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Tillage, Cover Crop and Crop Rotation Effects on Selected Soil Chemical Properties

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Abstract: Research results still vary, especially between locations, on the effects of agricultural practices on soil chemical properties and crop yield, and not all reasons for the variation are fully understood. Thus, this study investigated the influence of tillage, cover crop and crop rotation management practices on selected soil chemical properties. The study was conducted on a silt-loam soil in central Missouri during the 2011 to 2013 growing seasons. The soil was managed by moldboard plow tillage at two levels (tillage [till] vs. no-tillage [NT]). Cover crop management included cereal rye (*Secale cereale*) at two levels (cover crop [CC] vs. no cover crop [NC]). The main crops that were grown were a corn (*Zea mays* L.) and soybean (*Glycine max* L.) rotation. The soil samples were collected each year at 0–10 cm, 10–20 cm, 20–40 cm and 40–60 cm depths for the analysis of soil chemical properties. The results showed that after 3 years of study, the relative increase in percent soil organic matter (OM) was 4% under the no-till management as compared with moldboard plow tillage. In addition, the relative change in the percentage of OM was 8% greater in the CC management compared with NC. Furthermore, the results show a significant improvement (p = 0.0304) in total carbon with a combination of no-till management and a corn/soybean rotation as compared with continuous corn and soybean. The interaction effects of the management practices on the soil chemical properties were difficult to predict throughout the study.

Keywords: tillage; cover crop; crop rotation; soil organic matter

1. Introduction

Soil and crop management practices such as tillage, cover cropping and crop rotation can affect soil quality and soil health indicators [1–3], specifically the soil pH and organic matter levels, and these properties can determine the chemical state of a soil. The chemical state of the soil in turn affects microbial activities and as a direct consequence also affects the soil health [4] and environmental quality.

Several authors have documented the beneficial effects of these practices on soil chemical properties. For example, conservation tillage has been reported to increase C sequestration from the atmosphere [5,6]. Furthermore, several authors [7–12] have pointed out that no-tillage (NT) can act as a sink of C, based on the increase of organic carbon (OC) content in the upper 20 cm of the soil. At this depth, the absence of plowing, deposition of residues on the soil surface, and slower turnover of the OC are among the reasons for sequestering C. Evaluating two long-term (18 and 20 years old) tillage sites in Michigan, Senthilkumar et al. [13] found a greater loss of soil C when conventional tillage (CT) was used as compared to NT. They also noticed that in some cases, NT increased the soil C content.

Crop rotation has shown some positive effects compared to monoculture, as demonstrated by its ability to enhance soil organic carbon (SOC) [14,15], especially in crop rotations that include a leguminous species [4,15–17], as is the case in the current study. Legumes can add both organic matter and N to the soil [4,18] and thus enhance soil fertility. The C/N ratio of a crop is a determining factor for soil N availability, regardless of the placement of their residues in the soil [19]. Leguminous crops have low C/N ratios, as opposed to non-leguminous crops that have a higher carbon content, and this therefore favors nitrogen immobilization over nitrogen mineralization by soil microorganisms. These researchers [19] reported that the changes observed in total organic C and N in response to tillage and rotation were significantly related to the quantity and quality of plant residues returned to the soil.

Nitrogen fertilization (used in this study) can also increase OC by increasing the crop yield and the amount of residue returned to the soil compared with no fertilization [20]. Thus, crop rotations (especially with a legume) and nitrogen fertilization can influence the OC sequestration in tilled and non-tilled soils due to differences in the mineralization rates of crop residues and soil organic matter.

Cover crops (CC) can influence soil hydraulic properties like the water content, pore size distribution and water infiltration, and these may in turn influence the soil chemistry. For example, Haruna et al. [21] reported that CC improved macropores by 24% compared with NC, and this increased the soil saturated hydraulic conductivity. Furthermore, Haruna et al. [22] reported that CC management improved water infiltration parameters compared with NC management. Under laboratory conditions, [23] reported that CC improved the soil water content and OC, and this led to a higher heat capacity under CC management compared with NC management. All these properties may influence soil chemical properties directly and indirectly.

Despite their numerous benefits, these practices can also have a negative impact on soil chemical properties [24]. For example, the physical act of tillage disrupts the soil structure and can cause the increased decomposition of previously stable soil organic matter [6].

