Increased Corn Rotation Frequency Cropping System Impacts on Soil Functional Properties

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Masters of Science

By

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The undersigned, appointed by the dean of the Graduate School,

have examined the Thesis entitled

INCREASED CORN ROTATION FREQUENCY CROPPING SYSTEM IMPACTS ON SOIL FUNCTIONAL PROPERTIES

Presented by Jeremy Tyler Matson

A candidate for the degree of

Masters of Science

And hereby certify that, in their opinion, it is worthy of acceptance.

Dr. D. Brenton Myers

Dr. William Wiebold

Dr. Newell Kitchen

Dr. Randy Miles

Dedication

To

My Father in Heaven and all of my family and friends who have impacted my life and made this endeavor possible.

My wife Jessica, and our boys Braxton and Peyton Matson

Mark and Sherri Matson & Drew and Tamra Kriser

Josh, Erin, Emma, and Lydia Matson

Jason and Brittany Matson

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Caleb, Liz, and Bridger Kriser

Heidi Kriser

Avrey Kriser

Brigham Kriser

Liza Lou Kriser

Thank you for your sacrifices, love, and support during this endeavor.

I love you all!

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Active Carbon (AC)

Arbuscular Mycorrhizal (AM)

Bulk Density (BD)

β-glucosidase (β-g)

Calcium (Ca)

Carbon:Nitrogen Ratio (C:N)

Cation Exchange Capacity (CEC)

Corn Rotation Frequency (CRF)

0.0 = Continuous soybean

0.33 = One year of corn in a three year corn-soybean rotation

0.50 = Alternating corn-soybean rotation

0.66 = Two years of corn in a three year corn-soybean rotation

1.0 = Continuous corn

Electrical Conductivity ($EC_{1:1}$)

Field Water Content (FWC)

Gram Negative (gram neg.)

Gram Positive (gram pos.)

Magnesium (Mg)

Microbial Biomass Carbon (MBC)

Nitrogen (N)

Phospholipid Fatty Acid Analysis (PLFA)

Phosphorus (P)

Potassium (K)

Potentially Mineralizable Nitrogen (PMN)

Soil Management Assessment Framework (SMAF)

Soil Organic Carbon (SOC)

Soil Organic Matter (SOM)

Total Nitrogen (TN)

Water Filled Pore Space (WFPS)

Water Stable Aggregates (WSA)

CHAPTER 1

MEASURING IMPACTS OF INCREASED CORN ROTATION FREQUENCY ON SOIL FUNCTION

1.1 Abstract

Corn (*Zea mays L.*) intense rotations have become more common in the southern region of the U.S Corn Belt due to high grain production levels and economic benefits (Zhang & MacKenzie, 1997). As a result of increasing corn demand and economic competitiveness to soybean (*Glycine max*), many producers are altering management practices and implementing crop rotations which include more corn. This increase in corn adoption has raised concerns about the long-term sustainability of corn-intense cropping systems, and their overall impact to soil function. The objective of this study was to determine the influence of crop rotations with varying frequencies of corn and soybean on soil function in a long term (nine year) no-till management system. Soil samples were collected in the spring of 2014, at 0 to 5cm (Layer 1) and 5 to 15cm (Layer 2) depths. Soil function was represented by measurements of physical, chemical, and biological soil properties. Indicators were analyzed for previous crop effects and by calculating corn rotation frequency (CRF) ratings which were assigned to each treatment based on the total number of corn (C) years within a completed 6 year rotation cycle (e.g. S-S = 0.0, S-S-C = 0.33, C-S = 0.50, C-S-C = 0.66, C-C = 1.0). By calculating frequency, long term impacts of increased corn within rotations could be more easily identified. Plots previously in soybean averaged 33% greater water stable aggregates (WSA) in Layer 1 and 40% greater in Layer 2 compared to those previously in corn. In addition, greater electrical conductivity ($EC_{1:1}$) levels were observed at 0 to 5cm when soybeans were planted previously (0 to 5cm). Surface residues, potassium (K), and magnesium

(Mg) concentrations were all larger following corn. As CRF increased, favorable trends in a majority of the soil properties examined at the surface layer were observed. Soil organic carbon (SOC), water filled pore space (WFPS), soil organic matter (SOM), active carbon (AC), β-glucosidase (β-g), and phospholipid fatty acids (PLFA) (estimation of microbial biomass and diversity) displayed increasing trends with greater corn frequency while bulk density (BD) and $EC_{1:1}$ values decreased. In addition, continuous corn had the highest concentrations of soil total nitrogen (TN). Unfavorable effects with increasing CRF included reduced soil extractable phosphorus (P) at both depths. No significant differences were observed in pH_w, cation exchange capacity (CEC), calcium (Ca), or Mg based on CRF at either sampled depth. Greater CRF indicated the potential for better soil functional capacity in Layer 1, while Layer 2 showed similar functional potential among all rotation treatments.

1.2 Introduction

Growing demand for corn and its financial competitiveness as a cash crop has led to increased use of more corn-intense cropping systems (Plourde et al., 2013). The enactment of the Energy Independence and Security Act (EISA) in 2007 has resulted in an increase in biofuel demands to be met by corn ethanol production (Mehaffey et al., 2012). These authors suggests that this demand will have to be met in areas already producing corn, which includes the United States Corn Belt. Increases in corn production have already been seen in some areas (Zhang & MacKenzie, 1997) and are expected to dramatically increase in many others in the next few years. However, increases in corn adoption and the increased use of continuous corn cropping systems have raised concerns about long-term sustainability and impacts on soil function. These concerns are often discussed among some other negative effects associated with continuous corn which include increases in insect and disease pressures, reduced ability to control weeds, greater reliance on nitrogen (N) fertilizers, and most importantly declines in productivity (Gentry, Ruffo, & Below, 2013).

Corn yields have been observed to increase when corn is grown in rotation with soybean compared to continuous corn (Gentry et al., 2013; Porter et al., 1997; Raimbault & Vyn, 1991). This increase has been attributed to an unexplained "rotation effect" although, the specific mechanisms responsible for this effect are not fully understood (Bullock, 1992; Copeland et al., 1993; Crookston et al., 1988; Gentry et al., 2013). Yield reductions in continuous corn are substantial, in some cases as much as 28% (Peterson & Varvel, 1989). Corn yield declines have been observed in various studies and have been observed on the research plots that were examined for this specific study. It has been suggested, that increased corn yields in rotation may be a result of reduced crop residues, which may enhance mineralization and increase N availability (Gentry et al., 2013; Shrader et al., 1966), or increases to overall soil quality (Karlen et al., 2006). The focus of this study was to determine how increased corn frequency in a corn-soybean rotation influenced soil function by identifying changes to representative soil measurements.

Soil functions are the physical, chemical, and biological services that allow the soil to operate effectively with respect to explicit ecosystem and agronomic goals. Soil functions include complex interactions between soil properties and processes which have been identified as essential for a specific use – such as agricultural production - to occur (Reicosky et al., 1995). However, measuring soil function is a challenge due to the many parameters that could and should be analyzed. This has resulted in extensive research to identify representative soil measurements which are sensitive to changes in management practices (e.g. crop rotation, tillage, cover crops).

Two measurements that have been identified as the most sensitive and reliable include SOM and SOC (Havlin et al., 1990a; Reeves, 1997). These measurements are specifically recognized for their influence on soil nutrient status, soil aggregation (Tisdall & Oades, 1982), water relations (Hudson, 1994), and microbial functions (Schulten & Schnitzer, 1995). In addition to SOM and SOC, more than 80 soil measurements have been identified to represent soil physical, chemical, and biological functions (Andrews et al., 2004).

Physical property indicators most commonly measured when examining soil function include BD, WSA, and WFPS. Bulk density indicates soil compaction, which can influence soil and plant processes by restricting root growth and impeding water infiltration. Soil WSA are indicators of soil aggregate strength. Aggregate stability results in reduced detachment of soil particles when disruptive forces are imposed (e.g. water and wind erosion) (Kemper & Rosenau, 1986). Benefits associated with improved aggregation include enhanced water infiltration, improved soil nutrient status, and the promotion of root growth (Kemper & Rosenau, 1986). Water-filled pore space is a combination of soil water content and total porosity which influence microbial activity and alter gas exchange occurring within the soil. (Dobbie & Smith, 2001; Linn & Doran, 1984).

Soil chemical properties include pH, $EC_{1:1}$, and soil nutrients (e.g. N, P, K, Ca, Mg). Soil pH directly effects soil nutrient availability and can alter biological functions of the soil. Electrical conductivity is a measure of soil salinity, which influences plant nutrient uptake and can cause soil particle dispersion leading to negative effects on soil hydrological function. These measurements reflect the chemical state of the rhizosphere and soil nutrient status both of which impact plant growth and development (Smith et al., 1996; Veum et al., Accepted).

Soil biological measurements represent the processes driven by microbial organisms which influence soil functions and processes including residue decomposition, nutrient cycling, and soil aggregation (Chantigny et al., 1997; Stott et al., 2010). A wide range of measurements are available for soil biological properties, but usually include carbon measurements (e.g. SOM, SOC, and active carbon), availability of N for microorganism use (e.g. potentially mineralizable nitrogen (PMN) and total nitrogen), soil enzymes assays (e.g. β-glucosidase), and measurements representing microbial populations (e.g. microbial biomass and the PLFA).

1.2.1 Phospholipid Fatty Acid Analysis (PLFA)

Chemical, physical, and biological properties of soils can lead to dynamic changes in microbial activity and population structure. However, these microbial effects are difficult to quantify and measurements can have large variability.

The PLFA analysis may be the most comprehensive analysis currently available for identifying change that occurs in microbial communities (Bossio et al., 1998; Bossio & Scow, 1998). Soil PLFA has been shown to be a reliable indirect measurement of total microbial biomass through the characterization and quantification of phospholipid chemical structure in soils (Bashan et al., 2012). This method is used to group microorganisms into eight main categories which approximate the microbial community composition. The microbial groups identified from PLFA's are fungi (total and arbuscular mycorrhizal (AM)), bacteria (total, gram positive (gram pos.), gram negative (gram neg.)) actinomycetes or actinomycetales, eukaryotes, and anaerobes (Frostegård et al.,2011).

It is understood that crop type can have some impact on microbial communities (Garbeva et al., 2004), but more investigation of these impacts in a wide range of cropping systems is needed to link PLFA measurements to soil functional changes. For instance, the PLFA analysis may provide a better understanding of how corn-soybean rotations used in this study may influence microbial communities.

When examined together, soil physical, chemical, and biological properties, can help identify changes in soil function occurring due to changes in cropping systems over time. As discussed earlier, observed declines in yield with more corn intense (continuous corn) cropping systems could be caused by detrimental changes in soil physical, chemical, or biological function (Karlen et al., 2006). However, few studies exist that examine extensive soil measurements monitoring change in soil properties as a result of long term corn-soybean rotation differences. Additionally, few studies examine a gradient of increased corn in rotation.

1.3 Objectives

The objective of this research study was to evaluate changes to soil function as a result of differences in the frequency of corn in rotation within a no-till corn-soybean cropping system.

Specifically, I sought to identify differences in soil physical, chemical, and biological measurements due to; 1) rotation treatment including rotation phase; 2) previous crop effects; and 3) corn rotation frequency

1.4 Materials and Methods

1.4.1 Site Specifications

This research was conducted at the University of Missouri's Bradford Research and Extension Center, Located in Columbia, Missouri (38°53´24.19" N, 92°12´45.02" W). Soils at the research site consisted of a Mexico silt loam (fine, smectitic, mesic, Vertic Epiaqualf) and ranged in slope from 0 to 2%. The 2013 average precipitation was 1085 mm with a mean temperature of 12.5°C. The experiment was established in 2005 as a randomized block design in a no-till management system (Houx et al., 2011). Rotation treatments included continuous corn (C-C), continuous soybeans (S-S), and various corn soybean rotations (C-S, S-C, C-S-S, S-S-C, C-C-S, C-S-C, S-C-C, and S-C-S) (Figure 1). This design allowed for every rotation phase to be present in each year. Measurements described in this study were collected in March prior to the 2014 growing season. The crop previous to spring of 2014 can be identified from the rotation code by examining the last letter in the 3 year rotations and the first letter in the alternating rotations. For instance, in the S-C-C rotation phase, the final letter designates the previous (2013) crop to be corn. Alternating rotations such as S-C would indicate the previous crop to be soybean.

Each treatment was replicated four times with plots that measured 9 m x 12 m. Management practices for the study represent typical no-till production methods. Corn and soybeans were generally planted in mid-May and received conventional weed control by using both pre and post-emergent herbicides. Insecticides were applied on an as needed basis. To meet corn nitrogen requirements, ammonium nitrate was surface applied at 200 kg N ha^{-1}. Phosphorus and K were applied as needed according to soil test results uniformly across the experiment, but not applied prior to the 2014 growing season.

102	103	106	107	110	201	204	205	208	209	302	303	306	307	310	401	404	405	408	409
S-C	S-C-S	S-S-C	S-C-C	S-S	S-C-C	C-C	C-S-S	C-C-S	S-C-S	C-S-S	C-S	C-S-C	S-C-C	S-C	C-S-S	S-C-C	C-S	S-C-S	C-C-S
´13: S	´13: S	´13: C	´13: C	´13: S	´13: C	´13: C	´13: S	´13: S	´13: S	´13: S	´13: C	´13: C	´13: C	´13: S	´13: S	´13: C	´13: C	´13: S	´13: S

4 rows of corn fill planted east/west

101	104	105	108	109	202	203	206	207	210	301	304	305	308	309	402	403	406	407	410
C-C	C-S-S	C-C-S	C-S	C-S-C	S-S	C-S-C	S-S-C	S-C	C-S	S-S	C-C	S-C-S	S-S-C	C-C-S	S-S-C	S-C	S-S	C-S-C	C-C
´13: C	´13: S	´13: S	´13: C	´13: C	´13: S	´13: C	´13: C	´13: S	´13: C	´13: S	´13: C	´13: S	´13: C	´13: S	´13: C	´13: S	´13: S	´13: C	´13: C

Corn
Soybean

SW

Figure 1. 2013 plot and treatment map (planted north/south)

1.4.2 Sample Collection and Processing

Soil samples were collected in March of 2014, at 0 to 5cm (layer 1) and 5 to 15cm (layer 2) depths (Figure 2). Within each plot, nine soil cores measuring 3.18 cm in diameter were extracted in a fixed pattern which captured areas in and between crop rows within each plot (Figure 3).The sampling area was cleared to the bare soil surface prior to soil core extraction in order to prevent residue collection within the sample. These nine samples were then composited by depth to achieve a representative sample. Composited samples were then placed in an air tight plastic bag and frozen prior to analysis.

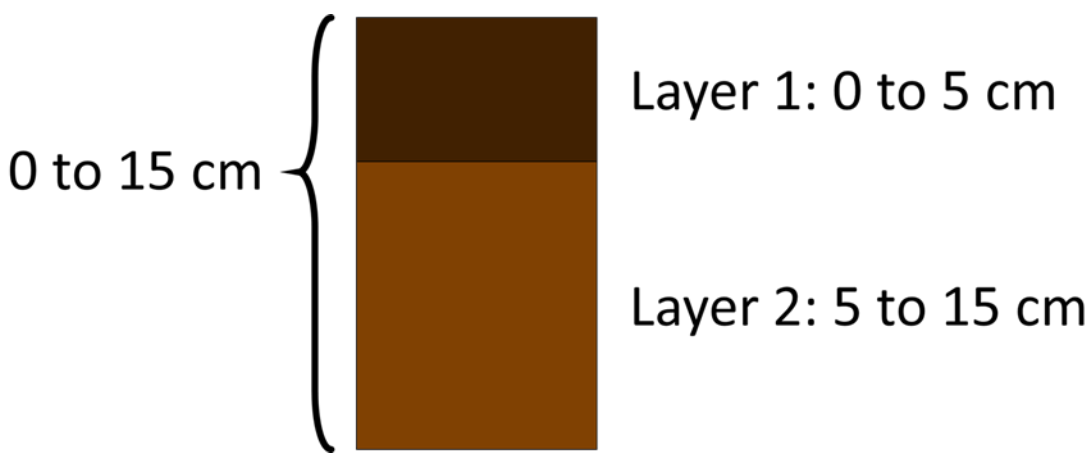

Figure 2. Sample dimensions and naming scheme. A full 15cm was sampled in two layers referred to as Layer 1 and Layer 2 throughout. Layer 1 includes the top 5cm of the soil and layer 2 includes the next 10 cm.

Before analysis, samples were thawed at ambient air temperature followed by a recording of moist soil weight. Samples were sieved through a 6-mm screen while moist to enable thorough mixing for subsampling. A splitting process then occurred to allocate soil as needed for analysis, which included portions kept frozen, oven dried, rapid air dried, and the remaining bulk soil was dried at ambient air temperature prior to being ground and passed through a 2mm sieve.

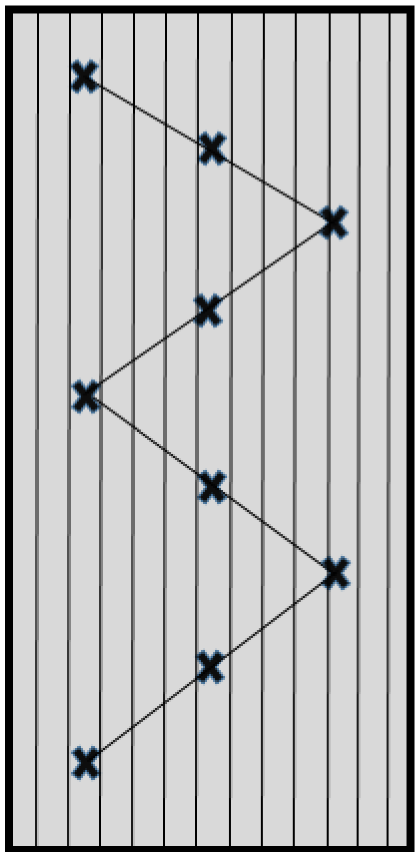

Figure 3. Sample pattern and locations for extracted soil cores (**X**) within each individual plot. Lines represent the 12 corn or soybean rows planted within each plot.

1.4.3 Residue Sampling

Surface residue samples were collected in late May of 2014 after crop emergence to determine differences in the amount of residues produced by each rotation. Five residue samples were taken randomly from each individual plot using a square steel quadrat with sharpened edges (30 X 30 cm). All loose residues falling within the quadrat were removed from the soil surface and placed in ovens to dry at 48° C.

Partially buried residues were cut at the surface. Each sample was then sifted to remove any foreign materials (e.g. soil particles), and dry weights were recorded.

1.4.4 Soil Analysis

In order to characterize corn-soybean rotation effects on soil function selected physical, chemical, and biological properties were examined for each treatment. Physical properties included BD, WSA (USDA, 2014), and WFPS.

Calculations for physical measurements were as follows;

BD = field moist weight of soil * [1-(FWC)]/volume of soil collected

FWC = (moist soil weight – oven dry soil weight)/oven dry soil weight

WFPS % = (% volumetric water content/% soil porosity) * 100

Chemical properties included pH_w (water), $EC_{1:1}$ (Whitney, 1998), Bray-I extractable P, K, Mg, Ca, and CEC (Warncke & Brown, 2012).

Soil biological properties examined were SOM, SOC (Burt, 2004), PMN (Horneck et al., 1989), TN (Burt, 2004), β-g (Eivazi & Tabatabai, 1988), AC (Weil et al., 2003), and PLFA (Buyer & Sasser, 2012).

1.4.5 Calculating Corn Rotation Frequency (CRF)

The experiment presented here includes five corn-soybean rotations. The design of these rotations allow for each crop phase to be present in each year of the experiment leading to a total of 10 unique rotation sequences which are replicated four times. The multi-phase design is helpful for annual interpretation of yield differences resulting from interactions with weather that drive growing season specific yield variation. However, this study examined long term effects of increased corn rotations on soil function occurring as a result of nine cropping seasons since rotation treatments were established. To better portray the impacts of increased corn within rotations, CRF ratings were assigned to each treatment based on the total number of corn years within a completed 6 year rotation cycle (see Table 8 in section 1.5.3). By assigning CRF ratings, long term impacts of increasing corn within rotations could be observed and more easily identified. Soybean frequency could be calculated as 1-CRF.

$$\boldsymbol{CRF} = \frac{\#\ \boldsymbol{of\ corn\ years\ in\ complete\ rotation\ cycle}}{\#\ \boldsymbol{of\ years\ in\ complete\ rotation\ cycle}}$$

Equation 1. Calculation for corn rotation frequency (CRF) ratings used to identify impacts of increased corn in rotation on soil function.

Multiple phase rotations with similar corn frequency but different crop sequences (e.g. C-S-S, S-C-S, and S-S-C) could have contained previous crop related differences in soil measurements that may mask or amplify frequency effects on soil functional measurements in any specific year. Therefore, we examined the data for potential interaction effects due to corn frequency and previous crop. These analyses were limited to the non-continuous treatments since previous crop is a constant for continuous plantings.

1.4.6 Statistical Analysis

Presentation of the results will be in terms of three types of analysis on soil measurements and surface residues; 1) the effect of the designed treatment where phases are considered to be individual factor levels; 2) the effects of previous crop and corn frequency in multi-phase rotations; and 3) the effect of increasing corn rotation frequency factor levels. Analyses 2 and 3 merge similar multi-phase rotations into fixed corn frequency factor levels. All analyses were performed using a Linear Mixed Effect Model (SPSS 22.0) (IBM Corp, 2013). Effect estimates were compared using Fisher's least significant difference (LSD) test at $P \leq 0.05$. Previous crop effects were analyzed using a two-way ANOVA (SPSS 22.0) with previous crop and CRF set as fixed factors. Layer 1 (0 to 5cm) and 2 (5 to 15cm) depths for individual measurements were considered separately for all analyses. Additionally, Pearson correlation coefficients were calculated to show correlations between measurements.

1.5 Results and Discussion

Results collected represent the accumulated changes to soil function that occurred over a nine-year period due to a range of corn-soybean rotations. These measurements and analyses captured snapshots of conditions in March of 2014.

