Y	1.33Y	50.1Y	0Y
CC$_{2007}$		13.5Yb+	664.6Yb	1.40Yb	51.7Yb	0.3Yb
CS$_{2007}$		13.6Yb	680.4Xb	1.40Yb	51.7Yb	0.3Yb
CSW$_{2007}$		15.9Xa	734.2Xa	1.64Xa	59.8Xa	1.9Xa
		Crop rotation and soil depth interaction				
Initial$_{(2002)}$	0-7.5	17.1#	779.6ns	1.59ns	54.0ns	0
	7.5-15	12.9	613.5	1.33	51.6	0
	15-22.5	11.6	563.9	1.25	47.7	0
	22.5-30	11.1	535.4	1.16	47.4	0
CC$_{2007}$	0-7.5	18.2	834.4	1.82	57.8	0.8ns
	7.5-15	13.4	672.2	1.40	54.0	0.5
	15-22.5	11.7	618.1	1.25	48.3	0.1
	22.5-30	10.5	533.9	1.12	46.5	-0.2
CS$_{2007}$	0-7.5	16.5	792.5	1.66	54.3	0.1
	7.5-15	14.1	693	1.45	54.6	0.6
	15-22.5	11.9	622.6	1.27	49.1	0.3
	22.5-30	11.9	613.5	1.20	48.8	0.3
CSW$_{2007}$	0-7.5	23.4	885.2	2.28	67.1	2.6
	7.5-15	17.5	758.8	1.82	67.2	3.1
	15-22.5	11.8	680.8	1.23	53.5	1.2
	22.5-30	10.9	611.9	1.20	51.5	0.8

Initial=Data collected from conventionally tilled (CT) continuous corn (CC) plots in 2002, CC$_{2007}$=Data collected from continuous corn plots in 2007, CS$_{2007}$=Data collected from corn-soybean rotation plots in 2007, CSW$_{2007}$=Data collected from corn-soybean-wheat rotation plots in 2007, TC=Tot carbon, AC=Active carbon, TN=Tot nitrogen, SCQ=Soil chemic quality, ΔSCQ=Rate of change in soil chemic quality and ns=Non-significant

*Means followed by same upper case (X to Z) letter in the column were not significantly different at $p \leq 0.05$ over time (2002 vs. 2007). +Means followed by same lower case (a to c) letters in the column were not significantly different at $p \leq 0.05$ among crop rotation treatments in 2007. # indicates significant crop rotation and soil depth interaction

Significant change in soil quality indicator properties by crop rotation at different soil depths over time could be attributed to placement and quality of crop residues, microbial food webs and soil microclimatic parameters (Bodnar *et al.*, 2004; Pagliai *et al.*, 2004). Relatively low value of qCO_2 explains that, for a certain quantity of organic carbon metabolized, ratio of respired C is less and greater C is assimilated into C_{mic} cells. A low qCO_2 also revealed that soil microbes are expecting relatively labile C as a basis for existence and thus can assign more resources for growth and activities like disintegration and plant nutrient recycling to improve soil quality (Anderson & Domsch, 1990; Islam & Weil, 2000). Decrease in qCO_2 may show a slight stress for soil microbial population under NT.

The high qCO_2 associated with low values of C_{mic} represent CT soils under stress and in poor condition (Islam & Weil, 2000). An increased qCO_2 has been designated as indicator of stress soil ecosystem like physical disturbance (Wardle & Ghani, 1995).

Table 3. Crop rotation impacts on soil physical quality indicators at different depths (Averaged across crop rotation).

Crop rotation	Depth of soil (cm)	ƒt	AS	POM	SPQ (%)	ΔSBQ (%/yr)
		------------- (%)	-------------	(g/kg)		
Initial$_{(2002)}$		35.6Y*	35.6Y	8.3Yb	58.8Y	0Y
CC$_{2007}$		45.2Xa+	36.8Yb	9.0Xa	60.9Yab	0.5Yab
CS$_{2007}$		45.5Xa	33.7Zc	8.2Yb	58.1Yb	-0.1Yb
CSW$_{2007}$		43.3Xa	44.1Xa	9.0Xa	63.4Xa	0.9Xa
		Crop rotation and soil depth interaction				
Initial$_{(2002)}$	0-7.5	51.8#	40.7#	12.3#	68.8ns	0
	7.5-15	44.4	35.8	8.1	58.8	0
	15-22.5	43.3	33.9	7.1	55.9	0
	22.5-30	37.7	32.1	5.8	51.5	0
CC$_{2007}$	0-7.5	50.2	49.5	13.3	74.1	1.1ns
	7.5-15	46.4	38.2	9.6	63.3	0.9
	15-22.5	44.4	32.4	7.2	55.8	0
	22.5-30	39.9	27.2	6.0	50.4	0
CS$_{2007}$	0-7.5	49.3	45.5	11.3	68.6	0
	7.5-15	46.2	33.1	8.7	59.1	0.1
	15-22.5	44.4	30.2	7.1	54.4	-0.2
	22.5-30	41.9	26.0	5.9	50.3	-0.2
CSW$_{2007}$	0-7.5	49.7	63.5	12.9	78.5	1.9
	7.5-15	43.2	46.2	9.3	65.8	1.4
	15-22.5	42.5	38.3	7.7	58.9	0.6
	22.5-30	37.7	28.5	6.2	50.4	-0.2

Initial=Data collected from conventionally tilled (CT) continuous corn (CC) plots in 2002, CC$_{2007}$=Data collected from continuous corn plots in 2007, CS$_{2007}$=Data collected from corn-soybean rotation plots in 2007, CSW$_{2007}$=Data collected from corn-soybean-wheat rotation plots in 2007, ƒt=Tot porosity, AS=Aggregate stability, POM=Sand free particulate organic matter, SPQ=Soil physic quality, ΔSPQ=Rate of change in soil physical quality and ns=Non-significant.

