Chapter 4
Conservation Tillage Assessment for Mitigating Greenhouse Gas Emission in Rainfed Agro-Ecosystems

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Abstract Global warming due to greenhouse gas emissions is currently receiving considerable attention worldwide. Agricultural systems contribute up to 20 % of this global warming. However, agriculture can reduce its own emissions while increasing carbon sequestration through use of recommended management practices, such as consernvation tillage (CT). The objective of this paper is to review the role of long-term CT in mitigating greenhouse gas emissions during corn production in rainfed tropical agro-ecosystems. The types of conservation tillage were no-tillage (NT) and minimum tillage (MT). In a long-term plot study, CO_2 emission from CT throughout the corn season was consistently lower than that from intensive tillage (IT). The cumulative CO_2 emissions of NT, MT, and IT in corn crops were 1.0, 1.5, and 2.0 Mg CO_2-C ha^{-1}season^{-1}, respectively. Soil carbon storage at 0–20 cm depth after 23 years of NT cropping was 36.4 Mg C ha^{-1}, or 43 % and 20 % higher than the soil carbon strorage of IT and MT, respectively. Thus, NT had sequestered some 4.4 Mg C ha^{-1}of carbon amounting to carbon sequestration rate of 0.2 Mg C ha^{-1} year^{-1}. IT, on the other hand, had depleted soil carbon by as much as 6.6 Mg C ha^{-1}, yielding a carbon depletion rate of 0.3 Mg C ha^{-1} year^{-1}. Assessment of the farmer's corn fields confirmed these findings. CO_2 emission from CT corn farming was similar to that of rubber agroforest and lower than IT corn farming. Based on carbon balance analysis, it can be concluded that corn crops in tropical rainfed agro-ecosystems were not in fact net emitters, and that NT was a better net sinker than other tillage methods.

Keywords Conservation tillage • CO_2 emission • Carbon storage

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4.1 Introduction

Global warming due to greenhouse gas (GHG) emissions is currently receiving consider-able attention worldwide. The impact of human activities on the atmosphere and the accompanying risk of long-term climate change on a global-scale are by now familiar topics to many people (Paustian et al. 2006). Global temperature rose 0.6 °C during the twentieth century, and is projected to increase by 1.5–5.8 °C during the twenty-first century. Historical records clearly show an accelerating increase in atmospheric GHG concentrations over the past 150 years (Intergovernmental Panel on Climate Change (IPCC) 2001). This is attributed to the advance of greenhouse gases such as CO_2, CH_4, and N_2O, in particular, due to the anthropogenic activities. Among the greenhouse gases, CO_2 is the most important gas, accounting for 60 % of global warming (Rastogi et al. 2002; Ruddiman 2003; Lal 2007). While most of the increase is due to CO_2 emissions from fossil fuels, land use and agriculture play significant roles. Overall, agricultural activities along with land use change, which predominantly occurs in the tropics, globally account for about one-third of the warming effect from increased GHG concentrations (Cole et al. 1997). In fact, although agriculture is its self subject to environmental risk due to global warming, ironically it is also estimated to contribute up to 20 % of global anthropogenic CO_2 emissions (Intergovernmental Panel on Climate Change (IPCC) 2006; Haile-Mariam et al. 2008). In Indonesia specifically, agriculture, land use change, and forests combine to contribute as much as 53 % of CO_2 emissions (Boer 2010). Agro-ecosystems emit CO_2 emission through direct use of fossil fuels in food production, indirect use of embodied energy in inputs, and cultivation of soils that cause the loss of carbon through decomposition and erosion (Ball and Pretty 2002).

