Carbon Storage and Carbon Dioxide Emission as Influenced by Long-term Conservation Tillage and Nitrogen Fertilization in Corn-Soybean Rotation

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ABSTRACT

Although agriculture is a victim of environmental risk due to global warming, but ironically it also contributes to global greenhouse gas (GHG) emission. The objective of this experiment was to determine the influence of long-term conservation tillage and N fertilization on soil carbon storage and CO_2 emission in corn-soybean rotation system. A factorial experiment was arranged in a randomized completely block design with four replications. The first factor was tillage systems namely intensive tillage (IT), minimum tillage (MT) and no-tillage (NT). While the second factor was N fertilization with rate of 0, 100 and 200 kg N ha^{-1} applied for corn, and 0, 25, and 50 kg N ha^{-1} for soybean production. Samples of soil organic carbon (SOC) after 23 year of cropping were taken at depths of 0-5 cm, 5-10 cm and 10-20 cm, while CO_2 emission measurements were taken in corn season (2009) and soybean season (2010). Analysis of variance and means test (HSD 0.05) were analyzed using the Statistical Analysis System package. At 0-5 cm depth, SOC under NT combined with 200 kg N ha^{-1} fertilization was 46.1% higher than that of NT with no N fertilization, while at depth of 5-10 cm SOC under MT was 26.2% higher than NT and 13.9% higher than IT. Throughout the corn and soybean seasons, CO_2-C emissions from IT were higher than those of MT and NT, while CO_2-C emissions from 200 kg N ha^{-1} rate were higher than those of 0 kg N ha^{-1} and 100 kg N ha^{-1} rates. With any N rate treatments, MT and NT could reduce CO_2-C emission to 65.2 %-67.6% and to 75.4%-87.6% as much of IT, respectively. While in soybean season, MT and NT could reduce CO_2-C emission to 17.6%-46.7% and 42.0%-74.3% as much of IT, respectively. Prior to generative soybean growth, N fertilization with rate of 50 kg N ha^{-1} could reduce CO_2-C emission to 32.2%-37.2% as much of 0 and 25 kg N ha^{-1} rates.

Keywords: Conservation tillage, carbon storage, CO_2-C emission, N fertilization

INTRODUCTION

In recent decade, global warming due to greenhouse gas (GHG) emission is receiving great attention (Rastogi *et al*. 2002; Lal 2007). Among the greenhouse gases, CO_2 is the most important gas, accounting for 60% of global warming (Rastogi *et al*. 2002). Agricultural systems are estimated to contribute up to 20% of the global anthropogenic CO_2 emissions (IPCC 2006; Haile-Mariam *et al.* 2008). In contrast to agriculture in developed countries that only contributes less CO_2 emissions, Indonesia agriculture along with land use change and forest contributes to CO_2 emission as much as 53% (Boer 2010). Intensive agriculture contributes to CO_2 emission through direct use of fossil fuels from food production, indirect use of embodied energy in inputs, and cultivation of soils that cause the loss of carbon through decomposition and erosion (Pretty and Ball 2001). As business as usual practice in agriculture, intensive tillage (IT) produces favorable soil microenvironment that can accelerate microbial decomposition of plant residues. Tillage breaks down soil aggregates, helps in mixing soil and organic particles, and enhances gas diffusivity and air-filled porosity resulted in a higher CO_2 production (Rastogi *et al*. 2002). The higher CO_2 emission in intensive tillage therefore, should be reduced, other wise it will decrease C storage in the soil and end up with the decrease of soil quality and soil productivity (Paustian *et al.* 2004).

Conservation tillage (CT) as a recommended management practices, can act as a sink that can both sequester C and reduce CO_2 emission, thus

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reducing agriculture's potential on global warming (Pretty and Ball 2001; Rastogi *et al.* 2002; Six *et al.* 2004; Lal 2007; Smith 2010). In fact, in the Kyoto Climate Protocol and IPCC *Guidelines for National Greenhouse Gas Inventories*, conservation tillage is listed as an option for carbon sequestration (Sedjo *et al.* 1998; Egglestone *et al.* 2006). By implementing CT therefore, Indonesia has an opportunity to reduce national GHG emission as much as 26% in 2020. This is because in upland agriculture, CT has been rapidly expanded since about 1990, particularly in the region with lack of labors, such as in Sumatra, Borneo and Celebes. Yet in 1998, CT has been explicitly stated in national land preparation policy (Utomo *et al.* 2004).

