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CO_2, CH_4 and N_2O Fluxes from Soybean and Barley Double-Cropping in Relation to Tillage in Japan

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Key words: Carbon budget, greenhouse gas, mitigation, nitrous oxide (N_2O), no-tillage, soil respiration.

Summary

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To examine whether no-tillage cultivation of upland fields mitigates greenhouse gas emissions from agriculture, seasonal changes in CO_2, CH_4, and N_2O emissions were measured for conventional tillage cultivation and no-tillage cultivation over a whole year (May 13, 2002 to May 13, 2003) in Tsukuba, Japan, which has a temperate climate. The soil respiration rate depended on soil temperature, and increased with a rise of soil temperature. Annual soil respiration amount was 2845 ± 967 g CO_2 m^{-2} y^{-1} in the conventional tillage cultivation plot and 2198 ± 656 g CO_2 m^{-2} y^{-1} in the no-tillage cultivation plot, *but there was no significant difference between the two plots. Thus, the annual soil respiration amount under no-tillage conditions cultivation showed a decrease by 23% from that under conventional tillage. When organic matter was incorporated into the soil by plowing-in of the crop residue in the conventional tillage plot after harvesting the crops, the soil respiration rate and N_2O flux increased rapidly. The majority of the difference (648 g CO_2 m^{-2} y^{-1}) of the annual soil respiration amount between the conventional tillage and the no-tillage plots corresponded to the difference in that from fallow periods (444 g CO_2 m^{-2} per period). A comparison of total greenhouse gas emissions in terms of carbon equivalent (the sum of emissions of each type of greenhouse gas multiplied by its global warming potential) from soybean and barley double-cropping using conventional tillage and no-tillage methods showed that lower carbon emission of 183 g carbon m^{-2} y^{-1} was possible by the use of no-tillage cultivation. These results clearly show that no-tillage cultivation is one of the most promising strategies for mitigation of greenhouse gas emission from the agricultural sector.

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Introduction

Human activity is leading to the emission into the atmosphere of vast quantities of greenhouse gases. As a result, global warming is becoming a reality. There are moves internationally to work on the prevention of global warming, such as the Kyoto Protocol, which was adopted at COP3 in 1997. In developed countries, including countries such as Russia that are undergoing a transition to market economies, the target values for reducing greenhouse gases such as CO_2 over a five-year period from around 2010 to 1990 levels require the following cuts in CO_2 emissions: EU 8%, US 7%, and Japan 6%, with an average reduction of 5.2% among the developed countries. At COP7, in 2001, a mutual agreement was approved on the operational rules to achieve the reduction target value of the Kyoto Protocol. Forest administration and farmland management areas were identified as uptake areas, i.e., negative greenhouse gas emission areas. If emission of greenhouse gases can be reduced by improving farming management, CO_2 absorption by forest and farmland will be able to be set against national CO_2 emissions.

The ratio of amount of total greenhouse gases emitted in terms of carbon equivalent (the sum of emissions of each type of greenhouse gas multiplied by its global warming potential) from the agriculture sector to that of all sectors in Japan in fiscal 2001 was 2.6%; and thus the contribution of the agriculture sector is low. However, the emissions of greenhouse gases from the agricultural sector in proportion to those of total CH_4 and total N_2O are high, at 67% (enteric fermentation 33% and rice cultivation 29%) of CH_4 and 57% (manure management: 34% and agricultural soil: 23%) of N_2O (MINISTRY OF THE ENVIRONMENT OF JAPAN 2003). Therefore, reduction of emissions of CH_4 and N_2O is needed in the agriculture sector.

Rice paddy fields emit large quantities of CH_4 while flooded and a small amount of N_2O while drained (e.g., NISHIMURA & al. 2004). On the other hand, upland fields emit large volumes of N_2O and absorb a small amount of CH_4 (BALL & al. 1999b, MALJANEN & al. 2003). Agricultural soils also emit CO_2 (PAUSTIAN & al. 2000) and soil CO_2 emissions are strongly dependant on plant and soil microbial activity that is in turn influenced by temperature (FORTIN & al. 1996). N_2O and CO_2 emissions from upland soils are responsive to management, including selection of crop species (KOIZUMI & al. 1993), tillage (BALL & al. 1999b), and application of fertilizers and manure (AKIYAMA & TSURUTA 2003). CO_2 emission due to soil respiration is often stimulated by tillage (ROBERTS & CHAN 1990). On the other hand, no-tillage may increase N_2O emission due to maintaining the soil in a wet condition (AULAKH & al. 1984) and anaerobic soil conditions (HANSEN & al. 1993). Recently, although studies concerning the assessment of greenhouse gas emissions from agricultural fields are increasing in number, there is still only limited research into the reduction of emissions by improvement of farming management.