The difference compared with fossil fuel based sectors, however, is that land use and agriculture have the opportunity to mitigate GHG emission through recommended management practices (RMP). Therefore, producers, scientists, and planners are faced with the challenge of increasing agricultural production without aggravating the risks of GHG emissions. In this regard, the management of soil resources in general and that of soil organic carbon (SOC) in particular, is extremely important. The world's soil resources may be the key factor in the creation of an effective carbon sink and mitigation of the greenhouse effect (Lal 1997). By employing RMP, agro-ecosystems can act as sinks that can both sequester carbon (C) and reduce CO_2 emission (Pretty and Ball 2001; Lal 2007). Conservation tillage as a RMP can enhance SOC, thus reducing agriculture's potential for global warming (Rastogi et al. 2002; 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; Eggleston et al. 2006).

Worldwide adoption of CT, and particularly no-tillage, has expanded rapidly since about 1990, particularly in the United States, South American countries, and Africa (Triplett and Dick 2008). As in other countries, CT in Indonesia which generally consists of no-tillage (NT) and minimum tillage (MT), was initially promoted by a few CT researchers in the 1980's. Farmers themselves successfully adopted and practiced CT in the 1990s due to the fact that it requires less cost and labor, yet maintains at least the same crop yield as IT. This was the case particularly in regions with labor shortages, such as Sumatra, Borneo, and Celebes (Utomo 2004). Then in 1998, CT was explicitly advocated in a national land preparation policy, resulting in increasing adoption of the techniques, particularly for corn production (Utomo et al. 2010a). As the second most important food crop in Indonesia, corn is mostly planted in rainfed agro-ecosystems. In Lampung Province, the area of corn harvested in 2011 was 380.917 ha, or 46 % of the total area of Sumatra's corn belt (Badan Pusat Statistik BPS 2012). However, rainfed agro-ecosystems, which account for about 91 % of total agricultural land in Indonesia, are inherently prone to degradation. To sustain these vulnerable agro-ecosystems, therefore, CT should be implemented and further improved.

The aim of this paper is to review research and assessment findings both from a long-term plot and from farmers' fields, in order to evaluate the potential of CT to mitigate CO_2 emissions in Indonesia's rainfed agro-ecosystems. In this paper, mitigation of CO_2 emissions is defined as a technological effort both to reduce GHG emissions and to sequester carbon in soils.

4.2 Soil, Carbon Dioxide Emission, and Conservation Tillage

Soil is a powerful natural sink of carbon in terrestrial ecosystems. Natural soils can retain carbon in stable microaggregates for up to hunded and thousands of years unless environmental conditions are changed and stable soil structure is damaged. Cultivation practices, such as plowing, break soil aggregates, exposing formerly protected SOC in soil to microbial attacks, and thus accelerating decomposition and CO_2 emission to the atmosphere (Luo and Zhou 2006). In general, these respiratory carbon losses from soil can be attributed to biological and chemical processes 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 and Yin 2005). Moreover, Luo and Zhou (2006) stated that CO_2 emitted from soil ecosystems constitutes part of the cabon cycle, and is mostly produced as a result of the soil respiration process. Depending on the sources of carbohydrate substrate supply, CO_2 production in the soil can be attributed to root respiration, microbial respiration in the rhyzosphere, litter decomposition, and oxidation of soil organic matter.

In tropical agro-ecosystems, soil respiration and decomposition happen more quickly, resulting in higher CO_2 emission and less C sequestration than in cooler climates (Desjardins, et al. 2002). Cultivation for land preparation produces a favorable soil microenvironment that can accelerate microbial decomposition of plant residues. Cultivation or intensive tillage (IT) is any tillage that requires clean and loose top soil for seed to grow. For this reason, soil should be totally tilled and no mulch is needed. But over the long-term, IT decreases soil quality and soil productivity (Rastogi et al. 2002; Paustian et al. 2006; Luo and Zhou 2006). Soil degraded by cultivation is also more susceptible to erosion, which carries carbon to rivers and oceans, where it is partially released into the atmosphere by outgassing (Luo and Zhou 2006).