Plant residue which used as mulch in CT is important, because it serves as substrate that is converted to microbial biomass and soil organic matter, and has the potential to enhance carbon sequestration in agricultural soils (Wright and Hons 2004; Smith and Collins 2007). Previous studies in temperate regions showed that long-term CT using plant residues could increased soil organic C in the upper layer of soil, but it did not store soil organic carbon more than IT for the whole soil profile (Wright and Hons 2004; Al-Kaisi and Yin 2005; Blanco-Canqui and Lal 2008).

The higher of soil C storage with respect to CT is related to the lower of CO_2 emission from CT than IT. In general, CO_2 emission from soil can be attributed to biological and chemical process within the soil that may include CO_2 from soil organic matter and crop residue decomposition, and from root respiration (Rastogi *et al.* 2002; Al-Kaisi *et al.* 2008). In biological process, soil micro flora contributes 99% of the CO_2 from decomposition of organic matter, while the contribution of soil fauna is much less. Root respiration, however, contributes 50% of the total soil respiration (Rastogi *et al.* 2002). Research conducted in temperate regions showed that CO_2 emission from CT was consistently lower than IT (Reicosky 2001; Al-Kaisi and Yin 2005; La Scala *et al.* 2005; Brye *et al.* 2006; Bono *et al.* 2008). As that of CT, N fertilization as part of integrated nutrient management can influence both soil C sequestration and CO_2 emission. The influence of N fertilization on CO_2 emission however, is not well understood. Increasing N fertilizer application rate was site specific and had inconsistent effect on depressing CO_2 emission (Al-Kaisi *et al.* 2008). This inconsistent effect creates challenge to carry out further study to understand the effect of N fertilization and its interaction with CT on soil storage and CO_2 emission.

The long-term experiments of CT and N application on C storage and CO_2 emissions have been conducted mostly in temperate regions, but very few conducted in tropical region such as in Indonesia. The objective of this experiment was to determine the influence of long-term (22 and 23 years) conservation tillage and N fertilization on soil carbon storage and CO_2-C emission in corn-soybean rotation system.

MATERIALS AND METHODS

Site Characteristics and Plot History

The long-term conservation tillage and N fertilization experiment was established in February 1987 at the experiment farm of *Politeknik Negeri Lampung*, Sumatra, Indonesia (Utomo *et al.* 1989; Utomo *et al.* 2010). Cropping pattern of this long-term experiment was cereal (corn or upland rice)-legume (soybean, mungbean or cowpea)-fallow (weed or bare soil) rotation. The long-term experiment is located at 105°13'45.5"-105°13'48.0"E, 05°21'19.6"-05°21'19.7"S, with elevation of 122 m from sea level. The land prior to long-term experiment initiation was a *ladang* (a rain-fed farming with period of fallow), which was abandoned for more than four years and covered by *alang-alang* (*Imperata cylindrica)* grass with average dry matter 12.2 Mg ha^{-1}. The soil is a *Typic Fragiudult* with slope ranging from 6 to 9%. Soil particle sizes composition in the soil surface layer sampled in 1987 was 160, 320 and 520 g kg^{-1} of sand, silt and clay, respectively. Initial bulk density at 0-20 cm depth was 0.90 Mg m^{-3}, total porosity 65.7%, pH_{H2O} 6.8, pH_{KCl} 5.8, soil organic-C 16.0 g kg^{-1} and soil organic-N 2.0 g kg^{-1} (Utomo *et al.* 1989). Due to the upper layer soil compaction, all plots of conservation tillage were plowed in 1997 and 2002. In 2003, due to the soil became acid, so that all plots were limed with 4 Mg ha^{-1} of $CaCO_3$ (Utomo 2004; Utomo *et al.* 2010).

Method and Analysis

The experiment was arranged in a factorial, randomized completely block design, with four replications. Plot size was four by six meters. The first factor was tillage systems; those were intensive tillage (IT) and conservation tillage (no-tillage, NT and minimum tillage, MT). While the second factor was nitrogen treatment 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 production. Nitrogen source for the N treatment was Urea 46% N. One third of N rates were applied by hand banding close to the rows a week after planting and two third of N rates were applied prior to generative period taken place. Hybrid corn (*Zea mays* L.) variety Pioneer 21 was planted at 3-5 cm depth at spacing of 75 × 25 cm on September 9, 2009; while soybean [*Soya max* (L.) Merr.] variety *Tanggamus* was planted at spacing 20 × 25 cm on May 10, 2010.

