

|                                                   |         |         |             |           |
|---------------------------------------------------|---------|---------|-------------|-----------|
| Phyton (Austria)<br>Special issue:<br>"APGC 2004" | Vol. 45 | Fasc. 4 | (327)-(338) | 1.10.2005 |
|---------------------------------------------------|---------|---------|-------------|-----------|

## CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O Fluxes from Soybean and Barley Double-Cropping in Relation to Tillage in Japan

By

I. NOUCHI<sup>1)</sup> & S. YONEMURA<sup>2)</sup>

**Key words:** Carbon budget, greenhouse gas, mitigation, nitrous oxide (N<sub>2</sub>O), no-tillage, soil respiration.

### S u m m a r y

NOUCHI I. & YONEMURA S. 2005. CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O fluxes from soybean and barley double-cropping in relation to tillage in Japan. - *Phyton* (Horn, Austria) 45 (4): (327)-(338).

To examine whether no-tillage cultivation of upland fields mitigates greenhouse gas emissions from agriculture, seasonal changes in CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O 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  $2845 \pm 967$  g CO<sub>2</sub> m<sup>-2</sup> y<sup>-1</sup> in the conventional tillage cultivation plot and  $2198 \pm 656$  g CO<sub>2</sub> m<sup>-2</sup> y<sup>-1</sup> 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<sub>2</sub>O flux increased rapidly. The majority of the difference ( $648$  g CO<sub>2</sub> m<sup>-2</sup> y<sup>-1</sup>) 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<sub>2</sub> m<sup>-2</sup> 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<sup>-2</sup> y<sup>-1</sup> 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.

<sup>1)</sup> National Institute for Agro-Environmental Sciences, 3-1-3 Kannondai, Tsukuba, Ibaraki 305-8604, Japan. Fax: 81-29-838-8199, e-mail: [nouchi@niaes.affrc.go.jp](mailto:nouchi@niaes.affrc.go.jp)

<sup>2)</sup> National Institute for Agro-Environmental Sciences, 3-1-3 Kannondai, Tsukuba, Ibaraki 305-8604, Japan. Fax: 81-29-838-8199, e-mail: [yone@niaes.affrc.go.jp](mailto:yone@niaes.affrc.go.jp)

## 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<sub>2</sub> over a five-year period from around 2010 to 1990 levels require the following cuts in CO<sub>2</sub> 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<sub>2</sub> absorption by forest and farmland will be able to be set against national CO<sub>2</sub> 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<sub>4</sub> and total N<sub>2</sub>O are high, at 67% (enteric fermentation 33% and rice cultivation 29%) of CH<sub>4</sub> and 57% (manure management: 34% and agricultural soil: 23%) of N<sub>2</sub>O (MINISTRY OF THE ENVIRONMENT OF JAPAN 2003). Therefore, reduction of emissions of CH<sub>4</sub> and N<sub>2</sub>O is needed in the agriculture sector.

Rice paddy fields emit large quantities of CH<sub>4</sub> while flooded and a small amount of N<sub>2</sub>O while drained (e.g., NISHIMURA & al. 2004). On the other hand, upland fields emit large volumes of N<sub>2</sub>O and absorb a small amount of CH<sub>4</sub> (BALL & al. 1999b, MALJANEN & al. 2003). Agricultural soils also emit CO<sub>2</sub> (PAUSTIAN & al. 2000) and soil CO<sub>2</sub> emissions are strongly dependant on plant and soil microbial activity that is in turn influenced by temperature (FORTIN & al. 1996). N<sub>2</sub>O and CO<sub>2</sub> 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<sub>2</sub> emission due to soil respiration is often stimulated by tillage (ROBERTS & CHAN 1990). On the other hand, no-tillage may increase N<sub>2</sub>O 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

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 (ITO & 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<sup>2</sup> 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 valleys. Chemical fertilizer was also placed in the valleys. The amount of applied fertilizer in each plot (g m<sup>-2</sup>) 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.

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 <sub>2</sub> O <sub>5</sub> : K <sub>2</sub> O, %) | Amount of chemical fertilizer, g per valley | Dry weight of whole plant, g m <sup>-2</sup> | Amount of carbon in whole plant, g m <sup>-2</sup> |
|---------------|----------|----------------------------|--------------------|------------------------------------------------------------------------------|---------------------------------------------|----------------------------------------------|----------------------------------------------------|
| 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<sup>2</sup>).