Crop residue and several soil measurements were greatly influenced by the number of corn years in rotation phase. Residue amounts increased as corn increased in rotation (Table 1). Soil measurements including BD, WFPS, SOM, SOC, PMN, and β-glucosidase also showed an increased trend with more corn in Layer 1 (Table 2). An inverse trend was observed in extractable P data in which P increased with more soybean in rotation. All other measurements showed no differences with increased corn or soybean in rotation. In Layer 2, fewer differences were observed between rotations. This was expected, due to the greater concentrations of residues, nutrients, and biological activity present at the soil surface in a no-till management system. Soil extractable P and WSA showed similar trends that increased with more soybean in rotation in Layer 2 (Table 3). No other defined trends were recognized at the 5 to 15cm depth.

Table 1. Summary statistics for crop residue amounts based on rotation in 2013. Residue appeared to increase with more corn in rotation.

Rotation	Mean	Std. Error	Lower Bound	Upper Bound
	Mg ha^{-1}			
C	10.8	0.68	8.64	13.00
C-S-C	9.2	0.45	7.80	10.71
S-C-C	9.6	0.97	6.51	12.73
C-C-S	5.9	1.09	2.46	9.40
C-S	6.5	0.55	4.80	8.32
S-C	5.9	0.72	3.62	8.21
S-S-C	7.5	0.61	5.54	9.48
S-C-S	3.4	0.50	1.84	5.02
C-S-S	4.5	0.21	3.87	5.22
S	2.2	0.20	1.62	2.92

Correlations were observed between individual measurements, which showed the complex interactions that occur between physical, chemical, and biological properties. Layer 1 physical properties were significantly correlated to chemical and biological measurements. Perhaps the most notable, was a negative correlation between BD and all biological measurements (Table 4). These correlations were highly significant ($r = -0.43, -0.66, -0.67, -0.70, p < 0.01$) for SOM, SOC, β-glucosidase, and active carbon. Contrary to the negative correlations observed between BD and biological measures, crop residues showed significant ($r = 0.42, 0.59, 0.61, 0.45$, $p < 0.01$) positive correlations with SOM, SOC, β-glucosidase, and active carbon. Crop residues also showed a strong negative correlation with soil BD, $EC_{1:1}$, and P ($r = -0.74, -0.58, -0.41$, $p < 0.01$). Many positive correlations were also observed between individual biological measurements (e.g. active carbon, SOC, SOM, and β-g).

Correlations at layer 2 showed fewer distinct patterns between measurements than were observed at the surface layer. However, some measurements only showed significant correlations at this deeper depth (e.g. PMN) (Table 5). Soil organic carbon was also positively correlated to SOM ($r = 0.38$, $p < 0.05$) at this depth, but did not significantly correlate to crop residues as was examined at the soil surface. Soil nutrients showed correlations with pH_w, $EC_{1:1}$, and CEC at both examined depths. In addition, crop residues also showed a significant ($r = 0.48$ and 0.58, $p < 0.01$) positive correlation to WFPS in Layer 1 and 2.

Overall, depth had a profound influence on soil measurement values and correlations. Most differences between rotations were observed in Layer 1 where cropping system would be expected to have the greatest influence on soil properties in a no-till management system.

Table 2. Summary of all soil physical, chemical, and biological measurement values for corn-soybean rotations in Layer 1 (0 to 5cm).

Rotation	BD	WSA	WFPS	pH_w	$EC_{1:1}$	OM	P	K	CEC	Ca	Mg	SOC	PMN	TN	β-g	AC
	$g\ cm^{-3}$	% Agg.	%	pH	$ds\ m^{-1}$	%	$mg\text{-}kg^{-1}$	$mg\text{-}kg^{-1}$	meq.	$mg\text{-}kg^{-1}$	$mg\text{-}kg^{-1}$	%	$mg\text{-}kg^{-1}$	%	µg.	$mg\text{-}kg^{-1}$
								0-5cm								
C	1.04	14	54	7.6	0.29	3.3	31	116	15	2633	189	2.38	81	2.8	327	998
C-S-C	1.10	11	57	7.7	0.30	3.1	34	108	16	2977	193	2.10	70	2.2	283	872
S-C-C	1.07	13	56	7.3	0.25	3.2	32	113	13	2377	200	2.13	70	2.4	312	867
C-C-S	1.13	17	49	7.5	0.35	3.1	40	114	14	2525	202	2.07	72	2.1	326	808
C-S	1.07	9	55	7.7	0.26	3.2	34	102	14	2615	177	2.12	81	2.2	285	916
S-C	1.12	19	49	7.5	0.40	3.1	43	119	15	2687	192	2.10	85	2.3	272	857
S-S-C	1.16	8	59	7.7	0.28	2.9	31	98	15	2733	159	2.01	61	1.9	226	768
S-C-S	1.17	15	47	7.5	0.39	2.9	41	119	13	2389	200	1.88	66	2.1	223	750
C-S-S	1.14	16	45	7.7	0.37	2.8	44	107	13	2428	172	1.96	61	2.1	222	815
S	1.19	15	48	7.7	0.35	2.8	46	116	15	2712	168	1.98	54	2.4	201	822

† Bulk Density (BD), Water Stable Aggregates (WSA), Water-Filled Pore Space (WFPS), Electrical Conductivity ($EC_{1:1}$), Organic Matter (OM), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Soil Organic Carbon (SOC), Potentially Mineralizable Nitrogen (PMN), Total Nitrogen (TN) β-glucosidase (β-g), Active Carbon (AC)

†† meq/100g (meq.), µg PNP/g soil/$hr.^{-1}$ (µg)

Table 3. Summary all of soil physical, chemical, and biological measurement values for corn-soybean rotations in Layer 2 (5 to 15cm).

Rotation	BD	WSA	WFPS	pH_w	$EC_{1:1}$	OM	P	K	CEC	Ca	Mg	SOC	PMN	TN	β-g	AC
	g cm^{-3}	% Agg.	%	pH	ds m^{-1}	%	mg-kg^{-1}	mg-kg^{-1}	meq.	mg-kg^{-1}	mg-kg^{-1}	%	mg-kg^{-1}	%	µg.	mg-kg^{-1}
	5-15cm															
C	1.35	7	64	7.6	0.18	1.6	6.2	63	14	2600	148	1.14	26	1.4	91	484
C-S-C	1.34	9	63	7.6	0.19	1.7	6.7	53	14	2529	136	1.16	25	1.2	96	372
S-C-C	1.34	6	63	7.4	0.17	1.7	5.8	57	13	2412	150	1.14	25	1.2	88	375
C-C-S	1.36	11	59	7.4	0.18	1.7	7.7	55	13	2382	145	1.15	23	1.1	97	368
C-S	1.36	7	65	7.5	0.18	1.7	7.1	52	13	2513	132	1.11	26	1.1	83	394
S-C	1.35	13	58	7.5	0.19	2.0	8.6	57	13	2380	127	1.17	26	1.2	109	426
S-S-C	1.34	7	62	7.6	0.17	1.8	6.7	51	14	2570	122	1.13	23	1.3	100	408
S-C-S	1.35	13	55	7.3	0.17	1.7	7.8	56	13	2385	151	1.12	18	1.2	82	413
C-S-S	1.35	11	55	7.5	0.17	1.6	8.6	53	12	2335	126	1.12	21	1.1	105	383
S	1.34	12	54	7.5	0.17	1.6	8.0	56	13	2482	120	1.15	19	1.2	93	337

† Bulk Density (BD), Water Stable Aggregates (WSA), Water-Filled Pore Space (WFPS), Electrical Conductivity ($EC_{1:1}$), Organic Matter (OM), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Soil Organic Carbon (SOC), Potentially Mineralizable Nitrogen (PMN), Total Nitrogen (TN) β-glucosidase (β-g), Active Carbon (AC)

†† meq/100g (meq.), µg PNP/g soil/hr.$^{-1}$ (µg)

Table 4. Pearson correlation matrix identifying significant correlations between physical, chemical, and biological soil properties in Layer 1 (0 to 5cm).

		1)	2)	3)	4)	5)	6)	7)	8)	9)	10)	11)	12)	13)	14)	15)	16)
Phys.	1) Res.	1															
	2) BD	-.74**	1														
	3) WSA	-.21	.12	1													
	4) WFPS	.48**	-.35*	-.79**	1												
Chemical	5) pH_w	-.10	.00	-.20	.19	1											
	6) $EC_{1:1}$	-.58**	.53**	.39*	-.59**	-.14	1										
	7) P	-.41**	.16	-.06	-.11	.15	.39*	1									
	8) K	-.07	.12	.33*	-.40**	-.65**	.31*	.16	1								
	9) Ca	.20	-.06	-.32*	.44**	.51**	-.10	.05	-.09	1							
	10) Mg	.09	.01	.02	-.08	-.70**	.24	-.10	.71**	.06	1						
	11) CEC	.20	-.04	-.31	.41**	.32*	-.03	.03	.09	.97**	.29	1					
Biological	12) OM	.42**	-.43**	.42**	-.11	-.28	-.13	-.36*	.30	.07	.32*	.14	1				
	13) SOC	.59**	-.66**	.14	.21	.10	-.38*	-.30	.00	.30	-.01	.29	.66**	1			
	14) PMN	.17	-.30	-.07	.26	-.25	.08	-.09	.10	.12	.30	.20	.30	.18	1		
	15) TN	.24	-.34*	.20	-.10	-.31*	-.04	-.02	.54**	-.02	.32*	.06	.27	.34*	.20	1	
	16) β-g	.61**	-.67**	.26	.06	-.27	-.29	-.25	.26	.06	.26	.11	.62**	.60**	.25	.44**	1
	17) AC	.45**	-.70**	.16	.11	.08	-.33*	-.21	.08	.16	-.01	.15	.59**	.82**	.43**	.57**	.51**

† Physical (Phys.), Residue (Res), Bulk Density (BD), Water Stable Aggregates (WSA), Water Filled Pore Space (WFPS), Electrical Conductivity ($EC_{1:1}$), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Cation Exchange Capacity (CEC), Organic Matter (OM), Soil Organic Carbon (SOC), Potentially Mineralizable Nitrogen (PMN), Total Nitrogen (TN), β-glucosidase (β-g), Active Carbon

†† Correlation is significant at **<0.01, *<0.05

Table 5. Pearson correlation matrix identifying significant correlations between physical, chemical, and biological soil properties in Layer 2 (5 to 15cm).

		1)	2)	3)	4)	5)	6)	7)	8)	9)	10)	11)	12)	13)	14)	15)	16)
Phys.	1) Res.	1															
	2) BD	.02	1														
	3) WSA	-.50**	-.46**	1													
	4) WFPS	.58**	.56**	-.85**	1												
Chemical	5) pH$_w$	.16	-.29	-.04	.12	1											
	6) EC$_{1:1}$	.16	.29	-.33*	.45**	.26	1										
	7) P	-.39*	-.18	.17	-.13	.27	.28	1									
	8) K	.07	.40*	-.03	.07	-.49**	.08	-.26	1								
	9) Ca	.23	.34*	-.43**	.52**	.33*	.60**	-.01	.32*	1							
	10) Mg	.10	.56**	-.12	.18	-.62**	.15	-.47**	.76**	.30	1						
	11) CEC	.21	.49**	-.43**	.52**	.07	.56**	-.16	.51**	.94**	.56**	1					
Biological	12) OM	.03	.13	.09	-.01	-.27	.21	-.10	.53**	.25	.41**	.36*	1				
	13) SOC	.11	-.25	.25	-.12	.37*	.42**	.01	.13	.41**	.01	.33*	.38*	1			
	14) PMN	.36*	-.20	-.41**	.43**	.40**	.43**	.30	-.43**	.14	-.39*	.01	-.28	.15	1		
	15) TN	.24	.24	-.16	.32*	-.10	.24	.03	.30	.25	.23	.28	.16	-.01	.04	1	
	16) β-g	.00	-.36*	.51**	-.40**	-.13	-.25	-.00	.13	-.25	.05	.21	.10	.20	-.19	.03	1
	17) AC	.24	-.04	-.06	.07	.32*	.16	-.13	-.02	.14	-.11	.05	.00	.25	.25	.22	-.18

† Physical (Phys.), Residue (Res), Bulk Density (BD), Water Stable Aggregates (WSA), Water Filled Pore Space (WFPS), Electrical Conductivity (EC$_{1:1}$), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Cation Exchange Capacity (CEC), Organic Matter (OM), Soil Organic Carbon (SOC), Potentially Mineralizable Nitrogen (PMN), Total Nitrogen (TN), β-glucosidase (β-g), Active Carbon

†† Correlation is significant at **<0.01, *<0.05

1.5.1 As Designed Rotation Treatment Analysis

Corn-soybean rotation including the number of corn or soybean years in rotation and the phase of corn and soybean had significant effects on accumulation of surface residues, soil BD, WFPS, $EC_{1:1}$, AC, SOC, and β-glucosidase in Layer 1 (Table 6). In addition, significant differences were also observed in WSA and WFPS in Layer 2. However, due to underlying factors within rotation phase (such as previous crop) it became difficult to identify and explain data trends for many soil measurements (Figure 4). In Figure 5, previous crop influence on $EC_{1:1}$ can be easily identified in which values for soybean were higher than those of corn. For this reason, previous crop effects were examined for all non-continuous multi-phase treatments.

Table 6. Measurement summary table for physical, chemical, and biological soil properties examined with F-statistics and P-values for rotation and corn rotation frequency (CRF).

		Rotation		CRF	
Measurement	Depth	F-Statistic	P-value	F-Statistic	P-value
Residue		17.4	0.00**	14.7	0.00**
			Physical		
Bulk Density	0-5cm	8.00	0.00**	13.2	0.00**
	5-15cm	0.20	0.99	0.16	0.95
WSA	0-5cm	0.87	0.55	0.04	0.99
	5-15cm	2.40	0.03*	1.27	0.30
WFPS	0-5cm	2.32	0.04*	0.68	0.60
	5-15cm	3.00	0.01**	3.05	0.02*
			Chemical		
pH_w	0-5cm	1.67	0.14	0.63	0.64
	5-15cm	0.87	0.55	0.44	0.77
EC 1:1	0-5cm	8.20	0.00**	1.27	0.30
	5-15cm	0.68	0.72	0.71	0.59
Phosphorus	0-5cm	2.07	0.06	1.82	0.14
	5-15cm	1.41	0.22	1.30	0.28
Potassium	0-5cm	0.68	0.72	0.24	0.91
	5-15cm	0.67	0.72	1.15	0.34
CEC	0-5cm	1.30	0.27	0.46	0.75
	5-15cm	0.43	0.90	0.34	0.84
Calcium	0-5cm	1.58	0.16	0.39	0.81
	5-15cm	0.60	0.78	0.45	0.77
Magnesium	0-5cm	0.57	0.80	0.69	0.60
	5-15cm	0.34	0.95	0.46	0.75
			Biological		
OM	0-5cm	1.15	0.36	2.77	0.04*
	5-15cm	0.94	0.50	1.11	0.36
Active Carbon	0-5cm	3.28	0.00**	6.63	0.00**
	5-15cm	0.97	0.48	2.31	0.07
SOC	0-5cm	2.87	0.01**	6.64	0.00**
	5-15cm	0.42	0.91	0.33	0.85
Total Nitrogen	0-5cm	1.19	0.33	2.46	0.06
	5-15cm	0.28	0.97	0.47	0.75
PMN	0-5cm	1.12	0.37	2.83	0.03*
	5-15cm	0.99	0.46	2.03	0.11
β-glucosidase	0-5cm	4.35	0.00**	10.0	0.00**
	5-15cm	0.83	0.59	0.06	0.99

† Water Stable Aggregates (WSA), Water Filled Pore Space (WFPS), Electrical Conductivity ($EC_{1:1}$), Cation Exchange Capacity (CEC), Soil Organic Carbon (SOC), Potentially Mineralizable Nitrogen (PMN)

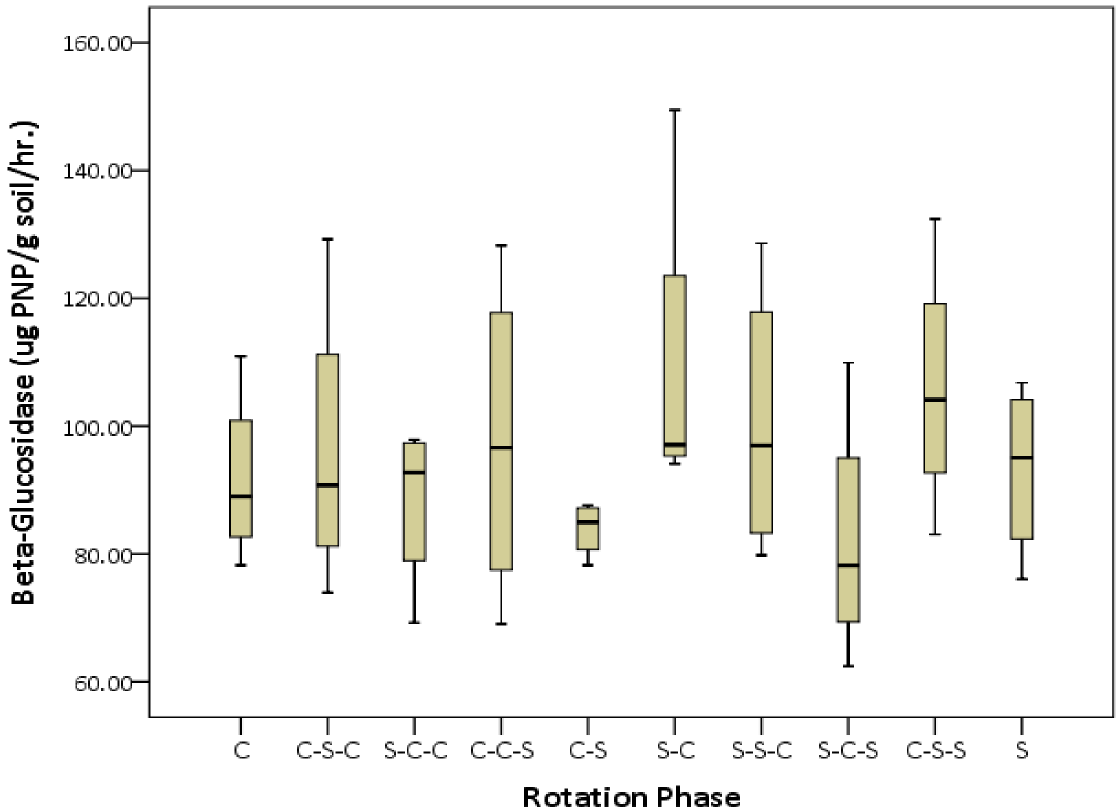

Figure 4. β-glucosidase concentrations observed in Layer 2 (5 to 15cm). Due to potential previous crop effects and variations in rotation phases, it is difficult to understand and interpret the influence of increased corn in rotation on these β-glucosidase values. Previous crop can be identified by observing the last letter in the three year rotation phase code (e.g. C-C-S) and the first letter of the alternating rotation code (e.g. S-C).

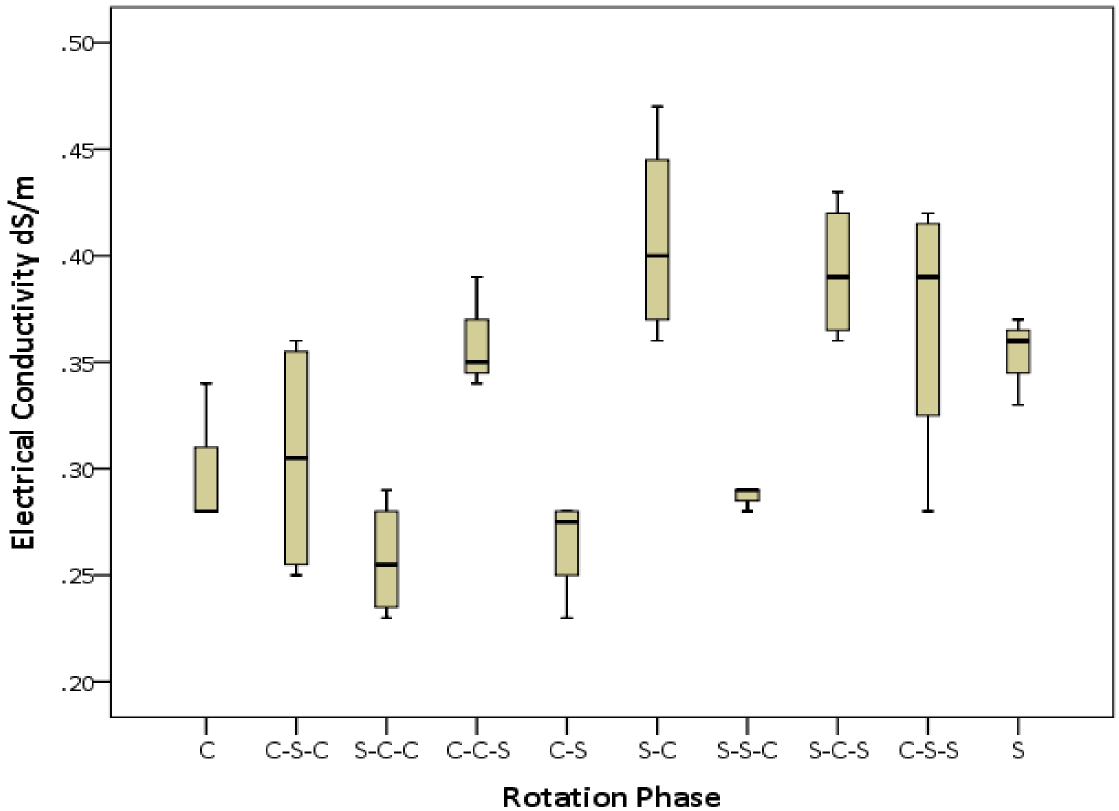

Figure 5. Rotation phase electrical conductivity$_{1:1}$ values in Layer 1 (0 to 5cm). Trends indicate a potential previous crop effect with higher values observed in soybean as previous crop. Previous crop can be identified by observing the last letter in the three year rotation phase code (e.g. C-C-S) and the first letter of the alternating rotation code (e.g. S-C).

1.5.2 Previous Crop Effects

Measurements were analyzed for potential previous crop effects and interactions due to CRF. These analyses were limited to the non-continuous multi-phase treatments since previous crop is a constant for continuous plantings. No significant interactions between previous crop and CRF were observed for any soil measurement, therefore we present only those results due to the main effects.

Previous crop had a significant effect on surface residues but only a minority of soil measurements examined (Table 7). Furthermore, WSA and extractable P were the only measurements to show a significant effect due to previous crop at both measurement depths and will be discussed in more detail in this section.

