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IMPACT OF NO-TILL AND CONVENTIONAL TILLAGE PRACTICES ON SOIL CHEMICAL PROPERTIES

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Abstract

There is a global concern about progressive increase in the emission of greenhouse gases especially atmosphere CO_2. An increasing awareness about environmental pollution by CO_2 emission has led to recognition of the need to enhance soil C sequestration through sustainable agricultural management practices. Conservation management systems such as no-till (NT) with appropriate crop rotation have been reported to increase soil organic C content by creating less disturbed environment. The present study was conducted on Vanmeter farm of The Ohio State University South Centers at Piketon Ohio, USA to estimate the effect of different tillage practices with different cropping system on soil chemical properties. Tillage treatments were comprised of conventional tillage (CT) and No-till (NT).These treatments were applied under continuous corn (CC), corn-soybean (CS) and corn–soybean-wheat-cowpea (CSW) cropping system following randomized complete block design. No-till treatment showed significant increase in total C (30%), active C (10%), and passive salt extractable (18%) and microwave extractable C (8%) and total nitrogen (15%) compared to conventional tillage practices. Total nitrogen increased significantly 23 % in NT over time. Maximum effect of no-till was observed under corn-soybean-wheat-cowpea crop rotation. These findings illustrated that no-till practice could be useful for improving soil chemical properties.

Key words: Tillage systems, Nitrogen, Total carbon, Active carbon, Passive organic carbon, Crop rotations.

Introduction

Carbon (C), as a core constituent of soil organic matter, regulates many soil properties and/or processes (Bindi & Olesen, 2011). It plays a significant role in agricultural production system and climate change and ultimately in global warming (Smith *et al.,* 2010; Cotrufo *et al.,* 2011; Ontl & Schulte, 2012). The impact of tillage practices on soil nutrients cycling especially C is extensively studied in last few years. For sustainable soil management, it is important to understand the properties and/or processes that control soil organic matter dynamics especially C. The fate of soil C is governed by various interacting factors i.e., degree of incorporation of organic matter, soil disturbance, quality and quantity of organic residue return, soil temperature and water content (Puget & Lal, 2005; Dębska *et al.,* 2010).

Regular plowing has been recognized as a key factor responsible for soil C loss. It accelerates biological decomposition of plant biomass due to more availability of oxygen and by exposing old physically-protected soil organic carbon (SOC) aggregates (LoPez-Fandoand Pardo, 2009; Di Bene *et al*., 2011). Increase in rate of soil CO_2–C efflux are the result of combination of different factors e.g., the breakdown of aggregates and mineralization of aggregate-protected organic matter (Kristensen *et al.,* 2000,Hazarika *et al.,* 2009), higher soil temperature (Alvarez *et al.,* 2001) and enhanced decomposition of incorporated organic matter (Alvarez *et al.,* 2001). The losses of C can result in poor soil physical conditions for growth and development of crops (Busscher *et al.,* 2001) and decrease soil's ability to retain nutrients for a longer period of time (Tisdale *et al.,* 1993). In general, tillage has caused C losses from 28 to 77% over time depending on geographical locations (climate) and soil type (Paustian *et al.,* 1997). SOC fractions of Corn Belt have been lost by traditional agricultural practices to approximately 40% of their original capacity (Lal, 2002).

Conservation tillage like No-till can play a significant role in achieving soil C sequestration by mitigating CO_2 emissions. No-till is now being advocated as an effective strategy to prevent soil degradation and increase C sequestration (Lal *et al.,* 2007; Derpsch *et al,* 2010) due to less disturbances, leaving more organic material to accumulate at the soil surface and slow decomposition rate as compared to soil under routine plowing (Baker *et al.,* 2007; Tobiašová, 2010). Number of studies has shown a greater C sequestration for tillage systems that minimize soil disturbance. SOM transformations are affected by management including tillage systems (Lee *et al.,* 2009; Svobodova *et al.,* 2010) Puget & Lal, (2005) found higher C concentrations over a period of 8 years NT practices was confined to top (0–5 cm) soil layer in central Ohio.

