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Long-term Tillage and Nitrogen Fertilization Effects on Soil Properties and Crop Yields

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ABSTRACT

The impact of agricultural intensification on soil degradation now is occurring in tropical countries. The objective of this study was to determine the effect of long-term tillage and N fertilization on soil properties and crop yields in corn-soybean rotation. This long-term study which initiated since 1987 was carried out on a Typic Fragiudult soil at *Politeknik Negeri Lampung*, Sumatra (105°13'45.5"-105°13'48.0"E, 05°21'19.6"-05°21'19.7"S) in 2010 and 2011. A factorial experiment was arranged in a randomized block design with four replications. The first factor was tillage system namely intensive tillage (IT) and conservation tillage (CT) which consisted of minimum tillage (MT) and no-tillage (NT); while the second factor was N fertilization with rates of 0, 100 and 200 kg N ha^{-1} applied for corn, and 0, 25, and 50 kg N ha^{-1} for soybean. The results showed that bulk density and soil strength at upper layer after 24 years of cropping were similar among treatments, but the soil strength under IT at 50-60 cm depth was 28.2% higher ($p<0.05$) than NT. Soil moisture and temperature under CT at 0-5 cm depth were respectively 38.1% and 4.5% higher ($p<0.05$) than IT. High N rate decreased soil pH at 0-20 cm depth as much as 10%, but increased total soil N at 0-5 cm depth as much as 19% ($p<0.05$). At 0-10 cm depth, MT with no N had highest exchangeable K, while IT with medium N rate had the lowest ($p<0.05$). At 0-5 cm depth, MT with no N had highest exchangeable Ca, but it had the lowest ($p<0.05$) if combined with higher N rate. Microbial biomass C throughout the growing season for NT was consistently highest and it was 14.4% higher ($p<0.05$) than IT. Compared to IT, Ap horizon of CT after 24 years of cropping was deeper, with larger soil structure and more abundance macro pores. Soybean and corn yields for long-term CT were 64.3% and 31.8% higher ($p<0.05$) than IT, respectively. Corn yield for long-term N with rate of 100 kg N ha^{-1} was 36.4% higher ($p<0.05$) than without N.

Keywords: Conservation tillage, crop yields, N fertilization, soil properties

INTRODUCTION

The impact of agricultural intensification due to the need of food on soil degradation now is occurring in tropical countries where the resources are scarce, fragile, and stressed by a harsh climate. Conversion to recommend soil management practices such as conservation tillage (CT) can reverse the degradation trend and lead to a gradual improvement in soil quality (Lal 2007). Conservation tillage is any tillage or cropland system that leaves at least 30% plant residues as mulch covering soil surface (Lal 1989; Lal 1997; Utomo 2004). In Indonesia CT that includes minimum tillage (MT) and no-tillage (NT) of corn and soybean now are increasingly adopted by farmers because of lower production costs compared to intensive tillage (Utomo 2004).

Plant residues from previous crop season which are used as mulch is important in CT practices. This is not only because its effective ness in reducing soil erosion, but also in converting the substrate to microbial biomass carbon (Wright and Hons 2004; Smith and Collins 2007; Utomo *et al.* 2010), and in increasing soil organic carbon that has influence on soil physical, chemical and biological properties especially in surface horizon (Stockfisch et al. 1999; Fernandez *et al.* 2007; Thomas *et al.* 2007; Brady and Weil, 2008; Quintero 2009; Utomo *et al.* 2012). In long-term period, shifting from intensive tillage (IT) to conservation tillage (CT), therefore, can promote better soil property.