Table 7. Significant previous crop effects and corn frequency effects on soil physical, chemical, and biological measurements (only measurements with significant previous crop effects shown).

		Previous Crop		Corn Rotation Frequency	
Measurement	Depth	F-Statistic	Sig. Value	F-Statistic	Sig. Value
WSA	0-5cm	14.51	0.03*	1.877	0.23
	5-15cm	18.93	0.02*	0.717	0.52
$EC_{1:1}$	0-5cm	47.33	0.00**	0.480	0.64
Phosphorus	0-5cm	28.45	0.01*	0.381	0.69
	5-15cm	17.77	0.02*	2.909	0.13
Potassium	0-5cm	211.90	0.00**	0.415	0.67
Magnesium	0-5cm	14.16	0.03*	1.087	0.39
Crop Residue	Surface	21.80	0.01*	8.093	0.02*

†Water Stable Aggregates (WSA), Electrical Conductivity ($EC_{1:1}$)
Significance at: *<0.05, **<0.01

1.5.2.1 Previous Crop Effect on Water Stable Aggregates

Significant previous crop effects were evident in soil WSA measurements at both layers (Table 7 and Figure 6). Plots previously in soybean averaged 33% greater aggregates in Layer 1 and 40% greater in Layer 2 compared to those previously in corn (Tables 2 and 3). This increase in aggregation by soybean may be explained by a negative linear relationship with soil moisture as discussed by Perfect et al. (1990) and Raimbault and Vyn (1991). Water filled pore space and field water content data showed related trends of significantly smaller soil moisture values from plots previously in soybean compared to those previously in corn (Tables 2 and 3). As soil moisture decreased percent WSA followed an increasing trend (Figure 7). Increases in soil moisture for corn treatments could have potentially been caused by increased surface residues from the previous year as found by Dam et al. (2005) and Maskina et al. (1993). Soil aggregates are more susceptible to compaction and disintegration when moist (Perfect et al., 1990). This greater soil moisture under corn residues may have resulted in increased disruption of soil aggregates due to the physical action of the sampling probe compared to soybean as was observed by Perfect et al. (1990).

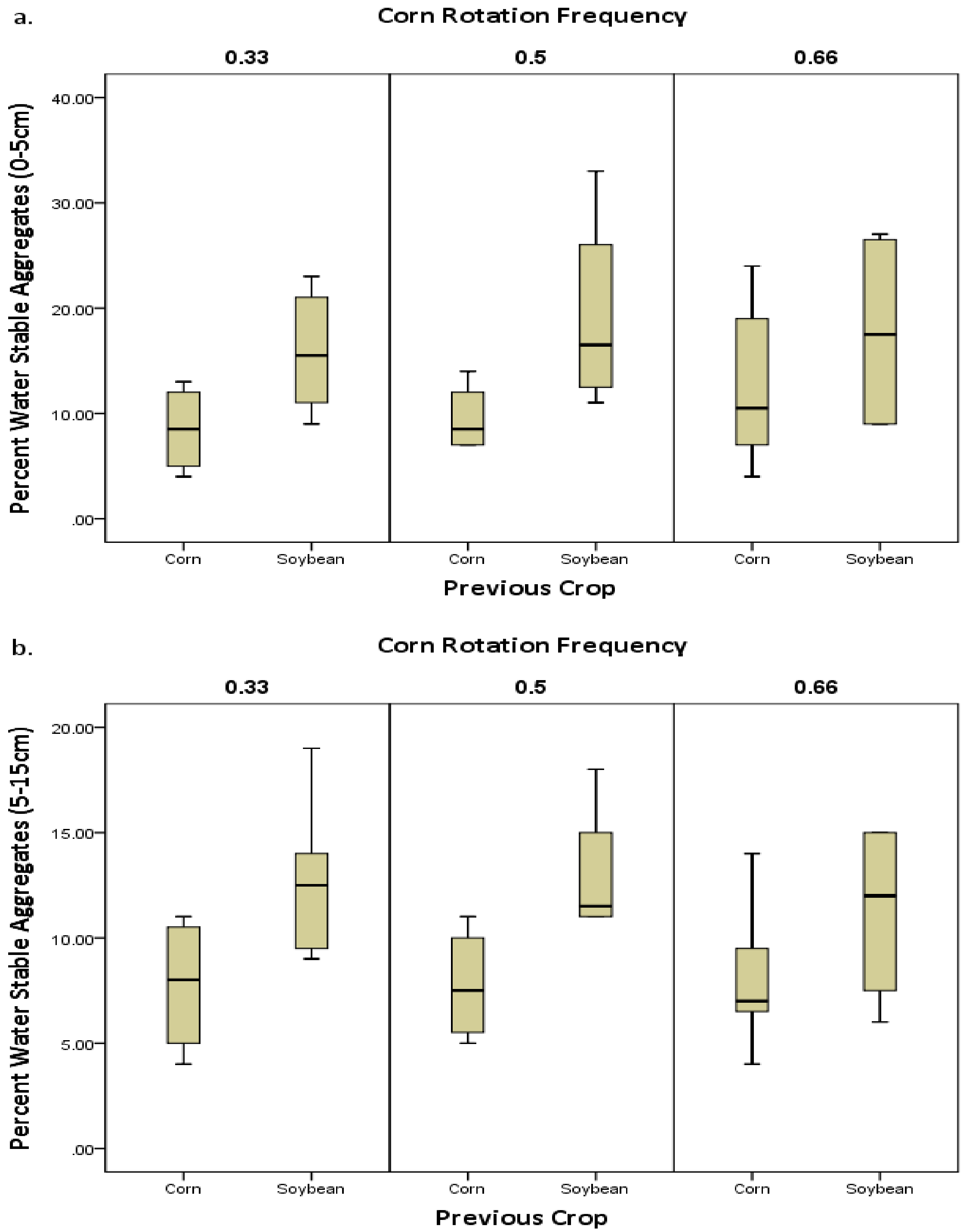

Figure 6. Previous crop effect on percent stable aggregates by three levels of Corn Rotation Frequency (CRF) for (a) Layer 1 (0 to 5cm) and (b) Layer 2 (5 to 15cm). Plots with soybean as previous crop had significantly greater water stable soil aggregates compared to those previously in corn.

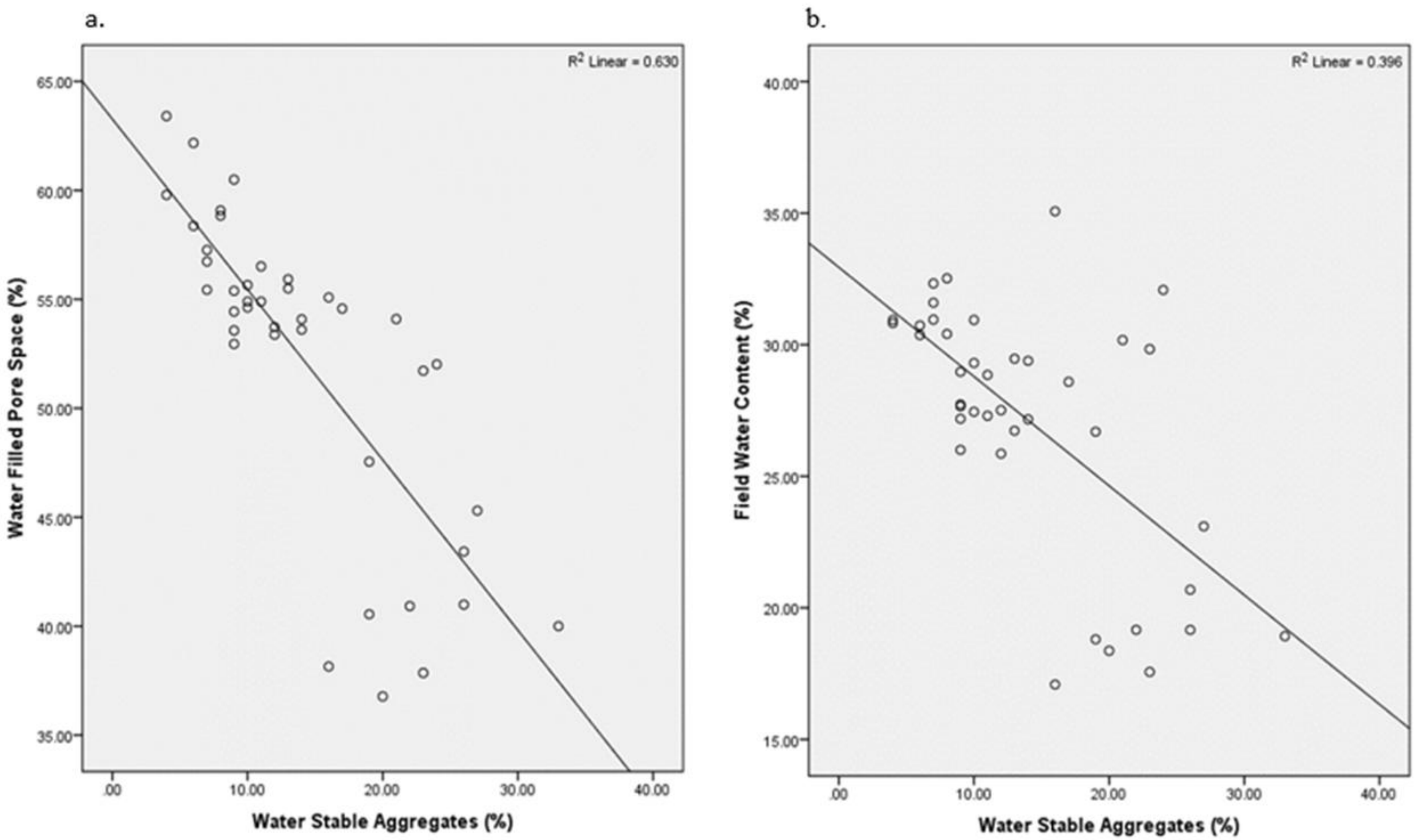

Figure 7. Negative correlations observed between (a) water filled pore space and water stable aggregates and (b) field water content and water stable aggregates.

1.5.2.2 Previous Crop Effects on Extractable Phosphorus

Plots previously in corn showed a significant decrease in extractable P levels averaging 25% in Layer 1 and nearly 20% in Layer 2 compared to soybean treatments (Tables 2, 3 and Figure 8). Edwards et al. (1992) also showed negative effects to soil extractable P levels with corn production. However, this decrease was attributed to an observed decrease in soil pH present in rotations with increased corn making P less available. Decreased soil pH_w was not observed in this study (Tables 2 and 3), due to close proximity to a limestone gravel road which caused pH_w to range near 7.5. As a result, changes in pH_w did not seem a likely cause for reduced P levels. Instead, we speculate and support the findings of Rubio et al. (2012) that greater P removal with corn grain withdrew more P from the soil than soybean grain removal would have (Equation 2) (Buchholz, 1983). This thought would be reasonable since P additions were uniformly applied across all plots. In addition, soybean residue was mostly decomposed at sampling time, which could have also contributed to increased P levels in plots previously in soybean.

$$\boldsymbol{Corn\ P\ removal = (0.20\ kg * 8159\ kg/Ha) = 1631\ kg/Ha}$$

$$\boldsymbol{Soybean\ P\ removal = (0.38\ kg * 2017\ kg/Ha) = 766\ kg/Ha}$$

Equation 2. Difference in phosphorus removal rates between corn and soybean.

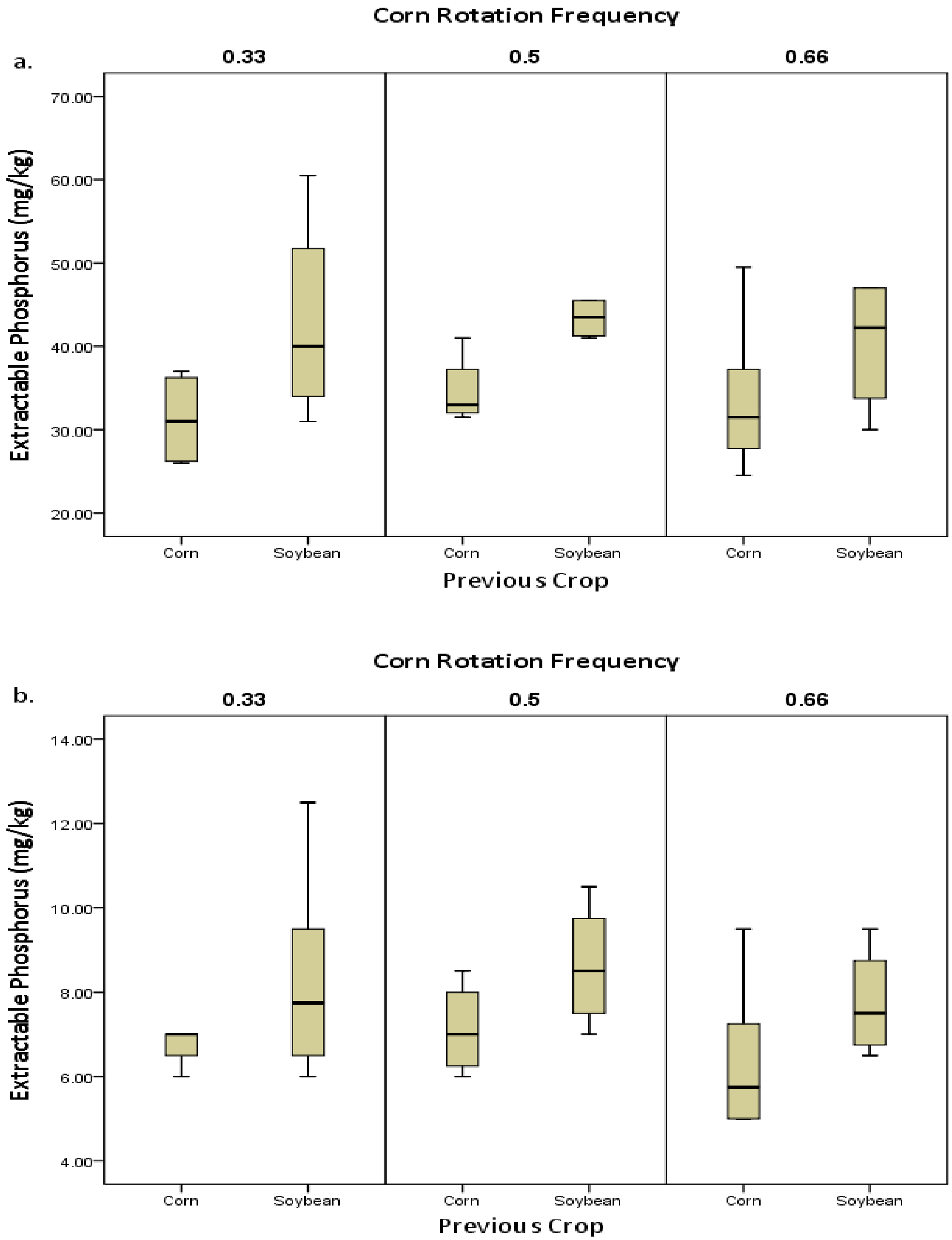

Figure 8. Previous crop effect on soil extractable phosphorus values by three levels of Corn Rotation Frequency (CRF) for (a) layer 1 (0-5cm) and (b) layer 2 (5-15cm). Plots with soybean as previous crop had significantly greater water stable soil aggregates compared to those previously in corn.

1.5.2.3 Biological Measurements

Overall, no significant previous crop effects or interaction between previous crop and CRF were observed in any of the biological measurements examined. This was unexpected due to the fact that biological measurements are considered highly sensitive to changes in land use practices (Dick et al., 1992; Schloter et al., 2003). However, these results may be due to a seasonal effect that is more pronounced than that of the cropping system. This effect has been demonstrated for microbial biomass in which seasonal variations showed minimum values during the winter season (Bardgett et al., 1997) near the time when sampling occurred. This seasonal effect can only be suggested however, since other time point measurements were not collected or analyzed.

Significant impacts of previous crop on soil measurements were limited to WSA and extractable P at both sampled depths. However, it is evident that differences occurred due to increased corn in rotation for many soil measurements (Table 6). As the objective of this study was to evaluate changes to soil function as a result of differences induced by increased corn within a no-till corn-soybean cropping system, the remainder of the results will be presented in terms of CRF.

1.5.3 Corn Rotation Frequency (CRF)

Corn rotation frequency ratings included 0.0, 0.33, 0.50, 0.66, and 1.0 and were calculated and analyzed to better understand the impact of increased corn within long-term corn-soybean crop rotations (Table 8). Analysis of measurements detailed above are presented in groups of functional types; residue, soil physical, chemical, and biological properties.

Table 8. Summary of rotation treatments with recent rotation history and frequency of corn in rotation (last three years shown). Corn rotation frequency (CRF) values were based on the number of corn years in each corn-soybean rotation within a complete six-year cycle of the experiment.

Rotation Type	Rotation	Rotation Sequence			CRF
		2011	2012	2013	
Continuous Soybean	S	S	S	S	0.0
3 year rotations	S-C-S	S	C	S	0.33
	C-S-S	C	S	S	0.33
	S-S-C	S	S	C	0.33
Alternating	S-C	S	C	S	0.50
	C-S	C	S	C	0.50
3 year rotation	C-S-C	C	S	C	0.66
	C-C-S	C	C	S	0.66
	S-C-C	S	C	C	0.66
Continuous Corn	C	C	C	C	1.0

† Corn Rotation Frequency (CRF), Soybean (S), Corn (C)

1.5.3.1 CRF Effects On Crop Residues

Residue amounts had a pronounced increase with increasing CRF (Table 9 and Figure 9). Continuous corn (CRF=1) residue accumulations were significantly larger (> 2.6 Mg/ha^{-1}) than all other corn frequencies examined. This concurs with other studies, and is reasonable considering that residue production for corn has been measured to be close to 3.5 times greater than soybean (Lal, 2005). In addition to greater magnitude of residues produced, corn residue has a wider Carbon Nitrogen (C:N) ratio of 60:1 (Sheaffer & Moncada, 2009). Microbial growth and development on organic residues with a large C:N ratio are more likely to be nitrogen limited which results in slower breakdown (Green & Blackmer, 1995). However, additions of nitrogen fertilizer for corn can assist in increasing decomposition rates. Over time, the magnitude of surface residues produced are likely to increase with greater CRF in corn-soybean rotations.

Table 9. Summary statistics for crop residue amounts based on corn rotation frequency (CRF) in 2013. Residue quantities were significantly different as CRF increased. Letters indicate significant differences between frequencies at P < 0.05.

CRF	Mean	Std. Error	Lower Bound	Upper Bound
	Mg ha^{-1}			
0.0	2.2 A	0.20	1.62	2.92
0.33	5.1 B	0.57	3.89	6.43
0.50	6.2 B	0.43	5.20	7.28
0.66	8.2 C	0.68	6.77	9.77
1.0	10.8 D	0.68	8.64	13.00

† Corn Rotation Frequency (CRF)

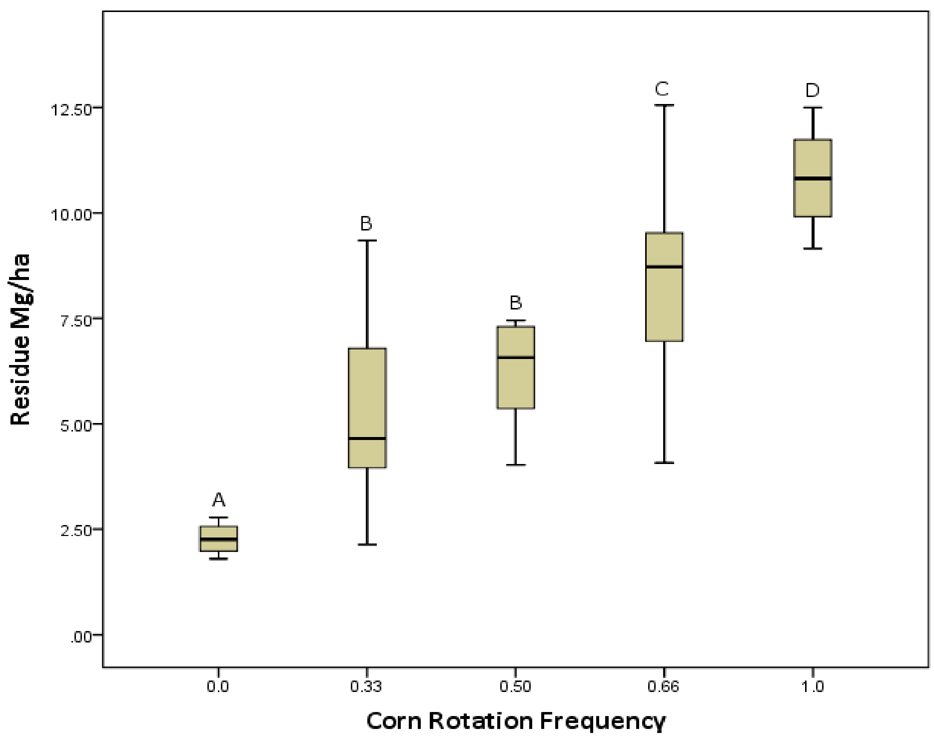

Figure 9. Surface residues show an increasing trend as corn rotation frequency (CRF) increases. Letters indicate significant differences between frequencies at P < 0.05.

1.5.3.2 CRF Effects On Physical Soil Properties

Bulk density decreased in Layer 1 (0 to 5cm) as CRF increased (Table 10 and Figure 10). Continuous corn (CRF=1) demonstrated the smallest BD values, which were 6.5% less than CRF=0.50 and 0.66, 10% less than CRF=0.33, and 13% smaller than CRF=0.0. Bulk densities in Layer 2 (5 to 15cm) were greater than in Layer 1 for all rotations although, no significant differences between frequencies were observed in the deeper layer. Studies have shown continuous corn to have smaller BD when compared to continuous soybean and other corn-soybean rotations however, none of these studies found differences to be significant (Gupta et al., 1987; Lal et al., 1994; Stott and Diack, 2004). Reduced BD in continuous corn rotations has been explained by the incorporation of less dense organic materials at the soil surface (Gupta et al., 1987). Increased SOM and SOC observed in this study support this explanation (Table 12) and could be partly responsible for improved BD values at greater CRF. In addition, it is likely that corn residue also played an important role in reducing equipment and human compaction within plots. In contrast, increased BD in continuous soybean may be a result of substantially fewer additions of organic materials into the soil surface and by more exposure to mechanical and human compaction.

