Contribution of nitrous oxide emission from soil covered with plastic mulch film in vegetable field

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Abstract

The effects of soil mulching on the emission of nitrous oxide (N_2O), a major greenhouse gas, from arable fields have rarely been investigated to date. In a previous study, we showed that a significant amount of N_2O is emitted to the atmosphere from an arable field in which soil is covered with plastic mulch films; N_2O is emitted both by permeation through the mulch films and by horizontal diffusion to the adjacent furrow soil surface. We continued measuring the N_2O flux from a field grown to lettuce and carrots for two years. With the results of our previous study, we also estimated the contribution of N_2O emitted during soil mulching to the cumulative emission. In winter, the contribution of N_2O emission during soil mulching was low, ranging from 4 to 12 %. In contrast, in summer, the contribution of N_2O emission during soil mulching after fertilization was high, ranging from 41 to 66 % of the cumulative emission. Among these, the contribution of N_2O emission by permeation through the mulch film was found to be particularly important, which ranged from 33 to 53 % of the cumulative emission. These results indicate that N_2O emission during soil mulching largely contributes to cumulative emission.

Key words: Furrow, Gas permeance, Nitrous oxide, Plastic mulch film, Soil gas diffusion.

1. Introduction

Covering ridge soil with plastic mulch films for cultivating crops is a major agricultural practice implemented worldwide. One main purpose of soil mulching is to keep soil temperature and water content high, at levels suitable for cultivating crops. Another purpose is to restrict arable weed growth. Soil mulching is also conducted prior to crop cultivation to reduce arable weeds and/or pathogenic microorganisms during the succeeding crop cultivation period. In this practice, often called 'soil solarization', the soil surface is continuously covered tightly with plastic film during the hot season. Thus, the temperature just below the mulch film increases markedly so that seeds and seedlings of

weeds and pathogenic microorganisms are expected to be severely damaged (Katan and Devay, 1991).

Nitrous oxide (N_2O) is a major greenhouse gas which has a 298-fold higher global warming potential than CO_2 for a period of 100 years (Forster *et al.*, 2007). It is produced in soil by various soil microbial species as a byproduct of nitrification and an intermediate product of denitrification (Bouwman, 1990; Hutchinson and Davidson, 1993). Fertilized agricultural soil is recognized as one of the major sources of N_2O .

Nitrous oxide production in soil generally increases under conditions of moderate or relatively high temperature and water contents, high inorganic N and organic matter contents, and low O_2 concentration. Since soil covered with plastic mulch films just after fertilization is generally exposed to such conditions, a significantly high amount of N_2O may be produced in the soil and emitted to the atmosphere. However, as described in the 2006 IPCC Guidelines for National

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Greenhouse Gas Inventories (De Klein *et al.*, 2006), the dynamics of N₂O production and transport in soil covered with plastic mulch films have rarely been investigated to date, since no methods of measuring the N₂O flux have been established yet.

In a previous study, we revealed that a significant amount of N₂O is emitted to the atmosphere from a field during soil mulching, both by permeation through mulch films and by horizontal diffusion to the adjacent furrow soil surface (Nishimura *et al.*, 2012). In this study, we showed detailed seasonal changes in N₂O flux over two years in a field grown to lettuce and carrots. We estimated the cumulative N₂O emission from the entire field including both ridge and furrow soils. The contribution of N₂O emitted during soil mulching to the cumulative emission was shown for the first time.

2. Materials and Methods

2.1 Outline of experimental field

The N₂O flux in the field was measured from December 2009 to January 2012 in an experimental field (36°01' N, 140°06' E) at the NARO Agricultural Research Center in Japan. The soil type in the field was volcanic acid soil (Andisols), and the surface layer (0 to 15 cm) had a clay loam texture. The bulk density of

the topsoil at a depth of 0–5 cm was 0.65 Mg m⁻³, and the soil pH in H₂O was 6.3. The C and N contents of the topsoil (0–5 cm depth) were 42 mg C g soil⁻¹ and 3.9 mg N g soil⁻¹, respectively.

