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Soil Nutrients Stratification Affected By Tillage and Nitrogen Source in a Corn Long-Term Experiment

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ABSTRACT

Corn (*Zea mays*) productivity rely on soil factors such as soil structure, water availability and nutrient dynamics, which are affected by soil management practices adopted on a long-term basis. Conservation practices as no till (NT), and cattle manure (CM) replacing mineral N sources have been proposed as a tool to increase soil health and sustainability. The long term effect on nutrients stratification has been investigated in a corn trial over 22 years. This study aims to investigate the nutrient stratification, and nutrient soil retention capacity in long term trial established in 1990 at Manhattan, KS. Studied treatments were conventional tillage (CT) and NT systems, with mineral fertilizer as ammonium nitrate (AN) and organic fertilizer as CM, both with an annual rate of 168 kg N ha^{-1}. For each treatment soil samples were collected at 5 cm increments to a 25 cm to analyzed pH, C, N, K, S, Cu, Fe, Mn, and Zn. Vertical stratification changes of soil pH, and macro and micro nutrient retention was evident for most of the treatments within the first 15 cm of depth. Higher nutrient availability was shown within the first 10 cm of depths (0-5 and 5-10 cm). Nutrient addition by CM enhance nutrient stratification; while NT reduce mineralization, and increase stratification. Results confirm NT and CM application practices as soil conservation and nutrient retention management.

Abbreviations: Conventional till, No till, Nitrogen, Cattle manure

INTRODUCTION

Long term experimental sites are valuable for determining agricultural systems performance and nutrient dynamics over time. Conventional soil agricultural practices can cause a decline in top soil qualities by affecting soil structure, water, and gas movement, minimizing soil microbial activity, as well as water and nutrient availability. Top soil layers concentrate most of the nutrient mineralization processes and biological activity affecting crop nutrient availability and playing a fundamental role in soil environmental services. Vertical stratification of nutrients in the soil layer is affected by soil type and structure, crop uptake and recycling, and therefore by the long term soil management practices that alter soil-plant relations and mineralization processes. Conventional tillage (CT) and no till (NT) practices impact corn yields, soil nutrient retention capacity, and soil quality factors such as carbon (C) sequestration, and water and nutrients retention. Nutrients dynamics in the soil will depend on the source of nutrients, environmental factors, such as rainfall, soil type, temperature, and management practices (Fixen et al., 2015).

Distribution of several nutrients through soil profile by different sources under CT and NT agricultural systems has been previously described (Jobbagy and Jackson, 2001). The NT practice is a conservative management practice that results in an increase in physical, chemical and biological soil characteristics leading to reduce soil erosion, increase soil organic matter (SOM), increase water retention, and balanced soil microorganism activity. Also, several studies indicate NT management leads to higher nutrient stratification, especially K and P (Mallarino and Borges, 2006). This compares to CT system which promotes an initial increase of microbial activity, and thus a high and fast mineralization of OM due to aeration which induce higher nutrient availability in the soil solution. But, this CT system creates nutrients susceptible system with losses in the environmental by soil compaction, erosion, and a continuous reduction of SOM levels which can lead to low crop yields. From a soil fertility perspective, fertilization through organic or mineral sources is necessary for attain the continuous demand of nutrients by corn. Mineral fertilizer applications tend to be immediately available for plant uptake, which is absorbed easily, faster and in higher concentration producing high crop yields. In contrast, nutrient availability from organic fertilizers depends on microbial activity and mineralization rates (Harris et al. 2011). However, organic fertilizers may have more stability and benefits environmental properties (Li et al., 2015); in addition to increase SOM.

In this study, the vertical distribution of soil nutrients in the top 25 cm was explored in a 22 years old corn (*Zea mays*) monoculture trial. This long term trial on tillage system and N source for corn production is focused on the vertical stratification of pH, C, N, P, K, Fe, Mn, Zn and S, and soil bulk density. Reach a comprehensive knowledge of the dynamic of organic and mineral fertilizers over soil management practices, as CT and NT, can help to grasp it impacts on chemical properties, biological activity and its effect on soil quality. Also, it provides guidance about the best management practices for corn production by considering agricultural soils leads to an efficient nutrient management, preserve or restore soil quality, farm soil productivity and operational costs.