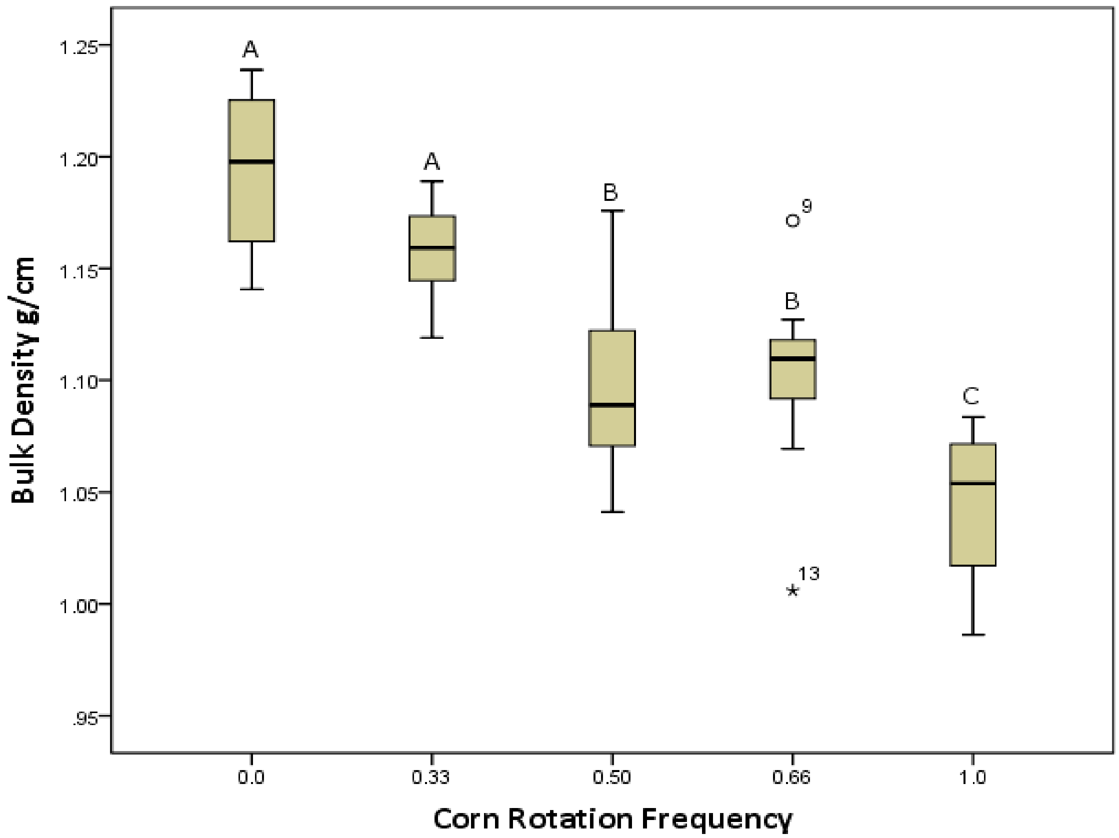

Figure 10. Decreased bulk density values observed with increasing corn rotation frequency in Layer 1 (0 to 5cm). Letters signify significant differences at $p < 0.05$.

Water stable Aggregates showed no significant differences due to CRF in either layer sampled (Table 10). However, similar studies have observed a lower proportion of WSA under continuous corn compared to soybeans and other small cereal grains (Raimbault & Vyn, 1991).

Water filled pore space showed no significant differences in Layer 1 but increased with CRF in Layer 2 (Table 10). Continuous corn (CRF=1) and CRF=0.66 had significantly greater WFPS than CRF=0.33 and continuous soybean (CRF=0). Additionally, alternating rotations (CRF=0.50) had significantly greater WFPS than continuous soybean. Increased WFPS at greater CRF is likely a result of increased residue production. These results support those by Maskina et al. (1993), who also attributed an increase in WFPS to increased residue rates from previous crops. Over the nine year period since study establishment, accumulations of surface residues would be expected to positively influence soil water storage and infiltration.

Table 10. Soil physical measurements and corresponding mean values for corn rotation frequencies (CRFs) in Layer 1 (0 to 5cm) and Layer 2 (5 to 15cm). Letters indicate significant differences between frequencies at P < 0.05.

CRF	Bulk Density	WSA	WFPS
	g cm^{-3}	%	%
		0 to 5cm	
0.0	1.19 A	15 A	48.5 A
0.33	1.15 A	13 A	50.8 A
0.50	1.10 B	14 A	52.2 A
0.66	1.10 B	14 A	54.1 A
1.0	1.04 C	14 A	54.5 A
		5 to 15cm	
0.0	1.34 A	12 A	54.9 A
0.33	1.34 A	10 A	58.1 AB
0.50	1.35 A	10 A	62.0 BC
0.66	1.35 A	9 A	62.4 C
1.0	1.36 A	7 A	64.1 C

† Corn Rotation Frequency (CRF), Water Stable Aggregates (WSA), Water filled pore space (WFPS)

Overall, physical measurements showed sensitivities to changes in CRF at both depths. Increased corn years in rotation showed benefits to BD (Layer 1) and WFPS (Layer 2) while no differences were observed in WSA at either depth. According to these results, it does not seem likely that yield decline observed in continuous corn is a result of decreased physical soil function.

1.5.3.3 CRF Effects On Chemical Soil Properties

Results for paste $EC_{1:1}$, pH_w, CEC, Ca, and Mg showed no significant differences at either layer sampled (Table 11). As stated previously, $EC_{1:1}$ was significantly influenced by previous crop, which appeared to overshadow any differences that may be present due to variations in CRF. Soil pH_w values were consistent for all treatments and ranged only slightly at either depth. Cation exchange capacity is commonly influenced more by soil clay content than by cropping system. Macronutrients Ca and Mg appeared to be less sensitive to changes in CRF when compared to other nutrients such as P and K. Similar results and explanations have been given within the literature describing less sensitivity of chemical soil properties to land management practices when compared to physical or biological properties (Andrews et al., 2002; DeMaria et al., 1999; Houx et al., 2011).

Soil P in the upper layer decreased as corn frequency increased. Continuous soybean (CRF=0) had significantly larger soil P concentrations (24 and 33%) than both CRF=0.66 and 1, respectively (Table 11). No significant differences in extractable P levels were observed in Layer 2.

No significant differences were observed in soil extractable K in Layer 1 (Table 11). However, in Layer 2 continuous corn (CRF=1) had the largest extractable K levels (63 mg/kg^{-1}) but were only significantly greater than CRF=0.33. Larger K levels in continuous corn could be a result of lower removal rates by corn as compared to soybeans (Buchholz, 1983). When one year of soybean was included into the rotation phase (e.g. 0.66) at 5 to 15cm, extractable K decreased by 13% compared to continuous corn.

Table 11. Soil chemical measurements and corresponding mean values for corn rotation frequencies (CRFs) in Layer 1 (0 to 5cm) and Layer 2 (5 to 15cm). Letters indicate significant differences between frequencies at $P < 0.05$.

CRF	pH_w	$EC_{1:1}$	P	K	Ca	Mg	CEC
	pH	ds m^{-1}	mg-kg^{-1}	mg-kg^{-1}	mg-kg^{-1}	mg-kg^{-1}	meq/100g
				0 to 5cm			
0.0	7.7 A	0.35 A	46 A	116 A	2712 A	168 A	15 A
0.33	7.6 A	0.34 A	39 AB	108 A	2517 A	177 A	14 A
0.50	7.6 A	0.33 A	39 AB	110 A	2651 A	184 A	15 A
0.66	7.5 A	0.30 A	35 B	112 A	2626 A	199 A	15 A
1.0	7.6 A	0.29 A	31 B	116 A	2633 A	189 A	15 A
				5 to 15cm			
0.0	7.5 A	0.17 A	8.0 A	56 AB	2482 A	120 A	13 A
0.33	7.5 A	0.17 A	7.7 A	53 A	2430 A	133 A	13 A
0.50	7.5 A	0.18 A	7.8 A	54 AB	2447 A	129 A	13 A
0.66	7.5 A	0.18 A	6.7 A	55 AB	2441 A	143 A	13 A
1.0	7.6 A	0.18 A	6.2 A	63 B	2600 A	148 A	14 A

† Corn Rotation Frequency (CRF), Electrical Conductivity ($EC_{1:1}$), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Cation Exchange Capacity (CEC).

Few differences among CRFs were observed in soil chemical measurements at either layer. These measurements appeared to be less sensitive to changes in CRF than were demonstrated by soil physical and biological measurements. Although beneficial impacts were not observed with increased corn frequency neither were particularly detrimental effects that could be responsible for the continuous corn yield decline.

1.5.3.4 CRF Effects On Biological Soil Properties

Continuous corn (CRF=1) had significantly larger SOM levels in Layer 1 than CRF=0.33 and continuous soy (CRF=0) (Table 12). Difference in SOM between CRF=1 and CRF=0 resulted in a 0.5% unit increase. Two corn years in a three year rotation (CRF=0.66) also had significantly greater SOC levels than one year of corn in a three year rotation (CRF=0.33) at this layer. These results were not surprising based on the greater amount of plant residues that are produced by corn. Barber, (1979) stated that SOC is a balance between loss (rate of decomposition) and gain (rate of organic matter additions). This relationship explains why soybean, a crop that produces smaller amounts of residues with narrower C:N ratios would result in lesser SOC accumulation at the soil surface. Soil organic matter values in Layer 2 were substantially smaller than surface values and showed no significant differences between CRFs. Organic matter levels were much smaller in Layer 2 as a result of an implemented no-till management system.

Table 12. Soil biological measurements and corresponding mean values for corn rotation frequencies (CRFs) in Layer 1 (0 to 5cm) and Layer 2 (5 to 15cm). Letters indicate significant differences between frequencies at P < 0.05

CRF	Organic Matter	SOC	PMN	Total Nitrogen	β-glucosidase	Active Carbon
	%	%	$mg\text{-}kg^{-1}$	%	µg.	$mg\text{-}kg^{-1}$
			0 to 5cm			
0.0	2.8 AB	1.98 AB	54 A	2.4 AB	201 A	822 AB
0.33	2.9 A	1.95 A	63 AB	2.0 A	224 A	778 A
0.50	3.2 ABC	2.11 B	83 C	2.3 AB	278 B	891 B
0.66	3.1 BC	2.10 B	70 ABC	2.3 A	307 B	849 B
1.0	3.3 C	2.38 C	81 BC	2.8 B	327 B	998 C
			5 to 15cm			
0.0	1.6 A	1.15 A	19 A	1.2 A	93 A	337 A
0.33	1.7 A	1.12 A	21 A	1.2 A	96 A	401 AB
0.50	1.8 A	1.14 A	26 A	1.2 A	96 A	410 AB
0.66	1.7 A	1.15 A	24 A	1.2 A	94 A	372 A
1.0	1.6 A	1.14 A	26 A	1.4 A	91 A	484 B

† Corn Rotation Frequency (CRF) Soil Organic Carbon (SOC), Potentially Mineralizable Nitrogen (PMN)
†† µg PNP/g soil/hr. (µg.)

Percent SOC was also significantly greater in continuous corn compared to all other corn frequencies in Layer 1. As CRF increased SOC tended to follow an increasing trend (Table 12 and Figure 11). Other significant differences were observed between alternating rotations (CRF=0.5) and CRF=0.66 which were both significantly larger than 0.33. No significant differences were observed between CRF in Layer 2. Many studies have shown an increase in SOC values with increasing additions of organic materials (Fahad et al., 1982; Havlin et al., 1990; Morachan et al., 1972). Specifically, Havlin et al. (1990) compared SOC in corn-soybean rotations and observed that increases in soil carbon content were "directly related to the quantity of residue produced". These trends are to be expected, considering SOM is composed of a large range of carbon dominated compounds. As residue inputs increase and are left on the soil surface, macro-fauna, arthropods, and other organisms incorporate them into the top portions of the soil profile which increases SOM as well as SOC levels. The absence of significant differences in SOC among levels of CRF at 5 to 15cm are likely a result of the implementation of a no-till management system in which crop residues are left on the soil surface. Since SOC is directly linked to residue quantity, SOC values in a no-till management system would be expected to decrease with depth.

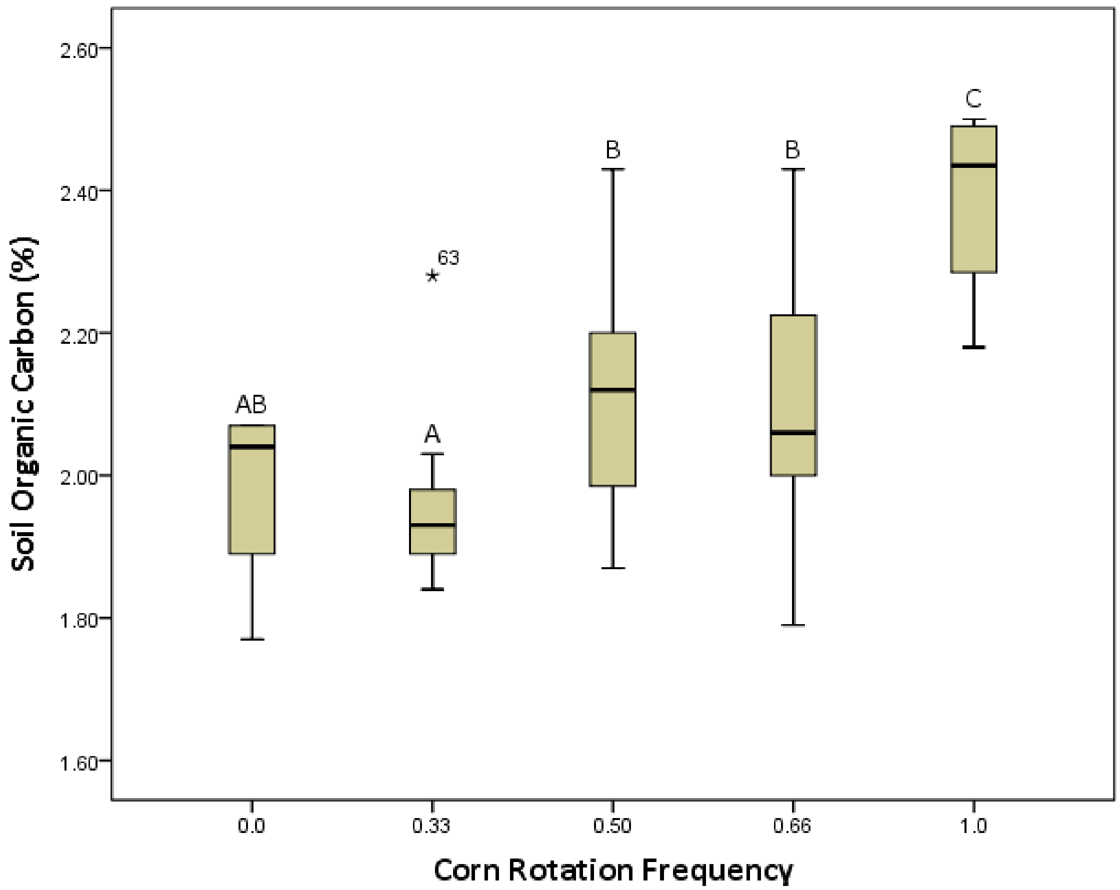

Figure 11. Soil organic carbon (SOC) shows an increasing trend with increased corn rotation frequency (CRF) in Layer 1 (0 to 5cm).

Active carbon was greatest at the greatest corn frequency (continuous corn) (Table 12). These values were significantly greater (>107 mg/kg^{-1}) than all other frequencies in Layer 1. In addition, CRF=0.66 and 0.50 had significantly greater active carbon levels than CRF=0.33. In Layer 2, continuous corn also had significantly greater active carbon concentrations than CRF=0.66 and 0 (112 and 147 mg/kg^{-1}). Greater active carbon levels in continuous corn could be in response to significantly greater SOC values. A highly significant correlation ($r = 0.82$, $p < 0.01$) was observed between active carbon and SOC data (Figure 12 and Table 4).

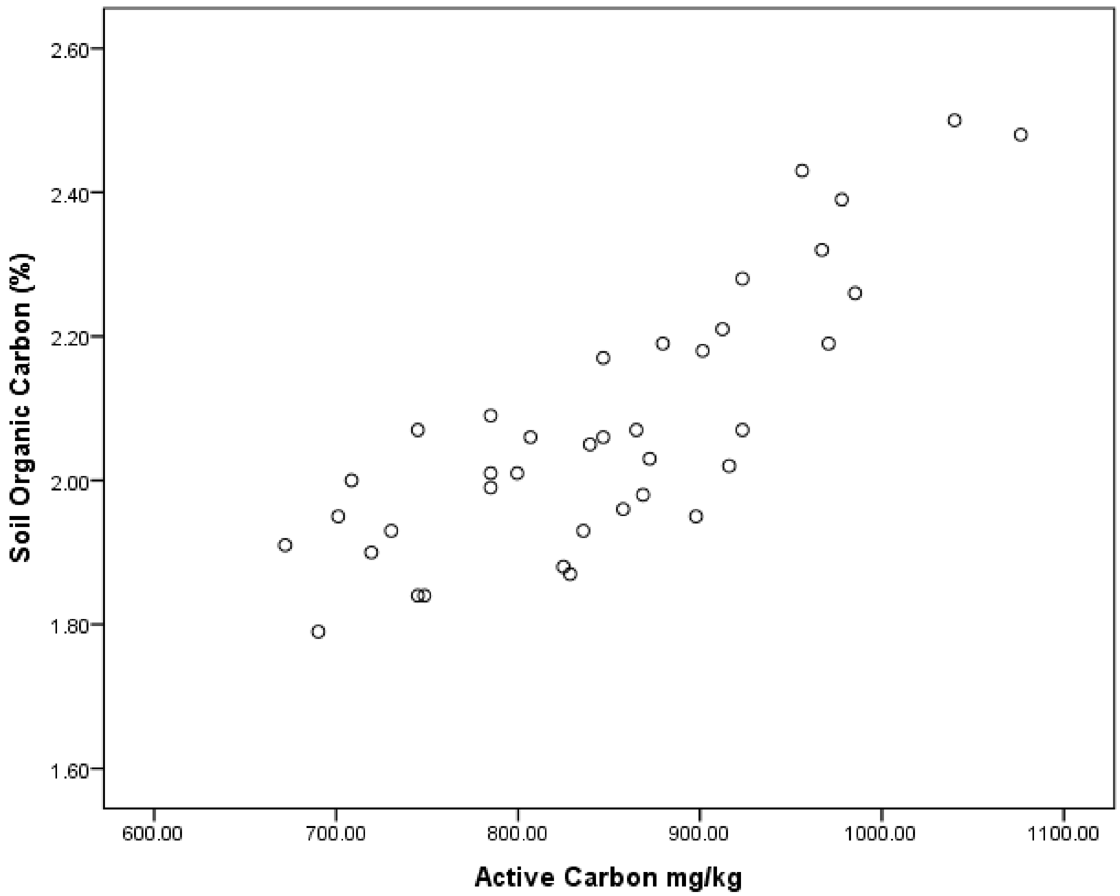

Figure 12. Scatter plot showing a positive correlation between active carbon and soil organic carbon data values in Layer 1 (0 to 5cm).

Soil functions including residue decomposition and nutrient cycling are influenced by microbial communities, specifically soil enzymes. An increasing trend was observed in soil β-glucosidase enzymes as corn frequency increased at the surface layer (Table 12). Corn Rotation Frequencies 0.5, 0.66, and 1.0 were significantly larger than CRF=0.33 and 0. Layer 2 β-glucosidase concentrations were less than half of those observed in the surface, but showed no statistical differences between frequencies. Larger concentrations of β-glucosidase have been observed when greater amounts of plant residues were added to the soil (Stott et al., 2010). Increases to β-glucosidase enzymes usually coincides with increasing microbial biomass levels, which were also observed through estimation by PLFA in this study (Table 16) (Stott et al., 2010). This increase in enzyme levels indicates the potential for enhanced decomposition of plant residues and nutrient cycling (Bandick & Dick, 1999; Stott et al., 2010).

Continuous corn also had slightly larger TN at both layers, although only significant from CRF=0.33 and 0.66 at layer 1 (Table 12). There were no other significant differences observed between CRFs. Crop rotation impacts on soil nitrogen status have shown conflicting results within the literature which has described soybeans depleting soil nitrogen (Havlin et al., 1990), increased nitrogen with increased corn residue additions (Havlin et al., 1990; Morachan et al., 1972), and no changes to total soil nitrogen status (Hickman, 2002). Our results do not indicate a depletion in total soil nitrogen after soybean, or show that corn-soybean rotations had a significant impact on total soil nitrogen status in Layer 1. In both layers, continuous corn was associated with greater TN levels, which seems likely to be a result of increased organic matter from corn residue accumulation. These observations coincide with those of Havlin et al. (1990) who showed TN increases as residue quantities increase in corn-soybean cropping systems. As organic matter increases within a soil, TN would be expected to increase due to a larger nitrogen pool from SOM.

The greatest PMN concentrations were observed at greater corn frequencies as well, with the smallest corn frequencies containing smaller levels (Table 12). Layer 1 differences showed CRF=1 and 0.50 to have significantly larger PMN concentrations (35 and 36%) than continuous soybean. Corn rotation frequency 0.50 also had significantly greater values than that of 0.33. No differences in PMN were observed in Layer 2. Potentially mineralizable nitrogen has been used to represent the organic N that could be quickly mineralized and made available for plant use (Drinkwater et al., 1996). This measurement can aid in understanding the N dynamics of a soil (Drinkwater et al., 1996). When combined together we can see that greater corn frequencies (especially CRF=1.0) result in both greater soil N currently available and greater N that could potentially be available through microbial mineralization.

As corn frequency increased within rotation favorable increases also occurred to most biological measurements in Layer 1. Continuous corn had the largest values for all measurements examined at this depth. Layer 2 soil biological measurements showed fewer differences with increased CRF for most measurements. Increases in CRF appeared to enhance overall biological soil function only near the soil surface. According to these biological soil function enhancements, it does not seem likely that yield declines in continuous corn are a result of declined biological function as measured here.