No-till induces SOC stratification with depth (Baker *et al.,* 2007). Carbon accumulation in NT is usually in the upper few centimeters of soil (Blanco-Canqui & Lal, 2008; Slepetiene *et al.,* 2011). Dolan *et al.,* (2006) reported that upper layers of soil (0–20 cm deep) under NT had 30% more C than soils under moldboard or chisel plow tillage. Moreover Blanco-Canqui & Lal, (2008) suggest that NT have not always resulted in net C storage in whole soil profile. Various studies, however, have noted more amount of SOC content in CT compared with NT from 15 to 30 cm depth where organic matter is incorporated, presumably due to a greater input of biomass C with depth in CT fields where decomposition also may be restricted (Haynes & Beare, 1996; Angers *et al.,* 1997). Most studies have suggested that generally long-term No-till or minimum plowed soils contained higher quantity of C in upper layers than CT (Freibauer *et al.,* 2004; Thomas *et al.,* 2007; Slepetiene *et al.,* 2011). This has led to the assumption that use of NT practices will lead to net SOC accumulation. Novak *et al.,* (2009) concluded that NT and CT influenced C contents and substrate properties added to the soil. Organic biomass storage enhanced (0.7 Mg SOC per ha) significantly in 0- to

3-cm soil depth after six year under NT. Because of absence of residue mixing in soils under NT had resulted significantly (1.25–2.51 Mg SOC per ha) reduction C content in 3-15 cm depth. One possible mechanism responsible for increase in soil C quantity under No-till system compared to tilled soil is lower carbon mineralization rate.

The mechanisms by which these increments in different C pools produced are not yet fully known. Soil C is mostly divided into active (labile) and passive (stable/recalcitrant) pools based on turnover rate (Parton *et al.,* 1987; Barbara *et al.,* 2010). Labile soil organic matter pools have a rapid turnover and mostly consist of young soil organic matter, sensitive to tillage operations and environmental factors (Chen *et al.,* 2009) and play significant role in short-term nutrients cycling (C and N) in terrestrial ecosystems (Schlesinger, 1990; Derpsch *et al,* 2010). The ability of NT to increase C in agricultural soils is known to differ among systems, locations, and soil depths, and with the methods used to evaluate SOC stock size (Vanden Bygaart & Angers, 2006). The main objective of long-term study was to estimate the effect tillage practices on soil chemical properties.

Materials and Methods

A long term field experiment (2000-2007) was conducted at The Ohio State University South Centers at Piketon, (39^{o}02′30’’N, 83^{o}02′00’’W), South-central Ohio, USA. The study was conducted on 10 hectares of the 260 hectares Vanmeter farm (known as the site of the Ohio Management Systems Evaluation Area, MESA) of the Ohio State University South Centers at Piketon South central Ohio. The area is under temperate climate. Air temperature ranged between 0 to 24^{o}C; relative humidity ranged between 79 to 93 per cent; soil temperature at 15 cm deep rang between 3 to 30^{o}C; solar radiation ranged between 9981 to 43037 KW m-2; and wind velocity ranged between 5 to 9 Km h^{-1}. Mean annual rainfall is 96+20 cm of which more than 50 per cent occur in April and September. The site has 170 days without any frost (Nokes *et al.,* 1997).

Soil analysis: Soil samples were randomly collected from different part of the field at a depth of 0-30 cm and analysis was done before the start of the experiment. Soil sample collected from site had the following characteristics: Sand 21% Silt 55% and Clay 24%, total porosity 44.6%, pH 6.2and electrical conductivity 206.4 mS/cm.

Field experiment and cultural practices: A field experiment was carried out with two factor tillage and crop rotations. Tillage treatments comprise of CT (conventional tillage) and NT (No-till) and three croprotations were continuous corn(CC), corn–soybean (CS) and corn–soybean–wheat CSW). The experiment was set up (2002) in factorial arrangement of randomized complete block (RCB) design with three replicates in plots size of 40 *100 m^2.