No-tillage cultivation is of interest as a farming management technique for greenhouse gas emission reduction. Tillage cultivation accelerates carbon oxidation by increasing soil aeration and soil residue contact, and accelerates soil erosion by

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increasing exposure to wind and rain. In contrast, no-tillage cultivation can reduce water and wind erosion, conserve soil moisture, and reduce fuel costs (LAL & al. 1999). ROBERTSON & al. 2000 reported that net GWP (Global Warming Potential, grams of carbon dioxide equivalent per square meter per year) of greenhouse gases from a no-tillage system was lower than that of a conventional tillage system, mostly because of increased carbon storage in non-tilled soil. About 37% of the land farmed in the US is now managed using conservational tillage systems including no-tillage (LAL & al. 1999). However, since Japan has a mild and humid climate, allowing thick weed growth, plowing tillage (conventional tillage) is usually conducted as a control technique. No-tillage cultivation is rarely carried out in upland fields, although research on no-tillage cultivation has been conducted in Japan on rice fields (ITOH & TAKAHASHI 1997).

There is little data on carbon storage related to plowing or budget data on greenhouse gases for no-tillage cultivation in Japan. We examined conventional tillage cultivation and no-tillage cultivation in upland fields, and investigated, by means of comparison experiments, whether no-tillage cultivation is able to reduce emissions of greenhouse gases to the atmosphere from upland field soil.

Material and Methods

Experimental site

This research was conducted in two frame fields (50 m × 10 m per frame) at the National Institute for Agro-Environmental Science, Tsukuba (36°01'N, 140°07'E; elevation above sea level 25 m), containing a Typic Low-humic Andosol soil to a depth of 5 m. The soil texture and characteristics are as follows. Soil texture was light clay, and total-C amount was 2.91%, and Total-N was 0.27%. These frame fields had previously been used to cultivate rice for 10 years as rice paddies, then converted to upland field and used to cultivate upland crops such as cabbage, for 5 years up to the previous year. Each of these fields was now divided into a conventional tillage cultivation plot (20 m × 10 m) and a no-tillage cultivation plot (20 m × 10 m) leaving turning areas (2 m × 10 m on the east side, 4 m × 10 m in the center and 4 m × 10 m for the west side) for a power tiller. Double-cropping cultivation of soybeans in the summer and barley in the winter was carried out in these fields. In this study, the whole plants, including harvested grains and beans were incorporated into the soil. The conventional plow tillage and the no-tillage cultivations were carried out using the following methods. When the former crops were reaped, aboveground parts including barley panicles and soybean pods were chopped into small pieces with a disc harrow and then broadcast on the soil surface. In the conventional plow tillage plot, the chopped plant material was incorporated into the soil using a rotary harrow, whereas in the no-tillage cultivation plot, the crops were left on the soil surface. The conventional plow tillage treatment disturbed the soil to a depth of approximately 20 cm.

To decompose the crop residues incorporated into the soil, the field was left fallow for about one month. Lime at 0.1 kg per 1 m^2 was scattered on the soil surface two days before sowing. Both the conventional tillage and the no-tillage plots were drilled with a three-disc drill that created seeding slits (valleys) about 5 cm deep. The ridge distance was 60 cm for both soybeans and barley. Barley and soybean seeds were sown in the valleysl. Chemical fertilizer was also placed in the valleys. The amount of applied fertilizer in each plot (g m^{-2}) by band application mode was 70% of the amount applied in usual broadcast mode. The experiments started in July 2001. The cultivation schedule, amount of chemical fertilizer, dry weight of whole plants of crops and carbon amount in the whole plants are shown in Table 1.

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Table 1. Field management operations throughout the study period (CT: conventional tillage; NT: no-tillage).