MATERIALS AND METHODS

This research was based on a long-term experiment established in 1990 at the North Farm of Kansas State University in Manhattan, KS (39^o 12’ 42’’N, 96^o 35’ 39’’W). The soil is a moderately well-drained Kennebec silt loam (fine-silty, mixed, superactive mesic Cumulic Hapludoll); the main chemical properties in the first 10 cm during 2012 are shown in Table 1. The local average annual precipitation is 800 mm and the annual mean temperature is 11.4^{o}C. Corn was grown continuously on the site from 1990 to 2012. The experiment was arranged in a split-plot randomized blocks with four replications, with tillage as the whole plot, and N source as the sub-plot. The tillage practices were CT with a chisel plow and offset disturbance and NT with zero soil disturbance. The N treatments were 168 kg N ha^{-1} as ammonium nitrate (AN), 168 kg N ha^{-1} as CM and a control (CO) treatment with no N application.

Table 1. Average soil properties within 0 to 5 cm after approximately 22 years of conventional till (CT) and no till (NT) practices. soil layer in the CT and NT plots.

Tillage	pH	Bray-P	K	CEC	Sand	Silt	Clay
		----- mg kg^{-1} ----		cmolc kg^{-1}	------------- g kg^{-1} -------------		
CT	6.2	55	371	17.1	100	700	200
NT	5.8	55	318	18.4	120	680	200

Rates of CM application were calculated based on N analysis and assuming 100% of the NH_4^+-N was available immediately after applied and approximately 35% of the organic N was mineralized the first years following application. From 1990 to 2001 the CM was fresh, changed from 2002 to present the manure was composted. Fertilizer application was done over spring before corn planting. In the CT, the N source was incorporated previous the planting, while in the NT systems was non-incorporated. All plots were amended with lime and fertilized with P and K following soil analysis.

Soil samples were taken in 2012 (after 22 years) at the 0 to 5, 5 to 10, 10 to 15, 15 to 20 and 20 to 25 cm deep soil layer using a 2.5 cm diameter soil probe. Samples were air-dried, ground and sieved (<2 mm). Air dried sub-samples were analyzed by Mehlich 3 Phosphorus for P using a Lachat Quickchem 8000, and an Ammonium Acetate extraction for K, and a DTPA extraction for Cu, Fe, Mn, and Zn both analyzed by an Inductively Coupled Plasma Spectrometer. Sub-samples of each soil samples were freeze dried and ground for soil organic C and N content analysis by dry combustion method using a C N analyzer (Flash EA 1112 Series, Thermo Scientific, Waltham, MA). Soil pH was determined using a 1:1 soil:water method. Bulk density (BD) was determined by taking soil samples at the 0 to 5, 5 to 10, 10 to 15, 15 to 20 and 20 to 25 cm deep using steel rings; values were used for nutrient mass estimation.

Data were analyzed with the PROC GLIMMIX procedure of SAS 9.4. The model included the fixed effects of tillage, N source, and soil sampling depth was included as a repeated measure; block was included as a random factor in the model. The SLICE option was used to compare significant differences between treatments interactions within the same depth. Soil BD, pH, C, N, P, K, Cu, Fe, Mn, SO, Zn, and pH values were treated as independent measurements; significant differences were established at $p<0.05$.

RESULTS AND DISCUSSION

Soil pH

The application of AN and CM decrease pH within the first 25 cm depth. Higher values by CO range from 7.40 to 7.55 without differences between depths. Application of CM showed a pH from 7.16 to 7.34 in descendent order by depth. The AN application showed significant changes in soil pH with no-significant differences between the last two depths. Soil pH behavior is related to N addition, both inorganic or mineral, which generally leads to a decrease of soil pH (Maltas et al., 2013). Long term application of CM increase SOM which performs as a sink by adsorbing ions in soil solution (Powlson et al., 2013); and promoting resistance to soil pH changes (Bohn et al., 2015). On the other hand, AN exceeds the soil capacity of retain or assimilate these ions, promoting a decrease in soil pH.

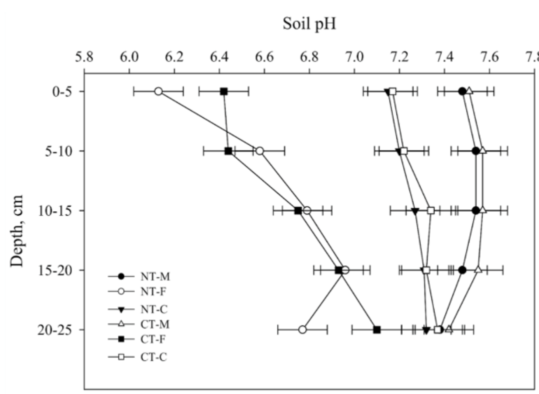

Figure 1 Soil pH by soil depth for the Tillage and Nitrogen source interaction. Error bars show standard error of the mean (n = 4).