Soil collection and processing: Ten soil core samples were taken up to 30 cm (segmented at 0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm) using a soil probe (1.9 cm internal diameter) by following systematic random sampling from each replicated plot in 1st week of November, 2007. The cores were pooled in a plastic bucket; each replication plot was made composite in field immediately, placed in plastic bags, and sealed. Soils were brought from the field to the laboratory in plastic bags kept on ice in a white cooler. In the laboratory, soil cores were lightly sieved to pass through a 4 mm mesh to separate roots, stones, and large organic residues. After sieving, the composite field moist soil was halved, and each sub sample was placed in a separate plastic bag. The soil from one sub sample was spread on a polyethylene sheet and air dried for 72 h with a fan at room temperature, and analyzed for chemical properties.

Total carbon and nitrogen: Total organic Carbon (TC) and total nitrogen (TN) contents were determined on finely ground (200 µm) oven dried soil samples by dry combustion method using Elementar CNSHO analyzer. The 200 µm sieved, air dried soil samples were oven dried at 105±2^{o}C for 24 h and kept in desiccators until a constant weight was obtained. Samples of 150 to 200 mg oven dried soils were placed in zinc capsules and analyzed for TC and TN contents. Since the pH of the collected soils was $\leq$ 6.5, the total C (TC) content of the soil was considered as C_{org} content.

Active and passive organic carbon: Active C (AC), based on $KMnO_4$ oxidation, was determined on air dried soil (Weil *et al.,* 2003). Exactly, 5 g ODE of soil was shake with 20 ml of 0.02M $KMnO_4$ (pH 7.2) at 100 rpm in 50 ml screw-top polypropylene tube for 2 min using a reciprocal shaker. Then they were centrifuged to get soil free aliquots at 2000 rpm for 5 min. The AC concentration was measured calorimetrically at 550 nm. The standards used were from 0 to 0.05M $KMnO_4$ solutions within the sample range. Passive carbon (PC) concentration was calculated after subtracting AC from TC.

The AC was calculated by assuming that 1 mM MnO_4 is consumed in the oxidation of 0.9 mM of organic C as follows:

$$\text{Active C (mg kg}^{-1}) = (0.02\text{ mol/L} - (a+b^{*}\text{absorbance}))^{*}(9000\text{ mg C/mol})^{*}(0.02\text{-L}/0.005\text{ kg})$$

where:
0.02 = initial $KMnO_4$ solution concentration (mol/L)
a = intercept and
b = slope of the standard curve
9000 = mg C (1 mol) oxidized by 1 mol of MnO_4 changing from Mn^{+7} to Mn^{+2}
0.02 L = volume of $KMnO_4$ solution reacted, and
0.005 = kg of soil used.
The C_{active} content was subtracted from C_{org} to calculate $C_{passive}$ content in soil.

Potassium sulfate extraction of microwaved and field moist soil carbon: To measure potassium sulfate extractable C (UMWC) a sample of 10 g ODE of field moist soil was placed in 50 mL screw-top polypropylene tubes followed by shaking with 25 mL of neutral 0.5M K_2SO_4 (pH 7.0) at 250 rpm for I hr in a reciprocal shaker, centrifuged at 2000 rpm for 5 min, and filtered to obtain soil free extracts. A 5 ml extract was taken in a Folin-Wu glass tube, mixed with 1 mL of 0.17M $K_2Cr_2O_7$ and 5 mL concentrated H_2SO_4 followed by digestion in a microwave oven at 480 J/mL of solution (Islam and Weil 1998). The absorbance of digestate was determined colorimetrically at 590 nm using sucrose C standard for calibration.

