SOIL QUALITY IN LONG-TERM CORN AND SOYBEAN ROTATIONS

BY

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THESIS

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ABSTRACT

Although soil quality is significant for crop productivity, input efficiency, and environmental stewardship, the effect of cropping systems on soil quality has not been examined very thoroughly for most cropping systems in the Midwest. Thus the advantages and disadvantages associated with standard agricultural practices, especially crop rotation, from the soil quality standpoint are either unknown or incomplete in most instances. The objective of this study was to evaluate soil properties under three common Illinois crop rotations more than ten years after establishment. Continuous corn (CCC), corn-soybean (CS), and corn-corn-soybean (CCS) rotations were arranged in a randomized complete block design (RCBD), with three or four replications at six University of Illinois Crop Sciences research centers, at Urbana, Monmouth, Perry, Dixon Springs, DeKalb, and Brownstown, with all phases present each year. We measured soil bulk density (BD), water aggregate stability (WAS), cation exchange capacity (CEC), soil organic matter (SOM), and plant-essential nutrients at the depths of 0-15, 15-30, 30-60, and 60-90 cm. Univariate and multivariate statistical analyses were conducted, including stepwise selection and canonical discriminant analysis (CDA). These approaches helped to clearly separate and identify locations, reflecting the different soil types and environments at each site. Crop rotations had little to no discernible effect on any of the soil properties evaluated.

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INTRODUCTION

The term soil quality has many definitions. One of the most basic definitions of soil quality is the capacity of the soil to function (Larson and Pierce, 1991; Doran and Parkin, 1994; Karlen et al., 1997). Doran et al. (1994) expanded this definition by describing soil quality as "the capacity of the soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation." This expanded definition establishes guidelines by which soil quality can be judged based on soil management, and expresses the importance of ecosystem services and how they are influenced by soil quality.

Soil quality is composed of dynamic characteristics that are indicative of chemical, physical, and biological processes. Chemical characteristics commonly used in assessments of soil quality include macro- and micronutrients and soil organic matter (SOM). Physical characteristics often used include bulk density (Bd) and water aggregate stability (WAS). While common biological characteristics include microbial biomass carbon and nitrogen (MBC and MBN). These soil quality characteristics are influenced by soil use and management and are dynamic (Larson and Pierce, 1994). While dynamic characteristics are central to the idea of soil quality, it's important to recognize that soil quality is also dependent on inherent soil composition.

Inherent soil composition is a function of the interaction of the five soil forming factors identified by Jenny (1941): The five factors of soil formation include time, parent material, topography, climate, and biological organisms. Inherent soil composition is an important part of soil quality because it forms a baseline from which soil quality can be measured. Along with forming a baseline, inherent soil composition defines the absolute capability of the soil, thus, dynamic soil characteristics and inherent soil composition can be thought of as complementary concepts when defining soil quality (Karlen et al., 2003).

Dynamic soil characteristics and inherent soil composition are inextricably linked and together dictate the resilience and resistance of the soil system. Soil resilience is the capability of the soil to recover structurally and functionally following a disturbance or degradation while soil resistance can be thought of as the continued ability of the soil to function without change through a disturbance (Seybold et al., 1999). These concepts are important when selecting soil quality indicators because the resistance and resiliency of the soil will impact the magnitude of change of chosen indicators and is also related to difference in soil type. For example, soil types with higher rates of 2:1 clays compared to non-swelling clays will have greater resistance to compaction caused by tillage and crop root penetration. Comparatively, soil types with greater amounts of sand and fine silt are more prone to erosion (Seybold et al., 1999).

The concept of soil quality is gaining attention, given that the long-term productivity and sustainability of agriculture are dependent on maintaining it (Larson and Pierce, 1994; Reicosky and Forcella, 1998). Management practices that protect the soil are needed; it is suggested that crop rotation is one management practice that may have a large influence on soil quality. Crop rotation influences soil quality by the quality and quantity of residues that are returned to the soil. Residue quality is influenced by chemical characteristics such as the C:N ratio and lignin, polyphenol, and structural carbohydrate concentrations of plant material which in turn depend on the crop species (Ajwa and Tabatabai, 1994; Martens, 2000). Physical characteristics such as residue particle size and level of integration into the soil also influence residue quality (Wagger et al., 1998). Residue quantity is a result of the above- and below-ground biomass of the crop that remains after grain harvest. Corn returns much more residue to the cropping system than soybean due to higher yields and greater plant biomass (Johnson et al., 2006). Both residue quality and quantity will impact the rate of decomposition, the stability of the residue constituents that are incorporated into SOM pools, and ultimately, the amount of SOM remaining in the soil system (Benjamin et al., 2010; Blanco-Canqui and Lal, 2004; Martens, 2000; Oades, 1988).

Finding soil characteristics that are sensitive to management practices (soil quality indicators) is crucial to assessment of soil quality (Arshad and Martin, 2002). A sensitive indicator is one that will display a statistically significant change in magnitude and/or direction in response to management changes and one that will not be confounded by short-term changes such as seasonal weather patterns (Doran and Parkin, 1994). A sensitive indicator will also reflect the resistance and resiliency of the soil. Villamil et al. (2008) found that WAS, Bd, and SOM have the greatest potential as soil quality indicators in no-till systems in Illinois. Zuber et al. (2015) found WAS, Bd, soil organic carbon (SOC), total nitrogen (TN), and K to be sensitive indicators of soil quality under long-term rotation and tillage. Other long-term rotational studies such as those conducted by Hickman (2002) and Houx et al. (2011) found rotation to have mixed effects on soil quality indicators. Hickman (2002) found that nutrient availability did not differ among four corn/soybean rotations even though crop rotations with more corn had reduced pH, which might have been expected to affect nutrient availability. Houx et al. (2011) found that rotations significantly impacted soil Ca, S, Al, Fe, and Mn concentrations and pH. Although these studies showed mixed results regarding the effect of crop rotation on micronutrients, both concluded that any differences in nutrient concentrations were likely due to the effect of greater nitrogen fertilization in rotations with more corn.

Although research has been conducted about sensitive soil quality indicators that are responsive to management practices such as crop rotation, there is a gap in research evaluating soil quality in common crop rotations in Illinois, particularly in long-term rotations. In Illinois, crop rotations are principally corn and soybean rotations; with most of the corn and soybean grown in 2-year rotations. In recent years, however, large demand for corn resulted in a shift of acreage to corn. With few other viable options besides corn and soybean, Illinois producers currently produce about 1.5 million more acres corn than beans (USDA-NASS, 2016). This difference is primarily due to production of corn that follows corn in sequence, either as continuous corn (CCC) or as corn following one or more seasons of corn that follow soybean, such as corn in a soybean-corn-corn (CCS) sequence. The CCS rotation is considered to bring some agronomic advantages associated with growing corn and soybeans in rotation compared to growing corn sequentially in the same field for sequential seasons. These advantages include disease control, weed management, insect pressure mitigation, and enhanced soil fertility.

Despite the significance of soil quality to crop productivity, input efficiency, and environmental sustainability, a complete assessment of physical, chemical, and biological properties is missing for many crop rotations common in Illinois. Thus, the advantages and disadvantage associated with each practice from the soil quality standpoint are either unknown or incomplete. The purpose of this study is to test whether changes in soils under different crop management systems actually do occur through the study and analysis of soil physical, chemical, and biological properties using multivariate techniques. We hypothesize that the soil properties that are the most closely related to crop residue quantity and quality such as SOM, WAS, and BD, will be the most important in separating the rotations as these soil properties are the ones most greatly influenced by residue quantity and quality.