Soil C

The CM application in NT showed 60% more retention of C than CT on 0 to 5 cm depth. While, NT-CM showed increase in C content with values from 2,964, 1,759 and 1,063 kg C ha^{-1} in the first 0-5, 5-10 and 10-15 cm, respectively. The 0-5 cm depth on NT-AN and NT-CO showed C content of 1,119 and 956 kg C ha^{-1}, respectively; no significant difference within the 5 to 25 cm were found on NT-AN and NT-CO with an average of 849.3 kg C ha^{-1}. For CT-CM showed higher C content with values of 1,780 and 1,474 kg C ha^{-1} in 0-5 cm and 5-10 cm, respectively; values were different between them and with the rest of the CT treatments. Total C retention in soil profile was 7,202 kg C ha^{-1} with CM; 39% higher than soil C retention for AN and CO with an average of kg C ha^{-1}.

Table 2. Total C (kg ha^{-1}) within 0 to 25 cm soil layer. Different letters within the column show significant differences ($p<0.05$) for Tillage and Nitrogen source interaction.

Depth	Conventional till			No till		
	AN	CM	CO	AN	CM	CO
cm	--kg C ha^{-1}--					
0-25	4,107 c	6,482 b	4,407 c	4,410 c	8,602 a	4,598 c

Macronutrients

Macronutrients, N, P, K, SO_4^-, showed significant differences as the result of the interaction between tillage and sources. Results for N showed how NT-CM exhibited 66% more than the CT-CM. The higher soil levels of P and K on CM treatment are correlated with their presence in livestock feed, which remains in the soil for plant uptake. However, it is possible to observe differences in P and K levels to CM, between NT and CT in the 0 to 5 cm layer, which represents a high loss of this nutrients probably due to surface runoff. Similarly, to P and K dynamic, the CM treatment showed the high values of SO_4^- in the soil with shallow losses over tillage system. The higher nutrient concentration under organic fertilization, in this case, CM can lead to an improvement of P and K levels into deeper layers of the soil compared with others treatments (Hansel et al., 2014).

Table 3. Soil retention of macronutrients by soil depth, and it total concentration within 0-25 cm soil profile. Different letters within the column show significant differences ($p<0.05$) for Tillage and Nitrogen source interaction. No letters mean there was not significant differences for Tillage and Nitrogen source interaction.

Depth	CT-AN	CT-CM	CT-CO	NT-AN	NT-CM	NT-CO
cm	----------kg N ha^{-1}----------					
0-5	12.8 cd	152.6 b	41.7 c	12.6 cd	338.3 a	8.4 d
5-10	15.0 b	108.8 a	37.9 b	26.9 b	136.4 a	21.7 b
10-15	41.0 b	16.8 a	40.1 b	37.0 b	35.9 a	32.1 b
15-20	46.5 b	24.3 a	41.7 b	39.0 b	19.0 a	40.5 b
20-25	48.1 b	28.8 ba	41.2 b	37.8 b	31.7 a	40.2 b
Total	163.3 c	331.2 b	202.6 c	153.3 c	561.4 a	142.9 c
	----------kg P ha^{-1}----------					
0-5	4.6 c	50.3 b	6.6 c	3.8 c	78.5 a	7.0 c
5-10	4.5 b	47.2 a	6.2 b	2.7 b	49.0 a	4.3 b
10-15	2.6 b	19.9 a	4.3 b	1.7 b	24.4 a	2.4 b
15-20	1.6	9.5	2.3	1.8	14.2	1.9
20-25	1.5	6.0	1.9	1.8	9.9	1.9
Total	14.9 c	132.8 b	21.3 c	11.7 c	176.0 a	17.4 c
	----------kg K ha^{-1}----------					
0-5	21.6 d	60.7 b	26.5 c	17.0 d	87.4 a	24.7 d
5-10	19.6 b	56.7 a	22.8 b	15.9 b	60.7 a	17.3 b
10-15	15.4 b	39.1 a	18.0 b	13.6 b	45.3 a	13.6 b
15-20	13.0 b	32.9 a	15.4 b	13.6 b	39.8 a	11.8 b
20-25	11.5 b	24.8 a	13.5 b	13.3 b	34.0 a	11.2 b
Total	81.1 c	214.2 b	96.3 c	73.4 c	267.1 a	78.7 c
	----------kg SO_4-S ha^{-1}----------					
0-5	0.14 c	0.68 b	0.14 c	0.14 c	1.38 a	0.20 c
5-10	0.14 c	0.88 b	0.17 c	0.12 c	1.21 a	0.16 c
10-15	0.09 c	0.56 b	0.13 c	0.09 c	0.92 a	0.12 c
15-20	0.09 c	0.44 b	0.09 c	0.07 c	0.73 a	0.10 c
20-25	0.09 c	0.42 b	0.09 c	0.06 c	0.62 a	0.10 c
Total	0.54 c	2.98 b	0.62 c	0.48 c	4.86 a	0.68 c