In 2008, land was covered with mixture of broadleaf weeds and *Imperata cylindrica* which left as fallow for a year. The dry matter weed weight was 13.3 Mg ha^{-1} with C/N 31.9. Weeds prior to corn crop were sprayed with *glyphosate* of 4.8 L *a.i.* ha^{-1} and mixed with *Rhodiamine* 1.0 L ha^{-1} on August 20, 2009; while weeds prior to soybean season which also dominated by mixture of weeds were sprayed on April 13, 2010 with the same herbicide. The deadly weeds and previous corn stalk residues were used for mulch covering the soil surface of CT, while in IT all deadly above-ground weeds and corn stalk residues were removed. Different from NT in which the soil was not being plowed at all, soil surface of MT was slightly plowed at 0-5 cm depth; while in IT treatment plots were plowed twice at 0-20 cm depth.

Soil C storages in this experiment which measured as soil organic carbon (SOC) were taken on May 10, 2010 (after 23 years of cropping). As reported by Wright and Hons (2004); Blanco-Canqui and Lal (2008); Utomo *et al.* (2010) that SOC in conservation tillage is mostly observed in the upper layer of soil, therefore, samples in this experiment were taken at depths of 0-5 cm, 5-10 cm and 10-20 cm. Soil organic carbon in all depths were determined with Walkey and Black method (Nelson and Sommers 1984).

In corn season, CO_2 measurements were taken throughout the season from 28 August to 10 December 2009. Those measurements were taken before plowing, one day after plowing (1 DAP), 2 DAP, 3 DAP, 20 DAP, 40 DAP, 60 DAP and 80 DAP. In soybean season however, due to technical problem in the field, measurement of CO_2 emission in the first 3 days after plowing were not measured. Measurements of CO_2 were taken from 11 June to 6 September 2010, those included 20 DAP, 40 DAP, 60 DAP, 80 DAP and 120 DAP. To determine the effect of long-term no-tillage and N fertilization on CO_2 emissions *in situ*, upside down jars with diameters of 12 cm were inserted into plots at 2 cm depth, and small vials with containing 10 mL KOH 0.1N were placed in the jars. Evolved CO_2 was corrected for amounts found in the blank jar along with sample measurement. After two hours field measurement which taken at 9 to 11 in the morning and at 3 to 5 in the afternoon, the KOH trap was titrated with HCl 0.1 N to determine the CO_2-C equivalent (Anderson 1984; Anas (1989). To calculate the amount of CO_2 evolved from soil trapped by KOH, formula modified by Anas (1989) was used. The data in this paper were expressed as kg CO_2-C ha^{-1} day^{-1}.

Statistical Analysis

Analysis of variance and means test with Honest Significance Different (HSD 0.05) were analyzed using the Statistical Analysis System package (SAS Institute 2003).

RESULTS AND DISCUSSION

Soil Organic Carbon

Soil organic carbon (SOC) plays a significant role in agro-ecosystem, due to it is directly related to productivity (`Lal 2007;` Smith and Collins 2007). After 23 years of cropping, SOC at depth of 0-5 cm was significantly ($p < 0.05$) affected by tillage, N fertilization and interaction of tillage with N fertilization. Within this upper layer of soil, soil organic C under NT with 200 kg N ha^{-1} fertilization was 46.1% higher than NT with no N fertilization, but there were no different than other treatment combinations (Table 1). This finding indicates that NT has ability to increase SOC within the upper layer of soil only if combined with optimum N fertilization. This was attributed to the strong influence both tillage treatment and N fertilization on plant residue decomposition. Every season, previous plant residues in conservation tillage (CT) were used as mulch covering the soil surface. The weight of dry matter weed prior to experiment was 13.3 Mg ha^{-1} with C-N ratio 31.9. Additions of previous plant residues on the surface and less soil disturbance could increase soil organic C particularly in upper layer of the soil. Conversely, with no plant residues as mulch on the surface and because of soil disturbance, IT could decrease soil organic C due to erosion and decomposition. The presence of plant residues in CT will create better micro climate that can enhance soil biota activity (Lavelle 1984; Brito-Vega *et al.* 2009). This *in situ* mulch can act as an effective insulator and precursor of soil organic matter, and serve as substrate as well that can be converted to microbial biomass (Blevins *et al.* 1984; Wright and Hons 2004). While N fertilization provide available N that can enhance biomass production, resulted in higher SOC. With no N fertilization on the other hand, the higher N immobilization with respect to NT could reduce plant residue decomposition (Blevins *et al.* 1984).

Plant residues used in CT combined with N fertilization in CT, therefore are important in agriculture, due to could enhance carbon sequestration in agricultural soils.