The objectives of this study are to quantify the effects of continuous corn, corn-corn-soybean, and corn-soybean rotations on soil quality and to provide updated information on the influence of crop rotation on soil quality to help guide producers in management decisions. This is important as producers seek to develop new techniques and evaluate existing management practices to mitigate and minimize environmental consequences associated with intensive farming practices.

MATERIALS AND METHODS

Site Descriptions

The study was conducted at six University of Illinois Department of Crop Sciences research centers; the Northwestern Illinois Agricultural Research and Demonstration Center in Monmouth, IL, the Orr Agricultural Research and Demonstration Center, the Crop Sciences Research and Education Center in Urbana, IL, the Brownstown Agronomy Research Center, the Dixon Springs Agricultural Center, and the Northern Illinois Agronomy Research Center in DeKalb, IL. Details about the sites including site abbreviation, coordinates, mean annual temperature, mean annual rainfall, and soil series can be found in Table A.1. Further soil information is contained in Table A.2.

The two sites in southern Illinois –BT and DS – were managed as no-till while the other sites were managed using conventional tillage. Conventional tillage consisted of primary (first-pass) tillage using a combination disk-ripper or chisel operated 25 to 35 cm deep in the fall after harvest, and secondary (second-pass) tillage with a soil finisher before planting in the spring. Commercially available corn and soybean cultivars were planted in 76- and 38-cm rows, respectively. Corn was planted at 79 to 91,000 seeds ha^{-1} and soybean at 370 to 395,000 seeds ha^{-1}. Fertilizer and pest management decisions were based on best management practices for each location according to the Illinois Agronomy Handbook (Fernández & Hoeft, 2009).

Soil Sampling and Analysis Procedure

Three soil core samples were taken in 2014, after crop harvest, with an automated soil sampler (Amity Tech, Fargo, ND) to 90 cm deep randomly within each subplot and cut in 0-15, 15-30, 30-60, and 60-90 cm segments. After measuring gravimetric water content (W, %) at each depth, soil bulk density (BD, Mg/m^3) was determined using the core method (Blake and Hartge, 1986). Field moist soil was analyzed for available N (N-NO_3^- and N-NH_4^+in mg/kg) using KCl extraction (1:5 ratio soil to solution) followed by flow injection analysis with a Lachat automated analyzer (Lachat Intruments, Loveland, CO). Soil samples were then air dried and sieved to pass a 2-mm screen. Soil aggregates of the soil fraction ranging between 1-2 mm from each depth were tested for water aggregate stability (WAS, %) with an Eijkelkamp wet sieving apparatus (Eijkelkamp, Giesbeek, The Netherlands) following Kemper and Rosenau (1986). Samples were sent to a commercial laboratory (Brookside laboratories, Inc., New Bremen, OH) for the determination of soil organic matter (SOM, %) by loss on ignition (Schulte and Hopkins, 1996); cation exchange capacity (CEC, meq/100gr soil) by the summation method; soil pH (1:1 soil:water) via potentiometry; available phosphorus (P, mg/kg) with Bray I extraction; and extractable nutrients (K, S, Ca, Mg, Na, B, Fe, Mn, Cu, Zn, and Al) using Mehlich-III soil test extractant (Mehlich, 1984). Soil organic matter values were adjusted according to equations developed by Konen et al. (2002) for Illinois soils.

Experimental Design and Statistical Analysis

The experiment aimed to test the effects of long-term corn rotations (Rot: CCC, continuous corn; CCS, corn-corn-soybean; and CS, corn-soybean) on soil properties and crop yields. The rotation experiment was initiated in 2002 and all phases were present in each year rendering a total of 6 rotations/phases under study: CCC, CCS, CS, CSC, SC, and SCC. The rotations were arranged in a randomized complete block design (RCBD) with 4 replications (blocks) at each of 6 locations (BT, DK, DS, MN, OR, UR) in Illinois. Soil properties were determined at 4 successive depths: 0-15, 15-30, 30-60, and 60-90 cm.

A 6 x 6 x 4 between-subjects multivariate analysis of variance (MANOVA) was performed on the soil data set that included BD, WAS, pH, CEC, SOM, TN, P, K, S, Ca, Mg, Na, B, Fe, Mn, Cu, Zn, and Al. Water content (W) was used as a covariate. Independent variables or factors were location (L), rotation (R), and depth (D). The GLM procedure of SAS software version 9.4 (SAS Institute, Cary, NC) was used to conduct the MANOVA on standardized data (mean=0, std=1). We used the macro %multnorm (http://support.sas.com/kb/24/983.html) on the model residuals to evaluate assumptions. A priori contrasts were specified to investigate the overall effect of rotations on soil properties at each location of interest, setting the experiment-wise probability of Type I error or alpha level (α) at 0.05. Non-significant overall factor interactions with depth (D) were found on the preliminary full model MANOVA, with probabilities >0.50 in all situations; thus the interactions with D were removed from the model. Since the MANOVA detected significant overall main effects of L and R as well as a significant overall L x R interaction effect (Table A.1), we further explored the variables that contributed to maximized L, R and L x R group differences with canonical discriminant analysis (CDA) using the CANDISC procedure in SAS on location-detrended data (Khattree and Naik, 2000). The lda function included in the MASS package and plotting capabilities within the R environment, version 3.2.2 (The R Foundation for Statistical Computing, 2015), were used to aid in the visualization of the CDA results. To reduce the number of groups and facilitate interpretation, a new classification variable LR was created that grouped the different phases of each rotation into the 3 rotations of interest: CCC, CCS, and CS, at each of the studied locations, thus rendering a total of 18 levels for this factor. Cross-validation of our linear discriminant functions obtained with the CDA was carried out to estimate the probabilities of correct classification of new observations into the LR groups as suggested by Johnson and Wichern (2002).

RESULTS

Univariate Analysis

Soil quality attributes were clustered into three groups to facilitate analysis and interpretation. Group 1, General Soil Quality attributes (Table A.3 & A.4, Fig. A.1), was composed of pH, CEC, SOM, BD, PR, and WAS. Group 2, Macronutrients (Table A.5 & A.6, Fig. A.2), consisted of TIN, Pbray, K, Ca, S, Mg, and Na and Group 3, Micronutrients (Table A.7, Fig. A.3), was composed of B, Fe, Cu, Mn, Zn, and Al.

General Soil Quality Attributes

Tables A.3 & A.4 show the results of the analysis of variance for the effects of location, rotation, and depth and their interactions on general soil quality attributes across sites. A significant three-way location x rotation x depth interaction was found in BD at DS, where the mean BD in the CCC rotation was 36% lower than all other rotations at this site at the 30-60 cm depth. There were no other differences at a specific depth among rotations at any other site.

No differences in CEC, SOM, PR, or WAS were observed among rotations across the six sites (Table A.A.3 & A.4, Fig. A.1), however, significant differences for each general soil quality attribute were found among the locations. In CEC, from 0-30 cm, the sites clustered together into four distinct groups. DeKalb had the highest CEC followed by UR and MN which were comparable. The CEC at OR was greater than that at DS and BT. From 30-90cm DK and UR again showed the highest mean CEC levels but the CEC level of DK showed a sharp downward trend while levels at BT and DS trended upwards. In SOM, from 0-30cm, mean SOM values observed at DK, MN, and UR were more than double those at BT, DS, and OR. From 60-90 cm, the highest SOM levels were observed at OR, UR, and MN, which were more than double the levels observed at the same depth at BT, DS, and DK. Although DK had the highest SOM among locations at 0-30 cm, the SOM values at 30-60 and 60-90 were 63 and 80% less, respectively, than in the surface 30 cm. Penetration resistance, at the surface, at UR and MN, was 11% lower than at all other sites however from 30-60cm, these sites exhibited PR similar to all other sites except for OR. WAS levels were statistically similar among all sites from 0-30cm. However, from 30-90cm, UR, DK, and MN, exhibited WAS values that were 18% higher than those observed at BT, DS, and OR.