Table 1 shows the outline of the vegetable cultivation, the types and amounts of the applied fertilizer, and the vegetable yields. The field was grown to vegetables twice a year: lettuce (*Lactuca sativa* L., cultivar; Steady) in winter and carrots (*Daucus carota* L., cultivar; Koyo-2) in summer. Lettuce plants were grown under a transparent plastic tunnel to keep the area inside warm. We developed two treatments using differently applied fertilizers. One involved plots applied with a commercial compound organic fertilizer (Agret673, Asahi Industries Group, Japan for lettuce; Agret666, Asahi Industries Group, Japan for carrots), hereafter referred to as OF plots. The other involved plots applied with poultry manure compost and fish meal (as supplemental application for carrots), hereafter referred to as PM plots. Note that no fertilizer was applied to the OF plots in the summer of 2010 to investigate the effect of residual nutrients in the soil on the succeeding carrot growth. The lettuce yield ranged from 4.27 to 7.12 kg m⁻², and the carrot yield ranged from 4.91 to 6.29 kg m⁻².

Prior to the lettuce cultivation, the ridge soil was

Table 1. Outline of fertilization, crop cultivation and soil mulching practice of the experimental field.

Treatment	Type of fertilizer	Date and amount of N fertilization (kg N ha ⁻¹) *	Soil mulching †	Vegetable cultivation period (seeding/transplanting-harvest)	Vegetable yield (kg m ⁻²) ‡
OF	Commercial organic fertilizer	09/12/17 (285)	09/12/17–10/01/14	lettuce (10/01/25–10/04/26)	5.97
		(no fertilization)	10/06/15–10/07/19	carrot (10/07/20–10/12/07)	4.91
		11/01/11 (135)		lettuce (11/01/26–11/04/27)	5.17
		11/06/16 (90), 11/09/14 (90)	11/06/16–11/07/20	carrot (11/07/21–11/11/09)	6.19
PM	Poultry manure compost	09/12/17 (285)	09/12/17–10/01/14	lettuce (10/01/25–10/04/26)	4.27
		10/06/15 (90), 10/09/22 (120 §)	10/06/15–10/07/19	carrot (10/07/20–10/12/07)	5.23
		11/01/11 (360)		lettuce (11/01/26–11/04/27)	7.12
		11/06/16 (90), 11/09/14 (120 §)	11/06/16–11/07/20	carrot (11/07/21–11/11/09)	6.29

*, represented by total N per unit area of ridge

†, period with impermeable mulch film maintained as tight soil surface cover

‡, represented by fresh weight of edible biomass (lettuce, headed aboveground biomass; carrot, root biomass) per unit area of ridge

§, applied with fish meal instead of poultry manure compost

covered with a black plastic (polyethylene) mulch film (0.02 mm thick) just after fertilization for the lettuce. For the first lettuce cultivation, the mulch film was placed on Dec. 17, 2009 and was maintained as a tight soil surface cover without perforation until it was perforated on Jan. 15, 2010 for the transplanting of lettuce seedlings. The perforated mulch film was kept in the field thereafter and was removed on Jun. 15, 2010 (just before the next mulch film application in summer). For the second lettuce cultivation, the mulch film was placed on Jan. 11, 2011 and was immediately perforated for the transplanting of lettuce seedlings. The perforated mulch film was kept in the field thereafter until it was removed on Apr. 27, 2011 (just after the lettuce harvest). The diameter of each round hole made by perforation was about 5 cm. From June to July in 2010 and 2011, the ridge soil was covered with a transparent plastic (polyethylene) mulch film (0.02 mm thick) just after fertilization (except for the OF plots in 2010) for the succeeding carrot cultivation. In the OF plots from June to July in 2010, the ridge soil was also covered with the transparent plastic mulch film, although it was not fertilized. The mulch film was maintained as a tight soil surface cover without perforation and was then removed for the carrot seeding. The depth of plowing was about 15 cm. The ridge was 12 m in length and 1.2 m in width. The furrow between ridges (distance from the edge of a ridge to that of the adjacent ridge) was 0.6 m in width. Note that all of the fertilizers were applied only to the ridge soil, not to the furrow soil.