Across the Midwestern United States, studies have been carried out on the effects of agricultural management practices on soil properties (see [25]). However, in central Missouri, where tillage and crop rotation are also practiced, studies that quantify the combined effects of the various agricultural management practices on soil chemical attributes are not readily available. Such information will be useful for recommending management practices to producers to enhance the productivity and sustainability of crop production. Therefore, the objective of this study was to assess the combined effects of tillage, cover crop and crop rotation on the chemical properties of a silt-loam soil.

2. Materials and Methods

2.1. Site Description

The study was conducted at Lincoln University of Missouri's Freeman farm in Jefferson City. Its geographic coordinates are 38°58′16″ N latitude and 92°10′53″, with an elevation of 166 m above sea level and a 2% slope. The soil is classified by the USDA as a Waldron silt loam (Fine, smectitic, calcareous, mesic Aeric Fluvaquents). It has a fine sub-angular blocky structure in the Ap horizon, which extends from the surface to a depth of about 20 cm. The Ap horizon is underlain by C1 (20–35 cm), C2 (35–43 cm), Cg1 (43–71 cm), Cg2 (71–101 cm) and Cg3 (101–152 cm) horizons, all of similar structure. This lack of a B-horizon further makes this study unique as there are fewer studies on such shallow, less developed but agriculturally important soils. The mean annual average temperature at the study site is 13 °C, with January (−6 °C) and July (31 °C) being the coldest and warmest months, respectively. The mean annual precipitation between 2011 and 2013 was 990.6 mm, with the months of May and August usually receiving the greatest and least precipitations, respectively. However, 2012 was a particularly dry year with an average precipitation of about 752.09 mm.

Twenty-four plots (each measuring 12.2 × 21.3 m) of each corn (*Zea mays* L.) and soybean (*Glycine max*) were established on a 4.05 ha field and arranged in a 3-factor factorial design with 3 replications. The 3 factors (treatments) were two types of tillage management (no-tillage and conventional tillage), two types of cover crop (cereal rye [*Secale Cereale*]) management (no-cover crop and cover crop) and four types of rotation (continuous corn, continuous soybean, corn/soybean and soybean/corn rotations). The type of tillage was moldboard plow, henceforth called conventional tillage. Tillage was done in the spring season of each year, to a depth of about 15 cm. After tillage, the field was disked. Corn and soybean were planted each year in the months of May and June respectively and harvested in late October. Cereal rye was planted in 12 plots of each corn and soybean in October, after harvesting the corn and soybean crops. It was terminated in May of the following year by using a dilute solution of glyphosate [*N*-(phosphonomethyl) glycine; $C_3H_8NO_5P$] in water in a ratio of 1:3. All corn and soybean plots received 26 kg N ha^{-1}, 67 kg P_2O_5 ha^{-1}, and 67 kg K_2O ha^{-1}, applied by broadcasting just before planting. However, the corn plots received an additional 202 kg N ha^{-1} from urea incorporation. Urea was injected into the no-till plots. More information about the study site can be found in [21,22,26].

2.2. Soil Sampling and Analysis

The soil samples were collected in each plot using cylindrical cores of a diameter of 6.3 cm at four different depths: 0–10, 10–20, 20–40 and 40–60 cm. this corresponds to depths 1, 2, 3 and 4, respectively. Due to the differences in sampling depths, the cylindrical cores that were used were of two different heights: 10 cm (for samples at 0–10 and 10–20 cm) and 20 cm (for samples at 20–40 and 40–60 cm). The volumes of the cores were 311.57 cm^3 (for the 10 cm probe) and 622.98 cm^3 (for the 20 cm probe). The soil samples were taken after the full emergence of the seedlings. The bulk density was measured using the core method [27]. The oven-dry samples were crushed and passed through a <2 mm sieve and sent to a commercial laboratory for the determination of selected soil chemical properties. The properties included the soil pH, cation exchange capacity (CEC), carbon/nitrogen (C/N) ratio and the percentage of Mg, Ca, and Na on the soil CEC. The soil organic matter was measured by combustion (loss of ignition at 360 °C) [28], and the total carbon (TC) was calculated by dividing the soil organic matter by a factor of 2.0 [29].