However, numerous experiments on soil properties between NT and IT performed different results, depending on *in situ* condition and period of measurement (Fengyun *et al.* 2011). A classic study on long-term NT in Kentucky, USA, showed that after 10 years of continuous NT corn production, there were no deterioration of soil physical properties and higher soil moisture under NT corn compared to IT (Blevins *et al.* 1983). While in chemical properties, when high N fertilizer rates were used, the rapid acidification of the soil surface under long-term NT was observed, exchangeable K and Ca decreased with depth (Blevins and Frye 1993). Recent studies confirmed that long-term continuous NT increased SOC and improved soil physical properties (Quintero 2009; Blanco-Canqui *et al.* 2010). Study on Holdrege silt loam (fine-silty, mixed, mesic Typic Argiustolls) in Nebraska had shown that after 27 years of cropping, there are differences in soil chemical properties between IT and NT at some depths (Tarkalson *et al.* 2006).

In Indonesia however, there are no recorded data on soil property changes as influenced by long-term management practices. The study was undertaken to determine the effect of long-term (23 and 24 years) conservation tillage and N fertilization on soil properties and crop yields in a corn-soybean rotation system.

MATERIALS AND METHODS

Long-term Experiment Site History

This field study was conducted in 2010 and 2011 at the experiment farm of *Politeknik Negeri Lampung*, Sumatra, Indonesia. The plot site is located at 105^{o}13’45.5"-105^{o}13’48.0"E, 05^{o}21’19.6"-05^{o}21’19.7"S with elevation from sea level is 122 m. As part of long-term conservation tillage experiment which initiated in 1987, this study was carried out on a *Typic Fragiudult* soil with the slope ranged from 6 to 9% (Utomo *et al.* 1989; Utomo *et al.* 2010). Due to increasing soil compaction within 5 cm depth, all plots of CT were plowed after 10 years of cropping (1997) and after 15 years of cropping (2002). In fact, there was a significant acidifying effect of continuous cropping after 14 years. To avoid further acidification, therefore, all plots in 2003 were limed with 4 Mg ha^{-1} of $CaCO_3$ (Utomo 2004; Utomo *et al.* 2010).

Methods and Field Procedures

A factorial experiment of soybean-corn rotation was arranged in a randomized block design with four replications. The first factor was tillage treatment, namely intensive tillage (IT), minimum tillage (MT) and no-tillage (NT); while the second factor was nitrogen treatment with rates of 0, 100 and 200 kg N ha^{-1} for corn, while 0, 25 and 50 kg N ha^{-1} for soybean. Plot size of this long-term experiment was four by six meters (Utomo *et al.* 1989). The cereal-legume-fallow rotation sequences were set each year. Soybean [*Soya max* (L.) Merr.] variety *Tanggamus* was planted at spacing 20 × 25 cm on May 10, 2010; while hybrid corn (*Zea mays* L.) variety *Pioneer* 21 was planted at 3-5 cm depth at spacing of 75 × 25 cm on January 9, 2011.

Prior to soybean crop season in 2010, plot land was covered with mixture of broadleaf weeds and *alang-alang* (*Imperata cylindrica)*. In CT plots, those weeds were sprayed with *glyphosate* of 4.8 L a.i. ha^{-1} and mixed with *Rhodiamine* 1.0 L ha^{-1}. Similar weed treatment was also executed prior to corn season in 2011. In CT system, all dead weed and previous crop residues were used for mulch covering the soil surface, while in IT system, all weeds and previous crop residues were removed from the plots. In no-tillage (NT) system, the soil was undisturbed except slit for planting the seed; while minimum (MT) system, the soil was slightly plowed at 0-5 cm depth. In contrast to CT system, the soil was plowed twice at 0-20 cm depth. Nitrogen source for the N treatment was Urea 46% N. Nitrogen fertilizer application was applied as hand banding in the row close to the crop. A week after planting, P and K fertilizers at rates of 100 kg SP-18 ha^{-1} and 100 kg KCl ha^{-1} were applied as basal fertilizers, respectively (Utomo *et al.* 2010).

Soil samples for selected soil physical properties were taken after corn harvest in 2011. Soil bulk density was determined by the core method (Blake and Hartge 1986) at depths of 0-5, 5-10 and a 10-20 cm depth, while total porosity was calculated from bulk density and particle density. Soil strength (penetration resistance) was measured at the depths of 0-2.5, 2.5-10, 10-20, 20-30, 30-40, 40-50, 50-60 cm, respectively using a hand-pushed penetrometer (Eijkelkamp Agrisearch Equipment). Soil moisture and soil temperature at 0-5 cm depth were measured using soil moisture and soil temperature tester.