Soil resources have the potential capacity to sequester carbon. Based on the principles of either increasing plant carbon input or slowing soil carbon decomposition rates, soil carbon can be sequestered through a variety of recommended management practices (RMP). Conservation tillage as a RMP is a tillage system that keeps at least 30 % of the soil surface covered by plant residue and reduces soil disturbance (Lal 1989; Utomo 2004). The function of crop residue covering the soil surface is to protect the soil from sun, rain, and wind, and to feed the biota. Crop residue serves as a 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). There are several types of CT, including (a) *no-tillage*: the soil is left undisturbed except for hills, slots, or bands; and weeds are controlled primarily with herbicide; (b) *ridge tillage*: soil is undisturbed, and planting is on ridges; (c) *strip tillage*: soil is undisturbed, and 1/3 of the soil surface is tilled; (d) *mulch* tillage: soil is totally tilled, with mulch on the soil surface; and (e) *reduced tillage/minimum tillage*: at least 30 % of the soil surface is covered by plant residue (Lal 1989; Utomo 2004).

Long-term CT involving crop residue and less tillage can reduce soil erosion and improve soil organic matter. Therefore, through its effect on C dynamics, aggregation, and soil structure, and its interaction with cropping systems, CT is expected to result in lower CO_2 emissions and higher soil C sequestration than IT (Lal 1997).

4.3 Reducing Carbon Dioxide Emission

4.3.1 Carbon Dioxide Emission at the Long-Term Plot

Field research on mitigation of CO_2 gas emissions from a corn plot was conducted from 2009 to 2011 as part of the long-term plot research commenced in 1987 in Lampung, Indonesia (105° 13′E, 05° 21′S). The experiment was a factorial, randomized complete block design, with 4 replications. Tillage treatments comprised conservation tillage (NT and MT), and IT, while nitrogen fertilization rates were 0, 100, and 200 kg N ha^{-1} (Utomo et al. 1989).

Regardless of N fertilization, average CO_2-C emission from tillage treatment measured before plowing was 3.3 kg CO_2-C $ha^{-1}day^{-1}$. It appears that just one day after plowing (1 DAP), CO_2-C emission from IT increased sharply to reach a maximum magnitude of 14.6 kg CO_2-C ha^{-1} day^{-1}. Thereafter, CO_2-C emission from IT dropped sharply at 3 DAP and then gradually declined, while emission from CT was relatively level to the end of the season (Fig. 4.1a) (Utomo et al. 2012). This was similar to research findings by Al-Kaisi and Yin (2005), which found that CO_2 emission was generally lower with less tillage compared to moldboard plow usage, with the greatest differences occurring immediately after tillage operations.

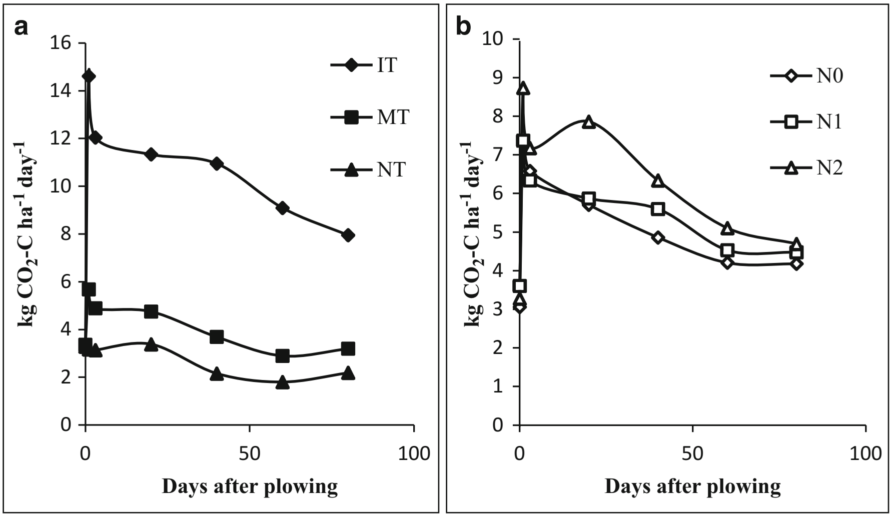

Fig. 4.1 Pattern of CO_2-C emission in corn season as affected (**a**) conservation tillage, and (**b**) N fertilization; IT = intensive tillage, MT = minimum tillage, NT = no-tillage, N0 = 0 kg N ha^{-1}, N1 = 100 kg N ha^{-1}, N2 = 200 kg N ha^{-1} (Utomo et al. 2012)