2.3. Statistical Analysis

A statistical analysis was carried out using Statistix software ver 9.0. A test of the variance homogeneity within the different treatments was conducted to evaluate the variability in the measurements. The data was normally distributed. Given that the cover crop was planted at the end of the first year (2011) and that its effects could be assessed only in the second (2012) and third (2013) years, we used, for the analysis of variance, a two factors factorial design in 2011 (Table 1), and four factors factorial designs in 2012 (Table 2) and 2013 (Table 3). The statistical differences were reported at $p \leq 0.05$.

Table 1. Tillage and sampling depth effects on selected soil chemical properties in 2011.

Treatment	pH	OM (%)	TC (%)	C/N	CEC (Cmol kg^{-1})	Base Saturation (%)		
						Mg	Ca	Na
Tillage (TL)								
No-Till	6.78 a	1.69 a	0.91 a	8.95 b	14.22 a	22.90 a	65.16 a	0.95 a
Conventional Tillage	6.79 a	1.64 a	1.02 a	9.28 a	14.81 a	22.48 a	65.81 a	0.96 a
Depth of Sampling (DS)								
0–10 cm	6.71 a	1.66 a	0.93 a	9.05 a	14.57 a	22.43 a	64.06 c	0.96 a
10–20 cm	6.80 a	1.66 a	0.91 a	9.07 a	15.09 a	22.81 a	65.88 b	0.90 a
20–40 cm	6.79 a	1.65 a	0.93 a	9.15 a	13.88 a	22.52 a	65.49 b	0.97 a
40–60 cm	6.85 a	1.68 a	1.08 a	9.18 a	14.53 a	22.99 a	66.49 a	0.94 a

Table 1. *Cont.*

Analysis of variance		Base Saturation (%)							
Sources of variation	**df**	**pH**	**OM**	**TC**	**C/N**	**CEC**	**Mg**	**Ca**	**Na**
Block	2	*p*-values							
TL	1	0.830	0.368	0.202	0.001	0.109	0.337	0.258	0.834
DS	3	0.288	0.982	0.456	0.722	0.137	0.788	0.023	0.326
Interactions									
TL × DS	3	0.732	0.633	0.593	0.097	0.685	0.823	0.398	0.837
Error (MS)	182	0.136	0.129	0.352	0.412	6.328	9.078	15.84	12.93
Total	191								

Mean values followed by different alphabet in the same treatment and sampling depth are statistically significant at the 0.05 probability level. *p*-values ≤ 0.05 are statistically significant. C/N: Carbon-Nitrogen ratio; CEC: Cation exchange capacity; OM: Organic matter; TC: Total Carbon.

Table 2. Tillage, crop rotation, cover crop, and sampling depth effects on selected soil chemical properties in 2012.

Treatments		**pH**	**OM (%)**	**TC (%)**	**C/N**	**CEC (Cmol kg^{-1})**	**Base Saturation (%)**		
							Mg	**Ca**	**Na**
Tillage (TL)									
No-Till		6.76 b	1.50 a	0.90 a	8.58 a	13.66 a	22.31 b	64.80 a	1.10 a
Conventional Tillage		6.89 a	1.47 a	0.89 a	8.87 a	13.39 a	23.65 a	65.09 a	1.25 a
Crop Rotation (CR)									
Continuous Corn		6.86 a	1.56 ab	0.96 a	8.87 a	13.59 a	23.38 a b	64.88 a	1.22 a
Continuous Soybean		6.84 a	1.36 c	0.84 b	8.84 a	13.23 a	22.77 a b	65.29 a	1.31 a
Corn Soy rotation		6.74 a	1.41 bc	0.84 b	8.74 ab	13.49 a	22.25 b	64.67 a	1.11 a
Soybean-Corn rotation		6.85 a	1.62 a	0.95 a	8.28 b	13.80 a	23.50 a	65.14 a	1.06 a
Cover Crop (CC)									
No-Rye		6.83 a	1.42 b	0.87 a	8.48 b	13.10 b	22.75 a	65.21 a	1.18 a
Rye		6.81 a	1.56 a	0.93 a	8.88 a	13.95 a	23.20 a	64.68 a	1.17 a
Depth of Sampling (DS)									
0–10 cm		6.34 b	1.88 a	1.10 a	9.08 a	13.62 b	20.09 b	60.15 b	1.11 a
10–20 cm		6.93 a	1.20 c	0.78 c	9.04 a	12.40 c	23.24 a	65.73 a	1.15 a
20–40 cm		7.04 a	1.34 b	0.77 c	8.27 b	12.74 c	24.15 a	67.08 a	1.26 a
40–60 cm		6.98 a	1.54 b	0.94 b	8.34 b	15.33 a	24.42 a	66.82 a	1.19 a
Analysis of variance		**Base Saturation (%)**							
Sources of variation	***df***	**pH**	**OM**	**TC**	**C/N**	**CEC**	**Mg**	**Ca**	**Na**
Block	2	*p*-values							
TL	1	0.0193	0.6674	0.7415	0.2478	0.4181	0.0022	0.5759	0.1708
CR	3	0.409	0.0056	0.0163	0.0812	0.6691	0.1435	0.763	0.3732
CC	1	0.7479	0.015	0.0949	0.0186	0.0103	0.2961	0.298	0.9729
DS	3	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001	0.0001	0.8147
Interactions									
TL × CC	1	0.6365	0.8491	0.3019	0.0223	0.9515	0.7127	0.4469	0.4579
CR × CC	3	0.0013	0.2716	0.1600	0.5863	0.3058	0.0009	0.2509	0.7655
TL × CC × DS	3	0.8129	0.0973	0.0076	0.3105	0.0730	0.8888	0.8115	0.6116
Lack of fit	42								
Error (MS)	135	0.1451	0.1672	0.0633	1.366	5.0535	8.847	12.41	0.581
Total	191								