Treatment	Crops	Date of sowing	Date of harvesting	Chemical fertilizer ($N: P_2O_5: K_2O$, %)	Amount of chemical fertilizer, g per valley	Dry weight of whole plant, g m^{-2}	Amount of carbon in whole plant, g m^{-2}
CT	Soybeans	July 12, 2001	Oct. 31, 2001	3: 10: 10	875	424	180
Fallow period	-	(Oct. 31 to Nov. 16, 2001)					
CT	Barley	Nov. 16, 2001	May 13, 2002	8: 8: 8	940	970	409
NT	Barley	Nov. 16, 2001	May 13, 2002	8: 8: 8	940	917	392
Fallow period	-	(May 13 to June 10, 2002)					
CT	Soybeans	June 10, 2002	Oct. 10, 2002	3:10:10	875	754	360
NT	Soybeans	June 10, 2002	Oct. 10, 2002	3:10:10	875	739	352
Fallow period	-	(Oct. 10 to Nov. 6, 2002)					
CT	Barley	Nov. 6, 2002	May 13, 2003	8: 8: 8	940	965	521
NT	Barley	Nov. 6, 2002	May 13, 2003	8: 8: 8	940	865	467

There were 16 valleys with 20 m length in the each plot (200 m^2).

Measurement of greenhouse gases

CO_2, CH_4 and N_2O fluxes were monitored in three replicates of each plot using the closed soil chamber method. The concentration of CO_2 (soil respiration) was continuously measured by means of a ventilation-type cylindrical chamber installed with automated gas sampling and analyzing equipment. The cylindrical chamber consisted of two parts: a foundation bottom section (diameter 21 cm; height 7 cm) made of stainless steel was inserted 3 cm into the ground over a ridge, and a lid section (diameter 21 cm; height 9.5 cm), made of grey vinyl chloride plates, was attached with inlet and outlet tubes for air flow and a small hole to allow extra air to escape. In the CO_2 measurement, it is single-unit by 3 pieces in foundation bottom section and 1 lid section. The lid's cylindrical chamber was transported at weekly intervals among the three bottom sections per set to reduce soil environmental changes. Dehydrated ambient air that had passed through a refrigerator was introduced into the cylindrical chambers at a rate of 1.5 l min^{-1}, controlled by a pump (AP-220ZN, Iwaki Co. Ltd., Japan) and a mass flow controller (SEC-E40, STEC Co. Ltd., Japan), and the outlet air was removed at a rate of 1.4 l min^{-1} using a pump (MV-76HG, Enomoto Micro Pump Co. Ltd., Japan). The gas sampling system allows remote collection of inlet dehydrated air before distribution to six chambers per frame field (three chambers per plot) and outlet dehydrated air through the refrigerator from within the six chambers through gas sampling units at programmed 5 minute intervals. The CO_2 concentrations were measured by means of an infrared CO_2 analyzer (Model ZRC, Fuji Electric Co. Ltd., Japan). The CO_2 analyzer was recalibrated with a standard concentration (approximately 600 ppmv) of CO_2 gas every 3 hours.

CH_4 and N_2O fluxes were determined in rectangular chambers (length 40 cm; width 40 cm; height 10 cm). The chamber also consisted of two parts: a foundation bottom section (length 40 cm, width 40 cm, height 5 cm), made of stainless steel, was inserted 3 cm into the ground over a ridge, and a lid section (length 40 cm, width 40 cm, height 10 cm), made of grey vinyl chloride plates fitted with two gas sampling ports. Three air samples (0.5 l) within the chamber were collected into a 1 l Tedlar (Polyvinyl fluoride) bag every 30 minutes using an air pump (MP-2N, Shibata Science Technology Ltd., Japan). The CH_4 and N_2O fluxes were calculated from the decrease or increase of CH_4 and N_2O concentrations inside the chamber with elapse of time. Air sampling for six chambers was started at 9:30 am on Wednesdays at weekly intervals throughout the whole year and ended before 11:30 am. CH_4 concentrations were determined using a gas chromatograph (GC-9A, Shimadzu Co., Japan) equipped with hydrogen flame ionization detectors at 100 °C using he-

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lium as the carrier gas and an integrator (Chromatopac CR-7A, Shimadzu Co., Japan). Separation of CH_4 gas was accomplished at 60 °C using a 5 m steel column packed with Porapak Q. N_2O concentrations were determined using a gas chromatograph (GC-8A, Shimadzu Co., Japan) equipped with ^{63}Ni electron capture detectors at 340 °C using argon gas containing 5% CH_4 as the carrier gas and the integrator. Separation of N_2O was carried out on a 3 m steel column (100 °C) packed with Porapak Q.