Soil samples for selected soil chemical properties were taken at depths of 0-5 cm, 5-10 cm and 10-20 cm prior to soybean planting time in 2010. Those included soil pH (1:2.5), total soil N (macro-Kjeldahl), and exchangeable K and Ca (NH_4OAc, AAS). The reference site adjacent to the plots which naturally covered by *alang-alang* (*Imperata cylindrica)* and similar to the initial condition of the plots was sampled at depths of 0-5, 5-10 and 10-20 cm (Table 1). Microbial biomass C which was sampled at depth of 0-20 cm throughout the corn season was determined using the chloroform fumigation-incubation method.

For soil morphological characteristics after 24 years of cropping (1987-2011), representative of micro soil pedons were selected only on plot of long-term tillage systems (IT, MT and NT) combined

Table1 1. Soil chemical characteristic at *reference site* prior to soybean planting, 2010.

Depth	pH		Organic C	Organic N	P	Ca	Mg	K	Na
(cm)	H_2O	KCl	(g kg^{-1})	(g kg^{-1})	(mg kg^{-1})	....	(C mole kg^{-1})	....	
0-5	6.0	5.2	13.6	1.4	4.2	7.82	2.74	0.97	0.66
5-10	5.9	5.0	19.4	1.8	4.4	7.36	2.38	0.79	0.52
10-20	5.9	5.1	17.6	1.7	4.2	6.78	2.02	0.70	0.55

with highest N rate treatments 50 or 200 kg N ha^{-1}). To assess soil morphological characteristics after 24 years of cropping, the micro soil pedons with depth of around 50 cm was taken after corn harvest in 2011.

Soybean and corn grains were harvested on July 2010 and February 2012 from 1 m^2 and 8.5 m^2 in the center of each plot, respectively. Soybean yield value was computed on 12% grain moisture basis, while corn yield value was on 14% grain moisture basis.

Statistical Analysis

Statistical analysis of the data was run using the Statistical Analysis System package (SAS Institute 2003). The mean separations among treatments were obtained by honest significant difference (HSD 0.05).

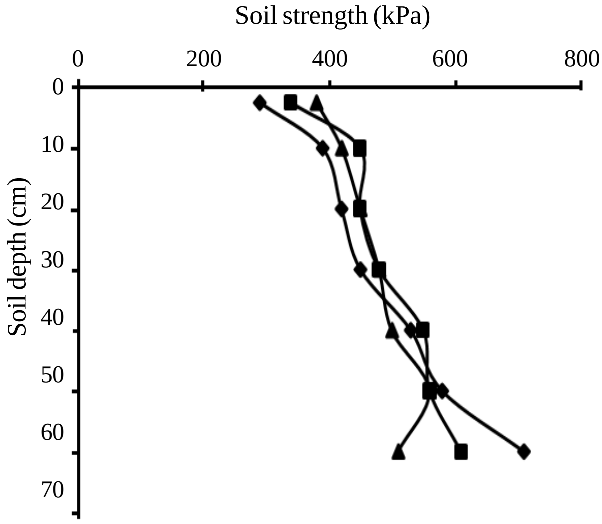

Figure 1. Soil strength after 23 years of cropping (1987-2010) as affected by tillage system at 0-60 cm depth; intensive tillage (—◆—), MT= minimum tillage (—■—), and NT= no-tillage (—▲—)

RESULTS AND DISCUSSION

Soil Bulk Density and Soil Strength

Soil bulk density is one of the most common variables used to assess soil physical properties, which influences total soil porosity, movement of water and nutrient and the penetration resistance of root (Fengyun *et al.* 2011; Mallory *et al.* 2011). Different from reported by Singh and Kaur (2012), soil bulk densities in this long-term experiment at depths of 0-5 and 5-10 cm were not affected either by long-term tillage or by N fertilization treatments. No response of bulk density to the treatments was also reflected on total soil porosity parameter. In fact, the different results among researchers on bulk density studies are very much depending on *in situ* condition and period of measurement (Fengyun *et al.* 2011). Soil moisture during sampling date was relatively moist and was not significantly difference among treatments (*unpublished data*). The average of bulk density and porosity of long-term CT at 0-10 cm depth were 1.08 Mg m^{-3} and 59.3%, respectively.