*Means followed by same upper case (X to Z) letter in the column were not significantly different at $p \leq 0.05$ over time (2002 vs. 2007). +Means followed by same lower case (a to c) letters in the column were not significantly different at $p \leq 0.05$ among crop rotation treatments in 2007. # indicates significant crop rotation and soil depth interaction.

The beneficial effects of crop rotation especially CSW on soil quality are primarily related to greater variations in quality of substrates than CC or CS rotation. The C_{mic} and qCO_2 are sensitive indicators to detect differences in substrate-use efficiency of C_{mic} among cropping systems (Anderson & Domsch, 1985; Insam & Haselwandter, 1989). Soils under CSW showed a greater C_{mic} but lower qCO_2, implying a more efficient and stable ecosystem. Anderson & Domsch, (1990) revealed soil biota respired greater per unit of biomass in sole cropping (eg., CC) than crop rotation (eg., CSW).

Significantly higher TC, AC and TN contents under CSW are most probably related to greater differences in inputs, decomposition of organic materials and stoicheometry of C and N (Saggar *et al.*, 2001; Huang *et al.*, 2002). Since legume biomass decompose (low CN ratio) faster than non-legumes (high CN ratio), the incorporation of soybeans and cow pea (as a cover crop) in the CSW may have resulted in greater availability of both C and N in the soil. Since C and N stoicheometrically linked in soil organic matter, a greater content of soil C invariably led to an increase in TN under CSW over time. The inclusion of wheat as a crop attributed to deeper and fibrous rooting volume to enhance soil aggregation especially macroaggregation (Monroe & Klavidko, 1987). In CSW, primary particles and new formed microaggregates may have pulled into close contacts with each other by physical enmeshing and in response to greater secretion of binding agents from plant root excretion and enhanced fungal activities. The increasing number of contacts between and/or among soil primary particles and microaggregates facilitated macroaggregation and greater aggregate stability over time. Fallow periods in annual cropping (eg., CC) may exert adverse influence on soil aggregation because of absence of quality C addition. Several studies have reported that soil aggregate stability is more influenced by amount of OM addition to soil than quality (Tisdall & Oades, 1982; Bruce *et al*., 1992; Abiven *et al*., 2007).

Among crop rotation treatment combinations, a significantly greater C_{mic} and BR with lower qCO_2 greater TC, AC and TN, and improved physical properties (AS and POM) under CSW over time might be result of combined effect of quantity and quality of substrates (Staben *et al*., 1997; Islam 2008; Aziz *et al*., 2009). Significant improvement in soil quality properties can be achieved through conserving or improving soil chemical, physical and biological capacities, which are interdependent to increase overall soil quality (Islam 2008; Aziz *et al*., 2009). For example, decline physical soil conditions has adverse impact on biological and chemical quality soil and ultimately with time on over all soil quality (Dexter, 2004).

Table 4. Crop rotation impacts on soil quality index (Averaged across tillage).

Crop rotation	Depth of soil (cm)	SQI (%)	ΔSBQ (%/yr)
$Initial_{(2002)}$		50.9Y*	0Y
CC_{2007}		53.4Yb+	1.0Yb
CS_{2007}		52.6Yb	0.8Yb
CSW_{2007}		60.0Xa	2.3Xa
	Crop rotation and soil depth interaction		
$Initial_{(2002)}$	0-7.5	60.4ns	0
	7.5-15	52.1	0
	15-22.5	47.4	0
	22.5-30	43.7	0
CC_{2007}	0-7.5	64.3	2.8ns
	7.5-15	55.2	0.6
	15-22.5	49.0	0.3
	22.5-30	45.1	0.3
CS_{2007}	0-7.5	60.7	2.0
	7.5-15	64.4	0.5
	15-22.5	48.7	0.2
	22.5-30	46.7	0.6
CSW_{2007}	0-7.5	72.5	4.4
	7.5-15	65.1	2.6
	15-22.5	53.8	1.3
	22.5-30	48.8	1.0

Initial=Data collected from conventionally tilled (CT) continuous corn (CC) plots in 2002, CC_{2007}=Data collected from continuous corn plots in 2007, CS_{2007}= Data collected from corn-soybean rotation plots in 2007, CSW_{2007}=Data collected from corn-soybean-wheat rotation plots in 2007, SQI=Soil equity index, ΔSQ1=Rate of change in soil quality index and ns=Non-significant.

*Means followed by same upper case letter (X to Z) in the column were not significantly different at $p \leq 0.05$ over time (2002 vs. 2007). + Means followed by same lower case letter (a to c) in the column were not significantly different at $p \leq 0.05$ among crop rotation treatments. # indicates significant crop rotation and soil depth interaction.

Conclusions

Soil quality is an integrated function of biological, chemical and physical properties of soil. Results of this study showed crop rotation had significant impact on C_{mic}, BR, qCO_2, TC, AC, TN, AS and POM except ft at different depths of soil when measured and/or calculated as selected SQ indicators. Among crop rotations, CSW performed best to improve soil quality properties and SQ over time. The study revealed that SBQ can be used as a sensitive indicator of soil quality evaluation including soil C sequestration in response to sustainable management practices. Moreover, a routine measurement of SBQ can be used as an early indicator of both soil quality and C sequestration.

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