At a deeper layer however, there was no interaction effect ($p<0.05$) of tillage and N fertilization on SOC. At depth of 5-10 cm, SOC was only affected by tillage ($p<0.05$), while at depth of 10-20 cm was only affected by N fertilization ($p < 0.05$). Regardless of N fertilization, SOC under MT at 5-10 cm depth was 26.2% higher than NT, but only 13.9% higher than IT (Table 2). Because of slightly tilled, the previous plant residues on MT were slightly mixed and caused more contact with soil particles, resulted in more plant residue decomposition rate with respect to MT. On the other hand, because of undisturbed soil surface, the plant residues in NT after one season had not totally decomposed yet. Unpublished data shown that residue decomposition rates for IT, MT, NT were 75%, 67% and 65%, respectively. At a deeper layer, the strong response of SOC to N fertilization was occurred. Soil organic carbon from 200 kg N ha^{-1} rate at 10-20 cm depth was 20.9% and 25.8% higher than those of 0 and 100 kg N ha^{-1} rates, respectively (Table 3). This obvious response was mainly attributed to the fact that in this depth, the plant residues and soil N content were limited.

Tabel 1. Interaction effect of conservation tillage and N fertilization on soil organic carbon after 23 years of crop season at 0-5 cm depth.

Tillage treatment	N fertilization (kg N ha^{-1})		
	0	100	200
	………..... (g kg^{-1}) …….…		
Intensive tillage	18.4 ab	16.2 ab	19.6 b
Minimum tillage	17.6 ab	20.2 b	19.3 ab
No-tillage	14.1 a	15.4 ab	20.6 b

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

Table 2. Effect of conservation tillage and N fertilization on soil organic carbon after 23 years of crop season at 5-10 cm and 10-20 cm depth.

Treatment	Depth (cm)	
	5-10	10-20
	…….… (g kg^{-1}) ………..	
Intensive tillage	16.5 ab	14.4 a
Minimum tillage	18.8 b	14.6 a
No-tillage	14.9 a	14.5 a
0 kg N ha^{-1}	15.2 a	13.8 b
100 kg N ha^{-1}	16.7 a	13.2 a
200 kg N ha^{-1}	18.3 a	16.6 c

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

Similar study which carried out in Texas also showed that after 20 years of cropping, SOC under NT for all cropping sequence at 0-5 cm depth was 64% greater than IT, but at 5-15 cm depth, it was only 28% greater than IT (Wright and Hons 2004). The higher SOC in the upper soil layer in long-term CT particularly if combined with optimum N rate is in agreement with those reported by researchers in subtropics ecosystem (Zibilske *et al.* 2002; Al-Kaisi and Yin 2005; Blanco-Canqui and Lal 2008).

Carbon Dioxide Emission

Corn season, 2009. Measurements of CO_2 in corn season were taken before plowing (treatment) and after plowing throughout the season from 28 August to 10 December 2009. As those reported by Rastogi *et al.* (2002) and Al-Kaisi *et al.* (2008), CO_2-C emission in this paper is referred to CO_2 regardless of the source of soil CO_2.

Prior to experiment, CO_2-C emission was not significantly ($p<0.05$) affected by any treatments. After plowing (treatment), however, CO_2-C emissions throughout the corn season were significantly ($p<0.05$) affected either by tillage or by N fertilization, while at 1 DAP, 40 DAP, 60 DAP and 80 DAP were significantly ($p<0.05$) affected by interaction of tillage and N fertilization as well. Regardless of N fertilization, average of CO_2-C emission from tillage treatment measured before plowing was 3.3 kg CO_2-C day^{-1} ha^{-1}. It appears that just one day after plowing (1 DAP), CO_2-C emission from IT increased sharply to reach maximum magnitude to 14.6 kg CO_2-C day^{-1} ha^{-1}. Compared to before plowing, CO_2-C emissions from IT and MT were 342% and 67.1% higher, while from NT was only 3.7% lower. Thereafter, CO_2-C emission from IT was dropped sharply at 3 DAP and then gradually declining, while from CT was relatively leveled off up to the end of the season (Figure 1a). It turned out that CO_2-C emission from IT throughout the season was consistently highest among tillage treatments, while from MT was the intermediate and from NT was the least (Tables 3 and 4). The CO_2-C emission averages from IT, MT and NT for one season basis were 11.0, 4.2 and 2.6 kg CO_2-C day^{-1} ha^{-1}, respectively; with ratios of IT to MT was 2.6 and IT to NT was 4.1.

Table 3. Effect of long-term conservation tillage and N fertilization on CO_2-C emission in corn crop, 2009.