Macronutrients

The only measured soil property that discriminated among rotations was soil Mg (Tables A.5 & A.6). Continuous corn, CSC, and SC had the highest observed mean values of Mg. The mean Mg values in these rotations were significantly higher than the mean values in the CCS, SCC, and CS rotations. Differences in Mg levels among locations were also found. At 0-30 cm, DK, MN, PR, and UR had higher levels of Mg than we found at BT and DS. When deeper depths were examined at BT and DS, Mg showed evidence of possible leaching and accumulation as these sites exhibited the lowest levels of Mg at 0-30cm and had Mg levels comparable to the other sites at 60-90cm.

Difference in soil K levels among locations were found, but not among rotations within any one location (Table A.5, Fig. A.2). In all rotations, DK, MN, and UR exhibited higher levels of K than those observed at BT, DS, and OR. Brownstown, DS, and OR had statistically similar levels of K among all rotations

No differences were observed in TIN, P, S, Ca, or Na levels among rotations within each location (Tables A.5 & A.6 and Fig A.2) but differences in macronutrients were observed among locations. TIN declined with depth at all locations. Monmouth, OR, UR, and DK had higher TIN than BT and DS. Dixon Springs exhibited consistently lower levels of Pbray across all depths, opposingly, OR showed consistently higher levels of Pbray. From 0-15cm all sites exhibited statistically similar levels of S. As the depth of the profile increased, S levels at DK, MN, OR, and UR decreased. The opposite was seen at BT and DS where S was observed to increase more than 40% as depth increased. DeKalb, MN, and UR exhibited high levels of Ca across all depths relative to BT, DS, and OR. From 0-30cm all locations showed statistically similar Na levels; but 30-90cm BT and DS exhibited an almost 20% increase in observed Na values compared to DK, MN, UR, and OR.

Micronutrients

Boron and Mn were the only two micronutrients whose levels were significantly influenced by location and rotation (Table A.7, Fig. A.3). although these micronutrients showed significant location x rotation responses, no differences were found among rotations within each location. At BT, soil B levels in the CCS, CSC, and SCC rotation phases were low relative to these same rotation phases at other locations. In all rotations BT and OR had high levels of Mn compared to all rotations at the other locations. BT and DK exhibited significantly lower levels of B throughout all soil depths relative to the other four locations while B levels at OR were intermediate. It’s important to note that unlike in B, the locations that exhibited the highest levels of B in all rotations were not the locations that exhibited significantly higher levels of Mn throughout the soil profile.

No differences in Fe, Cu, Zn, or Al were observed among rotations at any of the locations although differences among locations were observed (Table A.7, Fig. A.3). Fe levels throughout the soil profile, especially from 30-90cm, at OR, were high relative to all other locations. At BT, DK, MN, OR, and UR, Fe levels declined with depth. At DS, Fe levels declined from 0-30cm but increased more than 10% from 30-90cm. Cu observations were relatively high at DK, OR, and UR. While levels of Cu at MN were moderate compared to both the high levels at DK, OR, and UR and the low levels at BT, DS. No significant differences among locations, at any depth, were observed for Zn. All locations exhibited similar levels of Al from 0-30 cm; but from 30-90cm, BT, DK, and DS levels of Al were observed to increase more than the observations at MN, OR, and UR.

Overall, we found that Bd, K, B, and Mn showed location-specific responses to crop rotation, but only Mg was able to be used to discriminate between rotations among locations. Based on this analysis of soil quality properties, we were unable to identify if any of the crop rotations were more sustainable across the state. We did not find a consistent difference in any of the soil properties examined that could indicate an effect on crop rotation on soil quality. To further explore the differences in soil properties at the six locations, a multivariate analysis was conducted.

Multivariate Analysis

The results found in the univariate analysis were supported by a multivariate approach. The STEPDISC procedure in SAS identified 18 significant variables. Canonical discriminant analysis (CDA) was then used, using the CANDSIC procedure in SAS, to further explore the variables that contributed to maximized L group differences.

Four canonical coefficients were retained by CDA, and they explained 96.3% of the total variance of the data (Table A.8). Can1 explained 67.9% of the total variance while Can 2, Can3, and Can4 explained 28.4% of the data cumulatively. Can1 was strongly positively loaded by SOM, Ca, and Mg, and strongly negatively loaded by Na. Can2 was strongly positively loaded by Cu, and strongly negatively loaded by CEC. Can3 was strongly positively loaded by Mg and

SOM, and strongly negatively loaded by Na. Can4 was strongly positively loaded by Ca, S, and Fe, and strongly negatively loaded by CEC.

The class mean on Can 1 was negative for both BT and DS, and positive for DK, MN, and UR. The OR class mean on Can1 approached zero and fell in between these two groups. The class mean for Can2 approached zero for all locations except for OR, where it was strongly positive. The DK and DS class means for Can3 were also positive. While the class mean for Can3 was negative at both MN and OR. Class means on Can4 are positive, although not strongly, for all sites but DS and UR.

Cross-validation of the CDA (Table A.9) indicated that with the use of 4 linear discriminant functions, correct classification of observations was achieved 98-100% of the time. When rotation was examined using multivariate methods, the STEPDISC procedure did not determine any variables to be useful in segregating observations based on rotation. Not only were no variables selected, all of the discriminant functions in the CDA had eigenvalues less than zero, and thus were not significant. This very efficient segregation of observations based on location corroborated the results found in the univariate analysis.

DISCUSSION

Prior research conducted in Illinois on soil quality has documented the effects of several agronomic practices such as long-term rotations and tillage on various soil quality aspects. For example, Zuber et al. (2015) reported that WAS, TN, and K were affected by crop rotations containing wheat and successive soybean crops. Another study by Villamil et al. (2008) found that WAS, BD, and SOM had the greatest potential as soil quality indicators in no-till systems in Illinois. These studies have focused on crop rotations but have not looked at the CCS rotation nor have they had experimental sites across the state.

In this study, we tested the impact of long-term corn and soybean rotations on soil physical, chemical, and biological properties using univariate and multivariate techniques. We found that rotation had little to no effect on most of the soil properties. Magnesium was the only soil property that was impacted solely by rotation. Although Mg was affected by rotation, there was no clear trend in soil Mg levels among rotations. The lack of a clear trend in rotational effects on Mg levels could be due to several things. All sites had relatively high buffering capacities due to either high SOM or clay content which could minimize effects of rotation on Mg levels. The rotations studied may have also been too similar for differences to be found, although in a study conducted by Houx et al, (2011) where continuous soybean was compared with CS, no differences in Mg were found between the contrasting rotations. Although, an average soybean crop will remove 30% more Mg in the grain than the average corn crop both crops remove less than 8 lb Mg/acre, this could explain the lack of a clear trend among rotations (IPNI, 2012). In similar long-term rotation studies, rotation was found to have no significant effect on Mg (Hickman, 2002; Zuber et al., 2015).