Carbon content in soils and plants

Soil samples (depth 0 - 10 cm) were collected in July 2001 for determination of carbon. The plants were each divided into three plant parts (leaves and stems, roots and seeds). Each plant part was dried at 70 °C for 6 days and weighed. Analysis of soil and plant samples for carbon content was conducted using the dry combustion method on a C-N analyzer (Model MT-700, YANAGIMOTO Co. Ltd., Japan).

Results and Discussion

Dry weight of whole plants

The average dry weight of whole plants of soybean and barley at harvest in both plots is shown in Table 1. The dry weight of whole plants from the no-tillage plot was 2 to 10% below those from the conventional tillage plot, though the differences were not statistically significant.

Soil respiration rate (CO_2 flux)

Fig. 1 shows daily changes in soil respiration rates for 50 days during the growing of barley, harvesting, plowing, and fallow period. The soil temperature at 2 cm depth is also shown. The soil respiration rates increased at higher soil temperatures, showing a parallel relationship to exist between soil temperature and soil respiration rate. A clear diurnal variation was recognized in the soil respiration rates. The hourly soil respiration rates of soybeans and barley during the entire growing period ranged from 10 to 500 $mgCO_2\ m^{-2}\ h^{-1}$ in both the conventional tillage and the no-tillage plots. These results are consistent with many reports (e.g., KOIZUMI & al. 1993). After conventional plowing tillage, the soil respiration rates rapidly increased up to 2,200 mg $CO_2\ m^{-2}\ h^{-1}$. It is well known that the soil respiration rates increase rapidly after tillage (1 hour to 4 days) (ELLERT & JANZEN 1999, LA SCALA Jr. & al. 2001). This high level of soil respiration rates continued four weeks after plow tillage (Fig. 1). The tillage-induced flash of CO_2 suggests that the transport coefficient and heterotrophic production of CO_2 was enhanced after plow tillage, as pointed out by ELLERT & JANZEN 1999. On the other hand, the soil respiration rates in the no-tillage plot also tended to increase to 900 mg $CO_2\ m^{-2}\ h^{-1}$ as a result of harvesting and then broadcasting the crop residues on the soil surface, although they returned to the pre-harvest baseline after several days.

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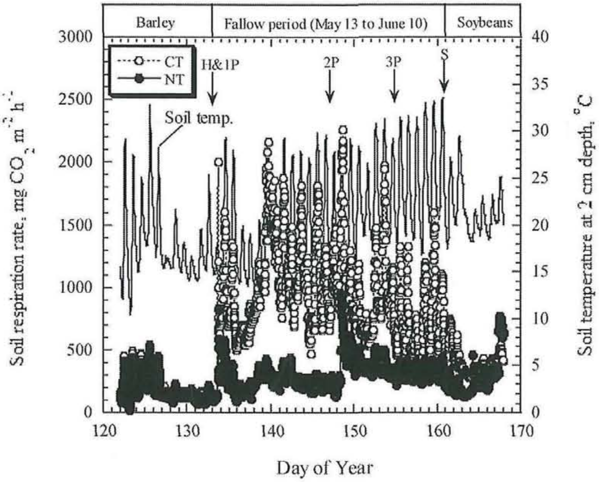

Fig. 1. Daily changes in soil respiration rates for 50 days (May 2 to June 16, 2002) during growing barley, harvesting, plowing (1st to 3rd) and sowing of soybeans with data on soil temperature at a depth of 2 cm. H is harvesting; 1P, 2P and 3P are first plowing, second plowing and third plowing, respectively; FA is fertilizer application; S is sowing.