#### Measurement of greenhouse gases

CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O fluxes were monitored in three replicates of each plot using the closed soil chamber method. The concentration of CO<sub>2</sub> (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<sub>2</sub> 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<sup>-1</sup>, 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<sup>-1</sup> 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<sub>2</sub> concentrations were measured by means of an infrared CO<sub>2</sub> analyzer (Model ZRC, Fuji Electric Co. Ltd., Japan). The CO<sub>2</sub> analyzer was recalibrated with a standard concentration (approximately 600 ppmv) of CO<sub>2</sub> gas every 3 hours.

CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> and N<sub>2</sub>O fluxes were calculated from the decrease or increase of CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> concentrations were determined using a gas chromatograph (GC-9A, Shimadzu Co., Japan) equipped with hydrogen flame ionization detectors at 100 °C using he-

lium as the carrier gas and an integrator (Chromatopac CR-7A, Shimadzu Co., Japan). Separation of  $\text{CH}_4$  gas was accomplished at 60 °C using a 5 m steel column packed with Porapak Q.  $\text{N}_2\text{O}$  concentrations were determined using a gas chromatograph (GC-8A, Shimadzu Co., Japan) equipped with  $^{63}\text{Ni}$  electron capture detectors at 340 °C using argon gas containing 5%  $\text{CH}_4$  as the carrier gas and the integrator. Separation of  $\text{N}_2\text{O}$  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 ( $\text{CO}_2$ 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  $\text{mgCO}_2 \text{ m}^{-2} \text{ h}^{-1}$  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  $\text{mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$ . 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  $\text{CO}_2$  suggests that the transport coefficient and heterotrophic production of  $\text{CO}_2$  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  $\text{mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$  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.

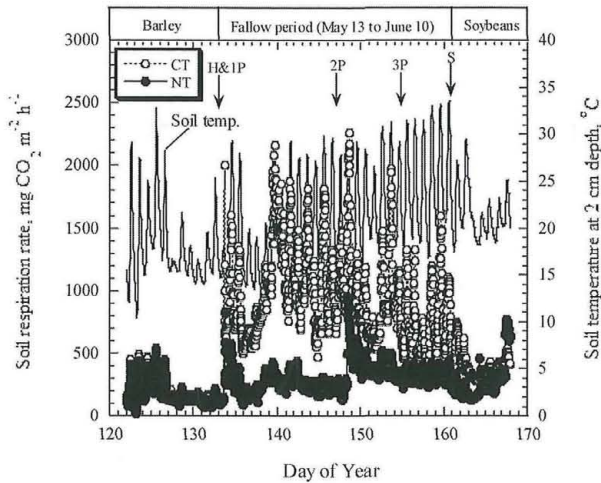


Fig. 1. Daily changes in soil respiration rates for 50 days (May 2 to June 16, 2002) during growing barley, harvesting, plowing (1st to 3rd) and sowing of soybeans with data on soil temperature at a depth of 2 cm. H is harvesting; 1P, 2P and 3P are first plowing, second plowing and third plowing, respectively; 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  $2845 \pm 967 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$  in the conventional tillage plot and  $2198 \pm 658 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$  in the no-tillage plot, but there was no significant difference between the two plots (Table 2).  $\text{CO}_2$  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  $\text{CO}_2$  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  $\text{CO}_2$  emission can be attributed to emissions during the fallow period.

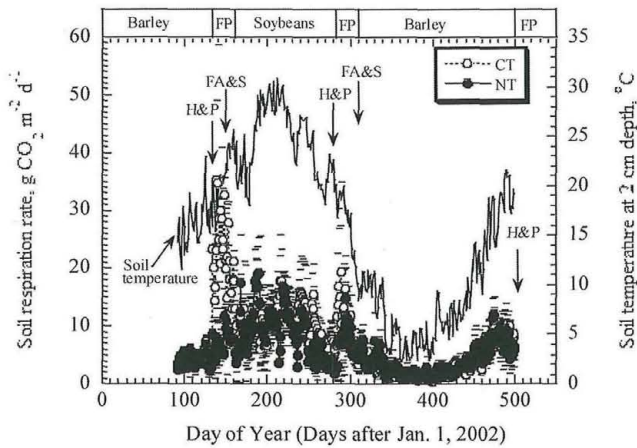


Fig. 2. Seasonal changes in daily soil respiration rates for the whole year from the conventional tillage and the no tillage plots under a double-cropping agroecosystem. FP is fallow period; H is harvesting; P is plowing; FA is fertilizer application; S is sowing. The horizontal bar over each symbol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