While Mg was the only soil property impacted by rotation, BD showed a three-way interaction of depth x location x rotation. Bulk density was expected to show a response to rotation due to the relationship between soil physical structure and crop residue inputs (Karlen et al., 1994; McDaniel et al., 2014), particularly in rotations that return higher amounts of biomass to the system i.e. CCC and CCS vs CS (Lal et al.,1994). Although a significant interaction was found, the only difference at an individual site was at DS, where BD was 36% lower than all other rotations at the 30-60 cm depth. Varvel and Wilhelm (2010) reported similar reduced BD under continuous corn rotations, however, the significant differences attributed to rotation occurred from 0-30cm compared to a reduction from 30-60cm in this study. Reduced BD in the CCC rotation at the lower depth in this study is likely due to greater aggregate stability from greater root inputs from corn compared to soybean (Coulter et al., 2009). Lack of significant differences in BD among rotations at the other sites may be related to relatively high SOM levels at these locations, as soil organic matter helps preserve soil physical properties such as pore structure, soil aggregation, and aggregate stability (Zhang et al., 2005; Six et al., 1999; Six et al., 2002).

Potassium, B, and Mn showed significant location x rotation interactions. It was expected that in rotations with soybean there would be lower levels of K throughout the soil profile due to 25% greater removal of K in soybean grain when compared to removal in corn (IPNI, 2013), similar to the findings of Russell et al. (2006) and Jagadamma et al. (2008). Contrary to the results of Russell et al. and Jagadamma et al., Houx et al. (2011) found K to be unresponsive to rotation. The lack of a significant response in B levels among rotations within each location is likely due to the relatively low removal rates of B when compared to other nutrients although on average corn removes 73% more B than soybean (IPNI, 2013) In contrast, the need for Mn of soybeans is almost 10 times that of corn but the increased yield of corn may offset this, which could explain the lack of effect of rotation on observed Mn levels among rotations within each location in this study as well as the results reported by Houx et al (2011). The separation of these sites based on mean K values is likely due to differences in soil type and in particular, differences in clay and OM levels, type and degree of weathering of parent material, the type of clay mineral, and soil drainage and aeration (Fernández & Hoeft, 2009). At BT, from 30-90cm, observed values of K increased which is likely due to the increased clay content of the soil at the lower depths. While the separation based on B and Mn is likely due to the close association of B with SOM which is likely the reason for the low levels of B observed at BT. While the lower levels at DK are likely attributed with decreasing SOM and increasing pH at lower depths. The intermediate levels at OR are possibly due to a lack of B-supplying soil minerals in the soil profile due to the more recently deposited alluvial parent material (Mengel et al., 2007).

The findings of this study provide new information about the impact of rotations on soil quality indicators in Illinois. The lack of response to rotation in many of the soil properties is surprising due to the extent to which crop residue is related to virtually all soil physical and chemical properties and processes. The amount of crop residue remaining after harvest has been found to be directly related to SOM (Benjamin et al., 2010) which in turn, is related to higher fertility levels, particularly P and K levels (Franzluebbers et al., 1994; Power et al., 1998). Residue quality, which is dictated by the C:N ration, lignin, polyphenol, and structural carbohydrate concentrations of plant material (Ajwa and Tabatabai, 1994; Martens, 2000), is also important to soil quality and SOM levels as it is directly tied to the rate of decomposition and formation of stable compounds. Crops such as corn, that return low quality residues to the soil system, will have residues that decompose more slowly than high-quality residues such as those from soybean. This slower decomposition will lead to more stable aggregates that resist degradation (Martens, 2000; Blanco-Canqui and Lal, 2004).

Most importantly, this study highlights the importance of inherent soil quality characteristics as influenced by the five soil forming factors identified by Jenny (1941). The grouping of sites in this study is due to differences in inherent soil characteristics. DeKalb, MN, and UR group together. These sites are located in northern Illinois and are classified as Mollisols. These soils were formed under native prairie vegetation and are characterized by a mollic epipedon. The mollic epipedon contributes to higher fertility, greater aggregate stability, and a higher buffering capacity relative to the soil at BT, DS, and OR. The soils at BT and DS which group together, are located in southern Illinois. They were formed in transition areas between native prairie vegetation and deciduous forests, and have lower SOM levels. These soils are older than the soils in the north and thus have experienced greater weathering which has contributed degradation of SOM and lower aggregate stability. An argillic horizon is a distinguishing feature of these soils. The argillic horizon is identified by the illuvial accumulation of silicate clays. Soil above the argillic horizon is often low in fertility while soil below the horizon is higher in fertility. This occurs due to leaching and accumulation of soil minerals. The site located at OR, in west-central Illinois, groups by itself and is an intermediate between the northern and southern sites. This soil is classified as an Entisol because it shows little to no horizon development due to recent alluvial deposition. The main distinguishing feature of this soil is the lack of horizonation which is accompanied by a loamy and clayey texture. Although these soils were formed under different conditions and differ in age and degree of weathering, the lack of response to long-term rotations indicates the resiliency and durability of the soil systems despite outstanding differences (Brady & Weil, 2007; Soil Survey Staff).

CONCLUSION

This study therefore indicates that in Illinois, we cannot identify if any of the studied rotations are more sustainable than one another based solely on the responses of the studied soil quality attributes. We were able to discriminate among rotations within each location using K, B, and Mn. We were able to separate rotations among locations using Mg but we were unable to identify trends in Mg responses to crop rotations. Bulk density was also found to be somewhat responsive to rotation. Our results offer evidence about the resilience and resistance of soils in Illinois and suggest that inherent soil properties are more influential than rotation on soil quality. Agronomic practices such as tillage are perhaps more important to improving soil quality than crop rotation. However, some limitations are worth noting. Although this study addressed common cropping systems in Illinois, the similar management practices along with high yields in both crop species may contribute to reduced differences in soil quality attributes.

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APPENDIX

Table A.1. Site names, abbreviations (Abb), coordinates, mean annual temperature (T, °C), mean annual rainfall (Rain, mm).

Site	Abb	Coordinates	T	Rain	Soil Series
Brownstown	BT	38°57’ N, 88°57’ W	12.9	1040	Cisne silt loam
Dixon Springs	DS	37°45’ N, 88°72’ W	14.7	1252	Grantsburg silt loam
DeKalb	DK	41°50’ N, 88°50’ W	9.5	921	Drummer silty clay loam
Monmouth	MN	40°55’ N, 90°43’ W	10.9	1000	Muscatune silt loam Sable silty clay loam
Orr	OR	39°79’ N, 90°.82’ W	11.6	996	Orion silt loam
Urbana	UR	40°3’ N, 88°14’ W	10.9	1051	Flanagan silt loam

Table A.2. Soil description: Site abbreviation, soil series, soil series description, drainage class (DC), permeability (P), and parent material (PM).

Site	**Soil Series**	**Series Description**	**DC**	**P**	**PM**
BT	Cisne silt loam	Fine, smectitic, mesic Mollic albaqualfs	P	VS	loess
DS	Grantsburg silt loam	Fine-silty, mixed, active, mesic Oxyaquic Fragiudalfs	MW	MS	loess
DK	Drummer silty clay loam	Fine-silty, mixed, superactive, mesic Typic Endoaquolls	P	M	loess
MN	Muscatune silt loam	Fine-silty, mixed, superactive, Aquic Argiudolls	SP	M	loess
	Sable silty clay loam	Fine-silty, mixed, superactive, mesic Typic Endoaquolls	P	M	loess
OR	Orion silt loam	Coarse-silty, mixed, superactive, nonacid, mesic Aquic Udifluvents	SP	M	alluvium
UR	Flanagan silt loam	Fine, smectitic, mesic Aquic Argiudolls	SP	MS	Loess

Table A.3 Mean values of soil pH, cation exchange capacity (CEC, meq/100g), and soil organic matter (SOM, %), determined within Locations (L) at successive depths (D) and for each L and D combination (interaction L x D). Probability values (p-values) and degrees of freedom (df) associated with different sources of variation in the statistical analysis.