Treatment combination	Day after plowing (DAP)		
	2	3	20
	...... (kg CO_2-C day^{-1} ha^{-1})		
Intensive tillage	14.33 c	11.97 c	11.25 c
Minimum tillage	5.41 b	4.86 b	4.72 b
No-tillage	2.79 a	3.13 a	3.37 a
0 kg N ha^{-1}	7.19 a	6.53 ab	5.68 a
100 kg N ha^{-1}	7.27 a	6.29 a	5.84 a
200 kg N ha^{-1}	8.07 b	7.14 b	7.83 b

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

The higher CO_2-C emission with respect to IT was mainly because tillage broke and inverted the soil to allow rapid CO_2 loss and O_2 entry; and mixed the residues and organic particles that could enhance microbial attack (Reicosky 2001; Rastogi *et al.* 2002; Smith and Collins 2007). On the other hand, less tillage reduced gas diffusivity and air-filled porosity, and kept soil organic C unexposed (Rastogi *et al.* 2002). These findings are in agreement with those reported by Reicosky (2001); Desjardins, *et al.* (2002); La Scala *et al.* (2005); Brye *et al.* (2006) that CO_2-C emission from IT was significantly higher than CT.

Although not as strong as tillage treatment, N treatment significantly ($p<0.05$) affected CO_2-C emissions. It turned out that CO_2-C emissions from 200 kg N ha^{-1} rate were consistently higher than those of 0 kg N ha^{-1} and 100 kg N ha^{-1} rates (Tables 3 and 4). There were two peaks of CO_2-C emissions occurred in this emission pattern (Figure 1b). The first peak of CO_2–C emission was reached at 1 DAP and the second peak was at 20 DAP. After the second peak, CO_2–C emissions from N treatment were gradually declining and ended up with very close magnitude. The averages of CO_2-C emission from N0, N1 and N2 treatment for one season basis were 5.4, 5.6 and 6.4 kg CO_2-C day^{-1} ha^{-1}, respectively; with CO_2-C emission ratios of N0 to N1 was 1.0 and N0 to N2 was 0.8.

The significant effect of N fertilization on CO_2-C emissions at the first three days after plowing was associated with residual effect of long-term N fertilization. Residual N has induced microbial activity in the soil that resulted in more CO_2-C emission. It can be noted that in this long-term experiment, N treatment has been applied since 1987 (24 years of application). At 20 DAP and the rest of sampling dates, however, higher of CO_2-C emissions from higher N rates were attributed to the direct effect of N fertilization on CO_2 production. According to Rastogi *et al.* (2002), and Smith and Collins (2007) application of nitrogenous fertilizer affects CO_2-C emission directly by providing nitrogen to crop and microbe for their growths, and indirectly by influencing soil pH. Nitrogen fertilization provided more available N to both crops and microbes that could accelerate root respiration and microbial decomposition of organic matter (Rastogi *et al.* 2002; Luo and Zhou 2006; Smith and Collins 2007). In fact, root respiration is important contributor to *in situ* soil respiration; it

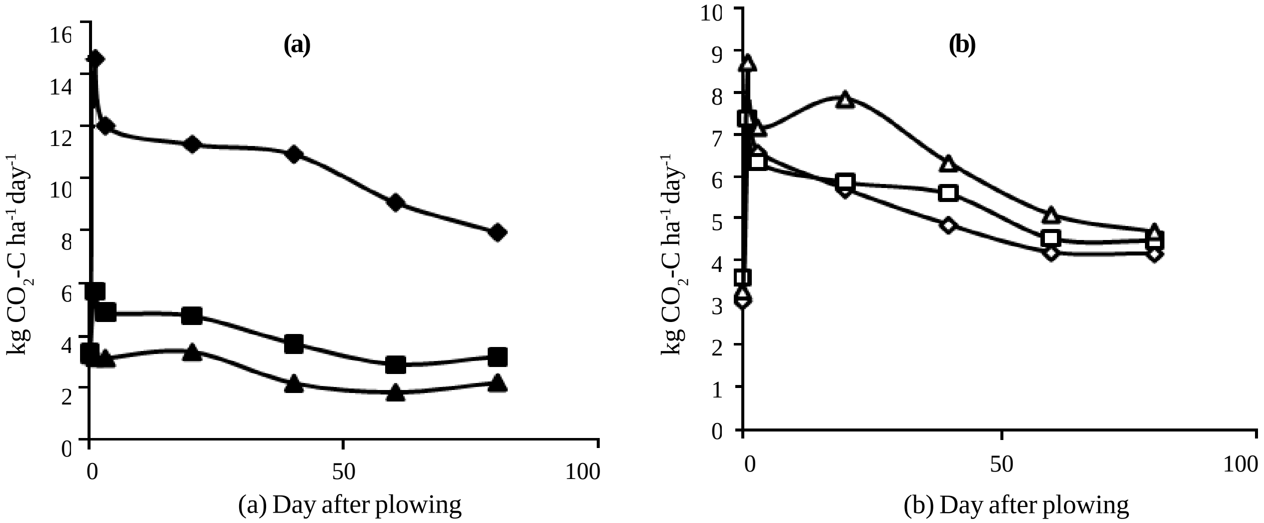

Figure 1. Pattern of CO_2-C emission in corn season as affected by (a) conservation tillage and (b) N fertilization; ◆ = intensive tillage, ■ = minimum tillage, ▲ = no-tillage, ◇ = 0 kg N ha^{-1}, □ = 100 kg N ha^{-1} , and △ = 200 kg N ha^{-1}.