Table 2. CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions<sup>a)</sup> from the conventional tillage (CT) and the no-tillage (NT) plots during cultivation period and whole year.

| Cultivation          | CO <sub>2</sub> , g CO <sub>2</sub> m <sup>-2</sup> |            | CH <sub>4</sub> , g CH <sub>4</sub> m <sup>-2</sup> |                 | N <sub>2</sub> O, g N <sub>2</sub> O m <sup>-2</sup> |                |
|----------------------|-----------------------------------------------------|------------|-----------------------------------------------------|-----------------|------------------------------------------------------|----------------|
|                      | CT                                                  | NT         | CT                                                  | NT              | CT                                                   | NT             |
| Fallow <sup>b)</sup> | 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 <sup>c)</sup> | 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 standard 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<sub>4</sub> is absorbed by upland soil (e.g., KELLER & al. 1990, DOBBIE & al. 1996), but little is known about the effect of tillage on CH<sub>4</sub> uptake. Although BALL & al. 1999b reported that the CH<sub>4</sub> uptake rate was reduced by tillage due to the disturbance of CH<sub>4</sub>-oxidizing microbes, our results showed the opposite. The amount of CH<sub>4</sub> uptake in the soil for the whole year in the conventional tillage plot is significantly higher than that in the no-tillage

plot (Fig. 3). The annual methane uptake amounts were  $0.040 \pm 0.001 \text{ g CH}_4 \text{ m}^2 \text{ y}^{-1}$  in the conventional tillage plot and  $0.027 \pm 0.011 \text{ g CH}_4 \text{ m}^2 \text{ y}^{-1}$  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  $\text{CH}_4$  uptake under no-tillage cultivation to be 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).

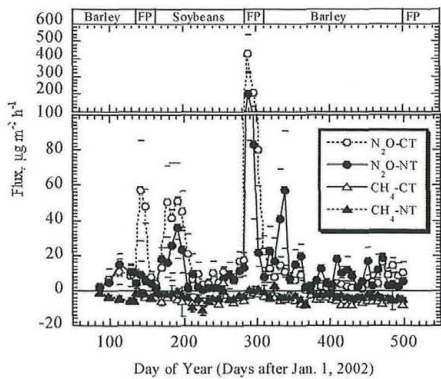


Fig. 3. Seasonal changes in  $\text{CH}_4$  and  $\text{N}_2\text{O}$  fluxes over the whole year from the conventional tillage and the no-tillage plots under a double-cropping agroecosystem. FP is fallow period; H is harvesting; P is plowing; FA is fertilizer application; S is sowing. The horizontal bar above each symbol represents the standard deviation

$\text{N}_2\text{O}$

$\text{N}_2\text{O}$  is chiefly emitted by soils as a result of denitrification in anaerobic soils and of nitrification in aerobic soils. It is well known that  $\text{N}_2\text{O}$  emissions are favored by (i) medium-high soil moisture, limiting  $\text{O}_2$  diffusion (ii) high mineral - N availability and (iii) high organic carbon availability (SINGH 2000).  $\text{N}_2\text{O}$  flux peaks were observed for 2 to 4 weeks after fertilizer application (Fig. 3). This enhancement of  $\text{N}_2\text{O}$  flux after fertilizer application is widely observed (e.g., AKIYAMA & TSURUTA 2002). The increase in  $\text{N}_2\text{O}$  flux during this period is presumed to be  $\text{N}_2\text{O}$  chiefly generated due to nitrification (AKIYAMA & TSURUTA 2003). Moreover, high  $\text{N}_2\text{O}$  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

1998). Our results show that  $\text{N}_2\text{O}$  emission from crop residues could be an important source of  $\text{N}_2\text{O}$  when the quantity of residues is high. Notably,  $\text{N}_2\text{O}$  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  $\text{N}_2\text{O}$  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  $\text{N}_2\text{O}$  flux peaked during the fallow period in November, reaching 431 in the conventional tillage plot and  $220 \mu\text{g m}^{-2} \text{h}^{-1}$  in the no-tillage plot.