For potassium sulfate extractable microwaved C (MWC), a 10 g ODE of field moist soil sample was taken in a 50 mL screw-top polypropylene tube followed by microwave energy exposure at 800 J/g ODE of soil. To reduce heat pocket buildup within the moist soil, soil was first irradiated at 400 J/g and then stirred few seconds to uniform mixing for second exposure of irradiation at 400 J/g. After microwaving, soils were allowed to cool down for half an hr and microwaved and un-microwaved soils were then extracted with 25 mL of 0.5M K_2SO_4 (pH 7.0) at 250 rpm for 1 hr in a reciprocal shaking. After shaking, the soil suspensions were centrifuged at 2000 rpm for 5 min and then filtred to obtain soil free aliquots. A 5 mL extract was taken in a Folin-Wu glass tube, mixed with 1 mL of 0.17M $K_2Cr_2O_7$ and 5 mL concentrated H_2SO_4, and digested in a microwave oven at 480 J/mL of solution (Islam and Weil 1998). The absorbance of digestate was determined colorimetrically at 590 nm using sucrose C standards for calibration.

The 0.5 M K_2SO_4 extraction of post-microwaved and field moist soils for measuring soluble C was calculated as microwave extractable C (MWC_{ext}) and extractable C (C_{ext}), respectively (Islam and Weil, 1998)

$$\text{Extracted C (mg C kg soil}^{-1}) = (a + bx)^* ((0.025) / (10^*OD/FM))$$

where:
a = regression intercept
b = regression coefficient
x = absorbance of the solution, and
OD/FM = ratio of oven dried and field moist soils

Statistical analysis: PRC ANOVA techniques of SAS were used for data analysis (Anon., 2008). Means of treatments were separated by using an F protected LSD test with $p \leq 0.05$. Regression of TC, AC and PC over TN were fitted to polynomial (linear, quadratic and cubic) functions using Sigma Plot 1 and the best fit was graphically represented.

Results

Tillage exerted significant ($p<0.05$) effect on total C (TC) and total N (TN) concentration (Table 1). The NT had significantly increased TC concentration by 22% over time. In contrast, the TC concentration decreased by 30% in CT. Overall, the net difference in TC concentration was highly significant (30%) between NT than CT. Tillage had non-significant effects on total nitrogen concentration. However, TN increased significantly 23% in soil under NT over time. The active carbon (AC) concentration increased significantly by 5 and 15% in CT and NT, respectively over time (Table 2). Likewise, the passive C (PC) concentration was significantly influenced by tillage. On average, the NT had a significantly higher (22%) and the CT had lower (11%) PC concentration when compared with their initial values of 2002. The net increase in PC concentration by NT was even higher (31%) than CT. Tillage had significant effect on salt extractable C concentration in soil (Table 2). On average, the NT had a significantly higher (18%) concentration of 0.5M K_2SO_4 extractable C from microwaved soil (MWC) than CT. The 0.5M K_2SO_4 extractable C (UMWC) concentration under NT was also significantly higher than CT. The difference in UMWC concentration (~8%) between NT than CT was significant. The NT had a significantly higher PC/AC than CT, and the difference was highly significant. Over time, proportionally more PC was accumulated in NT than CT. Irrespective of tillage treatments, the TC, TN, AC, PC, and PC/AC decreased non-significantly with increasing soil depth (Tables 1 and 2). However, the effect was more pronounced on surface soil (0-15 cm). Moreover, tillage and soil depth had a significant interaction on MWC and UMWC concentration.

Discussion

Significant differences of carbon concentration in response to tillage at different soil depths and within soil profile over time are due to variations in tillage intensity, substrate placement and quality, biological activities, and physico-chemical nature of soil (Causarano *et al.,* 2008). Numerous studies have reported that conservation tillage especially NT maintains higher levels of soil C than CT or traditional tillage (Dıaz-Zorita & Grove, 2002; Wright *et al.,* 2005ab).

Previously, it is also reported that NT created a relatively undisturbed and more suitable environment by improving soil biological, chemical and physical conditions (Beare *et al.,* 1997). NT results in the deposition of crop residues on upper soil layer, which reduce moisture and energy exchange from soil to atmosphere (Dou & Hons, 2006). These fluctuations increase the moisture content and decrease soil temperature and aeration, thus allowing plant organic residues to stay intact for longer period of time, and thereby facilitating more C accumulation under NT (Havlin*et al.,* 1990; Franzluebbers *et al.,* 1995; Dao, 1998).