Fig. 2 shows the seasonal changes in soil respiration rates with soil temperature. The change pattern of the soil respiration closely corresponded to the pattern of change of the soil temperature, rising in summer and falling in winter except for the fallow periods. The annual soil respiration rate (May 13, 2002 - May 13, 2003) was 2845 ± 967 g CO_2 m^{-2} y^{-1} in the conventional tillage plot and 2198 ± 658 g CO_2 m^{-2} y^{-1} in the no-tillage plot, but there was no significant difference brtween the two plots (Table 2). CO_2 emissions from the no-tillage plot tended to be lower and were 23% below than those from the conventional tillage plot. These results suggest that CO_2 emissions from upland fields can be reduced by no-tillage cultivation. The amount of soil respiration during the fallow periods was markedly reduced by no-tillage cultivation (Table 2). On the other hand, the amounts emitted during the crop growing periods in this experiment were relatively small in both plots. Thus, most of the annual total CO_2 emission can be attributed to emissions during the fallow period.

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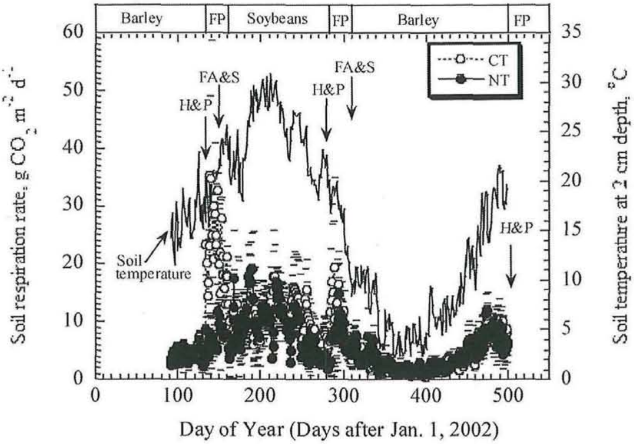

Fig. 2. Seasonal changes in daily soil respiration rates for the whole year from the conventional tillage and the no tillage plots under a double-cropping agroecosystem. FP is fallow period; H is harvesting; P is plowing; FA is fertilizer application; S is sowing. The horizontal bar over each symbol represents the standard deviation.

Table 2. CO_2, CH_4 and N_2O emissions[a)] from the conventional tillage (CT) and the no-tillage (NT) plots during cultivation period and whole year.

Cultivation	CO_2, g CO_2 m^{-2}		CH_4, g CH_4 m^{-2}		N_2O, g N_2O m^{-2}	
	CT	NT	CT	NT	CT	NT
Fallow[b)]	633 ± 205	208 ± 61*	-0.013 ± 0.001	-0.002 ± 0.001	0.019 ± 0.007	0.004 ± 0.002*
Soybeans	1281 ± 470	1066 ± 243	-0.013 ± 0.006	-0.011 ± 0.004	0.059 ± 0.024	0.033 ± 0.017*
Fallow[c)]	278 ± 159	209 ± 94	-0.002 ± 0.001	0.000 ± 0.001	0.117 ± 0.023	0.05 ± 0.029
Barley	653 ± 133	715 ± 259	-0.026 ± 0.006	-0.015 ± 0.006*	0.029 ± 0.015	0.057 ± 0.027*
Whole year	2845 ± 966	2198 ± 656	-0.04 ± 0.014	-0.027 ± 0.011*	0.224 ± 0.069	0.144 ± 0.075*

Values in each column are the mean of three samples and stansdard deviation.

a) Negative values indicate uptake by soil.

b) Spring fallow period (May 13 to June 10, 2002)

c) Autumn fallow period (October 10 to November 6, 2002)

* Asterisk indicates significant difference ($P < 0.05$) between the conventional tillage (CT) and the no-tillage (NT) plots

Methane

It is well known that a small amount of CH_4 is absorbed by upland soil (e.g., KELLER & al. 1990, DOBBIE & al. 1996), but little is known about the effect of tillage on CH_4 uptake. Although BALL & al. 1999b reported that the CH_4 uptake rate was reduced by tillage due to the disturbance of CH_4-oxidizing microbes, our results showed the opposite. The amount of CH_4 uptake in the soil for the whole year in the conventional tillage plot is significantly higher than that in the no-tillage

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plot (Fig. 3). The annual methane uptake amounts were 0.040 ± 0.001 g CH_4 m^2 y^{-1} in the conventional tillage plot and 0.027 ± 0.011 g CH_4 m^2 y^{-1} in the no-tillage plot (Table 2). The annual amount of methane uptake in the no-tillage plot decreased to 68% of that in the conventional tillage plot. These results show that no-tillage cultivation reduces the uptake of atmospheric methane. We believe reason for reduction in CH_4 uptake under no-tillage cultivation tobe that gas diffusivity at the soil surface is demonstrably lower under no-tillage conditions, due to compaction, than under conventional tillage (HANSON & al. 1993, DOBBIE & al. 1996).