Although it is thought that no-tillage cultivation increases  $\text{N}_2\text{O}$  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  $\text{N}_2\text{O}$  emissions from no-tillage plots were higher than conventional tillage plots in Scotland, and the greater emissions of  $\text{N}_2\text{O}$  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  $\text{N}_2\text{O}$  emissions from conventional tillage and the no-tillage plots were  $0.224 \pm 0.069$  and  $0.144 \pm 0.075 \text{ g N}_2\text{O m}^{-2} \text{ y}^{-1}$ , respectively (Table 2). No-tillage cultivation significantly reduced the annual  $\text{N}_2\text{O}$  emission by 36% from conventional tillage cultivation.  $\text{N}_2\text{O}$  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  $\text{N}_2\text{O}$  emissions than conventional tillage cultivation.

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

Annual emissions of  $\text{CO}_2$ ,  $\text{CH}_4$ , and  $\text{N}_2\text{O}$  as  $\text{CO}_2$  equivalents using GWP, which gives coefficients of 1 for  $\text{CO}_2$ , 21 for  $\text{CH}_4$ , and 310 for  $\text{N}_2\text{O}$  (IPCC 1996), under the conventional tillage plot were 2845, 0.840, and  $69.6 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$ , respectively. Similarly, those of  $\text{CO}_2$ ,  $\text{CH}_4$ , and  $\text{N}_2\text{O}$  in no-tillage condition plots were 2198, -0.571, and  $44.8 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$ , respectively. This makes the annual emission of carbon equivalent greenhouse gases from the conventional tillage plot and the no-tillage plot 2,914 and  $2242 \text{ gCO}_2 \text{ m}^{-2} \text{ y}^{-1}$ , respectively, suggesting that no-tillage cultivation reduced emissions by  $672 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$  (corresponding to  $183 \text{ g C m}^{-2} \text{ y}^{-1}$ ) compared with conventional tillage cultivation. The contribution by  $\text{CO}_2$  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  $\text{N}_2\text{O}$  to the GWP emission of greenhouse gases in ROBERTSON & al. 2000 accounted for about

(336)

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 ( $-118 \text{ g C m}^{-2}$  for soybean cultivation and  $-24 \text{ g C m}^{-2}$  for the whole year), giving a positive value ( $94 \text{ g C m}^{-2}$  for barley cultivation), indicating that the soil operates as a  $\text{CO}_2$  source during soybean cultivation (and over the whole year) and a  $\text{CO}_2$  sink during barley cultivation. KOIZUMI & al. 1993 estimated the carbon balances in conventional tillage under double-cropping systems, without taking into account  $\text{N}_2\text{O}$  emission, to be approximately  $-400 \text{ g C m}^{-2} \text{ y}^{-1}$  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  $\text{N}_2\text{O}$  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<br>as crop<br>residues,<br>$\text{g C m}^{-2}$<br>(x) | Emissions <sup>a)</sup><br>of $\text{CO}_2$ , $\text{CH}_4$<br>and $\text{N}_2\text{O}$ as<br>$\text{CO}_2$ equivalents<br>using<br>GWP,<br>$\text{g C m}^{-2}$<br>(y) | Carbon<br>balance<br>(x - y) | Supplied<br>as crop<br>residues,<br>$\text{g C m}^{-2}$<br>(x) | Emissions <sup>a)</sup><br>of $\text{CO}_2$ , $\text{CH}_4$<br>and $\text{N}_2\text{O}$ as<br>$\text{CO}_2$ equivalents<br>using<br>GWP,<br>$\text{g C m}^{-2}$<br>(y) | Carbon<br>balance<br>(x - y) |
| Spring fallow <sup>b)</sup><br>followed by<br>soybeans | 409                                                            | 527                                                                                                                                                                    | -119                         | 392                                                            | 350                                                                                                                                                                    | 42                           |
| Autumn fallow <sup>c)</sup><br>followed by<br>barley   | 360                                                            | 266                                                                                                                                                                    | 94                           | 352                                                            | 261                                                                                                                                                                    | 91                           |
| Whole year                                             | 769                                                            | 793                                                                                                                                                                    | -24                          | 744                                                            | 611                                                                                                                                                                    | 133                          |