1.5.3.5 CRF Effects On PLFA

The biological measures discussed above are somewhat indirectly related to soil microbial communities, but are indicators of the processes these communities mediate. Phospholipid fatty acid characterization provides a more direct measure of total microbial populations and classifies them to broad taxonomic levels. Layer 1 total Phospholipid Fatty Acids (PLFA) were greater as CRF increased (Figure 13). At this depth, continuous corn (CRF=1) resulted in significantly larger PLFAs compared to all other CRF's indicating greater estimated microbial biomass (Table 16). Surface results had nearly 100% more PLFA structural groups as were observed in Layer 2. Fewer differences were seen at this depth, although continuous corn still had significantly greater PLFA's than CRF = 0 and 0.33.

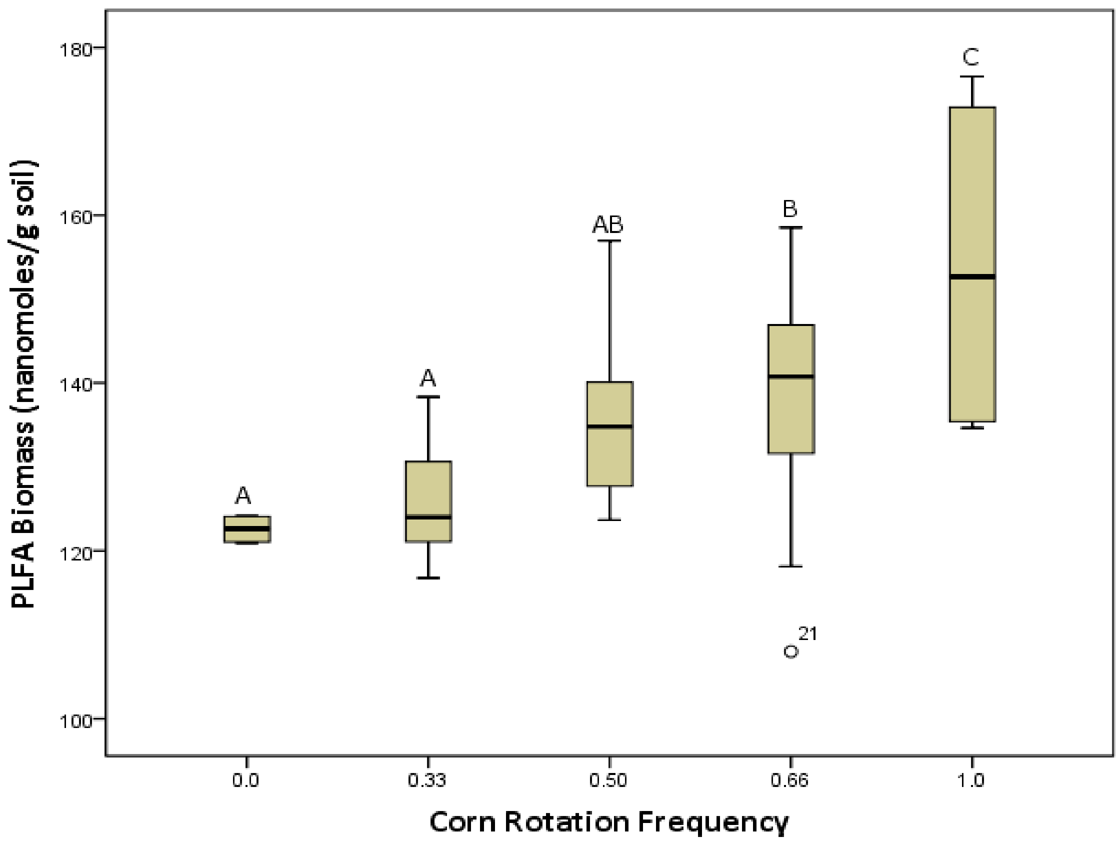

Figure 13. Increased PLFA biomass as corn rotation frequency (CRF) increases in Layer 1 (0 to 5cm). Letters signify significant differences at $p < 0.05$.

In addition to increases to microbial populations, significantly more unique PLFA peaks were identified in continuous corn than that of the lesser CRFs in Layer 1 indicating enhanced microbial diversity (Table 16). Individual peaks or groups of peaks seen in the PLFA chromatograph results correspond to specific types of PLFA compounds which tend to be specific to general groups of organisms. The fewest peaks were identified in the continuous soybean treatment indicating a lesser microbial diversity. No significant differences between frequencies were observed in Layer 2, potentially due to a small range between mean values and overall low microbial activity.

At both layers, continuous corn had greater values for seven of the eight microbial groups examined (Table 16). Of these seven groups, four were significantly larger in continuous corn than all other corn frequencies (gram negative, gram positive, actinomycetes, and bacteria) in Layer 1. In addition, arbuscular mycorrhizal fungi was significantly greater in plots with CRF=1 than those of CRF=0 and 0.33. The eukaryote and anaerobe microbial groups were not significantly different from other CRFs. Layer 2 results showed continuous corn to also have significantly greater AM fungi, gram negative bacteria, actinomycetes, and bacteria than CRF=0 and 0.33.

Continuous soybean (CRF=0) showed the smallest values for six of the eight microbial groups in Layer 1, and seven of the eight microbial groups in Layer 2. The two groups where CRF=0 did not have the smallest concentrations were AM fungi in Layer 1 and fungi in both Layer 1 and 2.

It has been suggested that microbial growth is a carbon limited process and is dependent on the presence of organic substrate materials (Grayston et al., 1998; Wardle, 1992; Whipps, 1991). Similar trends were observed between microbial and carbon measurements in this study, supporting the thought that SOM and SOC are the most influential factors driving microbial population growth and diversity. In addition, increased N content with greater corn frequency (and N fertilization) may also be responsible for enhancing microbial populations.

As microbial communities flourish, benefits to soil function will arise in the forms of enhanced residue decomposition, increased nutrient cycling and availability, as well as improved plant productivity (Kennedy & Papendick, 1995). Microbial population and diversity increased with more corn suggesting that continuous corn yield decline does not appear to be a result of suppressed microbial populations or diversity. This conclusion is in accordance with soil physical, chemical, and biological properties which indicate that soil function is enhanced with increased CRF.

Table 13. Summary table for total unique PLFA peaks, total PLFA's, and each identified microbial group, with F-statistics and P-values values for corn-soybean rotations and corn rotation frequency (CRF).

		Rotation		Corn Rotation Frequency	
Measurement	Depth	F-Statistic	P-value	F-Statistic	P-value
PLFA Peaks	0-5cm	1.208	0.32	2.004	0.11
	5-15cm	0.586	0.79	0.409	0.80
Total PLFA	0-5cm	2.374	0.03*	5.548	0.00**
	5-15cm	1.476	0.20	2.464	0.06
AM Fungi	0-5cm	1.456	0.20	2.475	0.06
	5-15cm	1.907	0.09	2.674	0.04*
Fungi	0-5cm	1.815	0.10	0.551	0.69
	5-15cm	0.968	0.48	1.050	0.39
Eukaryotes	0-5cm	0.853	0.57	0.272	0.89
	5-15cm	0.241	0.98	0.426	0.78
Gram Negative	0-5cm	2.387	0.03*	5.146	0.00**
	5-15cm	1.911	0.08	3.420	0.01*
Gram Positive	0-5cm	3.756	0.00**	6.111	0.00**
	5-15cm	0.888	0.54	1.678	0.17
Anaerobes	0-5cm	1.691	0.13	1.327	0.27
	5-15cm	0.909	0.53	0.388	0.81
Actinomycetes	0-5cm	2.636	0.02*	5.056	0.00**
	5-15cm	1.274	0.29	2.513	0.059
Bacteria	0-5cm	3.223	0.00*	4.848	0.00**
	5-15cm	1.449	0.21	2.673	0.04*

†Arbuscular Mycorrhizal Fungi (AM Fungi), Significance at: *<0.05, **<0.01

Table 14. Phospholipid Fatty Acid (PLFA) total peaks quantity by rotation and microbial group in Layer 1 (0 to 5cm).

Rotation	PLFA Peaks	Total PLFA	AM Fungi	Fungi	Eukaryotes	Gram Neg.	Gram Pos.	Anaerobe	Actinos	Bacteria
	0 to 5cm									
	nanomoles PLFA-g^{-1} soil^{-1}									
C	48	154	7.8	1.70	2.36	51	33	1.65	20	85
C-S-C	47	136	6.6	1.40	1.95	45	28	1.45	19	67
S-C-C	47	137	6.2	2.57	2.57	44	30	1.65	18	74
C-C-S	43	141	7.3	1.68	1.84	48	32	1.52	18	80
C-S	47	138	6.6	1.47	2.39	45	30	1.60	19	76
S-C	46	133	6.8	1.95	2.14	45	28	1.30	17	73
S-S-C	46	122	6.0	1.47	2.34	40	25	1.25	17	65
S-C-S	45	125	5.9	1.58	2.02	41	27	1.59	16	69
C-S-S	45	129	6.5	1.83	2.07	43	27	1.34	17	71
S	42	122	6.2	2.05	2.08	41	25	1.33	16	67

†Phospholipid Fatty Acids (PLFA), Arbuscular Mycorrhizal Fungi (AM Fungi), Actinomycetes (Actinos)

Table 15. Phospholipid Fatty Acid (PLFA) total peaks quantity by rotation and microbial group in Layer 2 (5 to 15cm).

Rotation	PLFA Peaks	Total PLFA	AM Fungi	Fungi	Eukaryotes	Gram Neg.	Gram Pos.	Anaerobe	Actinos	Bacteria
	5 to 15cm									
	nanomoles PLFA-g^{-1} $soil^{-1}$									
C	44	75	2.8	0.52	1.10	20	19	0.86	13	39
C-S-C	45	74	2.7	0.40	1.04	19	19	0.74	13	38
S-C-C	45	70	2.4	0.47	0.99	18	18	0.86	13	37
C-C-S	44	67	2.3	0.41	0.92	17	18	0.90	12	35
C-S	45	69	2.5	0.52	1.03	18	18	0.78	12	37
S-C	45	74	2.8	0.53	1.04	20	19	0.92	13	40
S-S-C	46	67	2.4	0.39	1.00	17	18	0.78	12	35
S-C-S	44	63	2.1	0.54	0.98	16	17	0.84	11	33
C-S-S	44	66	2.4	0.47	0.97	17	17	0.83	12	35
S	44	65	2.3	0.47	0.94	16	17	0.77	12	34

†Phospholipid Fatty Acids (PLFA), Arbuscular Mycorrhizal Fungi (AM Fungi), Actinomycetes (Actinos)

Table 16. Phospholipid Fatty Acid (PLFA) results by corn rotation frequency (CRF) for layer 1 (0 to 5cm) and layer 2 (5 to 15cm). Letters indicate significant differences between frequencies at $P \leq 0.05$.

CRF	PLFA Peaks	Total PLFA	AM Fungi	Fungi	Eukaryotes	Gram Neg.	Gram Pos.	Anaerobes	Actinos	Bacteria
					0 to 5cm					
					nanomoles PLFA-g^{-1} $soil^{-1}$					
0.0	42 A	122 A	6.2 A	2.0 A	2.0 A	41 AB	25 A	1.3 A	16 A	67 A
0.33	45 AB	125 A	6.1 A	1.6 A	2.1 A	41 A	27 AB	1.3 A	17 A	68 A
0.50	46 B	135 AB	6.7 AB	1.7 A	2.2 A	45 AB	29 BC	1.4 A	18 AB	75 A
0.66	45 AB	138 B	6.7 AB	1.8 A	2.1 A	45 B	30 C	1.5 A	18 B	74 A
1.0	48 B	154 C	7.8 B	1.7 A	2.3 A	51 C	33 D	1.6 A	20 C	85 B
					5 to 15cm					
0.0	44 A	65 AB	2.3 AB	0.47 A	0.9 A	16 A	17 A	0.77 A	12 AB	34 AB
0.33	45 A	65 A	2.3 A	0.47 A	0.9 A	17 A	17 A	0.82 A	12 A	34 A
0.50	45 A	72 BC	2.6 BC	0.52 A	1.0 A	19 B	19 A	0.85 A	13 ABC	38 BC
0.66	44 A	70 ABC	2.5 ABC	0.43 A	0.9 A	18 AB	18 A	0.83 A	13 BC	37 ABC
1.0	44 A	75 C	2.8 C	0.52 A	1.1 A	20 B	19 A	0.86 A	13 C	39 C

†Arbuscular Mycorrhizal Fungi (AM Fungi), Actinomycetes (Actinos.)

1.6 Conclusion

Several physical and biological measurements showed improvement with increased corn in rotation in Layer 1. Beneficial improvements were observed in surface residue amounts, BD, $EC_{1:1}$, TN, PMN, SOM, SOC, active carbon, β-glucosidase, and microbial populations and diversity. Our results support the observation made by Roldan (2003) who found that most soil functional characteristics improved in direct proportion to residue inputs.

Although the exact reasons for yield decline in continuous corn are still unknown, it does not seem likely that they are a result of decreases to soil function according to the measurements and soil depths we investigated. In fact, continuous corn exhibited the greatest soil functional potential compared to all other CRFs. Although positive impacts for many soil properties were observed in continuous corn, it is unreasonable to dismiss the fact that substantial decreases to corn yields are present in continuous corn production. This must be considered by producers when determining the implementation of a continuous corn cropping system. However, it may also be worth considering the potential improvements that increased corn in rotation can provide to agro-ecological systems.

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CHAPTER 2

IDENTIFYING CHANGES IN SOIL FUNCTION DUE TO INCREASED CORN FREQUENCIES USING THE SOIL MANAGEMENT ASSESSMENT FRAMEWORK (SMAF) INDEX

2.1 Abstract

Management practices and cropping systems may be causing changes to soil function, that are going undetected. For this reason, integrated soil function indices such as the Soil Management Assessment Framework (SMAF) have been developed to quantify management effects on soil function (Andrews et al., 2004). The objective of this study was to determine the effectiveness of the SMAF in comparing changes to soil function due to increased corn frequency within corn-soybean rotations in a no-till management system. Soil samples were collected in March of 2014, at surface 0 to 5cm (Layer 1) and subsurface 5 to 15cm (Layer 2) depths to examine physical chemical, nutrient, and biological soil properties. The measured values from these layers were then depth weighted and analyzed for the entire 0 to 15cm sampled. Soil quality indicators examined included bulk density (BD), pH_w, electrical conductivity ($EC_{1:1}$), phosphorus (P), potassium (K), soil organic carbon (SOC), and β-glucosidase. Indicators were analyzed by calculating corn rotation frequency (CRF) ratings which were assigned to each treatment based on the total number of corn (C) years within a completed 6 year rotation cycle (e.g. S-S = 0.0, S-S-C = 0.33, C-S = 0.50, C-S-C = 0.66, C-C = 1.0). Layer 1 SMAF scores followed an increasing trend with increased CRF. Scores ranged from 90.5 to 93.7% with CRF 1 = 93.7% > 0.66 = 92.7% > 0.50 = 92.3% > and 0.33 = 91.2% > 0.0 = 90.5%. Layer 2 scores showed no differences between CRF. Depth weighted (0 to 15cm) scores showed a similar trend as was observed at the surface and increased as CRF increased (CRF 1 = 82.3% > 0.66 = 80.8% > 0.50 = 80.6% > and 0.33 = 77.9% > 0.0 =

77.2%). However, differences between largest SMAF scores (CRF = 1) and smallest (CRF = 0) in Layer 1 and depth weighted were relative small 3 and 5%. Most indicator and category scores were not sensitive to changes in CRF which suggests that SMAF may not be useful when comparing cropping systems that are similar, even over a decade-scale paired in time study.

2.2 Introduction

The need to identify sustainable management practices and cropping systems in Missouri has never been greater due to ongoing soil degradation of marginal lands resulting in reduced productivity. However, quantifying the improvements given by a potentially more sustainable management system is a challenge because of the complexity of the processes, properties, and function of the soil system. Identifying sustainable management practices can be done through quantifying soil properties which represent soil function. Increased interest in concepts like soil quality and soil health has resulted in the development of tools which aid producers and researchers in measuring changes to soil properties due to management practices and cropping systems. These tools include soil quality test kits, specialized laboratory procedures, and numerous minimum data set indices (e.g. Haney Test, Cornell Soil Health Assessment, and Soil Management Assessment Framework). However, these tools have been criticized by many for their oversimplification of complex soil resources and processes (Karlen et al., 2008). Although criticisms may be warranted, these tools are useful for quantifying soil function and the interactions that occur between soil properties and processes especially when included in the context of a controlled experiment.

For decades, producers have relied on relatively few measurements from a basic soil nutrient analysis test to make management decisions. These tests provide insights to chemical properties of the soil which identify nutrient concentrations and the potential for plant availability, but do not comprehensively represent soil function. As a result, undetected changes to soil function may have or may be occurring due to management practices that go undetected. For this reason, integrated indices which include physical, chemical, nutrient, and biological soil properties have been developed to help enable detection of a wider array of changes in soil function (Andrews et al., 2004; Doran et al., 1996; Karlen et al., 2008).

Of the many integrated indices that have been developed, the Soil Management Assessment Framework (SMAF) may be the most comprehensive and versatile due to its incorporation of interpretive functions based on soil taxonomy, soil properties, and an extensive list of soil measurements that can be included (Andrews et al., 2004). Utilization of the SMAF occurs by a three-step process; 1) indicator selection; 2) indicator interpretation (through use of scoring algorithms); and 3) integration into the index (Figure 14) (Andrews et al., 2004). This three-step process has been recognized as effective for comparing effects on soil function due to cropping systems (Andrews et al., 2002; Karlen et al., 2006; Veum et al., 2013; Wienhold et al., 2007), management practices (including manure and synthetic fertilizer applications, tillage operations, and residue additions) (Andrews et al., 2002; Andrews et al., 2002; Cambardella et al., 2004;

Karlen et al., 1994) and landscape variation (Cambardella et al., 2004). This framework has influenced other soil function indices and has been used as a model for the development of the Cornell Soil Health Test (Idowu et al., 2008).

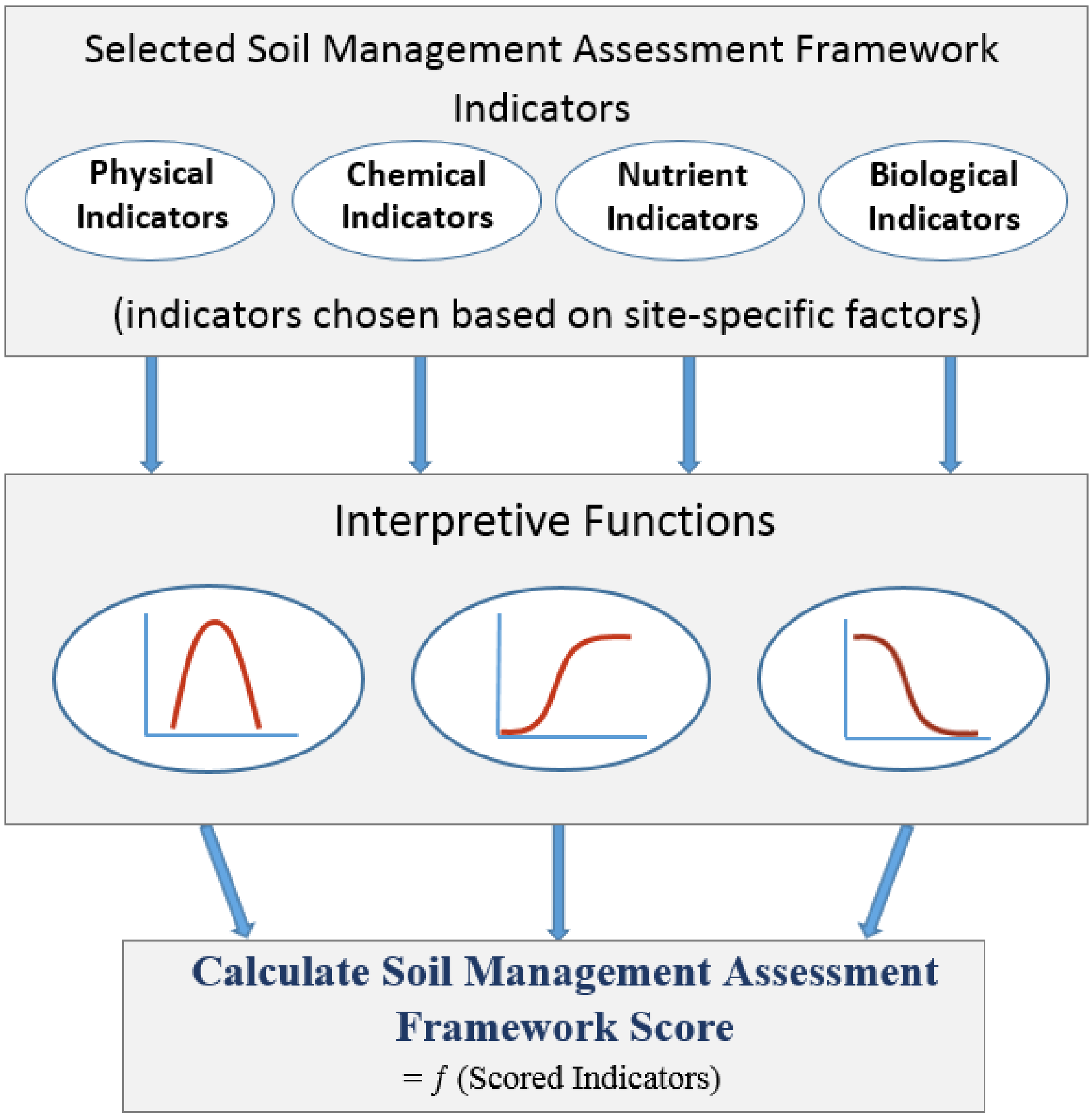

Figure 14: The three-step process found within the Soil Management Assessment Framework (SMAF) index adapted from Andrews et al. (2002) and NRCS, (2011).

The first step in the SMAF is indicator selection. Indicators are soil properties which quantify the state of soil functions or processes and are sensitive to changes in management practices (Andrews et al., 2004). In addition, the indicators are selected to be easy to accomplish and inexpensive to measure (Doran & Zeiss, 2000). Indicators can be chosen for use in the SMAF based on 169 decision rules which include a primary management goal (e.g. maximize productivity, waste recycling, or environmental protection) and several other criteria associated with soil functions (e.g. climate, soil texture, crop rotation, tillage practice etc.) (Andrews et al., 2004). In total, more than 80 soil quality indicators have been identified but only 13 have associated scoring algorithms that can be used in the second step of the SMAF (Table 17) (Andrews et al., 2004; Stott et al., 2010; Wienhold et al., 2009).