contributes approximately 50% of the total soil respiration (Rastogi *et al.* 2002; Luo and Zhou 2006). Previous research carried out by Utomo *et al.* (2010) showed that N fertilization had increased ($p<0.05$) microbial biomass C both in rhizosphere and in non-rhizosphere. However, the significant effect of N fertilization on CO_2-C emission in corn crop is not in agreement with those reported by Brye *et al.* (2006) and Al-Kaisi *et al.* (2008).

Table 4 shows interaction effect of tillage and N fertilization on CO_2-C emissions along the corn season. With residual 200 kg N ha^{-1}, CO_2-C emission from IT treatment at 1 DAP was the highest ($p<0.05$) among treatment combinations, while MT with any N rate fertilizations was the second and NT was the lowest CO_2-C emission. With any residual N rate treatments, NT and MT respectively reduced CO_2-C emission to 84.3% and 66.7% as much of IT. Although the magnitudes were decreasing as a function of after plowing time, CO_2-C emission from combination of IT and N fertilization were still consistently highest among treatment combination at 40, 60 and 80 DAP. With any N rate treatments, NT could reduce CO_2-C emission to 75.4%-87.6% as much of IT, while MT could reduce to 65.2 %-67.6% (Table 4). The higher CO_2-C emission with respect to combination of IT and higher N rate was associated with the synergetic effect of tillage and N fertilization treatments. Combination of IT and optimum N rate created a better soil micro climate and available N that could produce more soil CO_2 emission. High N content is generally associated with high growth rates, leading to high growth respiration (Luo and Zhou 2006).

Soybean season, 2010. Measurements of CO_2 *in situ* in soybean season were taken after plowing throughout the season from 11 June to 6 September 2010 at 20 DAP, 40 DAP, 60 DAP, 80 DAP and 120 DAP. Throughout the soybean season, CO_2-C emissions were affected ($p<0.05$) by tillage, but not affected by interaction effects of tillage and N fertilization. While at 60 DAP, CO_2-C emission was only affected ($p<0.05$) by N fertilization.

It was obvious that CO_2-C emision from IT throughout the soybean season was consistently higher ($P<0.05$) than CT (Table 5). At 20 DAP through 120 DAP, NT could reduce 42.0%-74.3% as much CO_2-C emission as IT, while MT could reduce only 7.0%-46.7% from IT. In contrast to corn season, however, the effect of N fertilization on CO_2–C emission throughout the soybean season was inconsistent as those reported by Brye *et al.* (2006) and Al-Kaisi *et al.* (2008). In fact that at 60 DAP, CO_2 emision from 50 kg N ha^{-1} was lowest ($p<0.05$) than other treatments, while CO_2-C emision from 25 kg N ha^{-1} was similar to that of without N fertilization. It turned out that 50 kg N ha^{-1} could reduce CO_2 to 32.2%-37.2% as much of 0 and 25 kg N ha^{-1} treatments. The lack response of N fertilization of N fertilization on CO_2-C emission in soybean season was reflected to no interaction effect of tillage and N fertilization treatments on CO_2-C emission.

Negative effect of higher N rate on CO_2–C emision was attributed to the negative effect of N to soybean and microbe growths, resulted in a lower CO_2-C. Proper N addition could enhance CO_2-C evolution to a certain level, otherwise reduction

Tabel 4. Interaction effect of long-term conservation tillage and N fertilization on CO_2-C emission in corn crop, 2009.

Treatment combination	Day after plowing (DAP)			
	1	40	60	80
Conventional tillage:	.... (kg CO_2-C day^{-1} ha^{-1})			
0 kg N ha^{-1}	13.77 c	9.16 c	8.12 d	7.32 c
100 kg N ha^{-1}	13.54 c	10.67 c	8.52 d	7.64 dc
200 kg N ha^{-1}	16.24 d	12.82 d	10.51 e	8.68 d
Minimum tillage:				
0 kg N ha^{-1}	5.41 b	3.11 ab	2.63 bc	2.79 b
100 kg N ha^{-1}	5.89 b	3.42 b	2.71 bc	3.11 b
200 kg N ha^{-1}	5.57 b	4.46 b	3.34 c	3.66 b
No-tillage:				
0 kg N ha^{-1}	2.55 a	2.23 ab	1.75 ab	2.31ab
100 kg N ha^{-1}	2.55 a	2.63 ab	2.31 b	2.55 ab
200 kg N ha-1	4.30 ab	1.59 a	1.35 a	1.67 a

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

Table 5. Effect of long-term conservation tillage and N fertilization on CO2-C emission in soybean crop, 2010.