a) Amount of  $\text{CO}_2$  equivalent was calculated based on its greenhouse gas emissions, using factors of 1 for  $\text{CO}_2$ , 21 for  $\text{CH}_4$  and 310 for  $\text{N}_2\text{O}$ .

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.

## Acknowledgements

We thank Mrs. F. SUZUKI, T. SUZUKI and T. ARA for their help in gas sampling during the experiments and managing the experimental field. We also thank Drs. K. YAGI, S. SUDO, H. SAKAI, S. NAKAI and K. TOGAMI at the National Institute for Agro-Environmental Sciences for their useful advice and help. This study was supported by the project entitled "Elucidation of Global Warming Impacts in Agriculture, Forestry and Fisheries, and Development of Mitigation Techniques" funded by the Ministry of Agriculture, Forestry and Fisheries of Japan.

## References

- AKIYAMA H. & TSURUTA H. 2002. Effect of chemical fertilizer form on  $N_2O$ , NO and  $NO_2$  fluxes from Andisol field. - *Nutr. Cycl. Agroecosyst.* 63: 219-230.
- & — 2003. Effect of organic matter application on  $N_2O$ , NO and  $NO_2$  fluxes from Andisol field. - *Global Biogeochem. Cycles* 17(4), 1100, doi:10.1029/2002GB002016.
- AULAKH M. S., RENNIE D. A. & PAUL E. A. 1984. Gaseous N losses from soils under zero-till as compared to conventional-till management systems. - *J. Environ. Qual.* 13: 130-136.
- BALL B. C., PARKER J. P. & SCOTT A. 1999a. Soil and residue management effects on cropping conditions and nitrous oxide fluxes under controlled traffic in Scotland 2. Nitrous oxide, soil N status and weather. - *Soil Till. Res.* 52: 191-201.
- , SCOTT A. & PARKER J. P. 1999b. Field  $N_2O$ ,  $CO_2$  and  $CH_4$  fluxes in relation to tillage, compaction and soil quality in Scotland. - *Soil Till. Res.* 53: 29-39.
- CHOUDHARY M. A., AKRAMKHANOV A. & SAGGAR S. 2002. Nitrous oxide emissions from a New Zealand cropped soil: tillage effects, spatial and seasonal variability. - *Agric. Ecosystem and Environment* 93: 33-43.
- CHRISTENSEN S. & TIEDJE J. M. 1998. Denitrification in the field, analysis of spatial and temporal variability. - In: JENKINSON D. S. & SMITH K. A. (Eds.), *Nitrogen efficiency in agricultural soils*, pp. 295-301. - Elsevier, Amsterdam.
- DAVIDSON E. A. & VERCHOT D. 2000. Testing the hole-in-the pipe model of nitric and nitrous oxide emissions from soils using the TRAGENT database. - *Global Biogeochem. Cycles* 14: 1035-1043.
- DOBBIE K. E., SMITH K. A., PRIEMÉ A., CHRISTENSEN S., DEGÓSKA A. & ORLANSKI P. 1996. Effect of land use on the rate of methane uptake by surface soils in northern Europe. - *Atmos. Environment* 30: 1005-1011.
- ELLERT B. H. & JANZEN H. H. 1999. Short-term influence of tillage on  $CO_2$  fluxes from a semi-arid soil on the Canadian prairies. - *Soil Till. Res.* 50: 21-32.
- FLESSA H. & BEESE F. 1995. Effects of sugarbeet residues on soil redox potential and nitrous oxide emission. - *Soil Sci. Soc. Am. J.* 59: 1044-1051.
- FORTIN M.-C., ROCHETTE P. & PATTEY E. 1996. Soil carbon dioxide fluxes from conventional and no tillage small-grain cropping systems. - *Soil Sci. Soc. Am. J.* 60: 1541-1547.
- HANSEN S., MAEHLUM J. E. & BAKKEN L. R. 1993.  $N_2O$  and  $CH_4$  fluxes in soil influenced by fertilization and tractor traffic. - *Soil Biol. Biochem.* 25: 621-630.
- IPCC (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE) 1996. *Climate change 1995: The science of climate change. Contribution of working group I to the second assessment report of intergovernmental panel on climate change* [HOUGHTON J. T., MERIA FILHO L. G., CALLANDER B. A., HARRIS N., KATTENBERG A. & MASKELL K. (Eds.)], Cambridge University Press, Cambridge, 572pp.
- ITO M. & TAKAHASHI M. 1997. Effect of winter weeds on growth and yield of direct-seeded rice in no-tillage dry paddy field. - *Jpn. J. Crop Sci.* 66: 436-441.
- KELLER M., MITRE M. E. & STALLARD R. E. 1990. Consumption of atmospheric methane in central Panama: effects of agricultural development. - *Global Biogeochem. Cycles* 4: 21-27.
- KOIZUMI H., USAMI Y. & SATOH M. 1993. Carbon dynamics and budgets in three upland double-cropping agro-ecosystems in Japan. - *Agric. Ecosystems and Environment* 43: 235-244.