The increased C content in NT may also be related to increased soil aggregation, as soil aggregates provide chemical and physical protection against plant residue decomposition and alter C mineralization kinetics (Six *et al.,* 2002). Surface accumulation of crop residues under NT may probably decompose at a slower rate than mixed organic materials in soil under CT due to less physical contact with soil, increases drying and rewetting, which result in reduce interactions with generalized biological feeders (Causarano *et al.,* 2008). This resulted in higher microbial population with greater number of fungi and larger size of fungi vorousmicrobes and earthworms (Lee, 1985; Holland and Coleman, 1987; Roper and Gupta, 1995).Therefore, it is expected that the decomposition of organic material will be more efficient in soil under CT versus NT. Moreover, surface placement of crop residues may accelerates humification of organic matter due to greater atmospheric exposure and interactions, which facilitate greater microbial decomposition and thus favor C accumulation under NT over time.

Table 1.Tillage impacts on total carbon and nitrogen concentration at different soil depths (Averaged across crop rotation).

Tillage Trts.	Depth of soil (cm)	TC	TN	C/N ratio
		---------------------- (g/kg)	----------------------	
Initial$_{(2002)}$		**13.2Y***	**1.33Y**	**9.8X**
CT$_{2007}$		**11.8Yb+**	**1.23Ya**	**9.6X**
NT$_{2007}$		**16.9Xa**	**1.72Xa**	**9.8X**
	Tillage and soil depth interaction			
Initial $_{(2002)}$	0-7.5	17.1ns	1.60ns	10.6ns
	7.5-15	12.9	1.33	9.6
	15-22.5	11.6	1.25	9.3
	22.5-30	11.1	1.16	9.6
CT$_{2007}$	0-7.5	14.9	1.52	9.8
	7.5-15	12.2	1.28	9.5
	15-22.5	10.3	1.08	9.4
	22.5-30	9.7	1.04	9.5
NT$_{2007}$	0-7.5	23.9	2.32	10.3
	7.5-15	17.8	1.83	9.7
	15-22.5	13.3	1.41	9.4
	22.5-30	12.5	1.31	9.6

Initial=Data collected from conventionally tilled (CT) continuous corn (CC) plots in 2002, CT$_{2007}$ = Data collected from conventionally tilled plots in 2007, NT$_{2007}$ = Data collected from no-till plots in 2007, TC = Total carbon, TN = Total nitrogen, and ns =Non-significant.
*Means followed by same upper case letter (X to Z) in the column were not significantly different at $p \leq 0.05$ over time (2002 vs. 2007).
+ Means followed by same lower case letter (a to c) in the column were not significantly different at $p \leq 0.05$ between tillage treatments in 2007.

Table 2. Tillage impacts on active, passive and extractable carbon concentration at different soil depths (Averaged across crop rotation).

Tillage Trts.	Depth of soil (cm)	AC (mg/kg)	PC (g/kg)	MWC	UMWC	PC/AC (ratio)
				------------- (mg/kg)	-------------	
Initial $_{(2002)}$		**622.9Y***	**12.5Y**	**69.6Y**	**47.4X**	**20.0Y**
CT$_{2007}$		**656.1Yb+**	**11.1Yb**	**72.5Yb**	**49.0Xa**	**16.9Yb**
NT$_{2007}$		**730.1Xa**	**16.1Xa**	**88.0Xa**	**53.1Xa**	**21.6Xa**
	Tillage and soil depth interaction					
Initial$_{(2002)}$	0-7.5	779.6ns	16.3ns	107.2#	67.5#	21.1ns
	7.5-15	613.5	12.2	65.8	43.6	20.0
	15-22.5	563.0	10.9	57.6	41.5	19.5
	22.5-30	535.4	10.5	47.9	37.1	19.6
CT$_{2007}$	0-7.5	783.5	14.1	87.3	49.9	18.1
	7.5-15	677.8	11.6	74.9	51.5	17.1
	15-22.5	589.9	9.7	66.5	48.4	16.4
	22.5-30	573.2	9.2	61.4	46.0	15.9
NT$_{2007}$	0-7.5	891.2	22.9	113.7	58.4	25.5
	7.5-15	738.2	17.0	89.3	52.4	22.8
	15-22.5	691.1	12.6	77.0	50.2	18.4
	22.5-30	599.7	11.9	72.1	51.4	19.7