During a single season, NT and MT reduced the CO_2-C emissions of corn production at the long-term plot to 76 % and 62 % of IT based emission, respectively. This was because tillage broke and inverted the soil to allow rapid CO_2 loss and O_2 entry, and mixed together the residues and organic particles that could enhance microbial attack (Reicosky 2001; Rastogi et al. 2002; Smith and Collins 2007). On the other hand, CT reduced gas diffusivity and air-filled porosity, and kept SOC unexposed, resulting in a lower CO_2 emission than that of IT (Rastogi et al. 2002). These findings are in agreement with those reported by Reicosky (2001); Desjardins et al. (2002); Scala et al. (2005); Brye et al. (2006).

Although the effects were not as strong as those of tillage treatment, N fertilization treatment in corn season also consistently increased CO_2-C emission (Fig. 4.1b). Emissions of CO_2 at the 200 kg N ha^{-1} fertilization rate were consistently higher than those at the 0 and 100 kg N ha^{-1} rates (Utomo et al. 2012). When tillage was combined with N fertilization, the synergetic effect was clearly observed. With residual 200 kg N ha^{-1}, CO_2 emission from IT treatment at 1 DAP was the highest among treatment combinations, while MT with any N rate fertilizations produced the second highest CO_2 emission, and NT was the lowest.

The higher CO_2-C emission when combining IT with a higher N rate was associated with the synergetic effect of tillage and N fertilization treatments. Combination of IT and an optimum N rate created a soil micro climate and available N that produced more soil CO_2 emission (Utomo et al. 2012).

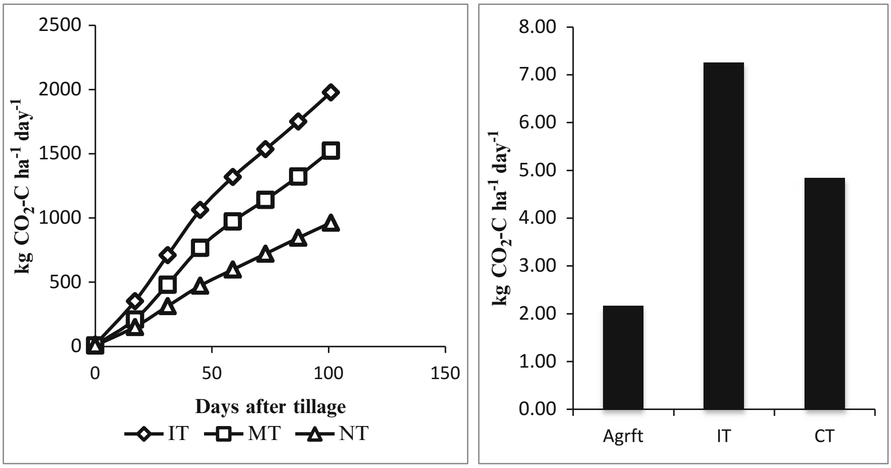

Fig. 4.2 Cumulative CO_2-C emission of corn at long-term plot (*left*) and CO_2-C emission at farmers' fields (*right*); Agrft = agroforest, IT = intensive tillage, MT = minimum tillage, NT = no-tillage and CT = conservation tillage (Utomo et al. 2010b; Utomo et al. 2011)

4.3.2 Cumulative CO_2 Emission at the Long-Term Plot

Cumulative soil CO_2 emission was set using the equation proposed by Al-Kaisi and Yin (2005). Cumulative soil CO_2 emissions of IT, MT, and NT were 1.98, 1.53 and 0.96 Mg CO_2-C ha^{-1} $season^{-1}$, respectively (Fig. 4.2, left). During a single season, NT reduced CO_2 emission to 52 % of IT based emission, while MT reduced emission to 23 % that of IT (Utomo et al. 2011).