Table 17. Soil measurements used to represent soil function in the Soil Management Assessment Framework (SMAF) at 0 to 15cm. Each of these indicators is paired with an interpretive scoring function.

Physical	Chemical	Nutrient	Biological
Bulk Density (BD)	pH_w	Potassium (K)	β-glucosidase
Water Stable Aggregates (WSA)	Electrical $Conductivity_{1:1}$ (EC)	Phosphorus (P)	Microbial Biomass Carbon (MBC)
Water-Filled Pore Space (WFPS)	Sodium Adsorption Ratio (SAR)		Soil Organic Carbon (SOC)
Available Water Capacity (AWC)			Potentially Mineralizable Nitrogen (PMN)

Interpretive scoring functions have been developed for each of the 13 chosen SMAF indicators for the 0 to 15cm depth, and provide individual measurement interpretation (Andrews et al., 2004). These scoring functions are categorized into more is better (e.g. water stable aggregates (WSA)), less is better (e.g. BD), or mid optimum (e.g. pH_w) types based on measured plant or soil response derived from experiments or within the literature (Andrews et al., 2002). These scoring functions change due to the soil context to allow more direct comparisons across management practices and locales. The indicator interpretation step allows a more equal consideration of limiting components in the third and final step of the SMAF calculation.

The final output stage of the SMAF allows the user to calculate an integrative soil functional potential score termed the SMAF score (Equation 3) (Andrews et al., 2004).

$$SMAF = \frac{Sum\ of\ all\ indicator\ scores}{Number\ of\ indicators\ examined} \times 100$$

Equation 3. Formula for calculating the Soil Management Assessment Framework (SMAF) score which is representative of soil function.

This step provides a unit-less value ranging from 0 to 100% with larger scores signifying greater soil functional capacity. The SMAF score can be deconstructed to identify soil functional changes to individual indicators or collectively to a functional category (e.g. physical, chemical, nutrient, or biological). These category scores provide the potential to better identify and understand specific changes to soil function as effected by management or cropping system practices.

Many SMAF studies have compared cropping systems with dramatic crop differences (e.g., perennial grasses vs. intense tilled monoculture crops) (Karlen et al., 2006; Veum et al., 2013; Veum et al., Accepted). These comparisons have shown changes in soil functional capacity however, they do not fully test the sensitivity of the SMAF framework. There is a need to assess the effectiveness of the SMAF index to discriminate changes between cropping systems with small differences (e.g. corn vs. soybeans), in similar management systems (e.g. no-till), over small time intervals (e.g. < 10 years). This experiment allows for the SMAF sensitivity to be tested and determine if soil function changes as a result of crop rotation (corn-soybean) within the same management system (e.g. no-till) can be detected over a nine year period.

2.3 Objectives

1. Determine the effectiveness of the SMAF for comparing changes in soil function due to increased CRF in corn-soybean rotations.
2. Assess limitations and provide recommendation for the implementation of the SMAF in comparing management differences.

2.4 Materials and Methods

2.4.1 Site Specifications

This research was conducted at the University of Missouri's Bradford Research and Extension Center, Located in Columbia, Missouri (38°53´24.19" N, 92°12´45.02" W). Soils at the research site consisted of a Mexico silt loam (fine, smectitic, mesic, Vertic

Epiaqualf) and ranged in slope from 0 to 2%. The 2013 average precipitation was 1085 mm with a mean temperature of 12.5°C. The experiment was established in 2005 as a randomized block design in a no-till management system (Houx et al., 2011). Rotation treatments included continuous corn (C-C), continuous soybeans (S-S), and various corn soybean rotations (C-S, S-C, C-S-S, S-S-C, C-C-S, C-S-C, S-C-C, and S-C-S) (Figure 15). This design allowed for every rotation phase to be present in each year. Measurements described in this study were collected in March prior to the 2014 growing season. Each treatment was replicated four times with plots that measured 9 m x 12 m. Management practices for the study represented typical no-till production methods. Corn and soybeans were generally planted in mid-May and received conventional weed control through the use of both pre and post-emergent herbicides. Insecticides were applied on an as needed basis. To meet corn nitrogen requirements, ammonium nitrate was applied via top dressing at 200 kg N ha^{-1}. Phosphorus and potassium were applied as needed according to soil test results uniformly across the experiment, but were not applied prior to the 2014 growing season.

102	103	106	107	110	201	204	205	208	209	302	303	306	307	310	401	404	405	408	409
S-C	S-C-S	S-S-C	S-C-C	S-S	S-C-C	C-C	C-S-S	C-C-S	S-C-S	C-S-S	C-S	C-S-C	S-C-C	S-C	C-S-S	S-C-C	C-S	S-C-S	C-C-S
´13: S	´13: S	´13: C	´13: C	´13: S	´13: C	´13: C	´13: S	´13: S	´13: S	´13: S	´13: C	´13: C	´13: C	´13: S	´13: S	´13: C	´13: C	´13: S	´13: S

4 rows of corn fill planted east/west

101	104	105	108	109	202	203	206	207	210	301	304	305	308	309	402	403	406	407	410
C-C	C-S-S	C-C-S	C-S	C-S-C	S-S	C-S-C	S-S-C	S-C	C-S	S-S	C-C	S-C-S	S-S-C	C-C-S	S-S-C	S-C	S-S	C-S-C	C-C
´13: C	´13: S	´13: S	´13: C	´13: C	´13: S	´13: C	´13: C	´13: S	´13: C	´13: S	´13: C	´13: S	´13: C	´13: S	´13: C	´13: S	´13: S	´13: C	´13: C

Corn
Soybean

SW

Figure 15. 2013 plot and treatment map (planted north/south)

2.4.2 Sample Collection and Processing

Soil samples were collected in March of 2014, at surface 0 to 5cm (layer 1) and subsurface 5 to 15cm (layer 2) depths (Figure 16). Within each plot, nine soil cores measuring 3.18 cm in diameter were extracted in a fixed pattern which captured areas in and between crop rows within each plot (Figure 17). The sampling area was cleared to the bare soil surface prior to soil core extraction in order to prevent residue collection within the sample. These nine samples were then composited by depth to achieve a representative sample. Composited samples were then placed in an air tight plastic bag and frozen prior to analysis.

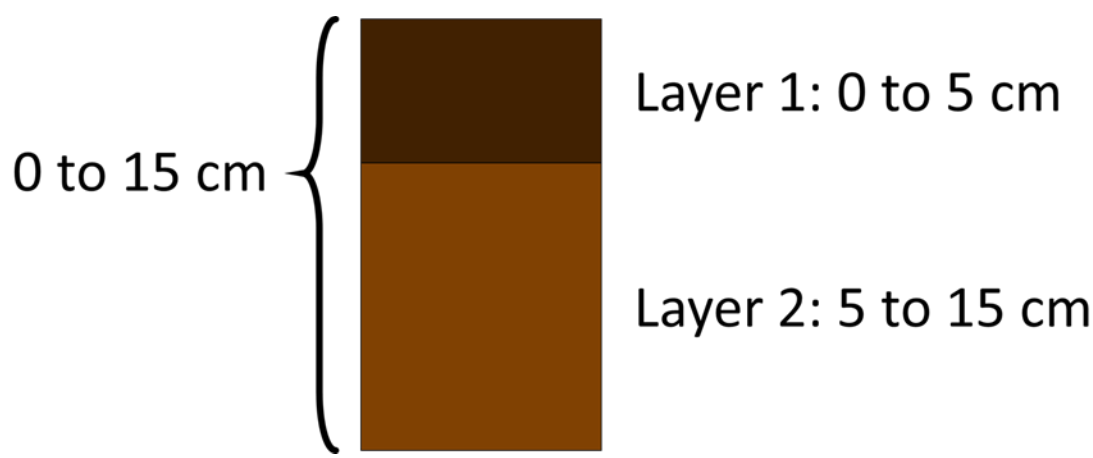

Figure 16. Sample dimensions and naming scheme. A full 15cm was sampled in two layers referred to as Layer 1 and Layer 2 throughout. Layer 1 includes the top 5cm of the soil and layer 2 includes the next 10 cm.

Before analysis, samples were thawed at ambient air temperature, followed by a recording of moist soil weight. Samples were sieved through a 6-mm screen while moist to enable thorough mixing for subsampling. A splitting process then occurred to allocate soil as needed for analysis which included portions kept frozen, oven dried, rapid air dried, and the remaining bulk soil was dried at ambient air temperature prior to being ground and passed through a 2mm sieve.

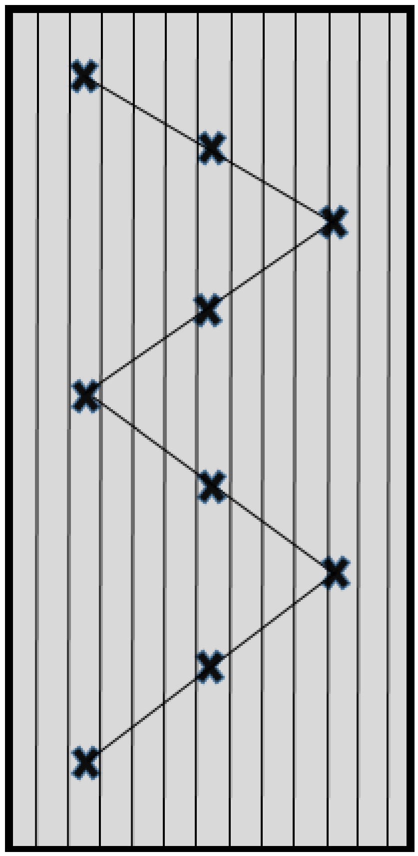

Figure 17. Sample pattern and locations for extracted soil cores within each individual plot.

2.4.3 Soil Analysis

Seven soil quality indicators were used within the SMAF index which included BD, pH_w, $EC_{1:1}$ (Whitney, 1998), extractable P (Bray I), K, SOC(Burt, 2004), and β-g (Eivazi & Tabatabai, 1988). Bulk density was calculated using the following equations:

BD = field moist weight of soil * [1-(FWC)]/volume of soil collected

FWC = (moist soil weight – oven dry soil weight)/oven dry soil weight

The 6 indicators not included within the SMAF for this research were WSA, potentially mineralizable nitrogen (PMN), Water filled pore space (WFPS), available water capacity (AWC), the sodium adsorption ratio (SAR), and microbial biomass carbon (MBC). Both WSA and PMN were excluded due to differences in lab procedures from those used within the SMAF. In addition, aggregate stability has not shown to be a sensitive indicator in this landscape (Stott et al., 2011; Stott et al., 2013; Veum et al., Accepted). Water-filled pore space was considered too transient to be included in the SMAF calculation. The SAR was not considered necessary due to regional soil characteristics. Additionally, AWC and soil MBC were not included due to resource constraints. The flexibility of the SMAF allows users to pick and choose indicators that best fit individual needs when determining changes in soil function (Andrews et al., 2004).

2.4.4 Calculating Corn Rotation Frequency (CRF)

The experiment presented here includes five corn-soybean rotations. The design of these rotations allow for each crop phase to be present in each year of the experiment leading to a total of 10 unique rotation sequences which are replicated four times. The multi-phase design is helpful for annual interpretation of yield differences resulting from interactions with weather that drive growing season specific yield variation. However, this study examined long term effects of increased corn rotations on soil function occurring as a result of nine cropping seasons since rotation treatments were established. To better portray the impacts of increased corn within rotations CRF values were assigned to each treatment based on the total number of corn years within a completed 6 year rotation cycle (Equation 4 and Table 18). By assigning CRF values, long term impacts of increasing corn within rotations could be observed and more easily identified. Soybean frequency could be calculated as 1-CRF.

$$\boldsymbol{CRF = \frac{\#\ of\ corn\ years\ in\ complete\ rotation\ cycle}{\#\ of\ years\ in\ complete\ rotation\ cycle}}$$

Equation 4. Calculation for corn rotation frequency (CRF) ratings used to identify impacts of increased corn in rotation on soil function.

Multiple phase rotations with similar corn frequency but different crop sequences (e.g. C-S-S, S-C-S, and S-S-C) could have contained previous crop related differences in soil measurements that may mask or amplify frequency effects on soil functional measurements in any specific year. Therefore, we examined the data for potential interaction effects due to corn rotation frequency and previous crop. Analyses for interaction effects were limited to the non-continuous treatments since previous crop is a constant for continuous plantings.

Table 18. Summary of rotation treatments with recent rotation history and frequency of corn in rotation (last three years shown). Corn frequency values were based on the number of corn years in each corn-soybean rotation within a completed six-year cycle of the experiment.

Rotation Type	Rotation	Rotation Sequence			CRF
		2011	2012	2013	
Continuous Soybean	S	S	S	S	0.0
3 year rotations	S-C-S	S	C	S	0.33
	C-S-S	C	S	S	0.33
	S-S-C	S	S	C	0.33
Alternating	S-C	S	C	S	0.50
	C-S	C	S	C	0.50
3 year rotation	C-S-C	C	S	C	0.66
	C-C-S	C	C	S	0.66
	S-C-C	S	C	C	0.66
Continuous Corn	C	C	C	C	1.0

† Corn Rotation Frequency (CRF), Soybean (S), Corn (C)

2.4.5 Alterations to the SMAF calculation

The SMAF includes crop specific interpretive scoring functions for pH_w, $EC_{1:1}$, and P. This ability to specify crop is an important aspect in tailoring SMAF to individual user needs. However, it can potentially cause problems when trying to compare cropping systems with different crop rotations. For example, in any given year half of the plots studied here were in corn while the other half were in soybean. Since crop specific scoring algorithms can potentially alter scores for measurements from specific plots, they can confuse interpretation of cropping history effects on soil function. To address these potential differences in scoring functions scores were calculated and analyzed based on both the intended rotation sequence (corn or soy) and by fixing all plots to the most limited crop (Corn) to more objectively compare the impact of cropping history on SMAF scores. Aside from a short section on calculating and comparing SMAF differences based on the crop rotations specific to each plot, all results will be shown with corn set as the target crop to maintain the integrity of SMAF score comparisons.

2.4.6 Statistical Analysis

Presentation of the results will be in terms of three types of analysis on soil experimental measurements; 1) the effects of previous crop and corn rotation frequency in multi-phase rotations; 2) the effect of increasing corn rotation frequency (CRF) factor levels; and 3) the effect of crop rotation differences specified within the SMAF. Analysis 1 and 2 merge like multi-phase rotations into fixed CRF factor levels. All analyses were performed using a Linear Mixed Effect Model (SPSS 22.0) (IBM Corp, 2013). Effect estimates were compared using Fisher's least significant difference (LSD) test at $P \leq 0.05$. Previous crop effects were analyzed using a two-way ANOVA (SPSS 22.0) with previous crop and CRF set as fixed factors. Additionally, Pearson correlation coefficients were calculated to show correlations between indicator, category, and total SMAF scores. Overall SMAF, SMAF category scores, and individual component indicator scores were analyzed by Layer 1 and Layer 2 separately, as well as by the full depth interval.

No significant previous crop effect or interactions between previous crop and CRF were observed within this data set. As the objective of this study was to use SMAF to identify changes in soil function caused by increased corn within a no-till corn-soybean cropping system, the results will be presented in terms of CRF.

2.5 Results

Results collected represent changes to soil function that occurred over the past nine years due to a range of corn-soybean rotations. These measurements and analyses captured snapshots of conditions in March of 2014.

Indicator, category, and combined mean SMAF scores were greatly influenced by depth and CRF (Table 19). Bulk density, SOC, and β-glucosidase indicators appeared to have differences due to CRF in Layer 1. These differences impacted physical and biological category scores as well as combined SMAF scores. Additionally, no differences were observed in chemical and nutrient category scores.

No differences were observed in indicator, category, or combined mean SMAF scores in Layer 2 (Table 19). This may be due to the implementation of a no-till management system in which most differences would be expected to occur at the soil surface.

Table 19. Indicator, category, and combined SMAF score summary table by depth with mean SMAF score, std. error, F-statistic, and P-values for corn rotation frequency shown.

Indicators/		Mean		Corn Rotation Frequency	
Categories	Depth	SMAF Score	Std. Error	F-Statistic	Sig. Value
Bulk Density	0-5cm	98.7	0.00	6.44	0.00**
	5-15cm	72.0	0.01	0.18	0.94
	0-15cm	88.7	0.01	1.29	0.29
Physical	0-5cm	98.7	0.01	6.44	0.00**
	5-15cm	72.0	0.01	0.18	0.94
	0-15cm	88.7	0.01	1.29	0.29
pH_w	0-5cm	79.0	0.01	0.61	0.65
	5-15cm	82.0	0.00	0.49	0.73
	0-15cm	81.0	0.09	0.38	0.82
$EC_{1:1}$	0-5cm	100.0	0.00	-	-
	5-15cm	100.0	0.00	-	-
	0-15cm	100.0	0.00	-	-
Chemical	0-5cm	89.6	0.00	0.76	0.55
	5-15cm	91.0	0.00	0.55	0.69
	0-15cm	90.7	0.00	0.46	0.76
Phosphorus	0-5cm	99.8	0.00	1.64	0.18
	5-15cm	57.6	0.02	1.64	0.18
	0-15cm	94.3	0.00	2.13	0.09
Potassium	0-5cm	83.3	0.00	0.29	0.87
	5-15cm	57.0	0.00	1.06	0.38
	0-15cm	65.8	0.00	0.73	0.57
Nutrient	0-5cm	91.6	0.00	0.23	0.91
	5-15cm	57.3	0.01	1.25	0.30
	0-15cm	81.2	0.00	0.49	0.74
SOC	0-5cm	85.3	0.00	5.42	0.00**
	5-15cm	31.7	0.00	0.24	0.91
	0-15cm	52.7	0.00	4.83	0.00**
β-glucosidase	0-5cm	98.4	0.00	13.92	0.00**
	5-15cm	33.0	0.02	0.08	0.98
	0-15cm	73.5	0.02	4.66	0.00**
Biological	0-5cm	91.9	0.00	8.85	0.00**
	5-15cm	32.4	0.01	0.48	0.99
	0-15cm	63.1	0.01	5.94	0.00**
Combined	0-5cm	92.1	0.26	3.81	0.01*
	5-15cm	61.9	0.65	0.56	0.69
	0-15cm	79.7	0.47	3.87	0.01*

† Electrical Conductivity$_{1:1}$ ($EC_{1:1}$), Soil Organic Carbon (SOC)
†† (-) No variance in data
Significance at: *<0.05, **<0.01

Depth weighted mean SMAF scores did not show any physical indicator differences, but mimicked the biological indicator, category, and combined SMAF score results of those observed in layer 1. Differences appeared to be driven by the 0 to 5cm depth since no differences were observed at 5 to 15cm.

Correlations were observed between individual indicator, category, and combined SMAF scores (Table 20, 21, and 22). These relationships show the complex interactions that occur between physical, chemical, nutrient, and biological soil properties. In layer 1, P had no significant correlations with other indicators, nutrient category, or combined SMAF scores (Table 20). This was due to low variance in P scores that were observed between all rotations examined. For a similar reason, BD (representing the physical category) was not significantly correlated to the combined SMAF score at this depth. Soil pH_w was highly correlated ($r = 0.58$, $p < 0.05$) to nutrient category scores indicating a management or soil genetic linkage between pH_w and nutrient levels.

Table 20. Pearson correlation matrix identifying significant correlations between individual indicator, category, and combined SMAF scores at the surface (0 to 5cm) layer.

		1)	2)	3)	4)	5)	6)	7)	8)	9)	10)	11)
Physical	1) BD	1										
Chemical	2) pH_w	.09	1									
	3) $EC_{1:1}$	a.	a.	a.								
Nutrient	4) P	-.04	-.08	a.	1							
	5) K	-.12	.62**	a.	.07	1						
Biological	6) SOC	.14	-.11	a.	-.19	.01	1					
	7) β-glucosidase	.38*	.18	a.	-.15	.08	.43**	1				
Category	8) Physical Score	1.0**	.09	a.	-.04	-.12	.14	.38*	1			
	9) Chemical Score	.09	.99**	a.	-.09	.62**	-.09	.20	.09	1		
	10) Nutrient Score	-.13	.58**	a.	.18	.98**	-.02	.06	-.13	.58**	1	
	11) Biological Score	.19	-.03	a.	-.24	.04	.96**	.65**	.19	-.00	.00	1
Total	12) Combined Score	.18	.69**	a.	-.09	.72**	.53**	.53**	.18	.71**	.68**	.60**

† Bulk Density (BD), Electrical Conductivity ($EC_{1:1}$), Phosphorus (P), Potassium (K), Soil Organic Carbon (SOC), β-glucosidase (β-g)

†† Correlation is significant at **<0.01, *<0.05

[a.] Cannot be computed because at least one of the variables is constant

Table 21. Pearson correlation matrix identifying significant correlations between individual indicator, category, and combined SMAF scores at the subsurface (5 to 15cm) layer.

		1)	2)	3)	4)	5)	6)	7)	8)	9)	10)	11)
Physical	1) BD	1										
Chemical	2) pH_w	-.25	1									
	3) $EC_{1:1}$	a.	a.	a.								
Nutrient	4) P	.19	-.26	a.	1							
	5) K	-.40**	.46**	a.	-.28	1						
Biological	6) SOC	.25	-.39*	a.	.04	.12	1					
	7) β-glucosidase	.34*	.17	a.	.04	.11	.19	1				
Category	8) Physical Score	1.0**	-.25	a.	.19	-.40**	.25	.34*	1			
	9) Chemical Score	-.26	.99**	a.	-.25	.47**	-.39*	.16	-.26	1		
	10) Nutrient Score	.07	-.10	a.	.94**	.04	.09	.08	.07	-.10	1	
	11) Biological Score	.38*	.07	a.	.05	.13	.39*	.97**	.38*	.06	.10	1
Total	12) Combined Score	.52**	.08	a.	.58**	.07	.29	.76**	.52**	.07	.63**	.78**

† Bulk Density (BD), Electrical Conductivity ($EC_{1:1}$), Phosphorus (P), Potassium (K), Soil Organic Carbon (SOC), β-glucosidase (β-g)

†† Correlation is significant at **<0.01, *<0.05

[a.] Cannot be computed because at least one of the variables is constant

Table 22. Pearson correlation matrix identifying significant correlations between individual indicator, category, and combined SMAF scores at the depth weighted (0 to 15cm) layer.