Location (L)	**Depth (D)**	**pH**			**CEC**			**SOM**	
L		Mean		SEM§	Mean		SEM	Mean	
BT		5.73		0.18	17.93		0.5	1.33	
DK		6.68		0.19	27.33		0.62	3.01	
DS		4.99		0.18	17.98		0.5	1.21	
MN		6.48		0.18	22.48		0.5	2.82	
OR		6.25		0.21	14.57		0.58	1.81	
UR		5.9		0.18	25.44		0.5	2.81	
	D								
	15	6.05		0.08	17.27		0.32	3.05	
	30	5.88		0.08	19.33		0.32	2.42	
	60	5.83		0.08	21.9		0.32	1.74	
	90	5.96		0.08	24.11		0.32	1.2	
L x D									
BT	15	5.73	a†	0.2	10.11	d	0.73	1.95	c
DK	15	6.27	a	0.22	29.37	a	0.97	5.15	a
DS	15	5.78	a	0.2	11.5	d	0.73	2.3	c
MN	15	6.62	a	0.2	21.46	b	0.73	3.82	b
OR	15	6.1	a	0.23	14.91	c	0.84	2.17	c
UR	15	5.92	a	0.2	21.71	b	0.73	3.72	b
BT	30	6	ab	0.2	10.28	d	0.73	1.32	d
DK	30	6.34	a	0.22	29.99	a	0.97	4.2	a
DS	30	5.13	b	0.2	15.88	c	0.73	1.03	d
MN	30	6.42	a	0.2	22.8	b	0.73	3.39	b
OR	30	6.2	a	0.23	14.43	c	0.84	1.71	c

Table A.3 (cont'd.)

UR	30	5.52	ab	0.2	26.69	a	0.73	3.58	b
BT	60	5.38	bc	0.2	20.39	b	0.73	1.07	c
DK	60	6.73	a	0.22	27.35	a	0.97	1.73	b
DS	60	4.53	c	0.2	21.72	b	0.73	0.81	c
MN	60	6.52	a	0.2	22.01	b	0.73	2.65	a
OR	60	6.51	a	0.23	13.62	c	0.84	1.65	b
UR	60	5.92	ab	0.2	26.96	a	0.73	2.51	a
BT	90	5.81	b	0.2	30.92	a	0.73	0.99	b
DK	90	7.4	a	0.22	22.63	c	0.97	0.94	b
DS	90	4.54	c	0.2	22.83	c	0.73	0.69	b
MN	90	6.36	b	0.2	23.62	c	0.73	1.43	a
OR	90	6.18	b	0.23	15.31	d	0.84	1.71	a
UR	90	6.25	b	0.2	26.4	b	0.73	1.43	a

Source of Variation	df	pH	CEC	SOM
Location (L)	5	<.0001	<.0001	<.0001
Rotation (R)	5	0.26	0.5003	0.9003
L x R	22	0.156	0.3544	0.9985
Depth (D)	3	0.009	<.0001	<.0001
L x D	15	<.0001	<.0001	<.0001
R x D	15	0.536	0.237	0.8527
L x R x D	66	0.998	0.7964	0.9988

§ SEM, standard error of the mean values. † Within a given depth, Location mean values followed with the same lowercase letters are not statistically different at a=0.05.

Table A.4 Mean values of soil bulk density (BD, Mg m^{-3}), penetration resistance (PR, kPa), and water aggregate stability (WAS, %), determined within Locations (L) at successive depths (D) and for each L and D combination (interaction L x D). Probability values (p-values) and degrees of freedom (df) associated with different sources of variation in the statistical analysis.

Location (L)		**BD**		**PR**			**WAS**	
L	SEM	Mean	SEM	Mean		SEM	Mean	
BT	0.09	1.47	0.01	7.17		0.02	3.65	
DK	0.11	1.37	0.02	7.25		0.03	4.24	
DS	0.09	1.47	0.01	7.22		0.02	3.5	
MN	0.09	1.28	0.01	6.94		0.02	4.19	
OR	0.1	1.41	0.02	7.32		0.03	3.9	
UR	0.09	1.36	0.01	6.95		0.02	4.32	
	0.04	1.35	0.01	6.69		0.02	4.01	
	0.05	1.41	0.01	7.22		0.01	3.87	
	0.05	1.38	0.01	7.47		0.01	4.03	
	0.04	1.44	0.01	_		_	3.87	
L x D								
BT	0.09	1.46	0.02	6.9	ab	0.05	3.85	a
DK	0.11	1.3	0.02	7.1	a	0.06	4.27	a
DS	0.09	1.41	0.02	7.07	a	0.05	3.83	a
MN	0.09	1.24	0.02	6.22	c	0.05	4.11	a
OR	0.1	1.36	0.02	6.77	b	0.05	3.98	a
UR	0.09	1.31	0.02	6.26	c	0.05	4.16	a
BT	0.11	1.48	0.02	7.14	c	0.02	3.4	bc
DK	0.14	1.41	0.02	7.37	a	0.03	4.3	a
DS	0.11	1.48	0.02	7.14	c	0.02	3.33	c
MN	0.11	1.32	0.02	7.15	c	0.02	4.19	a
OR	0.12	1.45	0.02	7.47	a	0.03	3.9	ab

Table A.4 (cont'd.)

UR	0.11	1.35	0.02	7.15	c	0.02	4.3	a
BT	0.11	1.43	0.02	7.45	b	0.03	3.77	bc
DK	0.15	1.37	0.02	7.27	b	0.04	4.42	a
DS	0.11	1.45	0.02	7.45	b	0.03	3.53	c
MN	0.11	1.25	0.02	7.45	b	0.03	4.28	ab
OR	0.13	1.44	0.02	7.7	a	0.03	3.85	bc
UR	0.11	1.34	0.02	7.45	b	0.03	4.49	a
BT	0.09	1.53	0.02	_		_	3.57	bc
DK	0.11	1.41	0.02	_		_	3.99	ab
DS	0.09	1.52	0.02	_		_	3.3	c
MN	0.09	1.32	0.02	_		_	4.2	a
OR	0.1	1.39	0.02	_		_	3.88	ab
UR	0.09	1.44	0.02	_		_	4.34	a

Source of Variation	BD	PR	WAS
Location (L)	<.0001	<.0001	<.0001
Rotation (R)	0.8397	0.3943	0.6514
L x R	0.3416	0.1327	0.9598
Depth (D)	<.0001	<.0001	<.0001
L x D	<.0001	<.0001	<.0001
R x D	0.2833	0.4541	0.4107
L x R x D	0.0252	0.905	0.1958

§ SEM, standard error of the mean values. † Within a given depth, Location mean values followed with the same lowercase letters are not statistically different at a=0.05.

Table A.5. Mean values of soil macronutrients 1: Total inorganic nitrogen (TIN, ppm), available phosphorus (P, ppm), and potassium (K, mg/kg), determined within Locations (L) at successive depths (D) and for each L and D combination (interaction T x D). Probability values (p-values) and degrees of freedom (df) associated with the different sources of variation in the statistical analysis.