Soil strength is the property of soil that can limit root penetration (Brady and Weil, 2008). As those of soil bulk density and porosity, the soil strength at the upper soil layer was not affected ($p<0.05$) by tillage and N fertilization. Soil strength (soil penetration) of all tillage treatment increased with depth, but the increased of soil strength under IT at 50-60 cm depth was 39% and 16% higher than NT and MT, respectively (Figure 1; Table 2). It indicated that long-term IT could induce soil compaction at 50-60 cm depth. Similar results were reported by Dickey *et al.* (1994) and Singh and Kaur (2012).

Soil Moisture and Soil Temperature

Soil moisture and soil temperature were measured during vegetative growth of soybean (2010) at 0-5 cm depth. Tillage system was the only treatment that significantly affected ($p<0.05$) soil moisture and soil temperature. It turned out that soil moisture under NT was significantly higher ($p<0.05$) than IT, but not significantly different from MT (Table 2). The higher of soil moisture under CT (NT and MT) compared to IT was in agreement with those reported by Blevins *et al.* (1983), Diaz-Zorita *et al.* (2004), and Singh and Kaur (2012). This was attributable to the effect of plant residues left on soil surface with respect of CT that could reduce

Tabel 2. Soil moisture, soil temperature and soil strength after 23 years of cropping (1987-2010) as affected by tillage systems and N fertilization.

Tillage treatments	Soil moisture (%) at 0-5 cm depth	Soil temperature (^oC) at 0-5 cm depth	Soil strength (kPa) at 50-60 cm depth
Intensive tillage	16.0 a	28.8 a	710 c
Minimum tillage	22.1 b	30.0 b	610 b
No-tillage	22.0 b	30.1 b	510 a

Values within a column followed by the same letter are not significantly different at 0.05 level.

water evaporation resulted in higher soil moisture content (Blevins *et al.* 1983; Utomo 2004). Strong effect of CT on soil moisture was also related to higher soil organic matter under this long-term CT soil (Utomo *et al.* 2010; Utomo *et al.* 2012). Mallory *et al.* (2011) confirmed that greater water storage in no-till soils can be attributed to the larger percentages of meso-pores and macro-pore continuity.

Soil temperature under NT in temperate region was usually lower than that of IT (Blevins and Frye, 1993; Rasmussen, 1999; Singh and Kaur, 2012). Difference from those findings, however, soil temperature at 0-5 cm under NT or MT in this experiment (tropical environment) was significantly higher ($p<0.05$) than soil temperature under IT (Table 2). Even though the presence of mulch in NT could potentially heating the heat to a greater depth, thus increased soil moisture (Table 3), but at 0-5 cm depth, the heat received by mulched NT tended to offset the cooling effect of evaporation with respect of NT.

Soil pH and Total Nitrogen

Soil pH is among important factors that can influence soil chemical characteristics and crop yields (Brady and Weil, 2008). Similar to those reported by Kumar and Yadav (2005), soil pH at all depths was not affected by tillage treatment and its interaction with N fertilization, but was affected by N fertilization except for 20-40 cm depth (Table 3). Less acidification effect of CT in this experiment was attributed to stronger buffering capacity with respect to CT. However, this finding was difference from those reported by Blevins and Frye (1993), Karlen *et al.* (1994) and Utomo *et al.* (2010) that soil pH under CT at surface layer was lower than IT.