Mean values followed by different alphabet in the same treatment and sampling depth are statistically significant at the 0.05 probability level. *p*-values ≤ 0.05 are statistically significant. C/N: Carbon-Nitrogen ratio; CEC: Cation exchange capacity; SOM: Organic matter; TC: Total Carbon.

Table 3. Tillage, crop rotation, cover crop and sampling depth effects on selected soil chemical properties in 2013.

Treatments	**pH**	**OM (%)**	**TC (%)**	**C/N**	**CEC (Cmol kg^{-1})**	**Base Saturation (%)**		
						Mg	**Ca**	**Na**
Tillage (TL)								
No-Till	7.00 a	1.68 a	0.92 a	8.79 a	11.68 a	24.45 b	66.30 a	0.63 a
Conventional Tillage	7.02 a	1.61 b	0.85 b	8.48 b	11.95 a	25.44 a	65.04 b	0.60 a
Crop Rotation (CR)								
Continuous Corn	6.97 a	1.64 ab	0.90 a	8.63 a	11.80 ab	24.61 a	65.76 a	0.63 a
Continuous Soybean	7.03 a	1.56 b	0.83 b	8.61 a	11.29 b	24.81 a	66.18 a	0.62 a
Corn Soy rotation	6.99 a	1.70 a	0.92 a	8.73 a	12.04 a	24.56 a	66.04 a	0.63 a
Soybean-Corn rotation	7.04 a	1.69 a	0.89 a	8.56 a	12.13 a	25.81 a	65.10 a	0.59 a
Cover Crop (CC)								
No-Rye	7.05 a	1.57 b	0.86 b	8.64 a	11.23 b	24.69 a	66.06 a	0.65 a
Rye	6.97 a	1.72 a	0.91 a	8.63 a	12.40 a	25.20 a	65.48 a	0.58 b
Depth of Sampling (DS)								
0–10 cm	6.80 c	1.78 a	0.99 a	9.03 a	11.34 c	23.60 b	64.28 b	0.59 a
10–20 cm	7.10 ab	1.47 c	0.80 c	8.77 a	11.46 c	25.30 a	65.97 a	0.64 a
20–40 cm	7.13 a	1.64 b	0.88 b	8.44 b	11.95 b	25.26 a	66.85 a	0.64 a
40–60 cm	7.00 b	1.69 ab	0.88 b	8.30 b	12.83 a	25.63 a	65.98 a	0.60