Although these figures are somewhat lower than those of the average bases method, the value of cumulative CO_2 emission is much closer to continuous CO_2 measurement. This finding is in accordance with findings reported by Al-Kaisi and Yin (2005). They reported that cumulative soil CO_2 emission from MT was 19 to 41 % lower than that from moldboard plow usage, and NT with residue was 24 % lower than NT without residue during the 480-h measurement period.

4.3.3 Carbon Dioxide Emission Assessment in Farmers' Fields

In 2010, assessment of CO_2 emission in farmers' fields was conducted in East Lampung District, Lampung Province, Indonesia (105°28′35″–105°28′39″E, 05°19′22″–05°19′26″S). The soil texture was loam to clay loam, with soil pH $_{H2O}$ 5.1–5.4, total soil N 0.15–19 %, soil organic C 0.7–1.0 %, available P 1.9–4.1 ppm, CEC 10.2–13.2 me 100 g^{-1}, and BD 1.2–1.3 Mg m^{-3} (Utomo et al. 2010b).

In this assessment, a similar effect was clearly shown, but the effect was not as marked as in the plot experiment (Fig. 4.2, right). This was not only because the farmer applied less fertilizer, but also because during MT farming mulch covered only around 40 % of the soil surface, while in the plot experiment it covered around 90 %. Emission of CO_2 from IT was the highest, while emission from rubber agroforest was the lowest (Utomo et al. 2010b). Rubber agroforest reduced CO_2 emission to 70 % that of IT farming, while MT farming reduced it as much as 33 % (Fig. 4.2, right).

4.4 Enhancing Carbon Sequestration

4.4.1 Soil Carbon Storage

At the long-term plot, the highest soil C storage after 23 years of cropping at 0–20 cm depth was obtained by treatment combining NT with a higher N rate, while the lowest soil C strorage was in IT with 0 kg N/ha as shown in Fig. 4.3, left. No-tillage and MT resulted in soil C storage 43 % and 20 % higher than IT, respectively. The initial carbon storage at 0–20 cm depth in 1987 (when this long-term plot was established) was 32.0 Mg ha^{-1}(Utomo et al. 2010a). Thus, during 23 years of cropping, NT had sequestered as much as 4.4 Mg C ha^{-1}of carbon, amounting to a carbon sequestration rate of 0.2 Mg C ha^{-1} year^{-1}. In contrast, IT had depleted 6.6 Mg C ha^{-1} of carbon, yielding with carbon depletion rate of 0.3 Mg C ha^{-1} year^{-1}. The higher C sequestration of CT than business as usual practice was attributed to addition of previous plant residues, and a lower rate of soil organic matter decomposition with respect to CT. Every season, the average weight of crop residue applied to the NT soil surface was 6–13 Mg ha^{-1} season^{-1} with a C-N ratio of around 32 (Utomo et al. 2010a).