Regardless the tillage system, soil pH at 0-5 cm depth was lower than that of 10-20 cm depth and soil pH under long-term CT tended to be higher than IT across the soil profile (Figure 2). Even though soil pH was not affected by long-term tillage, but refer to soil pH at reference site (Table 1), it indicated that in long-term crop production, any tillage had similar acidifying effect particularly just few cm at the upper soil layer.

As those reported by Blevins *et al* (1977) and Barak *et al* (1997), soil pH in this long-term experiment (after 23 years of cropping) was decreased ($p<0.05$) with increasing N rate. Soil pH with rate of 200 kg N ha^{-1} at 0-10 cm depths was 7% lower ($p<0.5$) than that with no N fertilizer, and even 11% lower ($p<0.05$) at 10-20 cm depth (Table 3). This was attributed to an acidifying effect of N fertilizer (urea) that could decrease soil pH as shown in this reaction (Havlin *et al.* 2005):

$$(NH_2)_2CO + 4\,O_2 \rightarrow 2\,NO_3^- + 2\,H^+ + CO_2 + H_2O$$

Hydrolysis and nitrification of urea as an acid forming fertilizer in well-drained soil will induce soil acidity (Barak *et al.* 1997). This is an indication that long-term nitrogen fertilization has stronger acidification effect than long-term tillage systems. Refer to reference site (Table 1), long-term N

Table 3. Soil pH after 23 years of cropping (1987-2010) as affected by N fertilization at 0-40 cm depth.

N rate (kg N ha^{-1})	Soil pH			
	0-5 cm	5-10 cm	10-20 cm	20-40 cm
0	5.93 b	6.13 b	6.31 b	5.99 a
25 or 100	5.92 b	6.15 b	---	---
50 or 200	5.54 a	5.70 a	5.67a	5.58 a

Values within a column followed by the same letter are not significantly different at 0.05 level

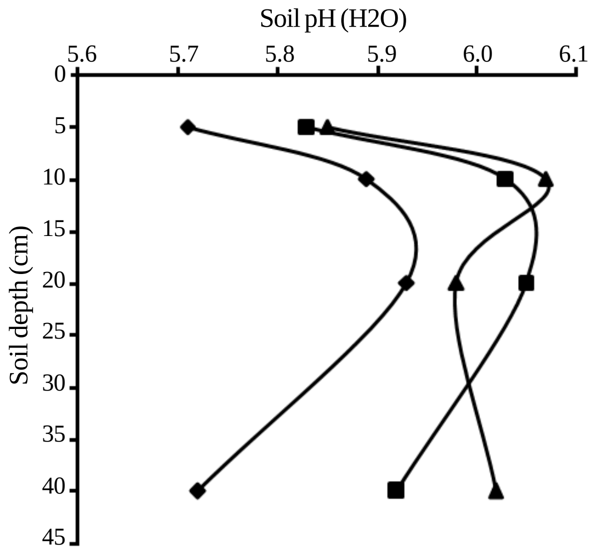

Figure 2. Soil pH profile after 23 years of cropping (1987-2010) as affected by tillage systems at 0-40 cm depth; intensive tillage (—◆—), minimum tillage (—■—) , and no-tillage (—▲—).

fertilization could reduce soil pH at the upper soil layer.

Total soil nitrogen is integral component of many essential plant compounds such as amino acids, chlorophyll and carbohydrate (Brady and Weil, 2008). At 5-10 cm depth, total N under MT was higher ($p<0.05$) than NT, but there were no different than IT (Table 4). Although plant residues from NT was returned back on to the soil surface, but due to N mineralization from plant residue probably could not exceed the higher N uptake, resulted in less total soil N with respect to NT. This finding was difference from those reported by Zibilske *et al.* (2002) and Brito-Vega *et al.* (2009).

Table 4. Total soil nitrogen after 23 years of cropping (1987-2010) as affected by tillage systems and N fertilization at 0-20 cm depth.