Treatment	Day after planting (DAP)				
	20	40	60	80	120
	.... (kg CO_2-C day^{-1} ha^{-1})				
Intensive tillage	17.38 b	15.23 b	18.31 b	16.13 b	16.14 c
Minimum tillage	14.01 ab	10.19 a	15.07 ab	7.51 a	8.60 b
No-tillage	10.11 a	7.91 a	10.67 a	5.94 a	4.14 a
0 kg N ha^{-1}	14.28 a	12.58 a	15.98 ab	10.99 a	9.82 a
25 kg N ha^{-}1	14.15 a	9.93 a	17.25 b	8.89 a	10.46 a
50 kg N ha^{-1}	13.08 a	10.83 a	10.83 a	9.71 a	8.60 a

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

occurred. This was due to luxury consumption of N by soil microbes in fact could suppress CO_2-C pro-duction (Abro *et al.* 2011). In nitrogen-sufficient such as in soybean crop season, N fertilization could exacerbate conditions of “nitrogen saturation”, resulting in less soil respiration. Nitrogen fertilization could also decrease phenol oxidase activity by 40% in soil and increase it by 63% in litter. Therefore, condensations of nitrogen rich compounds with phenolics could make soil organic matter more recalcitrant, resulting in decreases of microbial respiration (Luo and Zhou 2006). In contrast to corn season, less response of CO_2 gas emission to N fertilization in soybean season was also related to cropping pattern history of this long-term experiment which included soybean into cereal-legume rotation (Utomo *et al.* 1989). Unpublished data of this experiment supported this finding that there was no significant effect of long-term N fertilization on soybean growth and yield.

This finding was supported by result from incubation study carried out by Abro *et al.* (2011) that CO_2-C emission was significantly increased at optimum N rate, but declined at higher N rate. The response of CO_2-C emissions to tillage and N fertilization are shown in Figure 2a and 2b. The peaks of CO_2-C emission due to tillage and N fertilization were occurred at 20 DAP and 60 DAP, while the least of CO_2-C emissions occurred at 40 DAP and 80 DAP. These unique responses were related to soil moisture and soil temperature fluctuation along the season (Figures 2c and 2d).

In fact, the fluctuation of CO_2-C emissions throughout the season were highly correlated to soil moisture ($r = 0.50^{**}$ to 0.73^{**}) and soil temperature ($r = 0.64^{**}$ to 0.81^{**}). Soil moisture ranges at 2.5 cm depth throughout the season were 15 to 40% (w/w), and soil temperature ranges were 29.0 to 31.5^{o} C. Such favorable micro climate enhanced microbial growth, resulted in higher CO_2-C emissions.

Although the magnitude was fluctuating, CO_2-C emission from IT in soybean season was consistently higher than that of CT along the season. The CO_2-C emission averages from IT, MT and NT for one season basis were 16.8, 11.7 and 8.7 kg CO_2-C day^{-1} ha^{-1}, respectively; with IT to MT ratio 1.4 and IT to NT ratio 1.9. Different to corn season, however, CO_2-C emission in soybean was reduced by higher N rate. Carbon dioxide-C emissions average of N0, N1 and N2 treatment were 13.5, 12.6 and 11.1 CO_2-C day^{-1} ha^{-1}, respectively; with N0 to N1 ratio 1.1 and N0 to N2 ratio 1.2.

CONCLUSIONS

After 23 years of cropping, SOC under NT combined with 200 kg N ha^{-1} fertilization at depth of 0-5 cm was 46.1% higher than NT with no N fertilization, while at depth of 5-10 cm, SOC under MT was 26.2% higher than NT and 13.9% higher than IT. At depth of 10-20 cm, soil organic C in 200 kg N ha^{-1} treatment was 20.3% and 25.8% higher than those of 0 and 100 kg N ha^{-1} treatments, respectively.