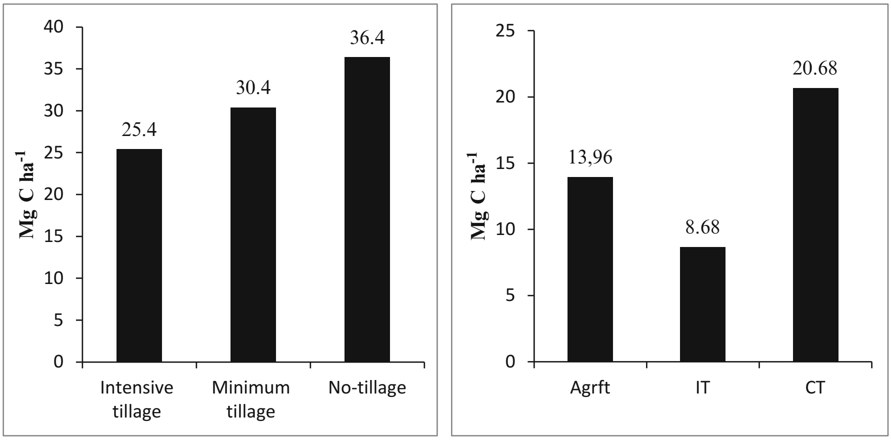

Fig. 4.3 Soil carbon storage at 0–20 cm depth after 23 years of conservation tillage (*left*) and farmers' fields (*right*); Agrft = agroforest, IT = intensive tillage, MT = minimum tillage, NT = no-tillage and CT = conservation tillage (Utomo et al. 2010b)

Table 4.1 Carbon balance of corn (during a single season)

Treatment	Root	Stalk	Grain	Total C-biomass (Mg C ha^{-1})	Emission	Net sequestration
Intensive tillage	1.2	3.6	2.5	7.3	2.0	5.3
Minimum tillage	1.6	3.4	4.5	9.5	1.5	8.0
No-tillage	2.1	5.3	5.0	12.4	1.0	11.4

Note: With optimum fertilization (Utomo et al. 2011)

This higher soil carbon sequestration is also reflected in improved soil quality and crop productivity with respect to CT. Utomo et al. (2013) recently reported that compared to the IT corn field, the CT corn field after 23 years of cropping had higher soil moisture, soil exchange bases, and soil microbial biomass. The corn yield of long-term CT was also 31.8 % higher than that of IT.

At the farmer's fields, that finding was confirmed by soil C storage at 0–20 cm depth under the different land use systems presented in Fig. 4.3, right. Soil C storage under CT farming was 138 % higher than under IT farming and 48 % higher than under rubber agroforest. The significant increase in soil C storage was attributable to the decomposition of previous crop residues and less soil erosion with respect to CT and rubber forest (Utomo et al. 2010b).

4.4.2 Carbon Sequestration of Corn Crops

Carbon sequestration of corn biomass was measured at harvest time. Through photosynthesis, plants fix CO_2 from the air and convert it into organic carbon compounds that are used to grow plant tissues or biomass (Luo and Zhou 2006). The total carbon of NT corn biomass was 12.4 Mg C ha^{-1}, 31 % higher than MT and 70 % higher than IT. With a better micro-climate and soil quality (Utomo et al. 2013), CT sequestered carbon in biomass at a higher level than other tillage systems, as reported by Lal (1997), Wright and Hons (2004), and Smith and Collins (2007). As shown in Table 4.1, NT's potential net sequestration reached 11.4 Mg C ha^{-1}, or 115 % and 43 % higher than IT and MT, respectively.

Dispite the fact that tillage systems generated CO_2 emissions, howevr, all tillage systems also seqestered carbon at a rate higher than their CO_2 emissions (Table 4.1). Thus, CT corn is not in fact a net CO_2 emitter, but instead is a net sinker. In the final analysis, therefore, it is evident that CT farming using RMP can mitigate CO_2 emission in a rain-fed tropical agro-ecosystem.

4.5 Conclusions and Policy Implication

In tropical rainfed agro-ecosystems, long-term conservation tillage of corn reduced CO_2 emission and increased carbon sequestration both in biomass and soil. Long-term conservation tillage of corn was also an effective net sinker of carbon.

However, further research is needed to improve the capacity of conservation tillage technology to mitigate greenhouse gas emissions in other crops and in different agro-ecosystems.

The policy implication of this strategic finding is that conservation tillage should be promoted by farmers, policy makers, and politicians as a recommended management practice for halting environmental degradation, reducing greenhouse gas emission, and strengthening food security.

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