Initial=Data collected from conventionally tilled (CT) continuous corn (CC) plots in 2002, CT$_{2007}$=Data collected from conventionally tilled plots in 2007, NT$_{2007}$=Data collected from no-till plots in 2007, AC=Active carbon, PC=Passive organic carbon, MWC=0.5M potassium sulfate extractable microwaved soil carbon, UMWC=0.5M potassium sulfate extractable field-moist soil carbon, and ns=Non-significant.
*Means followed by same upper case letter (X to Z) in the column were not significantly different at $p \leq 0.05$ over time (2002 vs. 2007).
+ Means followed by same lower case letter (a to c) in the column were not significantly different at $p \leq 0.05$ between tillage treatments in 2007.
# Indicates significant tillage and soil depth interaction

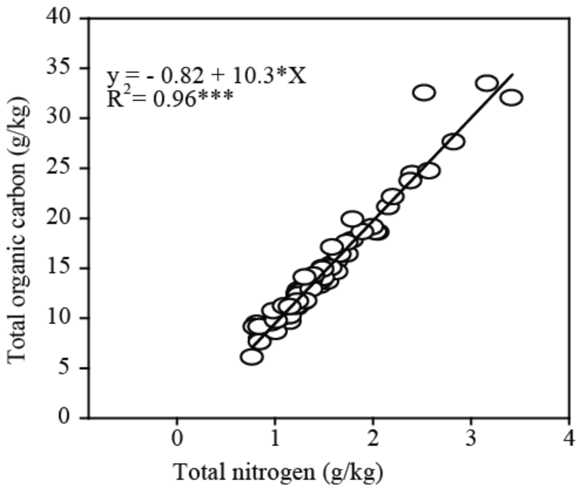

Fig. 1. Relationship between total nitrogen and carbon at different soil depths.

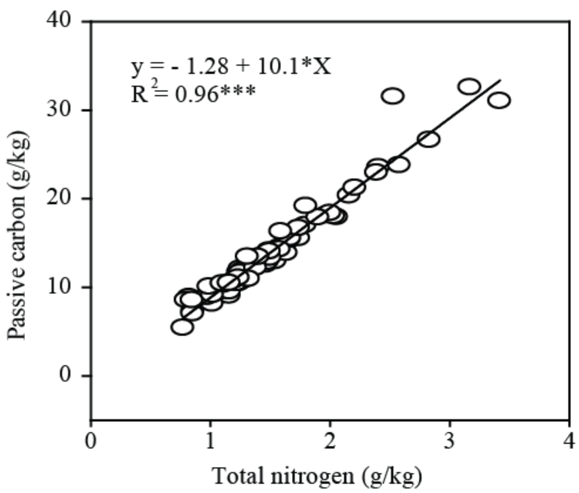

Fig. 2. Relationship between total nitrogen and passive carbon at different soil depths.

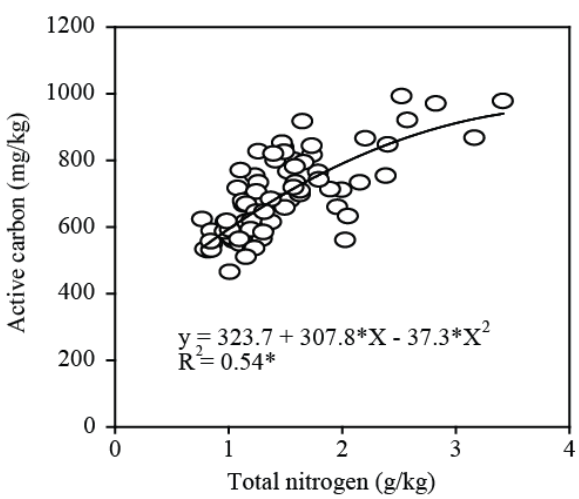

Fig. 3. Relationship between total nitrogen and total active carbon at different soil depths.