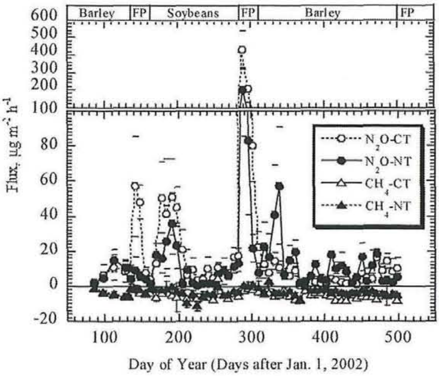

Fig. 3. Seasonal changes in CH_4 and N_2O fluxes over the whole year from the conventional tillage and the no-tillage plots under a double-cropping agroecosystem. FP is fallow period; H is harvesting; P is plowing; FA is fertilizer application; S is sowing. The horizontal bar above each symbol represents the standard deviation

N_2O

N_2O is chiefly emitted by soils as a result of denitrification in anaerobic soils and of nitrification in aerobic soils. It is well known that N_2O emissions are favored by (i) medium-high soil moisture, limiting O_2 diffusion (ii) high mineral - N availability and (iii) high organic carbon availability (SINGH 2000). N_2O flux peaks were observed for 2 to 4 weeks after fertilizer application (Fig. 3). This enhancement of N_2O flux after fertilizer application is widely observed (e.g., AKIYAMA & TSURUTA 2002). The increase in N_2O flux during this period is presumed to be N_2O chiefly generated due to nitrification (AKIYAMA & TSURUTA 2003). Moreover, high N_2O flux peaks were observed for 2 weeks just after the plowing-in of crop residues (Fig. 3). A similar phenomenon was reported by a number of researchers (SMITH & al. 1997, BALL & al. 1999a) who pointed that crop residues can enhance microbe activity and form local anaerobic zones, giving favorable sites for denitrification that contribute to "emission hot-spots". The formation of these hot-spots was governed by the creation of anaerobic conditions due to increased respiration, following the introduction of a source of decomposable organic matter to the soil microbes (FLESSA & BEESE 1995, CHRISTENSEN & TIEDJE

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1998). Our results show that N_2O emission from crop residues could be an important source of N_2O when the quantity of residues is high. Notably, N_2O fluxes after the incorporating of soybean into the soil in the conventional tillage and material standing on the soil surface in the no-tillage plots were respectively about 30-fold and 15-fold higher than in pre-harvest periods. It is well known that N_2O emissions increase with soil mineral nitrogen content (DAVIDSON & VERCHOT 2000, SKIBA & SMITH 2000). Since soybean seeds, in particular, have a high nitrogen content (content of nitrogen in soybean seeds and pods: 5.1%, while nitrogen in barley ears: 1.9%) in our analysis results, we conclude that N_2O flux peaked during the fallow period in November, reaching 431 in the conventional tillage plot and 220 $\mu g\ m^{-2}\ h^{-1}$ in the no-tillage plot.

Although it is thought that no-tillage cultivation increases N_2O emissions due to high soil water content and lower gas diffusivities near the soil surface (BALL & al. 1999b), some reports claim different effects. BALL & al. 1999b reported that N_2O emissions from no-tillage plots were higher than conventional tillage plots in Scotland, and the greater emissions of N_2O under no-tillage corresponded to lower in situ gas diffusivities and higher water content near the soil surface than in the ploughed treatments. On the other hand, CHOUDHARY & al. 2002 found no differences between conventional tillage and no-tillage treatments in winter oats and fodder maize double-cropping in New Zealand. In the present study, annual N_2O emissions from conventional tillage and the no-tillage plots were 0.224 ± 0.069 and 0.144 ± 0.075 $g\ N_2O\ m^{-2}\ y^{-1}$, respectively (Table 2). No-tillage cultivation significantly reduced the annual N_2O emission by 36% from conventional tillage cultivation. N_2O fluxes during crop cultivation periods in this experiment were relatively small in both plots and paralleled soil respiration rates. Longer experiments are required to evaluate whether no-tillage cultivation during crop growing periods results in less or more N_2O emissions than conventional tillage cultivation.