Treatments	Total N (%)		
	0-5 cm	5-10 cm	10-20 cm
Intensive tillage	0.17 a	0.16 ab	0.14 a
Minimum tillage	0.18 a	0.17 b	0.14 a
No-tillage	0.16 a	0.14 a	0.14 a
0 kg N ha^{-1}	0.16 a	0.14 a	0.14 ab
25 (100) kg N ha^{-1}	0.17 ab	0.16 ab	0.13 a
50 (200) kg N ha^{-1}	0.19 b	0.18 b	0.16 b

Values within a column followed by the same letter are not significantly different at 0.05 level.

Table 5. Exchangeable K and Ca after 23 years of cropping (1987-2010) as affected by interaction of tillage systems and N fertilization.

Treatment combinations	K		Ca
	0-5 cm	5-10 cm	0-5 cm
Intensive tillage:	……...... (Cmole kg^{-1})		….……..
0 kg N ha^{-1}	0.48 ab	0.39 ab	6.13 ab
25 (100) kg N ha^{-1}	0.28 a	0.21 a	5.71 ab
50 (200) kg N ha^{-1}	0.31 ab	0.22 a	6.20 ab
Minimum tillage:			
0 kg N ha^{-1}	0.75 b	0.70 b	7.40 b
25 (100) kg N ha^{-1}	0.62 b	0.57 b	6.89 ab
50 (200) kg N ha^{-1}	0.38 ab	0.34 ab	5.38 a
No-tillage:			
0 kg N ha^{-1}	0.55 b	0.50 b	6.51 ab
25 (100) kg N ha^{-1}	0.58 b	0.51 b	6.75 ab
50 (200) kg N ha^{-1}	0.60 b	0.45 ab	6.60 ab

Values within a column followed by the same letter are not significantly different at 0.05 level.

In this long-term experiment, strong influence of N fertilization on total soil N was more pronounce than tillage treatment. Total soil N due to higher N rate of all depths were significantly higher ($p<0.05$) than without N. This was attributed to the fact that not all N from N fertilizer was taken up by crops, but some was left in the soil due to immobilized by microbe. Referring to initial total soil N content of reference site (Table 1), higher N rate fertilization could induce more total soil N left within 0-10 cm depth of the soil.

This important finding indicated that long-term higher N fertilization rate has residual effect on total soil N within the 0-20 cm depth. Greater retention of N fertilizer due to N immobilization may improve crop N use efficiency by subsequent re-mineralization of the N in better synchrony with crop need (Utomo *et al.* 1989; Zibilske *et al*. 2002).

Exchangeable Potassium and Calcium

Potassium and calcium are important nutrients needed for plant growth. One of readily available forms of these important nutrients for plant growth is an exchangeable base (Brady and Weil 2008).

Table 5 showed that with medium N rate, exchangeable K under CT at 0-5 cm depth was 114% higher ($p<0.05$) than that of IT, while at 5-10 cm depths was 157% higher ($p<0.05$). At depth of 10-20 cm however, there was no interaction effect of tillage and N fertilization. Exchangeable K for NT was similar to MT in this depth, it was 114% higher ($p<0.05$) than IT. As that of decreasing soil pH due to N fertilization (Table 3), exchangeable K also decreased with increasing N rate. Exchangeable K for high N rate in this depth was not different from medium N rate, but it was 48% lower ($p<0.05$) than without N fertilization.

At 0-5 cm depth, exchangeable Ca for combination of MT and no N fertilization was the highest among other combination, while combination with higher N rate was the lowest (Table 5). Values of exchangeable Ca for MT at 5-10 cm and 10-20 cm depth were no different from that of NT, but it was 15% higher ($p<0.05$) than IT. As that of exchangeable K, exchangeable Ca at 10-20 cm depth was reduced by N fertilization as much as was 9%. The strong effect of CT on exchangeable bases was associated with decomposition of plant residues with respect to CT. However, these findings were not in agreement with research result from Kentucky that reported by Blevins and Frye (1993).