Location (L)	Depth (D)	TIN			Pbray			K	
Loc		Mean		SEM§	Mean		SEM	Mean	
BT		1.45		0.07	10.84		0.66	4.57	
DK		1.68		0.09	8.15		0.82	4.84	
DS		1.78		0.07	6.30		0.66	4.35	
MN		2.35		0.08	10.27		0.66	4.83	
OR		2.27		0.08	14.24		0.76	4.64	
UR		2.41		0.07	8.70		0.66	5.01	
	D								
	15	2.62		0.04	19.05		0.57	5.08	
	30	2.11		0.04	7.60		0.35	4.54	
	60	1.78		0.04	5.15		0.23	4.53	
	90	1.51		0.04	6.95		0.35	4.65	
L x D									
BT	15	2.29	bc†	0.10	22.08	a	1.31	5.07	a
DK	15	2.54	abc	0.13	16.67	ab	1.81	5.13	ab
DS	15	2.06	c	0.10	14.58	b	1.31	4.57	d
MN	15	2.99	a	0.10	17.58	ab	1.31	5.36	bc
OR	15	2.76	ab	0.11	21.17	a	1.52	5.06	ac
UR	15	3.06	a	0.10	21.54	a	1.31	5.33	ac
BT	30	1.47	c	0.10	9.17	abc	0.80	4.27	a
DK	30	2.01	bc	0.13	10.50	ab	1.05	4.84	a
DS	30	1.85	bc	0.10	3.46	d	0.80	4.14	a
MN	30	2.40	ab	0.10	6.83	bcd	0.80	4.69	a
OR	30	2.25	ab	0.11	12.61	a	0.93	4.61	b
UR	30	2.66	a	0.10	5.75	cd	0.80	4.82	b

Table A.5. (cont'd)

BT	60	1.16	c	0.10	3.88	c	0.54	4.36	a
DK	60	1.30	bc	0.13	3.17	c	0.62	4.63	ab
DS	60	1.82	ab	0.10	2.96	c	0.54	4.32	b
MN	60	2.22	a	0.10	6.63	b	0.54	4.56	b
OR	60	2.06	a	0.11	10.67	a	0.62	4.40	b
UR	60	1.96	a	0.10	4.00	bc	0.54	4.91	b
BT	90	0.87	b	0.10	8.25	b	0.81	4.58	bc
DK	90	0.86	b	0.13	2.25	c	1.06	4.77	ab
DS	90	1.39	ab	0.10	4.21	c	0.81	4.37	c
MN	90	1.81	a	0.10	10.04	a	0.81	4.72	ab
OR	90	1.99	a	0.11	12.50	a	0.93	4.49	bc
UR	90	1.94	a	0.10	3.50	c	0.81	4.96	a

Source of Variation	df	TIN	Pbray	K
Location (L)	5	<.0001	<.0001	<.0001
Rotation (R)	5	0.49	0.112	0.3310
L x R	22	0.141	0.472	0.0300
Depth (D)	3	<.0001	<.0001	<.0001
L x D	15	<.0001	<.0001	<.0001
R x D	15	0.676	0.521	0.526
L x R x D	66	0.701	0.775	0.779

§ SEM, standard error of the mean values. † Within a given depth, Location mean values followed with the same lowercase letters are not statistically different at a=0.05.

Table A.6. Mean values of soil macronutrients 2: Sulfur (S, PPM), calcium (Ca, mg/kg), magnesium (Mg, mg/kg), and sodium (Na, mg/kg) determined within Locations (L) at successive depths (D) and for each L and D combination (interaction T x D). Probability values (p-values) and degrees of freedom (df) associated with the different sources of variation in the statistical analysis.

Location (L)	**Depth (D)**	**S**			**Ca**			**Mg**			**Na**		
Loc		Mean		SEM	Mean		SEM	Mean		SEM	Mean		SEM
BT		2.98		0.03	1348		74.2	5.35		0.11	4.70		0.19
DK		1.88		0.04	3203		83.3	6.82		0.11	3.13		0.20
DS		2.99		0.03	1075		74.2	5.38		0.11	3.81		0.19
MN		2.03		0.03	3022		74.2	6.15		0.11	3.08		0.19
OR		1.92		0.04	1829		85.6	5.54		0.13	3.02		0.22
UR		2.07		0.03	2603		74.2	6.39		0.11	3.13		0.19
	D												
	15	2.24		0.02	2069		37.2	5.46		0.05	3.13		0.09
	30	2.34		0.02	2180		36.6	5.52		0.05	3.34		0.08
	60	2.50		0.02	2120		37.3	6.07		0.05	3.66		0.08
	90	2.38		0.02	2028		33.7	6.45		0.05	4.00		0.08
L x D													
BT	15	2.26	a	0.04	1127	d	86.3	4.47	d	0.12	3.70	a	0.20
DK	15	2.32	a	0.06	3357	a	104.0	6.76	a	0.13	2.95	a	0.22
DS	15	2.32	a	0.04	1395	cd	86.3	4.55	d	0.12	3.05	a	0.20
MN	15	2.19	a	0.04	3016	a	86.3	6.02	ab	0.12	2.95	a	0.20
OR	15	2.08	a	0.05	1782	c	99.6	5.40	b	0.13	2.96	a	0.23
UR	15	2.29	a	0.04	2311	b	86.3	6.19	ab	0.12	3.02	a	0.20
BT	30	2.44	b	0.04	1238	d	85.0	4.56	d	0.12	4.17	a	0.19
DK	30	2.22	bc	0.06	3573	a	101.9	6.76	a	0.13	3.11	a	0.20
DS	30	2.92	a	0.04	1299	d	85.0	4.87	cd	0.12	3.40	a	0.19
MN	30	2.17	c	0.04	3206	a	85.0	5.96	b	0.12	3.10	a	0.19
OR	30	1.89	d	0.05	1869	c	98.1	5.42	bc	0.13	2.98	a	0.22
UR	30	2.25	bc	0.04	2516	b	85.0	6.15	ab	0.12	3.07	a	0.19

Table A.6 (cont'd)

BT	60	3.52	a	0.04	1303	d	86.5	5.77	c	0.12	5.08	a	0.20
DK	60	1.60	d	0.06	3275	a	104.4	6.88	a	0.13	3.20	b	0.21
DS	60	3.46	a	0.04	947	d	86.5	5.82	bc	0.12	4.04	ab	0.20
MN	60	2.05	bc	0.04	3045	ab	86.5	6.10	bc	0.12	3.07	b	0.20
OR	60	1.82	cd	0.05	1849	c	99.9	5.60	c	0.13	3.03	b	0.23
UR	60	1.95	bc	0.04	2809	b	86.5	6.53	ab	0.12	3.17	b	0.20
BT	90	3.70	a	0.04	1722	b	78.6	6.61	a	0.12	5.85	a	0.19
DK	90	1.38	d	0.06	2608	a	91.0	6.90	a	0.13	3.27	b	0.20
DS	90	3.24	b	0.04	660	c	78.6	6.28	ab	0.12	4.75	a	0.19
MN	90	1.70	c	0.04	2820	a	78.6	6.50	ab	0.12	3.19	b	0.19
OR	90	1.87	c	0.05	1818	b	90.7	5.76	b	0.13	3.09	b	0.22
UR	90	1.78	c	0.04	2778	a	78.6	6.69	a	0.12	3.25	b	0.19

Source of Variation	df	S	Ca	Mg	Na
Location (L)	5	<.0001	<.0001	<.0001	<.0001
Rotation (R)	5	0.5886	0.132	0.047	0.094
L x R	22	0.9302	0.869	0.391	0.398
Depth (D)	3	<.0001	<.0001	<.0001	<.0001
L x D	15	<.0001	<.0001	<.0001	<.0001
R x D	15	0.8914	0.103	0.397	0.449
L x R x D	66	0.8557	0.851	0.988	0.913

§ SEM, standard error of the mean values. † Within a given depth, Location mean values followed with the same lowercase letters are not statistically different at a=0.05.