Annual budget of total greenhouse gas using global warming potential (GWP)

Annual emissions of CO_2, CH_4, and N_2O as CO_2 equivalents using GWP, which gives coefficients of 1 for CO_2, 21 for CH_4, and 310 for N_2O (IPCC 1996), under the conventional tillage plot were 2845, 0.840, and 69.6 $g\ CO_2\ m^{-2}\ y^{-1}$, respectively. Similarly, those of CO_2, CH_4, and N_2O in no-tillage condition plots were 2198, –0.571, and 44.8 $g\ CO_2\ m^{-2}\ y^{-1}$, respectively. This makes the annual emission of carbon equivalent greenhouse gases from the conventional tillage plot and the no-tillage plot 2,914 and 2242 $gCO_2\ m^{-2}\ y^{-1}$, respectively, suggesting that no-tillage cultivation reduced emissions by 672 $g\ CO_2\ m^{-2}\ y^{-1}$ (corresponding to 183 $g\ C\ m^{-2}\ y^{-1}$) compared with conventional tillage cultivation. The contribution by CO_2 to the three kinds of greenhouse gases is overwhelmingly large, accounting for 98% of greenhouse gas emissions in both the conventional tillage and the no-tillage plots. The result that GWP emission of greenhouse gases was decreased by no-tillage cultivation system confirms the results of ROBERTSON & al. 2000. However, it differed greatly from their results in that the contribution of N_2O to the GWP emission of greenhouse gases in ROBERTSON & al. 2000 accounted for about

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50%.

Table 3 shows the balance of carbon in the conventional tillage and the no-tillage plots for soybean cultivation (spring fallow period followed by soybean cultivation period), barley cultivation (autumn fallowing period followed by barley cultivation period), and over the whole year. The carbon balances of the soil in the no-tillage cultivation were positive, showing that the soil operated as a carbon sink. On the other hand, the carbon balances in the conventional tillage plot were negative (–118 g C m^{-2} for soybean cultivation and –24 g C m^{-2} for the whole year), giving a positive value (94 g C m^{-2} for barley cultivation), indicating that the soil operates as a CO_2 source during soybean cultivation (and over the whole year) and a CO_2 sink during barley cultivation. KOIZUMI & al. 1993 estimated the carbon balances in conventional tillage under double-cropping systems, without taking into account N_2O emission, to be approximately –400 g C m^{-2} y^{-1} for food crops, suggesting that there are major emissions of carbon from upland soils in Japan. In the present study, soybeans and barley panicles were incorporated into the soil or left on the soil surface, meaning that much greater amounts of carbon were supplied to the soil than in conventional cultivation systems. This major difference in carbon balance in upland soils between KOIZUMI & al. 1993 and our study might be due to the amount of supplied organic matter, but the actual reason is not clear. Further study is required to evaluate the difference in contribution of N_2O to GWP emission of greenhouse gases and carbon balance by tillage methods over the long term.

Table 3. Annual carbon storage and emission and budgets in the conventional tillage and the no-tillage plots under double-cropping system.

Cultivation	Conventional tillage plot			No-tillage plot		
	Supplied as crop residues, g C m^{-2} (x)	Emissions[a] of CO_2, CH_4 and N_2O as CO_2 equivalents using GWP, g C m^{-2} (y)	Carbon balance (x - y)	Supplied as crop residues, g C m^{-2} (x)	Emissions[a] of CO_2, CH_4 and N_2O as CO_2 equivalents using GWP, g C m^{-2} (y)	Carbon balance (x - y)
Spring fallow[b] followed by soybeans	409	527	-119	392	350	42
Autumn fallow[c] followed by barley	360	266	94	352	261	91
Whole year	769	793	-24	744	611	133

a) Amount of CO_2 equivalent was calculated based on its greenhouse gas emissions, using factors of 1 for CO_2, 21 for CH_4 and 310 for N_2O.

b) Spring fallow period (May 13 to June 10, 2002)

c) Autumn fallow period (October 10 to November 6, 2002)

Negative values represent carbon emissions from upland soil, indicating that it is a source of carbon, while positive values indicate a carbon sink.

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