Analysis of variance						**Base Saturation (%)**			
Sources of variation	**df**	**pH**	**OM**	**TC**	**C/N**	**CEC**	**Mg**	**Ca**	**Na**
Block	2					*p*-values			
TL	1	0.7308	0.0483	0.0067	0.0041	0.1681	0.0108	0.0014	0.290
CR	3	0.5717	0.0366	0.0307	0.7017	0.0115	0.0764	0.097	0.707
CC	1	0.0634	0.0001	0.0278	0.9681	0.0001	0.1825	0.0771	0.006
DS	3	0.0001	0.0001	0.0001	0.0001	0.0001	0.001	0.0001	0.277
Interactions									
TL × CR	3	0.3434	0.1902	0.0304	0.3479	0.0078	0.1873	0.3443	0.126
CR × CC	3	0.0028	0.5676	0.3786	0.6106	0.0038	0.0036	0.7357	0.009
TL × CR × CC	3	0.0502	0.7325	0.9003	0.8452	0.1135	0.081	0.5155	0.0053
Lack of fit	37								
Error (MS)	135	0.0859	0.0670	0.0274	0.5458	1.802	6.985	5.147	0.0273
Total	191								

Mean values followed by different alphabet in the same treatment and sampling depth are statistically significant at the 0.05 probability level. *p*-values ≤ 0.05 are statistically significant. C/N: Carbon-Nitrogen ratio; CEC: Cation exchange capacity; OM: Organic matter; TC: Total Carbon.

3. Results and Discussion

The results from the first year of the study are shown in Table 1. The bulk density and water content results can be found in [26]. There was no significant difference between the tillage practices for the bulk density; however, both the volumetric and gravimetric water contents were significantly higher under NT compared with the tillage management [26]. In the current study, there was no significant interaction among the management practices for any of the soil chemical properties analyzed in the first year. However, the tillage and sampling depths significantly affected the C/N ratio and the percentage of calcium saturation on CEC, respectively ($p < 0.05$) (Table 1). The percentage of calcium saturation on CEC was lowest in the top 10 cm and greatest in the 40–60 cm depth. The C/N ratio was 3.6% greater under the tillage management as compared with the no-till management. This suggests that NT can improve N mineralization as compared with tillage. Soil properties often change with an increasing soil depth because of an increasing soil bulk density, decreasing the soil porosity, water content and natural heterogeneity resulting from the chemical composition of the parent materials. A possible reason for the lack of interaction might be that this was the first year of study.

The effects of the tillage, cover crop and crop rotation on the soil chemical properties in the second year of the study (2012) are shown in Table 2. The significant interactions that were found were: the tillage x cover crop interaction for the C/N ratio ($p < 0.05$), the cover crop x crop rotation interaction for the soil pH and the percentage of magnesium saturation of the CEC ($p < 0.001$), and the tillage x cover crop x depth of sampling interaction for TC ($p < 0.05$). The tillage x cover crop interaction for the C/N ratio is shown in Figure 1, and it suggests that the C/N ratio was similar for no-till with and without CC and for conventional till with CC but was highest in conventionally tilled plots with NC. These results are in contrast to those reported by [30], who found that the soil organic C, total N, and C/N ratios were significantly higher in the no-till treatment (planted to rye as in our study) than in the conventional tillage treatment at the 0–5 cm depth but not at the lower depth. However, this study [30] was conducted after more than 10 years of tillage/no-till treatments application, while the current study was in the second year.