Throughout the corn and soybean seasons, CO_2-C emissions from IT were consistently higher than CT. In corn season, MT and NT combined with any N rate treatments could reduce CO_2-C emission to 65.2 %-67.6% and to 75.4%-87.6% as much of IT, respectively. While throughout the soybean season, MT and NT could reduce CO_2-C emission to 17.6%-46.7% and 42.0%-74.3% as much of IT, respectively. Prior to generative soybean growth, 50 kg N ha^{-1} rate could reduce CO_2 gas emission to

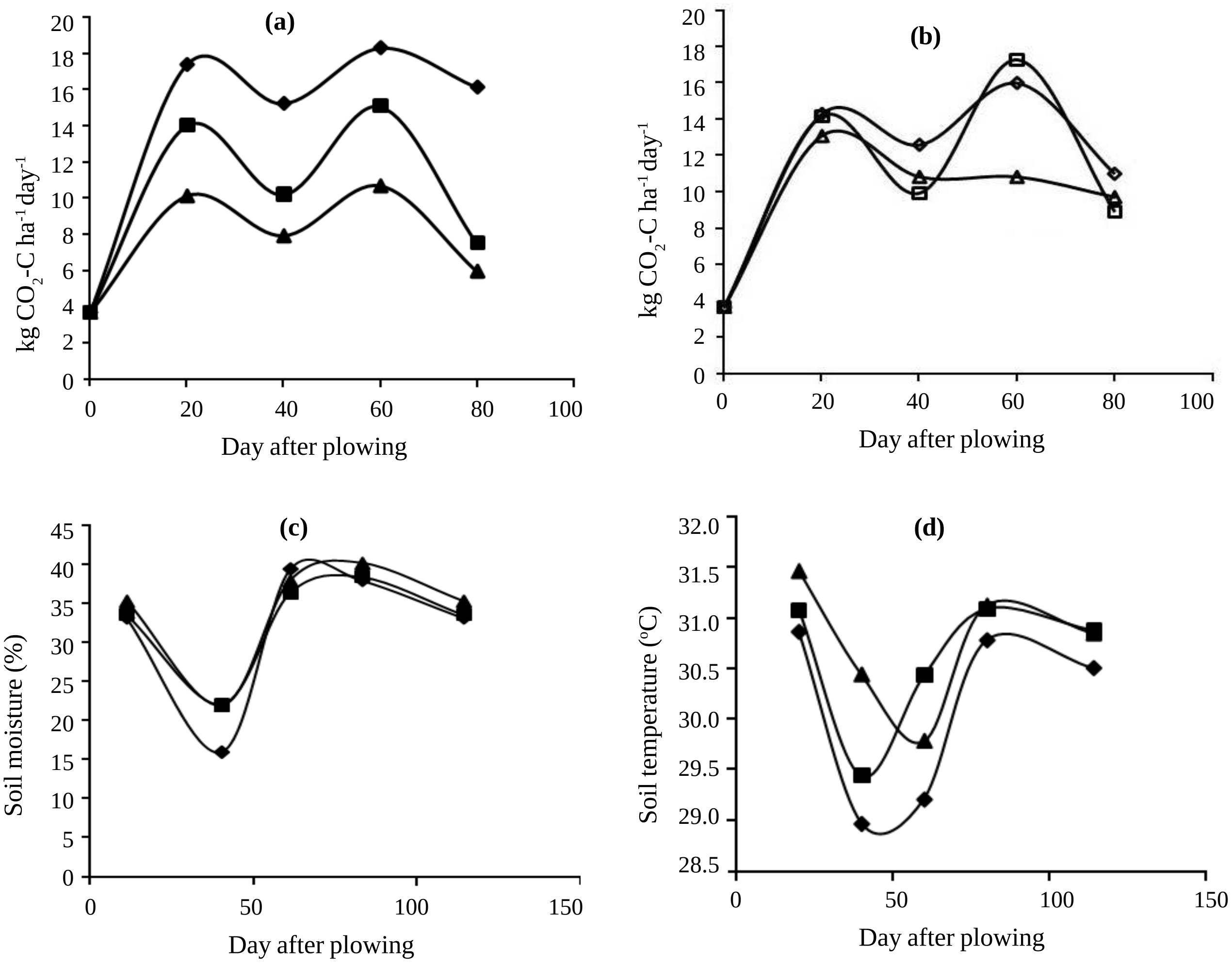

Figure 2. Pattern of CO_2-C emission in soybean season as affected by conservation tillage (a), N fertilization (b), pattern of soil moisture (c), and soil temperature (d) as affected by conservation tillage; ◆ = intensive tillage, ■ = Minimum tillage, ▲ = no-tillage, ◇ = 0 kg N ha^{-1}, □ = 25 kg N ha^{-1} , and △ = 50 kg N ha^{-1}.

32.2%-37.2% as much of 0 and 25 kg N ha^{-1} N rates.

The results suggest that conservation tillage as one of best practices in upland agriculture can strongly contribute to substantial reduction of national GHG emission.

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