2.2 Measurement of N₂O flux and other data in field

Nitrous oxide flux was measured at 2–24 day intervals throughout the experimental period. During the period without soil mulching, it was measured within the ridge for vegetable cultivation using the conventional closed-chamber method. A chamber consisting of gray polyvinyl chloride plates (5 mm thick) was placed on the ridge soil surface. The chamber had a basal area of 0.45 m² (0.6 m × 0.75 m) and a height that varied from 0.2 to 0.5 m, considering the growth of the vegetables inside the chamber. The general procedure for the flux measurement during the period with the perforated black mulch film (*i.e.*, around the lettuce cultivation period) was the same as that during the period without the mulch film, as shown above. The reason for this is as follows. Hayashi *et al.* (2004)

showed that the N₂O flux from a soil surface covered with a plastic mulch film is not significantly suppressed when the perforated open area of the applied mulch film is not lower than 2.5 % of the total covered area. This indicates that most N₂O emitted from the ridge soil surface is immediately released to the atmosphere via the holes made by perforation. In this study, the total perforation area of the mulch film for the lettuce plants was about 2.5 % of the total ridge area. Therefore, we assumed that the general results in the literature (Hayashi *et al.*, 2004) can also be applied to this study.

During the period with the impermeate mulch films, the N₂O flux measurement was conducted on the furrow soil surface between ridges using a chamber with a cross-sectional area of 0.18 m² (0.6 m × 0.3 m) and a height of 0.1 m. To obtain averaged flux data across the furrow, one 0.6-m side of the chamber base was located tangent to the edge of the mulch cover, *i.e.*, the other 0.6-m side was located along the center of the furrow.

The gas sampling for the flux measurement was conducted between 9:30 and 12:00. The chamber was closed for 30 min. The air inside the chamber was drawn three times, *i.e.*, 1, 15, and 30 min after closing the chamber, using a syringe and was then immediately injected into a 25 mL evacuated glass vial. The air between the soil and the mulch film was also taken by directly pricking the mulch film with a needle connected to a syringe and injecting the air into an evacuated vial. The N₂O concentration of the gas in the glass vial was analyzed using a gas chromatograph (GC-14A, Shimadzu, Japan) equipped with an electron capture detector and two switching valves for the preliminary separation of N₂O from other gases.

Nitrous oxide flux was calculated as

$$F = \rho \cdot \frac{V}{A} \cdot \frac{\Delta c}{\Delta t} \cdot \frac{P}{1013} \cdot \frac{273.15}{T}, \quad (1)$$

where F denotes N₂O flux [$\mu\text{g N}_2\text{O-N m}^{-2} \text{ h}^{-1}$], and ρ , V , A , $\Delta c/\Delta t$, P , and T denote gas density of N₂O ($= 1.25 \times 10^9 \mu\text{g N}_2\text{O-N m}^{-3}$), chamber volume [m³], area of the chamber base [m²], increasing rate of N₂O concentration in the chamber [$10^{-6} \text{ m}^3 \text{ m}^{-3} \text{ h}^{-1}$], air pressure (fixed to 1013 hPa), and air temperature [K], respectively.

Ambient air temperature data provided hourly by the Weather Data Acquisition System of the National In-

stitute for Agro-Environmental Sciences, located about 700 m from the field, were used as T . The temperature of ridge soil at a depth of 5 cm was measured with a copper-constantan thermocouple with three replicates and recorded on a data logger (CR1000, Campbell Scientific Instruments, USA) at a 10-min interval.

Samples of ridge soil at a depth of 0–15 cm were collected at 7–57 day intervals during the experiment for the analysis of soil inorganic N content. The soil samples were collected randomly from eight locations in each plot, mixed, and then extracted with potassium chloride solution (10 % w/w). Nitrate nitrogen (NO_3^- -N) was analyzed by hydrazine reduction-sulfanilamide and α -naphthylamine absorption spectrophotometry, and ammonium nitrogen (NH_4^+ -N) by indophenol blue absorption spectrophotometry in a continuous-flow analyzer (QuAAtro2-HR, BL-TEC, Japan).