Microbial Biomass Carbon

Microbial biomass C was measured at before planting, vegetative growth and after harvest of corn season in 2011. Microbial biomass C under NT was consistently higher ($p<0.05$) than IT along the corn season, while it was no significantly different ($p<0.05$) between NT and MT (Table 6). Contrast to reported by Utomo *et al* (2010), however, microbial biomass C in this season was not affected ($p<0.05$) by nitrogen fertilization. Strong effect of CT on microbial biomass C was probably attributable to the effect of surface residue and less soil disturbance. Shift from high to low soil disturbance such as conventional tillage to no-tillage, often promotes the accumulation of otherwise labile soil organic carbon that is less available to microbial attack, controls carbon decomposition rates and increases total microbial biomass (Paustian *et al.*1997; Six *et al.* 2006; Utomo *et al.* 2010). As labile component of soil organic C, soil microorganisms can contribute to microbial biomass C (Wang *et al.*2001).

Table 6. Soil microbial biomass carbon after 24 years of cropping (1987-2011) as affected by tillage systems at 0-20 cm depth.

Treatments	Soil Microbial Biomass C		
	Before planting	Vegetative growth	After harvest
	.... (kg CO_2-C $^{-}$day^{1})		
Intensive tillage	57.7 a	120.3 a	163.6 a
Minimum tillage	60.6 ab	133.9 ab	176.6 b
No-tillage	64.4 b	142.3 b	184.3 b

Values within a column followed by the same letter are not significantly different at 0.05 level.

Soil Morphological Characteristics

Representative soil pedons were selected only on plot of long-term tillage systems combined with highest N rate. It turned out that after 24 years of cropping (1987-2011), there were different soil morphological characteristics among tillage systems (Table 7). After 24 years of cropping, CT had deeper top soil layer than IT. The depth of Ap horizon under MT plot was the deepest, while the Ap under IT plot was the shallowest one (Table 8). With plant residue and slightly tilled, MT had better micro climate that could accelerate more biological tillage effect, resulted on much deeper Ap horizon.

Among the soil morphological characteristics, soil color of the tillage system was the most distinct one. The Munsell soil color chart of tillage treatments in Ap horizon ranged from 5YR 2.5/2 to 5YR 3/3, while in A/B horizon was similar (5YR 3/4). Value and chroma notation of no-tillage in Ap horizon was the lowest among other tillage treatments, while in intensive tillage was the highest. Slightly darker of no-tillage Ap horizon was attributed to the higher organic C in upper soil layer with respect to NT as those reported by previous researchers (Wright and Hons 2004; Al-Kaisi and Yin 2005; Blanco-Canqui and Lal 2008; Utomo *et al.* 2012).

Other soil morphological characteristics in this study were size of soil structure type and amount of macro pores. Soil structure size changed from fine sub angular blocky under IT to medium sub angular blocky under CT (MT or NT), while amount of macro pores changed from few under IT to many under CT (Table 7). The larger size of sub angular blocky under CT than IT soil indicated the better soil aggregation due to the lower surface soil disturbance with respect to CT. This condition also reflected on the larger macro pores occurred under long-term CT soil, which mostly formed from earthworm borrow (Derpch 1998; Utomo *et al.* 2010). This macro pores which connected to soil surface are important for aeration and drainage (Utomo *et al.* 2010). The better soil aggregation with respect of CT was in accordance with that reported by Edwards *et al.* (1988).

Soybean and Corn Yields

After 23 years of cropping (2010), soybean yields for MT and NT were 71.4% and 57.1% higher ($p<0.05$) than IT, respectively. While in corn season (2011), corn yield for MT was similar to NT, and it

Table 7. Soil morphological characteristics after 24 years of cropping (1987-2011) as affected by tillage systems and nitrogen fertilization.