		1)	2)	3)	4)	5)	6)	7)	8)	9)	10)	11)
Physical	1) BD	1										
Chemical	2) pH_w	-.34*	1									
	3) $EC_{1:1}$	a.	a.	a.								
Nutrient	4) P	-.06	-.13	a.	1							
	5) K	-.35*	.57**	a.	-.00	1						
Biological	6) SOC	.37*	-.39*	a.	-.14	.14	1					
	7) β-glucosidase	.42*	.14	a.	-.10	.30	.47**	1				
Category	8) Physical Score	1.0**	-.34*	a.	-.06	-.35*	.37*	.42**	1			
	9) Chemical Score	-.38*	.99**	a.	-.10	.56**	-.39*	.12	-.38*	1		
	10) Nutrient Score	-.33*	.39**	a.	.62**	.77**	-.00	.15	-.33*	.40**	1	
	11) Biological Score	.46**	-.01	a.	-.13	.29	.70**	.95**	.46**	-.01	.13	1
Total	12) Combined Score	.43**	.24	a.	.03	.50**	.55**	.92**	.43**	.23	.40**	.92**

† Bulk Density (BD), Electrical Conductivity ($EC_{1:1}$), Phosphorus (P), Potassium (K), Soil Organic Carbon (SOC), β-glucosidase (β-g)

†† Correlation is significant at **<0.01, *<0.05

[a.] Cannot be computed because at least one of the variables is constant

Layer 2 SMAF scores showed differing correlations between indicator, category, and total SMAF scores than were observed at the surface (Table 21). Soil extractable P did show strong significant correlations ($r = 0.94$ and 0.58, $p < 0.01$) with nutrient and combined SMAF scores however, soil K was not significantly correlated to either one. Soil test K from 5 to 15cm had a low range of values due to the surface application of fertilizers and stratification in the no-till system and showed no correlations between data. In addition, combined scores were not significantly correlated to pH_w, SOC, or chemical category SMAF scores.

Depth weighted (0 to 15cm) SMAF component and category scores showed many more significant correlations than were observed in layer 1 or 2 (Table 22). All scores were significantly correlated to bulk density scores except for the P individual indicator score. Nutrient category scores were significantly correlated to all other indicator, category and combined SMAF scores except for those associated with biological properties. As was observed in the subsurface layer, combined SMAF scores were not significantly correlated to pH_w, P, or chemical scores.

Soil paste $EC_{1:1}$ correlations were not computed at any depth because all plots scored 100%. Additionally, BD was the only indicator in the physical category, so correlations with BD and the physical SMAF score are identical.

2.5.1 Layer 1 (0 to 5cm)

Significant differences between CRF levels were observed in soil physical and biological categories as well as in the combined (physical, chemical, soil nutrient, and biological categories) SMAF scores in Layer 1 (Table 23). No differences were observed between CRF levels for soil chemical or nutrient categories.

The SMAF physical category scores varied only slightly (97.5-99%) between CRF but continuous soybean (CRF = 0.0) had significantly smaller scores than all other frequencies (Table 23). Decreased physical category scores in continuous soybean were a result of increased BD values (Table 26). Greater BD values observed in smaller corn frequencies are likely to be a result of substantially fewer additions of organic materials into the soil surface compared to rotations including more corn. Residues and organic matter are less dense than mineral soil and increased inputs can result in decreased BD as was observed by Gupta et al. (1987).

Biological category scores ranged from 88.2 to 96.5% and increased as corn frequency increased in rotation (Table 23). Continuous corn (CRF = 1) had a significantly greater biological score than all other frequencies while CRF = 0.66 and 0.50 were significantly greater than CRF = 0 and 0.33. This increasing trend in biological category scores was influenced by greater soil organic carbon and β-glucosidase indicator scores (Table 27). As CRF increased, crop residue production also increased which has been shown to directly influence SOC values (Havlin et al., 1990) and β-glucosidase enzymatic activities (Alves et al., 2004).

Table 23. Soil Management Assessment Framework (SMAF) functional category and combined scores by corn rotation frequency (CRF) in Layer 1. SMAF scores range from 0 to 100% with higher scores signifying greater soil function potential. Letters signify significant differences at $p < 0.05$.

CRF	Physical Scores	Chemical Scores	Nutrient Scores	Biological Scores	Combined Scores
	Layer 1 (0 to 5cm)				
0.0	97.5 A	88.0 A	92.3 A	88.2 A	90.5 A
0.33	99.0 B	89.8 A	91.1 A	89.0 A	91.2 A
0.50	99.0 B	89.6 A	91.1 A	93.1 B	92.3 AB
0.66	99.0 B	90.7 A	91.6 A	92.7 B	92.7 B
1.0	99.0 B	90.0 A	92.0 A	96.5 C	93.7 B

† Corn Rotation Frequency (CRF)

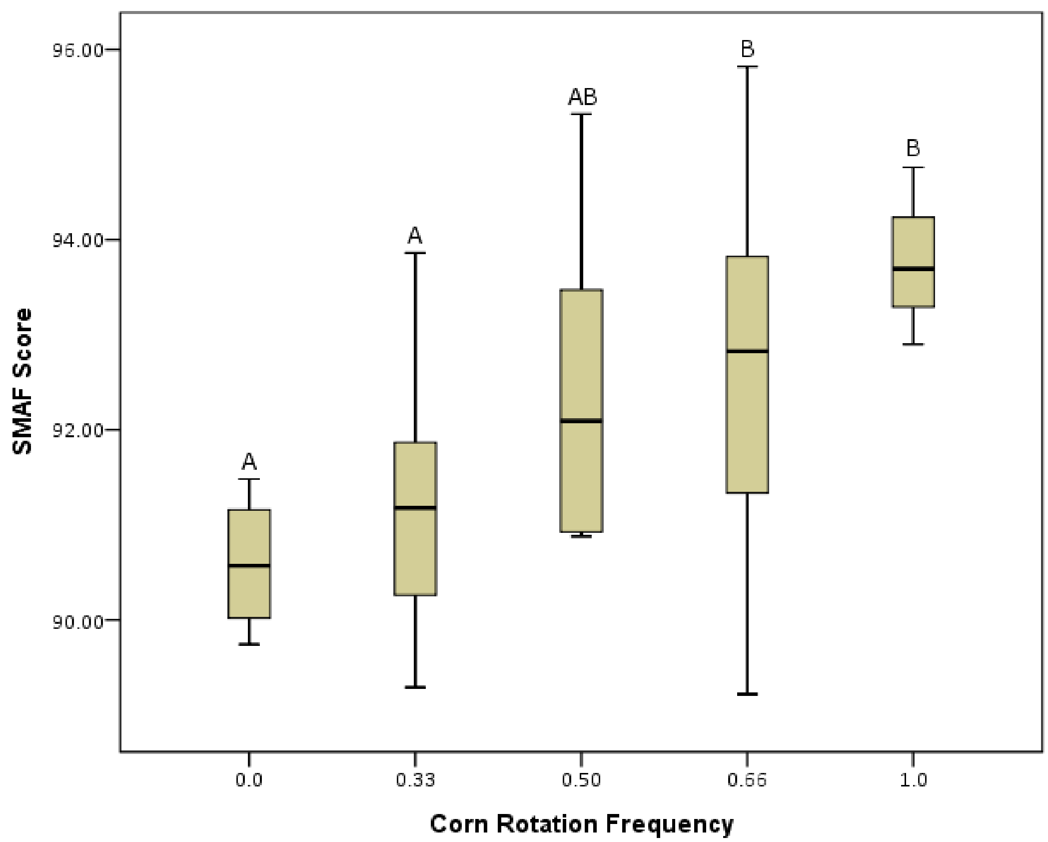

Figure 18. Combined Soil Management Assessment Framework (SMAF) scores for layer 1 show a significant increasing trend with increased corn rotation frequency (CRF). Letters signify significant differences at $p < 0.05$.

Combined SMAF scores reflected differences observed in the physical and biological category scores and increased as CRF increased (Figure 18). Soil Management Assessment Framework Scores ranged from 90.5 (CRF = 0) to 93.7% (CRF = 1) resulting in about a 3% change. Alternating corn-soybean rotations (CRF=0.5) had a combined SMAF score of 92.3%. These values are in accordance with those found in a similar soil landscape in a 17-year no-till corn-soybean rotation by Veum et al., (Accepted). They observed an overall SMAF score at the same depth to be 88%.

2.5.2 Layer 2 (5 to 15cm)

All layer 2 functional categories (except chemical) and combined SMAF scores decreased tremendously as compared to layer 1 scores (Table 24). Soil physical, nutrient, biological, and combined scores decreased by an average of 27, 38.5, 65, and 33%. These results were not unexpected due to the nature of a no-till management system in which residues, nutrients, and biological activity tend to be concentrated in the upper portions of the soil profile.

The largest differences were observed within biological scores which showed a 65% decrease with depth. Veum et al., (Accepted) noted similar biological score decreases on Missouri clay pan soils which showed an average decline of 50%. This decrease has been attributed to fewer available carbon substrates as well as sub optimum microbial climates present deeper into the soil (Fontaine et al., 2007). Microbial growth is a carbon limited process and is dependent on the presence of organic substrate materials (Grayston et al., 1998; Wardle, 1992; Whipps, 1991) which declined dramatically with soil depth in our study (Table 27). Overall, combined SMAF scores did not contain any significant differences between CRF (Figure 19). Comparing the alternating corn-soybean rotations (CRF=0.5) SMAF score at 5 to 15cm we found similar scores as those observed by Veum et al. (Accepted) (62.6% and 58% respectively).

Table 24. Soil Management Assessment Framework (SMAF) functional category and combined scores by corn rotation frequency (CRF) in Layer 2. SMAF scores range from 0 to 100% with higher scores signifying greater soil function potential. Letters signify significant differences at $p < 0.05$.

CRF	Physical Scores	Chemical Scores	Nutrient Scores	Biological Scores	Combined Scores
			Layer 2 (5 to 15cm)		
0.0	74.3 A	90.5 A	60.5 A	32.0 A	62.9 A
0.33	72.9 A	91.6 A	58.1 A	32.8 A	62.5 A
0.50	71.0 A	91.0 A	59.6 A	33.1 A	62.6 A
0.66	71.8 A	91.7 A	53.9 A	32.6 A	61.1 A
1.0	70.2 A	90.0 A	54.3 A	31.2 A	60.2 A

† Corn Rotation Frequency (CRF)

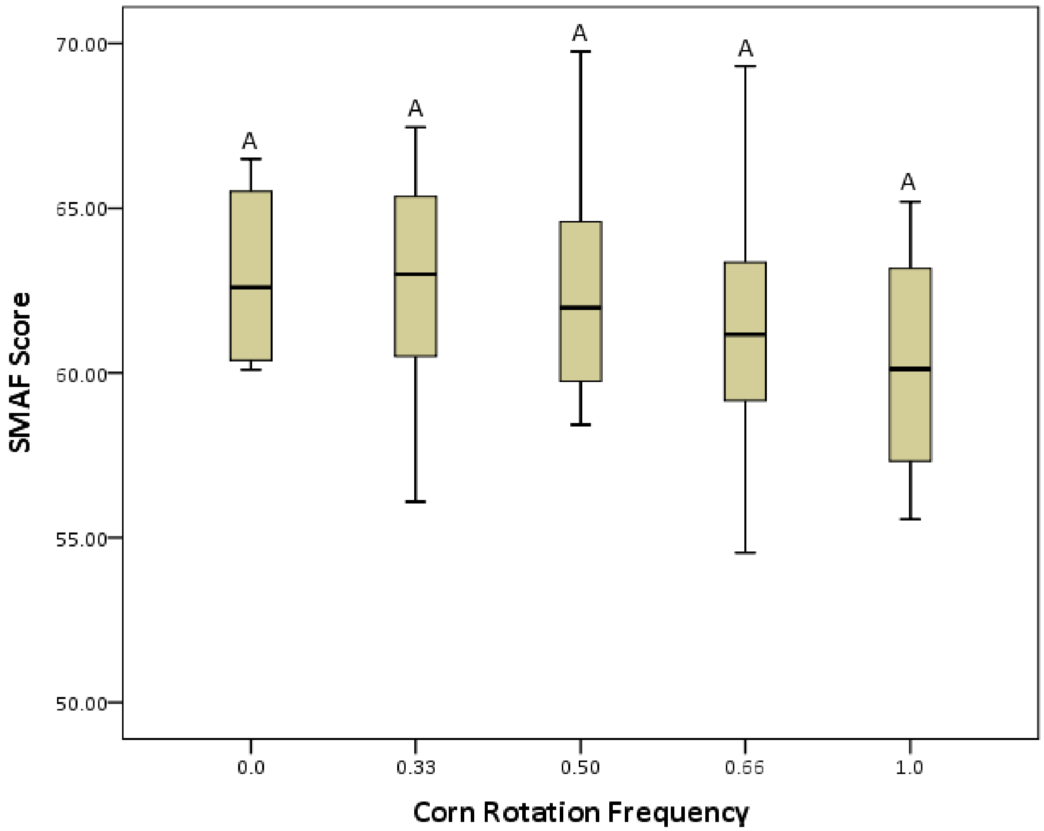

Figure 19. Combined Soil Management Assessment Framework (SMAF) scores for layer 2 show no significant differences due to corn rotation frequency (CRF). Letters signify significant differences at $p < 0.05$.

2.5.3 Depth Weighted (0 to 15cm)

Significant differences were observed in biological category and combined SMAF scores when calculated for the entire 0 to 15cm depth interval (Table 25). These differences showed an overall increase in SMAF scores with increased CRF (Figure 20). Physical scores increased with increasing CRF but were not significantly different. As CRF increased SOC and β-glucosidase indicator scores were greater and responsible for differences observed in biological category scores (Table 27). Combined SMAF scores were in turn influenced by differences in biological function and ranged from 77.2 in continuous soybean (CRF = 0) to 82.3% in continuous corn (CRF = 1) corresponding to a change in SMAF scores of 5%.

Table 25. Soil Management Assessment Framework (SMAF) functional category and combined scores by corn rotation frequency (CRF) at 0 to 15cm. SMAF scores range from 0 to 100% with higher scores signifying greater soil function potential. Letters signify significant differences at $p < 0.05$.

CRF	Physical Scores	Chemical Scores	Nutrient Scores	Biological Scores	Combined Scores
			0 to 15cm		
0.0	85.0 A	90.0 A	83.0 A	55.3 A	77.2 A
0.33	87.2 A	91.2 A	80.6 A	57.7 A	77.9 A
0.50	89.6 A	90.8 A	81.3 A	65.6 B	80.6 B
0.66	89.3 A	91.4 A	80.5 A	66.4 B	80.8 B
1.0	92.5 A	90.0 A	80.5 A	70.7 B	82.3 B

† Corn Rotation Frequency (CRF)

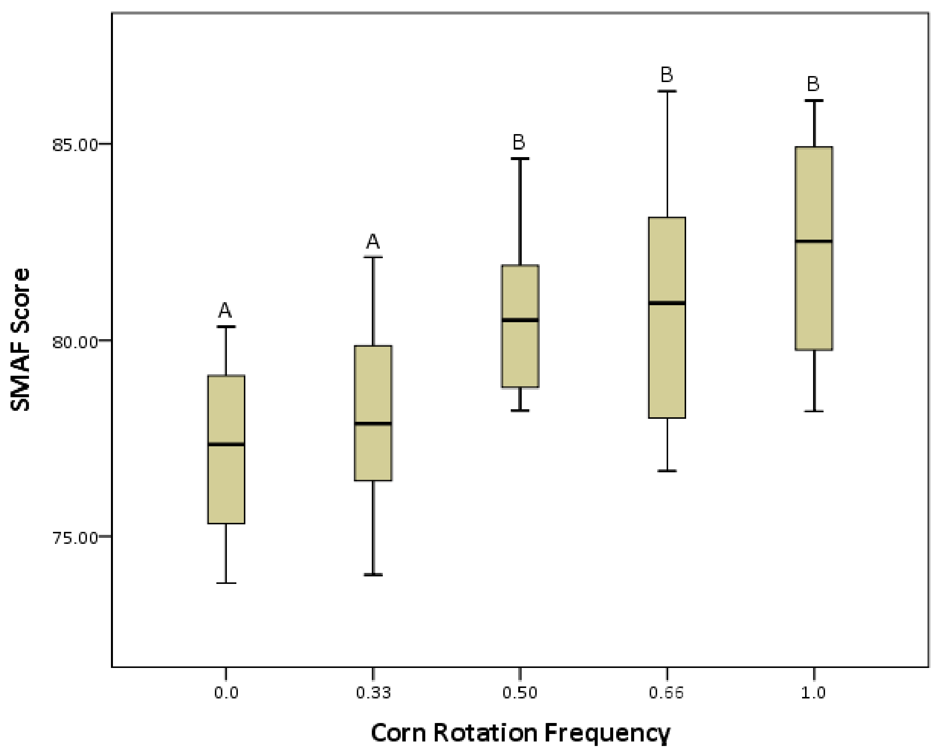

Figure 20. Combined Soil Management Assessment Framework (SMAF) scores for 0-15cm significantly increasing with increased corn rotation frequency (CRF). Letters signify significant differences at $p < 0.05$.

2.5.4 Summary

Chemical indicators at all depths showed no significant differences due to CRF. Similar SMAF studies have observed less sensitivity in the chemical category scores as compared to other soil properties (Stott et al., 2013; Veum et al., Accepted). These insensitivities are likely caused by individual indicator scoring algorithms that have broad ranges in sufficiency and that are more likely to effect the scores of soils in specific regions. For instance $EC_{1:1}$ has an important effect on the function of plant productivity in arid regions. However, Midwest soils are mostly not salt effected due to a relatively humid climate. Soil paste $EC_{1:1}$ values were all sufficient, and had maximum SMAF scores of 100% (Table 26). According to these results and those observed in other studies, it is possible that; 1) the SMAF index may include indicators that are not useful in some regions; and 2) sensitive measurements suitable for specific areas are not included within the SMAF.

Corn rotation frequency differences were observed in soil extractable P and K scores (Table 27). However, these differences did not influence nutrient category scores which showed no differences between CRF at all depths examined (Table 23, 24, and 25). Inverse relationships between P and K indicators appeared to cancel out any differences when averaged together. This averaging effect can hide significant changes that represent important information relating to management impacts on soil function.

No differences were observed in Layer 2 and significant differences were less pronounced at 0 to 15cm compared to Layer 1. As depth decreased, significant differences between physical and biological scores were lost. This data suggests; 1) depth is important when using the SMAF index and can impact overall scores; 2) soil function potential is less in the deeper soil profile than at the surface; and 3) SMAF score differences are less pronounced when measured at 0 to 15cm.

Layer 1 and the full 0 to 15cm depth had greater SMAF scores resulting from favorable BD, SOC, and β-glucosidase scores. However, the largest differences in SMAF scores between CRF=1 and CRF=0 were 3% and 5% for the surface depth weighted layers. It is difficult to interpret a 3 to 5% change over a nine year period, and results may not be sufficient to suggest that a meaningful change in soil function occurred between cropping systems. However, these results may be early indication of long term cropping system impacts on soil function.

Table 26. Physical and chemical indicator values with calculated SMAF Scores for all examined depths.

CRF	BD	BD SMAF Scores	pH_w	pH_w SMAF Scores	$EC_{1:1}$	EC SMAF Scores
	$g\ cm^3$				$ds\ m^{-1}$	
			Layer 1 (0 to 5cm)			
0.0	1.19 A	97.5 A	7.7 A	76.0 A	0.35 A	100 A
0.33	1.15 A	99.0 B	7.6 A	79.2 A	0.35 A	100 A
0.50	1.10 B	99.0 B	7.6 A	79.0 A	0.33 A	100 A
0.66	1.10 B	99.0 B	7.5 A	81.0 A	0.30 A	100 A
1.0	1.04 C	99.0 B	7.6 A	80.0 A	0.29 A	100 A
			Layer 2 (5 to 15cm)			
0.0	1.34 A	74.3 A	7.5 A	81.3 A	0.17 A	100 A
0.33	1.34 A	72.9 A	7.5 A	83.3 A	0.17 A	100 A
0.50	1.35 A	71.0 A	7.5 A	82.0 A	0.18 A	100 A
0.66	1.35 A	71.8 A	7.5 A	83.3 A	0.18 A	100 A
1.0	1.36 A	70.2 A	7.6 A	80.3 A	0.18 A	100 A
			Depth Weighted (0 to 15cm)			
0.0	1.29 A	85.0 A	7.6 A	79.5 A	0.23 A	100 A
0.33	1.28 A	87.2 A	7.5 A	82.0 A	0.23 A	100 A
0.50	1.27 A	89.6 A	7.5 A	81.0 A	0.23 A	100 A
0.66	1.27 A	89.3 A	7.5 A	82.5 A	0.22 A	100 A
1.0	1.25 A	92.5 A	7.6 A	80.0 A	0.22 A	100 A

† Corn Rotation Frequency (CRF), Bulk Density (BD), Electrical Conductivity ($EC_{1:1}$), Letters indicate significant differences between frequencies at $P \leq 0.05$

Table 27. Soil nutrient and biological indicator values with calculated SMAF Scores for all examined depths.

CRF	P	P SMAF Scores	K	K SMAF Scores	SOC	SOC SMAF Scores	β-g	β-g SMAF Scores
	$mg\text{-}kg^{-1}$		$mg\text{-}kg^{-1}$		%		μg*	
				Layer 1 (0 to 5cm)				
0.0	46 A	100 AB	116 A	84.0 A	1.98 AB	81.2 AB	201 A	94.8 A
0.33	39 AB	100 A	108 A	82.1 A	1.95 A	80.7 A	224 A	97.6 B
0.50	39 AB	100 A	110 A	82.4 A	2.11 B	86.1 B	278 B	99.9 C
0.66	35 B	99.8 AB	112 A	83.2 A	2.10 B	85.6 B	307 B	99.6 C
1.0	31 B	99.3 B	116 A	84.8 A	2.38 C	93.0 C	327 B	100 C
				Layer 2 (5 to 15cm)				
0.0	8.0 A	64.5 A	56 AB	56.8 A	1.15 A	32.0 A	93 A	31.7 A
0.33	7.7 A	61.0 A	53 A	55.3 A	1.12 A	30.8 A	96 A	35.0 A
0.50	7.8 A	63.4 A	54 AB	55.5 A	1.14 A	31.8 A	96 A	34.5 A
0.66	6.7 A	52.0 A	55 AB	56.3 A	1.15 A	32.0 A	94 A	33.0 A
1.0	6.2 A	47.2 A	63 B	61.3 A	1.14 A	32.0 A	91 A	31.0 A
				Depth Weighted (0 to 15cm)				
0.0	20 A	97.0 A	76 A	66.0 A	1.43 AB	50.0 AB	129 A	59.7 A
0.33	18 AB	94.9 A	72 A	64.2 A	1.40 A	48.4 A	138 AB	66.7 A
0.50	18 AB	95.6 A	73 A	64.6 A	1.47 B	53.1 B	157 BC	78.3 B
0.66	16 B	93.3 AB	74 A	65.1 A	1.46 B	52.9 B	165 C	80.0 B
1.0	14 B	90.5 B	81 A	69.0 A	1.56 C	59.2 C	170 C	83.0 B

† Corn Rotation Frequency (CRF), Phosphorus (P), Potassium (K), Soil Organic Carbon (SOC), β-glucosidase (β-g) Letters indicate significant differences between frequencies at $P \leq 0.05$.