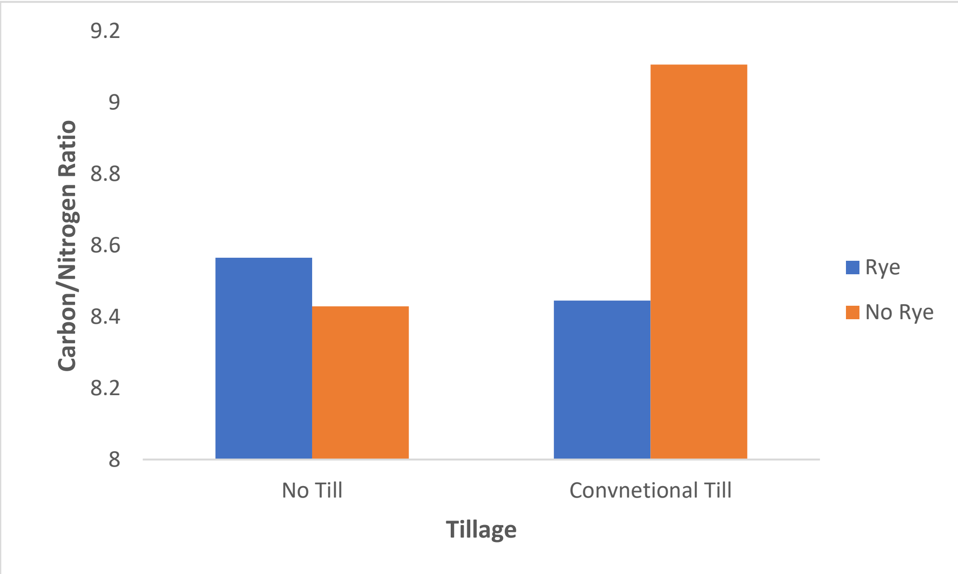

Figure 1. Effect of tillage and cover crop interaction on C/N ratio.

The crop rotation x cover crop interaction for the soil pH was significant (Table 2, Figure 2). It shows that under the CC management, the soil pH was highest under the continuous corn rotation system and lowest under the continuous soybean rotation. Under the NC management, the soil pH was lowest under the corn/soybean rotation. One possible reason for this result may be the additional nitrogen requirements of corn. Urea has been reported to increase soil acidity [31]. The extra urea applied for the corn might have slightly acidified the soil. This can reduce some nutrient availability in the soil solution and reduce nutrient runoff.

The soil chemical properties were also significantly affected by the tillage, cover crop, rotation and depth of sampling. The depth of sampling, in particular, significantly affected all soil chemical properties, except the percentage of sodium saturation on the CEC ($p < 0.001$). The soil pH was lower under NT compared with the tillage management. This could be due to the OM content. Even though OM was slightly lower under the tillage management, the physical act of tillage can better mix the OM into the soil compared with NT. Thus, the results from the current study shows that tillage may be a viable alternative if a rapid soil pH change is required.

The soil organic matter was lowest under the continuous soybean rotation, probably due to the lack of biomass. The total carbon results were similar to those of OM, as expected. Relatively, OM was about 9% higher under the CC management compared with the NT management, probably due to the CC residue return to the soil. Other researchers have reported similar findings [23,32]. As a result of the higher OM, the soil CEC was about 6% higher under the CC management as compared to the NT management. This can improve nutrient retention, crop productivity and environmental sustainability.

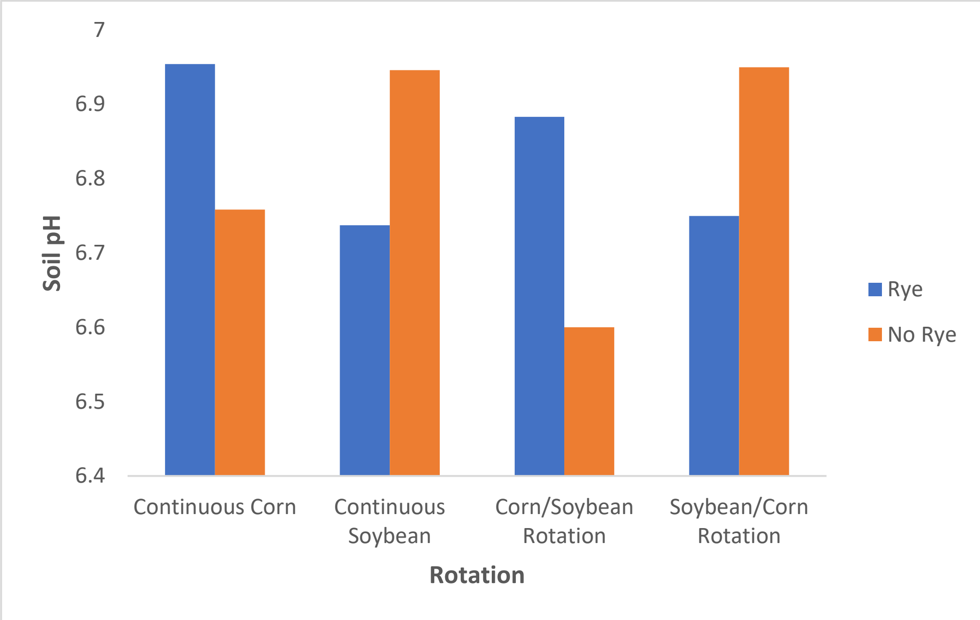

Figure 2. Effect of crop rotation and cover crop interaction on soil pH.