Tillage treatments	Horizon	Depth (cm)	Soil color	Soil structure	Macro pores
Intensive tillage	Ap	0-13	5YR 3/3	Subangular blocky, fine	Few
	A/B	13-30	2.5YR 4/6	Subangular blocky, medium	Few
	Bt	30+	Not determined	Not determined	Not determined
Minimum tillage	Ap	0-18	5YR 3/2	Subangular blocky, medium	Many
	A/B	18-33	2.5YR 4/4	Subangular blocky, medium	Few
	Bt	33+	Not determined	Not determined	Not determined
No-tillage	Ap	1.5-17	5YR 3/2	Subangular blocky, medium	Many
	A/B	17-28	5YR 3/4	Subangular blocky, medium	Few
	Bt	28+	Not determined	Not determined	Not determined

was 31.8% higher ($p<0.05$) than that of IT (Table 8). Strong responses of soybean and corn to CT which just observed after 23 years of cropping were attributed to the better soil properties under long-term continuous CT application (Tables 2, 4-7). This was also contributed by strong mulching effect with respect to CT, resulted in a higher nutrient uptake and crop yield (Lal 1989; Utomo *et al.* 1989; Fengyun *et al.* 2011).

As a legume, soybean had no response to N fertilization. Soybean yield for N rate of 25 kg N ha^{-1} was 1.9 Mg ha^{-1} or only 5% lower than N rates of 0 or 50 kg N ha^{-1}. On the other hand, as a cereal crop, corn had strong response to N fertilization. Corn yield for 100 and 200 kg N ha^{-1} were 36.4%

Table 8. Soybean and corn yields as affected by long-term tillage systems and N fertilization.

Treatments	Soybean, 2010	Corn, 2011
	…… (Mg ha^{-1})……	
Intensive tillage	1.4 a	4.4 a
Minimum tillage	2.4 b	5.8 b
No-tillage	2.2 b	5.8 b
0 kg N ha^{-1}	2.0 a	4.4 a
25 (100) kg N ha^{-1}	1.9 a	6.0 b
50 (200) kg N ha^{-1}	2.0 a	5.5 b

Values within a column followed by the same letter are not significantly different at 0.05 level

and 25.0% higher ($p<0.05$) than with no N fertilization, respectively (Table 8). These findings were in agreement with those reported by Dickey *et al.* (1994) and Fengyun *et al.* (2011).

CONCLUSIONS

Although the soil surfaces were continuously not tilled for 24 years, but the bulk density and soil porosity of conservation tillage (CT) at 0-10 cm depth were still no different from intensive tillage (IT). Soil strength tended to increase with depth, but at depth of 50-60 cm the soil strength under IT was 28.2% and 26.4% higher than no-tillage (NT) and minimum tillage (MT), respectively. Soil moisture and soil temperature under CT (MT=NT) at 0-5 cm depth were respectively 38.1% and 4.5% higher than IT.

Soil pH after 23 years of cropping was not affected by tillage, but decreased with increasing N rate up to 20 cm depth. Compared to no N fertilization, long-term high N rate decreased soil pH at 0-20 cm depth as much as 10% and increased total soil N at 0-5 cm depth as much as 19%. At 0-10 cm depth, MT with no N fertilization had highest exchangeable K, in contrast, IT with medium N rate application had the lowest. At 0-5 cm depth, MT with no N fertilization had highest exchangeable Ca, however, with higher N rate, MT had the lowest. Microbial biomass C throughout the growing season under long-term NT was consistently highest among other tillage systems, and it was 14.4% higher than IT.

There were different soil morphological characteristics among long-term tillage systems. After 24 years of cropping, Ap horizon of CT (MT and NT) was deeper and darker than IT. Soil structure size changed from fine sub angular blocky under IT to medium sub angular blocky under CT, while amount of macro pores changed from few under IT to many under CT.

Soybean and corn had strong responses to long-term tillage systems. After 23 to 24 years of cropping, soybean and corn yields for CT (MT=NT) were 64.3% and 31.8% higher than IT, respectively. Different from soybean, corn had strong response to N fertilization. Corn yield with 100 and 200 kg N ha^{-1} were respectively 36.4% and 25.0% higher than with no N fertilization.

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