2.6 SMAF Discussion

While working with the SMAF, questions arose from observations regarding the usefulness of the index and the methodology that should be followed with its use. Andrews et al., (2004), in designing the SMAF, expressed the need for further standardization and validation to create a more effective and useful tool. From the results and observations in this research and similar studies that have used the SMAF (Andrews et al., 2002; Andrews et al., 2004; Karlen et al., 2006; Stott et al., 2010; Stott et al., 2013; Veum et al., Accepted; Veum et al., 2013; Wienhold et al., 2007, 2009), it is clear that questions and concerns regarding model standardization and validation need to be addressed to improve the SMAF for future use. The SMAF has the potential to be a useful tool in comparing land use effects on soil function however, concerns must be addressed to make the SMAF a more suitable index.

2.6.1 Is component score averaging an appropriate scoring method?

Significant differences were observed between individual P and K indicator SMAF scores in this study (Table 27). Although significant, only a small range between scores occurred and did not influence the nutrient score at either of the depths investigated (Tables 23, 24, and 25). Phosphorus scores decreased with increasing corn frequency while K SMAF scores were greatest in continuous corn. Inverse trends between these indicators, specifically CRF=0.66 and 1 when averaged together washed out potential differences to overall scores (Figure 21).

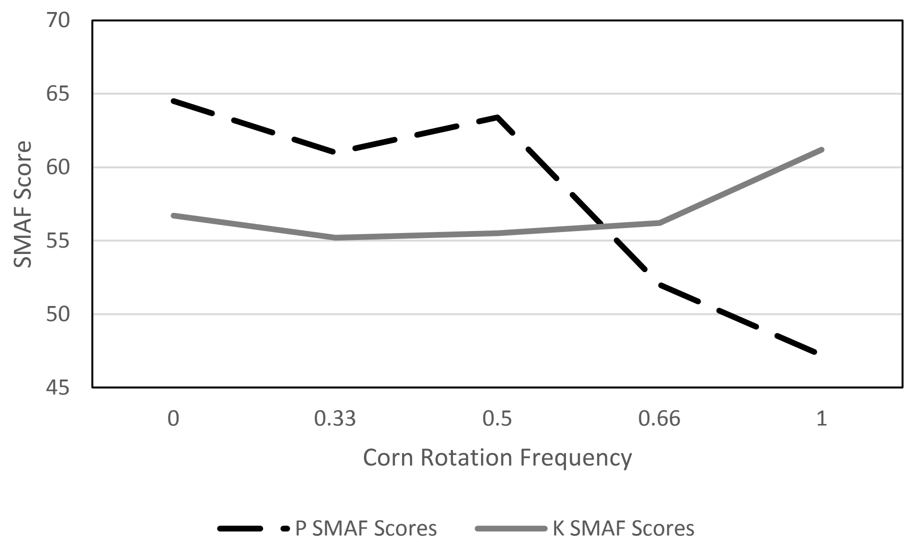

Figure 21. SMAF phosphorus (P) and potassium (K) scores showing an inverse relationship at CRF=0.66 and 1 which washed out potential differences in overall nutrient category scores in Layer 2.

Differences may be hidden in category and combined SMAF scores because of individual indicator and category averaging in the SMAF calculation. This observation contradicts the idea that SMAF gives more information as a whole than would be observed by data alone (Andrews et al., 2004).

2.6.2 What depth should be sampled for calculating the SMAF?

A standardized sampling depth has not been clearly defined within the SMAF index, but can tremendously influence the SMAF output scores. If the SMAF is to be used across regions to compare soils and land use practices sampling depth must be uniform. Concerns regarding sampling depth have been expressed by Wienhold et al. (2007), who discussed that most biological and chemical differences are concentrated at the soil surface. However, they continued to explain that if only surface samples are examined other changes deeper in the profile may not be captured.

The SMAF was developed using data collected from 0 to 15cm (Andrews et al., 2004), but has been used at various depths within the literature including 0 to 5cm and 5 to 15cm (Veum et al., Accepted), 0 to 7.5 cm and 7.5 to 15cm (Wienhold et al., 2007), 0 to 10cm (Veum et al., 2013), and 0 to 15cm (Andrews et al., 2002; Karlen et al., 2006). Differences in depth are not supported by the original SMAF design and could lead to data misinterpretation.

I suggest that the 0 to 15cm depth is most appropriate when using the SMAF index. The interpretive functions within the SMAF are not suitable to describe the sufficiency of sub-soils or even shallow sample layers (e.g. 0 to 5cm). In addition, 0 to 15cm is the current recommended sample depth in most states for nutrient analysis and the depth to which nutrient response models are typically calibrated.

However, the SMAF may not be sensitive enough to be sampled at 0 to 15cm, especially when comparing similar management systems. This insensitivity may be the reason why many studies have examined the SMAF at shallower depths trying to capture differences between management systems. Results from this data set would support this, by showing a loss of sensitivity in SMAF scores with added depth.

If the SMAF is insensitive when calculated at 0 to 15cm it may be necessary to calibrate it for split depth use. This type of technique has been developed and successfully used to depth weight soil productivity indices and root distribution (Kiniry et al., 1983; Scrivner et al., 1985). By including split depths, the SMAF tool can more accurately identify changes in Layer 1 where differences are likely to occur and where biochemical activities influence "soil forming processes, impacting nutrient cycling, and plant productivity" (Veum et al., Accepted). This does, however, dramatically increase the cost of using the SMAF.

Other issues regarding depth that need to be addressed included; 1) should sampling depth be different for dissimilar management systems (e.g. till vs. no-till); and 2) how will the SMAF account for different state nutrient soil sample depth and response models for nutrient recommendations? A standardized sampling depth must be clearly defined if the SMAF is to be used across regions and soils.

2.6.3 Does the SMAF include the most sensitive soil quality indicators?

In total, more than 80 soil quality indicators have been identified, but only 13 are defined with scoring functions in the interpretive step of the SMAF (Andrews et al., 2004; Stott et al., 2010; Wienhold et al., 2009). However, these 13 may not be the most sensitive in identifying differences in soil function for specific regions, cropping systems, or management practices. Two indicators having scoring functions observed to be less sensitive by the SMAF interpretation include electrical conductivity and aggregate stability. In addition, water-filled pore space is too transient to accurately represent its associated soil functions.

In this study, electrical conductivity for all corn rotation frequencies in all soil layers had maximum indicator scores of 100%. Similar results have been observed when comparing crop and soil management practices in Iowa and Texas (Stott, et al., 2011;

Stott et al., 2013). Soil $EC_{1:1}$ in these regions appear to be insensitive to changes in management or land use practices. Insensitivities in results are due to favorable $EC_{1:1}$ values that fall within the wide range of optimum values from the $EC_{1:1}$ interpretive scoring function.

Water stable aggregates were not measured in this study, but may also be another indicator that is insensitive in some locations. Soil WSA values of 47% or higher, are all assigned maximum scores within the SMAF index. As a result, maximum WSA SMAF scores have been observed in Missouri (Veum et al., Accepted), Iowa (Stott et al., 2011), and Texas (Stott et al., 2013) all of which ranged in stable aggregate values. As a result of a broad SMAF score optimum range, the aggregate stability indicator may not be precise enough to represent its associated soil functions (e.g., water infiltration and physical stability). If WSA are to be used within the SMAF to represent soil function then the component scoring functions must be sensitive to functional differences in WSA for every region (Veum et al., Accepted; Wienhold et al., 2009).

Indicators such as $EC_{1:1}$ and WSA are important indicators in identifying changes to soil functions such as water infiltration, physical stability, soil nutrient status, and promotion of plant growth and development (Kemper & Rosenau, 1986). As suggested by Veum et al. (Accepted), if the SMAF algorithms are not accurately representing associated soil functions they need to be re-parametrized.

2.6.4 Crop specified effects score interpretations

The interpretive scoring functions within the SMAF framework change for some indicators based on a target crop specified in the calculation. Changes in scoring functions account for variability in crop requirements and tolerance for pH_w, P, and $EC_{1:1}$.

Differences resulting from the crop specified within the SMAF model, greatly influenced chemical scores at all depths and soil nutrient scores in Layer 2 and 0 to 15cm depths (

Table **29**). Changing the target crop from soybean to corn altered optimum pH_w values from 6.25 (soybean) to 6.3 (corn). This small difference resulted in a large influence on pH_w indicator scores for all rotations specified as soybean, specifically that of continuous soybean. Continuous soybean layer 1 pH_w SMAF scores jumped from 44.5 to 76% (Table 28). Scores in Layer 2 and 0 to 15cm also increased 27% and 28%. All $EC_{1:1}$ values had a maximum score of 100% at all depths and did not change between target crops even though there is a crop specific interpretive scoring function. Chemical combined scores were significantly different at all depths when calculating SMAF with soybean interpretive scoring functions compared to corn.

Phosphorus was also influenced by target crop selected for the SMAF calculation. As a possible result of stratification in layer 1, phosphorus values all scored near maximum of 100%, and were not affected by selecting corn or soybean in the calculation (Table 28). However, in Layer 2 and the weighted (0 to 15cm) depth soybean scores decreased by changing crop from soybean to corn. Decreases to P scores were a result of increasing optimum P levels from 16ppm for soybean to 19ppm for corn. Significant differences to soil nutrient scores were observed between corn and soybean scoring functions in Layer 2, and reduced depth weighted scores although not significantly (

Table **29**).

The need for equal and consistent scoring algorithms is necessary for direct comparisons between cropping systems. In order for comparisons to be made using the SMAF model, crop differences must be accounted for and adjusted within the SMAF calculation. If crop rotations or treatments are not similar, the model should be calculated using the most limiting crop for all treatments when drawing comparisons.

Table 28. Target crop calculation differences to SMAF scores for individual indicators at all depths. Significant differences between SMAF scores were observed when calculating pH_w and P scores for corn compared to soybean at all depths.

CRF	pH_w Score		$EC_{1:1}$ Score		P Score	
	Layer 1 (0 to 5cm)					
	Soybean	Corn	Soybean	Corn	Soybean	Corn
0.0	44.5 A	76.0 A	100 A	100 A	100 AB	100 AB
0.33	60.7 AB	79.2 A	100 A	100 A	100 A	100 A
0.50	65.8 BC	79.0 A	100 A	100 A	100 A	100 A
0.66	72.2 BC	81.0 A	100 A	100 A	99.8 AB	99.8 AB
1.0	80.0 C	80.0 A	100 A	100 A	99.3 B	99.3 B
	Layer 2 (5 to 15cm)					
0.0	54.3 A	81.3 A	100 A	100 A	74.7 A	64.5 A
0.33	67.3 AB	83.3 A	100 A	100 A	67.9 A	61.0 A
0.50	69.5 AB	82.0 A	100 A	100 A	68.2 A	63.4 A
0.66	75.2 B	83.3 A	100 A	100 A	55.7 AB	52.0 A
1.0	80.3 B	80.3 A	100 A	100 A	47.2 B	47.2 A
	Depth Weighted (0 to 15cm)					
0.0	51.2 A	79.5 A	100 A	100 A	98.5 A	97.0 A
0.33	65.1 AB	82.0 A	100 A	100 A	96.2 A	94.9 A
0.50	68.2 B	81.0 A	100 A	100 A	96.4 A	95.6 A
0.66	74.2 B	82.5 A	100 A	100 A	93.8 A	93.3 AB
1.0	80.0 B	80.0 A	100 A	100 A	90.5 B	90.5 B

†Corn Rotation Frequency (CRF), Electrical Conductivity ($EC_{1:1}$), Phosphorus (P). Letters indicate significant differences between frequencies at $P \leq 0.05$

Table 29. Target crop calculation differences to SMAF category and combined (physical, chemical, soil nutrient, biological) scores at all depths. Significant differences were observed between corn and soybean chemical scores at all depths, nutrient scores in Layer 2, and combined scores in Layer 1.

CRF	Chemical Score		Nutrient Score		Combined Score	
	Layer 1 (0 to 5cm)					
	Soybean	Corn	Soybean	Corn	Soybean	Corn
0.0	72.5 A	88.0 A	92.3 A	92.3 A	86.1 A	90.5 A
0.33	80.6 AB	89.8 A	91.1 A	91.1 A	88.6 AB	91.2 A
0.50	83.1 BC	89.6 A	91.1 A	91.1 A	90.4 BC	92.3 AB
0.66	86.3 BC	90.7 A	91.6 A	91.6 A	91.4 CD	92.7 B
1.0	90.0 C	90.0 A	92.0 A	92.0 A	93.7 D	93.7 B
	Layer 2 (5 to 15cm)					
0.0	77.3 A	90.5 A	66.0 A	60.5 A	60.6 A	62.9 A
0.33	83.8 AB	91.6 A	61.5 AB	58.1 A	61.2 A	62.5 A
0.50	84.7 AB	91.0 A	62.0 AB	59.6 A	61.5 A	62.6 A
0.66	87.8 B	91.7 A	55.9 B	53.9 A	60.5 A	61.1 A
1.0	90.0 B	90.0 A	54.3 AB	54.3 A	60.2 A	60.2 A
	Depth Weighted (0 to 15cm)					
0.0	75.5 A	90.0 A	83.8 A	83.0 A	73.3 A	77.2 A
0.33	82.8 AB	91.2 A	81.1 A	80.6 A	75.7 A	77.9 A
0.50	84.3 B	90.8 A	81.6 A	81.3 A	78.9 B	80.6 B
0.66	87.1 B	91.4 A	80.8 A	80.5 A	79.6 B	80.8 B
1.0	90.0 B	90.0 A	80.5 A	80.5 A	82.3 B	82.3 B

†Corn Rotation Frequency (CRF). Letters indicate significant differences between frequencies at P ≤ 0.05

2.6.5 Are comparisons across soils valid when using the SMAF?

The intended purpose of the SMAF was to develop a tool that could be used across soils, climates, and management practices (Andrews et al., 2004). However, comparisons across soils may not be valid or even reasonable due to dissimilar inherent soil functional capacities. For example, the functional potential of a productive mollisol soil in Illinois is greater than a highly eroded clay pan soil in central Missouri. This comparison makes it difficult to understand if soil functional changes are a result of management practices or soil property differences. Perhaps the best use of the SMAF is for paired in-time comparisons at the same locations or in soils that have similar inherent soil function potential. If the goal of the SMAF is to quantitatively determine changes induced by land use practices then all other variables must remain constant.

For comparisons to be considered valid, the SMAF may need to be a soil region specific tool. This approach has been used within the Cornell Soil Health Test which was designed to compare soil function differences in New York and Northeastern region soils. This allows for soil specific properties and functional potentials to be addressed and considered for accurate and direct soil comparisons.

2.6.6 Is the SMAF effective for comparing cropping and management systems?

The SMAF has been suggested to be an effective tool for identifying differences in soil function resulting from changes in cropping systems (Andrews et al., 2002; Karlen et al., 2006; Veum et al., 2013; Wienhold et al., 2007) and management practices (Andrews et al., 2002). However, many of these suggestions have resulted from comparisons between cropping systems that were dissimilar. For example, in the Karlen et al. (2006) study it was concluded that "the SMAF is an effective tool for aggregating soil quality indicator data into index values that are effective for assessing alternative crop rotations." This conclusion may only be valid for some of the cropping systems in which they examined. When comparing substantially different cropping systems (continuous corn vs. corn-oats-meadow rotation) a mean differences of 9% was observed within long term experiments spanning 25-50 years. These differences may indicate as was concluded, that SMAF is an effective tool for assessing changes due to alternative crop rotations. However, within this same experiment when more similar cropping systems are compared (continuous corn vs. corn-soybean rotation) differences are much smaller and resulted in a mean difference of 3.5%, similar to what we found here in this study. It is difficult to interpret a 3.5% change over a 50 year period, and results may not be sufficient to suggest that a meaningful or actual change in soil function occurred between cropping systems. The conclusion that SMAF is useful for comparing more similar alternative cropping systems in this situation becomes more difficult to defend.

The SMAF may be better suited for comparing cropping systems or management practices which are dissimilar. However, this becomes an issue when the tool is designed to be used by producers. If the SMAF is designed to aid producers in detecting changes in soil function it must be sensitive enough to compare cropping systems and management practices which are similar.

2.7 Conclusion

Greater SMAF scores were associated with increased CRF in layer 1 and at 0 to 15cm. Increased scores resulted from favorable changes in physical (BD) and biological (SOC and β-g) properties examined. However, score differences were relatively small (3 and 6%) and may not be sufficient to conclude that an actual change in soil function occurred or was observed through use of the SMAF index. It is possible, that cropping system and management practices were too similar to identify changes to soil function.

However, these small differences may be important in indicating the "direction of change" between cropping systems that has occurred over the past nine years (Wienhold et al., 2007).

In addition, specific questions and concerns were identified and discussed with the intent to help better validate and standardize the SMAF index for future use. Further, validations to indicators and scoring algorithms are essential to create greater sensitivity in identifying differences in soil function for specific regions, cropping systems, or management practices. Currently, the SMAF is not validated for use or comparisons of soils that have not been incorporated into the model. If the SMAF is intended to compare management practices across soils and climates, all soil types in all climates must be considered. However, we are concerned that it may not be reasonable for comparisons to be drawn across all soils due to differences in inherent soil properties. We suggest that comparisons intended to discern management effects be made only to soils with similar properties and which are adjacent. Sampling depth standardization must also be established in the SMAF in order to make results and comparisons accurate and reliable. Currently, the SMAF is being used to identify soil function changes at depths that are not supported by its original design. This may be because, the SMAF is less sensitive when used at its developed depth (0 to 15cm) than at shallower depths (e.g. 0 to 5cm). It may be beneficial to examine other indices that use depth weighting techniques (such as the scrivener rooting index) to better account for depth differences. In addition to validation and standardization, concerns arose regarding some arithmetical aspects of the SMAF index. The use of component averaging may not be the best method for computing a SMAF score. By averaging individual indicators, inverse trends in data may wash out differences in category and combined scores. It may be more appropriate to use a multiplicative method which could provide a more dynamic range and greater sensitivity. In addition, we also have concerns with the selection of crop in the SMAF model. The specified crop can have a significant impact on SMAF scores, influencing indicator, category, and combined score outcomes. If SMAF is to be used as a comparison tool, all scoring algorithms must remain consistent and equal to draw a correct and direct comparison between treatments.

Users must recognize and consider the limitations that are associated with using the SMAF index. It is a new tool that needs validation and standardization. However, the SMAF may be the most effective index currently available for monitoring integrated soil function, and with adjustments and judicious use, has the potential for being a valuable tool for users in the future.

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FUTURE WORK

As shown in this thesis, a majority of my graduate work focused on obtaining and analyzing soil samples in order to identify soil property status for many long term cropping system trials (e.g. corn-soybean no-till rotation study, tillage study, and intensive cropping systems which include cover crops). In addition to soil measurements, plant measurements were also collected during the 2014 growing season to identify cropping system (Bradford F10) and tillage effects (Bradford F8) on plant growth. However, soil and plant measurements are sensitive to seasonal, monthly, and even daily variation which indicates the need for more measurement time points to provide a more extensive data set for these studies. For future work, I would like to see an additional year of soil data collected at the same seasonal time (early spring) and locations to provide a direct comparison between treatment differences at two time points for each of these studies. Additionally, more plant measurements are required to determine crop rotation and tillage impacts on plant growth, development, and productivity for the F8 and F10 Bradford studies. Dr. Myers and I, both have an interest in better linking together what takes place in the soil (soil function) and how it effects plant growth and development. For example, we found that continuous corn resulted in benefits to many soil properties however, when comparing corn growth and development throughout the 2014 season continuous corn treatments were behind developmentally and yielded far less than any other treatment. To provide better understanding of this soil to plant linkage additional soil and plant measurements will be required in future years.

Two soil data sets (field 1 and paired plots) were collected from the USDA-ARS research site in Centralia, MO. This data will be useful in providing an additional time point for identifying cropping system and landscape variation changes on soil function. In the future, I hope that additional time point measurements will be analyzed at these same locations at similar depth increments to draw paired in time comparisons. Soil data has been collected at previous time points from these locations however, sampling depth and seasonal sampling times have not been consistent making it difficult for these direct comparisons to be made. This will broaden our knowledge on short term (yearly) variations to soil functions based on differences in cropping system and landscape variations.

I would also like to see our results, observations, and thoughts influence changes and further standardization of the SMAF index. I believe that the questions and concerns that we expressed regarding the SMAF are valid and will aid in fulfilling the tools intended purpose. The SMAF has the potential of being a valuable tool for monitoring change in soil function if further validation and standardization occurs.

Overall, my hope is that this research will be used and added upon in future years to aid in the advancement of science at both soil and plant physiology levels.

VITA

Jeremy Tyler Matson was born on March 21, 1990 to Mark and Sherri Matson. Born and raised in Pocatello, Idaho, Jeremy attended Pocatello High School and graduated in 2008. In 2010, Jeremy attended Brigham Young University where he began a degree in Agronomy Crop and Soil Science, and worked as a research assistant investigating alfalfa nodulation and plant nutrition. In 2013 Jeremy received his bachelor's degree and was accepted as a master's student to the University of Missouri. In August, 2013 Jeremy began his Masters of Science degree in Plant Science under the advisement of Dr. Brent Myers, studying the long-term impacts of corn-soybean cropping systems on soil function. Jeremy completed his education and received his Master's degree in May of 2015.