Only two significant interactions (the crop rotation and cover crop for the pH and percent magnesium saturation on CEC) found in the second year of the study were noticed in the third year of the study (2013). The inconsistency of the interactions between the various management practices from one year to another points to their complexity and how difficult it may be for a farm manager to predict their effect. Other significant interactions found in 2013 included: the tillage x crop rotation for CEC (Figure 3) and TC ($p < 0.05$), the crop rotation x cover crop for CEC, the percent Mg^{2+} saturation on CEC and percent Na^{+} saturation on CEC; ($p < 0.01$), and the tillage, crop rotation and cover crop interactions for the pH and percent Na saturation on CEC ($p < 0.05$).

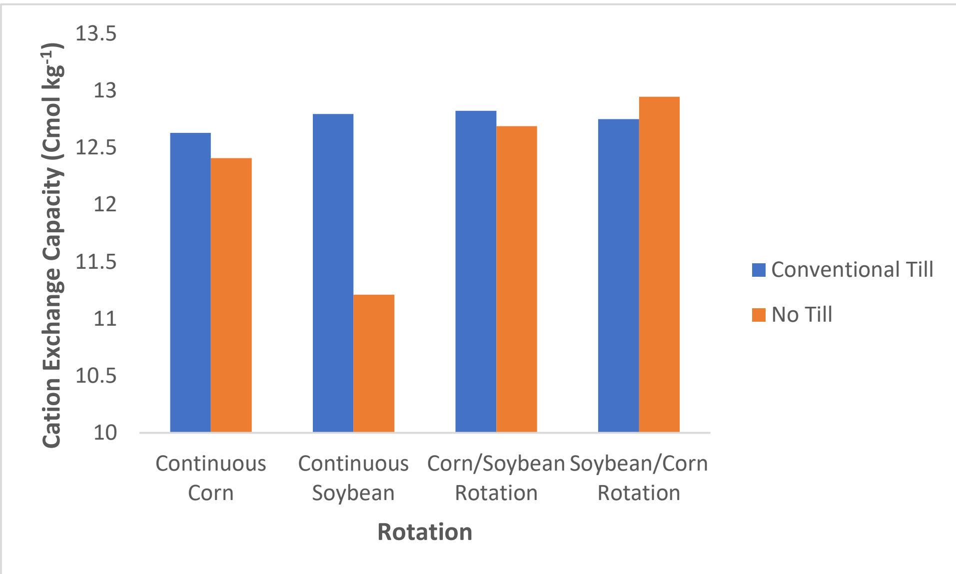

Figure 3. Effect of crop rotation and tillage interaction on cation exchange capacity.

The crop rotation x tillage interaction for CEC is discussed in Figure 3. It shows that CEC was lowest in the continuous soybean rotation under the NT management and highest in the NT management under the soybean/corn rotation. Under the tillage management, CEC was very similar for all of the crop rotation cycles. This suggests that after three years of implementation, the tillage management can reduce the variability of nutrient availability. Figure 4 shows the interaction between the crop rotation and cover crop for CEC. Similar to the crop rotation and tillage interaction, the soybean/corn rotation had the greatest CEC in the CC plots.