Table A.7. Mean values of soil micronutrients: Boron (B, mg/kg), iron (Fe, mg/kg), manganese (Mn, mg/kg), copper (Cu, mg/kg), zinc (Zn, mg/kg), and aluminum (Al, mg/kg) determined within Locations (L) at successive depths (D) and for each L and D combination (interaction T x D). Probability values (p-values) and degrees of freedom (df) associated with the different sources of variation in the statistical analysis.

Location (L)	**Depth (D)**	**B**			**Fe**			**Mn**	
L		Mean		SEM§	Mean		SEM	Mean	
BT		0.21		0.03	4.9		0.05	3.75	
DK		0.2		0.04	4.62		0.06	3.32	
DS		0.38		0.03	4.98		0.05	3.3	
MN		0.48		0.03	4.79		0.05	3.01	
OR		0.54		0.04	5.33		0.06	4.13	
UR		0.45		0.03	4.8		0.05	3.15	
	D								
	15	0.47		0.02	5.19		0.02	4.36	
	30	0.41		0.02	4.98		0.02	3.67	
	60	0.35		0.02	4.72		0.03	2.61	
	90	0.31		0.02	4.77		0.02	3.05	
L x D									
BT	15	0.29	b	0.04	5.51	a	0.05	4.64	ab
DK	15	0.27	b	0.04	5.13	bc	0.06	3.31	d
DS	15	0.54	a	0.04	5.12	bc	0.05	5.33	a
MN	15	0.56	a	0.04	4.88	c	0.05	4.21	bc
OR	15	0.56	a	0.04	5.42	ab	0.06	4.42	bc
UR	15	0.53	a	0.04	5.08	bc	0.05	3.74	cd
BT	30	0.19	b	0.04	4.89	bc	0.05	4.13	Ab
DK	30	0.17	b	0.05	5.14	ab	0.06	2.98	c
DS	30	0.42	a	0.04	4.68	c	0.05	3.97	ab

Table A.7 (cont'd.)

MN	30	0.51	a	0.04	4.82	bc	0.05	3.55	bc
OR	30	0.58	a	0.04	5.43	a	0.06	4.4	a
UR	30	0.53	a	0.04	5.09	ab	0.05	2.86	c
BT	60	0.17	c	0.04	4.44	cd	0.06	2.92	b
DK	60	0.16	c	0.04	4.04	d	0.08	2.88	b
DS	60	0.31	bc	0.04	4.96	ab	0.06	2.03	c
MN	60	0.46	ab	0.04	4.72	bc	0.06	1.91	c
OR	60	0.54	a	0.04	5.25	a	0.07	4.11	a
UR	60	0.38	ab	0.04	4.69	bc	0.06	2.3	bc
BT	90	0.17	c	0.04	4.77	b	0.06	3.3	b
DK	90	0.19	bc	0.05	4.18	c	0.07	4.11	a
DS	90	0.27	bc	0.04	5.17	a	0.06	1.86	c
MN	90	0.37	ab	0.04	4.75	b	0.06	2.37	c
OR	90	0.48	a	0.04	5.22	a	0.06	3.61	ab
UR	90	0.36	ab	0.04	4.34	c	0.06	3.69	ab

Source of Variation	df	B	Fe	Mn
Location (L)	5	<.0001	<.0001	<.0001
Rotation (R)	5	0.867	0.4509	0.279
L x R	22	0.018	0.1617	0.031

Table A.7 (cont'd)

Depth (D)	3	<.0001	<.0001	<.0001
L x D	15	<.0001	<.0001	<.0001
R x D	15	0.13	0.6747	0.642
L x R x D	66	0.865	0.9969	0.985

§ SEM, standard error of the mean values. † Within a given depth, Location mean values followed with the same lowercase letters are not statistically different at a=0.05.

Table A.8. Raw canonical coefficients of each soil quality attribute contributing to the discriminating power of each canonical function; eigenvalues and percent of variance explained by each function; and mean values of the discriminant functions found for each location under study.

Raw Canonical Coefficients

Variable	**Can1**	**Can2**	**Can3**	**Can4**
moist	-0.53	0.13	-0.13	-0.03
Bd	-0.27	0.25	0.28	0.00
CEC	-0.74	-1.16	-0.86	-1.20
pH	0.20	0.02	-0.56	0.70
SOM	0.96	-0.74	1.49	0.03
WAS	0.30	-0.10	-0.40	0.27
NO3	0.11	0.23	0.18	-0.34
K	0.08	-0.08	-0.67	0.14
Sul	-0.48	0.17	0.41	0.92
Ca	1.11	0.05	-0.69	1.37
Mg	1.97	0.40	2.69	-0.19
Na	-0.94	-0.12	-1.00	0.22
Bor	0.13	0.14	-0.55	-0.76
Fe	-0.31	0.37	-0.05	0.82
Mn	-0.31	0.26	0.98	-0.27
Cu	0.37	1.83	-0.25	-0.27
Zn	-0.20	-0.13	0.05	0.16
Al	0.44	0.56	0.51	0.55
Eigenvalues	14.8	2.7	2.4	1.1
Variance explained	67.9	12.3	10.9	5.2

Class Means on Canonical Variables

Loc	**Can1**	**Can2**	**Can3**	**Can4**
BT	-4.15	-0.93	0.11	1.48
DK	6.49	0.82	3.31	1.11
DS	-4.43	-0.14	1.28	-1.29
MN	2.58	-1.59	-1.90	0.23
OR	-0.52	3.61	-1.47	0.16
UR	3.36	-0.59	-0.20	-1.09

Table A.9. Cross-validation results showing the number of observations and percent of observations correctly classified for each location under study based on the discriminant function obtained with CDA on the selected soil quality attributes.

From:	**Classified into:**						
Location	**BT**	**DK**	**DS**	**MN**	**OR**	**UR**	**Total**
BT	94	0	2	0	0	0	96
	98	0	2	0	0	0	100
DK	0	48	0	0	0	0	48
	0	100	0	0	0	0	100
DS	0	0	96	0	0	0	96
	0	0	100	0	0	0	100
MN	0	0	0	87	0	1	88
	0	0	0	99	0	1	100
OR	0	0	0	1	71	0	72
	0	0	0	1	99	0	100
UR	1	0	0	0	1	94	96
	1	0	0	0	1	98	100
Total	95	48	98	88	72	95	496
	19.2	9.7	19.8	17.7	14.5	19.2	100
Priors	0.19	0.10	0.19	0.18	0.15	0.19	

Error Count Estimates for Loc							
	BT	**DK**	**DS**	**MN**	**OR**	**UR**	**Total**
Rate	0.02	0.00	0.00	0.01	0.01	0.02	0.01
Priors	0.19	0.10	0.19	0.18	0.15	0.19	

Fig A.1. Mean values of general soil quality attributes by location: Mean values of soil pH, cation exchange capacity (CEC, meq/100g), soil organic matter (SOM, %), soil bulk density (BD, Mg m^{-3}), penetration resistance (PR, kPa), water aggregate stability (WAS, %).