Many researchers reported that under NT, stable SOC fraction was significantly higher than soil under CT. As a result, NT not only had a strong vertical gradient, but also contained significantly higher C content of different pools than CT (Langdale *et al.,* 1984; Dalal *et al.,* 1991). However, a slight increase in soil C under NT in the lower layers (15-22.5 and 22.5-30 cm) might be the consequences of transportation of organic materials by earthworms and spring tales. Under NT, soil C accumulation at lower depths occurs at a slower and more modest pace via earthworm burrows and leaching of dissolved organic matter (Paustian *et al.,* 1997and Needelman *et al.,* 1999). Furthermore, large number of earthworm burrows may have facilitated plants to extend their root growth into deeper layers under NT. Several studies have reported that crops under NT showed more horizontal roots growth and larger root density in upper layers (Ballcoelho *et al.,* 1998). However, experimental results revealed that improvement in C and N concentrations at 30–50 cm soil depth may possibly be outcome of the greater contribution of roots growing in earthworm burrows and root excretions**.** Since the O_2 diffusion into deeper soil depth is low, a decrease in root biomass decomposition could promote greater C storage in deeper soil under NT. Moreover, organic residues composition underneath layer of soils in NT systems have smaller amount of humified C and N than top layers of soil, change in the composition might be explained by less biological activity due to reduced aeration of NT soils as result of decreased porosity (Gamba *et al.,* 2001).

NT practices increase SOC contents by protecting labile organic C (Wander & Yang, 2000; Liang *et al.,* 2002). With the onset of tillage, there is a significant loss of SOM, with a disproportionate amount coming from the labile SOM fraction (Gregorich *et al.,* 1997). Tiessen & Stuart, 1983 reported that after 3-7 years, the very little labile C has been oxidized and larger amount of C left was either chemically or physically protected. Therefore, in fields under long-term CT, it is likely that AC will decline with a proportional increase in PC.

Tilled soils have low C content due to higher soil temperature and aeration from the disturbance of tillage operations, destruction of soil macro aggregates to expose inaccessible organic matter, intimate mixing of fragmented crop residues with soil particles, dominance of generalized biological feeders with low C-use efficiency and accelerated disintegration of plant biomass and indigenous soil organic C (Follett & Peterson, 1988; Motta *et al.,* 2002). After tillage, soil CO_2 efflux is greater due different factors like aggregate distraction and biological mineralization of protected C aggregate OM (Rochette & Angers, 1999; Kristensen *et al.,* 2000), rise in temperature of tilled soil because of organic material mixing by machines, also facilitate mineralization of crop biomass (Alvarez *et al.,* 2001) and rapid decomposition of buried organic substances in tilled soils (Alvarez *et al.,* 2001). Due to relatively even distribution of crop residues by regular plowing increased SOM contact which results in a more favorable and uniform conditions for its breakdown. Soil under CT are comparatively well mix up and stratification is relatively slighter. Our results were in accordance with findings of other studies (Costantini *et* *al.,* 1996; Zibilske *et al.,* 2002). Higher disintegration of plant biomass and SOM mineralization under CT can be responsible for accelerate organic-N nitrification to nitrate formation for subsequent plant uptake or to facilitate leaching. This induced homogeneity of C and N allocation in tilled soil. Similar findings were reported by Campbell *et al*., (1996) and Zibilske *et al*., (2002).

When plotted TC, AC and PC contents over TN, there were significant relationships among themselves (Figs. 1-3). Both TC (Fig. 1) and PC (Fig. 2) linearly and significantly regressed on TN. The TN accounted for 96% variability (R^2=0.96***) of the C accumulation in soil and vice-versa. In contrast, the AC was moderately regressed (R^2=0.54*) on TN content (Fig. 3).

Conclusion

It was concluded from this long-term study that no-till system can be effective to increase soil chemical properties as compared to conventional tillage system. No till had significantly influence on chemical parameters as compared conventional tillage. No till can play effective role in enhancing soil fertility and can decrease soil carbon losses.

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