Micronutrients

The micronutrients Cu, Mn, and Zn were significantly affected by N source; except for Fe which was significantly affected by N source and depth. Highest concentrations of Cu and Zn was under NT-CM. Higher Mn retention was present in soil with AN amendment; while Fe was not significantly affected by the treatments interaction. In general, Mn and Zn retention is variable for all depths, while Fe interaction was mainly in within 0 to 5, and 5 to 10 cm. Long-term use of CM impacted Zn and Cu levels in the soil with an increase of levels in depth until 15 cm layer. Overall, changes in pH and micronutrient content on CM increase the solubility of Fe and Mn; while AN which decreased pH, especially under NT practices, creates an increase on Fe soil availability; Mn also showed be sensitive changes in pH.

Table 4. Soil retention of micronutrients by soil depth, and it total concentration within 0-25 cm soil profile. Different letters within the column show significant differences ($p<0.05$) for Tillage and Nitrogen source interaction. No letters mean there was not significant differences for Tillage and Nitrogen source interaction.

Depth	CT-AN	CT-CM	CT-CO	NT-AN	NT-CM	NT-CO
cm	--kg Cu ha^{-1}--					
0-5	0.050 c	0.213 b	0.043 c	0.043 c	0.385 a	0.040 c
5-10	0.058 b	0.210 a	0.045 b	0.065 b	0.208 a	0.053 b
10-15	0.048	0.093	0.045	0.050	0.098	0.053
15-20	0.048	0.058	0.050	0.053	0.073	0.053
20-25	0.048	0.055	0.053	0.058	0.060	0.055
Total	0.050 c	0.213 b	0.043 c	0.043 c	0.385 a	0.040 c
	--kg Fe ha^{-1}--					
0-5	1.94 abc	1.86 abc	1.08 bc	2.06 ab	2.33 a	0.95 c
5-10	2.17 a	1.80 ab	1.09 b	2.10 ab	2.13 ab	1.27 ab
10-15	1.56	1.35	1.22	1.56	1.81	1.35
15-20	1.50	1.31	1.40	1.90	1.87	1.45
20-25	1.85	1.37	1.92	2.57	1.93	1.73
6.71	1.94	1.86	1.08	2.06	2.33	0.95
	--kg Mn ha^{-1}--					
0-5	1.12 a	0.50 c	0.49 c	1.21 a	0.80 b	0.47 c
5-10	1.26 a	0.45 b	0.53 b	1.12 a	0.46 b	0.68 b
10-15	0.85 ab	0.42 c	0.62 bc	0.98 a	0.50 c	0.78 ab
15-20	0.79 abc	0.56 d	0.70 bcd	0.96 a	0.63 cd	0.89 ab
20-25	0.80 ab	0.66 b	0.83 ab	0.90 a	0.65 b	0.88 ab
Total	4.84 a	2.58 c	3.17 bc	5.16 a	3.05 bc	3.70 b
	--kg Zn ha^{-1}--					
0-5	0.10 c	1.70 b	0.09 c	0.09 c	3.13 a	0.11 c
5-10	0.10 b	1.57 a	0.09 b	0.07 b	1.41 a	0.06 b
10-15	0.07 b	0.41 a	0.07 b	0.05 b	0.59 a	0.04 b
15-20	0.06	0.12	0.05	0.06	0.29	0.04
20-25	0.05	0.11	0.05	0.06	0.17	0.05
Total	0.37 c	3.90 b	0.35 c	0.31 c	5.59 a	0.31 c

Soil nutrient retention capacity

Highest retention capacity for N, P, K, SO_4-S, Cu and Zn was under NT-CM, followed by CT-CM, with lower retention in AN and CO treatments (**Table 9**). The trend shows higher Mn retention under AN for CT and CM practices (**Table 10**). The increase in BD by NT and CM practices and it relation with an increase of SOC has been previously reported (Mikha et al., 2017). Results agree with previous studies showing long term conservation agricultural practices affect soil bulk density, SOC, and soil nutrients retention (Mikha et al., 2017).

CONCLUSIONS

The studied agricultural practices mainly affect the top 15 cm of soil, except for mobile nutrients and pH. There was no significant effect of CT system in stratification, except when combined with CM. In general, CM enhance mobile nutrients below the 15 cm. There is abundant evidence that minimum soil disturbance in NT and CM fertilization reduces organic matter mineralization, increase bulk density, maintain pH levels, engage stratification, and result in a larger C and N retention capacity. Results confirm the importance of no-till practices and nutrient dynamics, mainly for organic N source of fertilization, as soil conservation management practices.

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