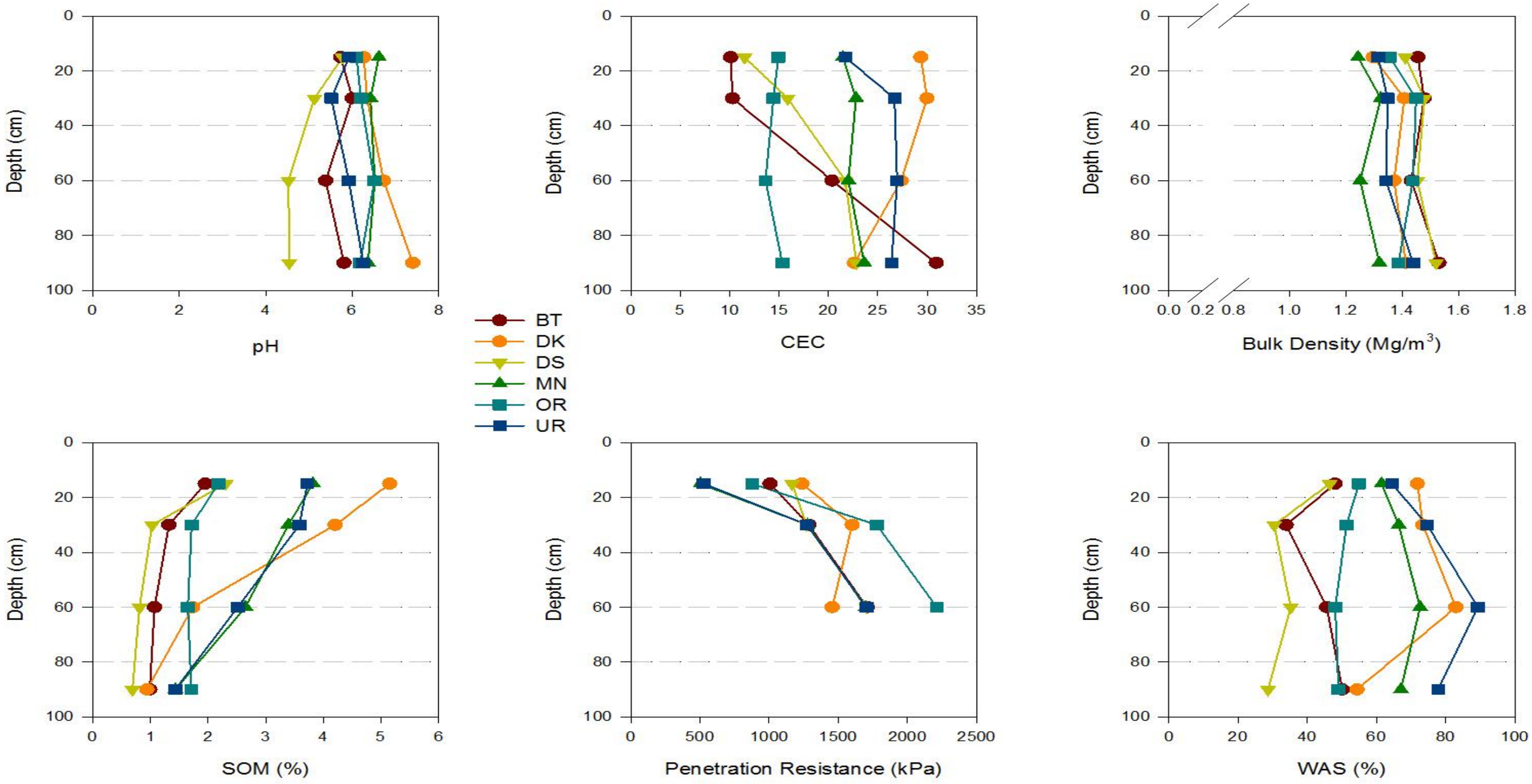

Fig A.2. Mean values of soil macronutrients by location: Total inorganic nitrogen (TIN, ppm), available phosphorus (P, ppm), potassium (K, mg/kg), sulfur (S, ppm), calcium (Ca, mg/kg), magnesium (Mg, mg/kg), and sodium (Na, mg/kg).

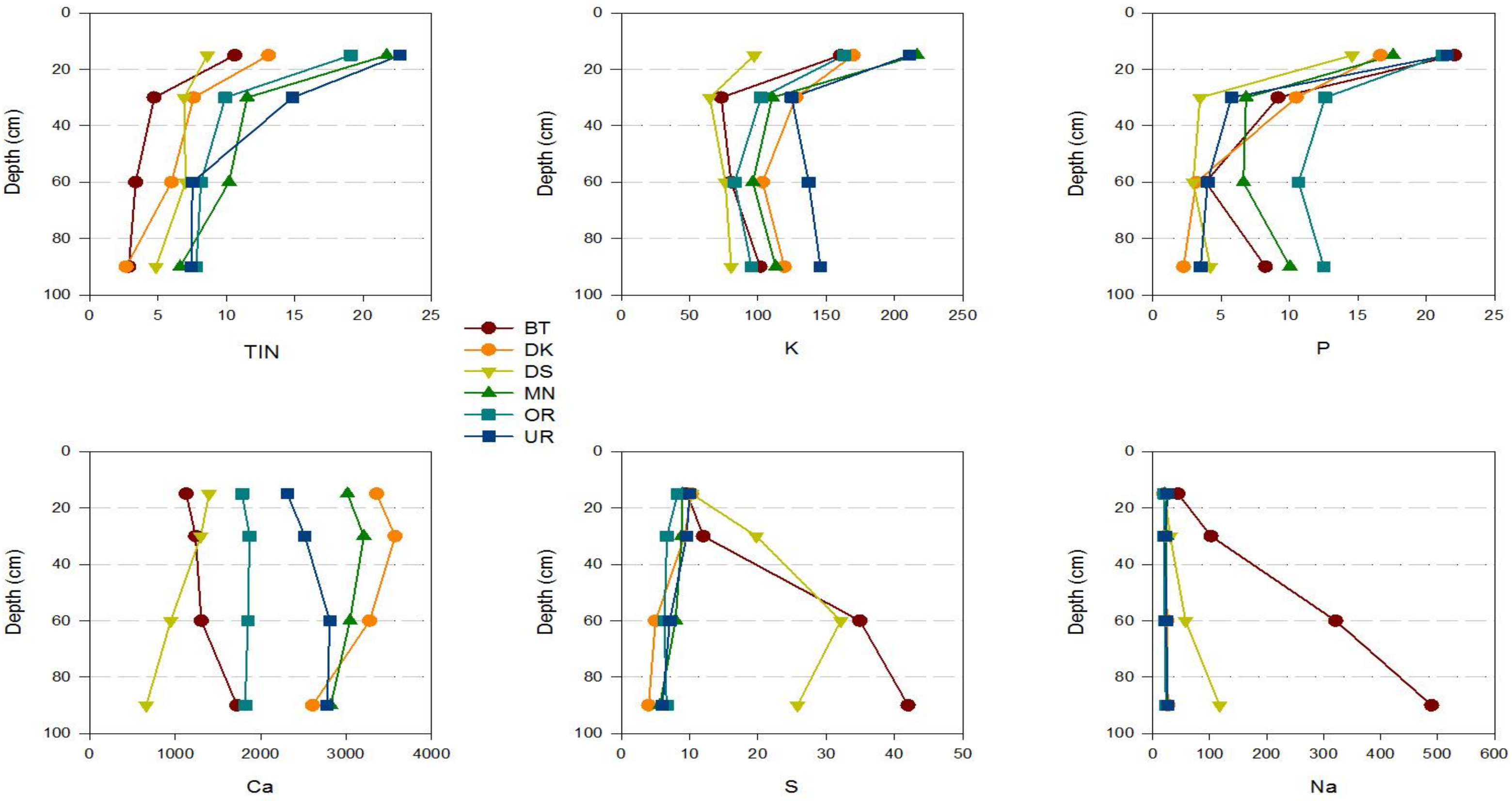

Fig A.3. Mean values of soil micronutrients by location: Boron (B, mg/kg), iron (Fe, mg/kg), manganese (Mn, mg/kg), copper (Cu, mg/kg), zinc (Zn, mg/kg), and aluminum (Al, mg/kg).