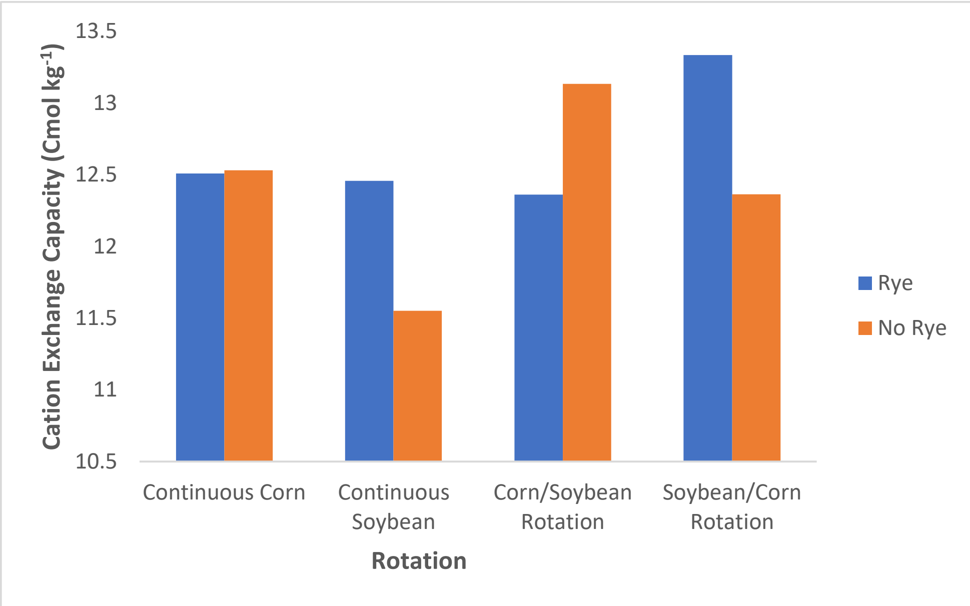

Figure 4. Effect of crop rotation and cover crop interaction on cation exchange capacity.

The soil pH and the percentage of Na^+ saturation on the CEC were significantly affected by the crop rotation x cover crop interaction and the tillage x crop rotation x cover crop interactions (Table 3). For the soil pH, the interaction suggests that the soil pH tended to be greater when rye was planted prior to a corn/soybean rotation and also when rye was planted without tillage prior to a corn/soybean rotation. The percentage of Na^+ saturation on CEC was generally the greatest under CC with the corn/soybean rotation and the lowest under the no-cover crop management with the corn/soybean rotation. Under the conventional tillage management, the percentage of Na^+ saturation on CEC was the greatest under cover crop with the soybean/corn management. Under the no-till management, the percentage of Na^+ saturation on CEC was the greatest under cover crop with the corn/soybean management.

Most of the significant main effects observed in 2012 were repeated in 2013. For example, OM was significantly affected by the tillage, crop rotation, cover crop and depth of sampling (Table 3). The relative changes in the percent organic matter were 4% greater under the no-till management compared with conventional tillage. This is expected since tillage mixes the soil, reduces aggregation and increases the rate of decomposition of organic materials [33–35].

On average, OM was greater within rotation compared with monoculture. In fact, OM was the greatest in the corn/soybean rotation and lowest under the continuous soybean plots. This could be because of the N availability from the soybean, which can increase the corn residue decomposition rates, thus transitioning to more OM as compared with the corn monoculture residues. The relative changes in the percentage of OM were 8% greater within the plots planted to rye compared with the NC management. An increase in OM can improve soil CEC and improve nutrient availability and environmental sustainability by increasing the nutrient and pollutant retention. Furthermore, by increasing OM, CC and crops included in rotation can improve soil aggregation [36] and increase water infiltration [22,37]. However, [38] and [39] did not observe any increase in organic matter with the use of various cover crops. The reason for these contrasting results could be that cover crops do not produce the same biomass under different climatic conditions, and it could also related be related to the difference in the quality of residues incorporated into the soil.

Finally, OM was significantly greater in the top 10 cm of the soil and lowest in the 10–20 cm depth of sampling. The lowest OM in the second depth could result from the higher soil bulk density reported at this depth [26], which can reduce root growth. Root growth can increase in the deeper depths after they break through this 'pan'. Soil organic matter has a profound effect on certain soil functions and crop productivity, and this underscores the need to develop and improve sustainable soil management systems [40].

4. Summary and Conclusions

This study was conducted to investigate the effects of tillage, cover crop and crop rotation management practices on the chemical properties of the soil. In the first year, conventional tillage had about a 4% greater C/N ratio as compared with the no-till treatment. However, in the second year of this study, the results showed that the interaction between tillage, cover crop and crop rotation significantly affected the soil pH, TC, C/N and percent Mg^{2+} saturation on CEC. In addition, OM was significantly affected by cover crop and crop rotation. After 3 years of study, many of the results found in 2012 were confirmed; for example, OM was noticeably greater in no-till, cover crop and rotation plots as compared to tilled, no-cover crop and continuous cropping plots, respectively. We can therefore conclude that no tillage, cover crop and crop rotation positively affected the soil chemical properties. However, the effects of these soil management practices on soil chemical properties took time in order to become prevalent. The results from this study can help producers decide on management practices that will help improve soil chemical properties and crop productivity, especially within central Missouri and on similar soils.

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