- LA SCALA JR., N., LOPES A., MARQUES JR. J. & PEREIRA G. T. 2001. Carbon dioxide emissions after application of tillage systems for a dark red latosol in southern Brazil. - *Soil Till. Res.* 62: 163-166.
- LAL R., KIMBLE J. M., FOLLETT R. F. & COLE C. V. 1999. The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect, p. 128. - Lewis Publishers, Boca Raton.
- MALJANEN M., LIUKANEN A., SILVOLA J. & MARTIKAINEN P. J. 2003. Nitrous oxide emissions from boreal organic soil under different land-use. - *Soil Biology & Biochem.* 35: 689-700.
- MINISTRY OF THE ENVIRONMENT OF JAPAN 2003. National GHGs inventory report of Japan.
- NISHIMURA S., SAWAMOTO T., AKIYAMA H., SUDO S. & YAGI K. 2004. Methane and nitrous oxide emissions from a paddy field with Japanese conventional water management and fertilizer application. - *Global Biogeochem. Cycles* 18: GB2017, doi:10.1029/2003GB002207.
- PAUSTIAN K., SIX J., ELLIOT E. T. & HUNT H. W. 2000. Management options for reducing CO<sub>2</sub> emissions from agricultural soils. - *Biogeochemistry* 48: 147-163.
- ROBERTS W. P. & CHAN K. Y. 1990. Tillage-induced increases in carbon dioxide from the soil. - *Soil Till. Res.* 17: 143-151.
- ROBERTSON C. P., PAUL E. A. & HARWOOD R. R. 2000. Greenhouse gases in intensive agriculture: contributions of individual gases to radiative forcing of the atmosphere.- *Science* 289: 1922-1925.
- SINGH S. N. 2000. Climate change with increasing N<sub>2</sub>O fluxes. - In: SINGH S. N. (Ed.), *Trace gas emissions and plants*, pp.231-248. - Kluwer Academic Publishers, Dordrecht.
- SKIBA U. & SMITH K. A. 2000. The control of nitrous oxide emissions from agricultural and natural soils. - *Chemosphere: Global Change Sci.* 2: 379-386.
- SMITH K. A., McTAGGART I. P. & TSURUTA H. 1997. Emissions of N<sub>2</sub>O and NO associated with nitrogen fertilization in intensive agriculture, and the potential for mitigation. - *Soil Use Mgmt.* 13: 296-304.

# ZOBODAT - [www.zobodat.at](http://www.zobodat.at)

Zoologisch-Botanische Datenbank/Zoological-Botanical Database

Digitale Literatur/Digital Literature

Zeitschrift/Journal: [Phyton, Annales Rei Botanicae, Horn](#)

Jahr/Year: 2005

Band/Volume: [45\\_4](#)

Autor(en)/Author(s): Nouchi I., Yonemura S.

Artikel/Article: [CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O Fluxes from Soybean and Barley Double-Cropping in Relation to Tillage in Japan. 327-338](#)