2.3 Estimation of cumulative N_2O emission

The cumulative N_2O emission from the entire field, including both the ridge and furrow soils, was estimated as follows. First, during the period without soil mulching, the cumulative N_2O emission from the ridge soil was estimated by the trapezoidal integration of the measured N_2O fluxes over the period. In a preliminary investigation, we observed that the background N_2O flux (the N_2O flux from bare soil without N fertilization) in this field generally falls within a low range, mostly lower than $10 \mu\text{g N m}^{-2} \text{ h}^{-1}$ (data not shown). Thus, in this study, we assumed the cumulative N_2O emission from the furrow soil (except during the soil mulching) to be equal to the standard background emission from well-drained Japanese soil proposed by Akiyama *et al.* (2006), *i.e.*, $1.0 \times D [\text{g N ha}^{-1}]$, where D denotes the number of days. For the period with the perforated mulch film, the cumulative N_2O emission was estimated in the same way as that for the period without the mulch film.

Second, the cumulative N_2O emission during the period with the imperforate mulch film was estimated as follows. The N_2O emission from the furrow soil surface was estimated by the trapezoidal integration of the measured N_2O fluxes over the period. The N_2O flux by permeation through the mulch film was estimated on the basis of Fick's diffusion law, with data on the N_2O concentration just below the mulch film, the soil temperature at 5 cm depth (measured in the field), and the gas permeance (permeation coefficient) of the mulch film. The gas permeance of the mulch film was measured

in a laboratory experiment. Then, the cumulative emission was also estimated by trapezoidal integration over the period. Our previous report (Nishimura *et al.*, 2012) provides more details regarding the N_2O flux measurement during the soil mulching with the imperforate mulch film. We could not measure the N_2O concentration just below the mulch film or the soil temperature at 5 cm depth for all the plots; we could measure them only in the OF plots (winter 2009–2010 and summer 2011) and PM plots (summer 2010), respectively. We assumed that the soil temperatures and the ratios of N_2O flux by permeation through the mulch film to that from the furrow soil surface were the same in both treatments, and estimated the N_2O flux by permeation in the plots without the N_2O concentration measurements using

$$F_{p2} = F_{f2} \cdot F_{p1}/F_{f1}, \quad (2)$$

where F_p and F_f denote the N_2O fluxes [$\mu\text{g N m}^{-2} \text{ h}^{-1}$] by permeation through the mulch film and from the furrow soil surface. Subscript 1 denotes data on the plots with N_2O concentration measurements just below the mulch film, while subscript 2 denotes data without such measurements.

The 'average' cumulative N_2O emission of the field, including emissions from both the ridge and the furrow, was then estimated using

$$N_{tot} = (w_r \cdot N_r + w_f \cdot N_f) / (w_r + w_f), \quad (3)$$

where N_{tot} , N_r and N_f denote the cumulative N_2O emission [kg N ha^{-1}] from the whole field, from the ridge, and from the furrow, and where w_r and w_f denote the widths of the ridge (= 1.2 m) and the furrow (= 0.6 m), respectively. We used the estimated N_2O emission by permeation through the mulch film as N_r during the period with the imperforate mulch film.

Nitrous oxide flux often shows diurnal fluctuation, with higher values in the daytime and lower in nighttime (Nishimura *et al.*, 2005). In addition, gas permeance of a mulch film also changes according to diurnal change in ambient temperature (Nishimura *et al.*, 2012). In this study, however, we did not conduct multiple flux measurements within a day due to insufficient manpower, and therefore we could not consider possible diurnal fluctuations in N_2O flux when estimating cumulative emission.

3. Results and Discussion

3.1 Seasonal changes in N₂O flux and soil inorganic N contents

Seasonal change in N₂O flux and soil NH₄⁺- and NO₃⁻-N contents are shown in Fig. 1. During the period with the impermeate mulch film, a significant amount of N₂O was emitted from the soil surface of the furrow between ridges. During the period with the

imperforate black mulch film in winter (from December 2009 to January 2010), the N₂O flux from the furrow in the OF and PM plots gradually increased throughout the period to reach their maxima of 122 and 95 $\mu\text{g N m}^{-2} \text{ h}^{-1}$, respectively, 25 days after fertilization with mulching. During the period with the impermeate transparent mulch film in summer, N₂O flux increased rapidly to reach its maximum within several days after fertilization with mulching. The maximum

Fig. 1. Seasonal changes in (a, c) N₂O flux from ridge and furrow soil surfaces and that by permeation through mulch film, and (b, d) soil NH₄⁺- and NO₃⁻-N contents.

The error bar in (a) and (c) shows the standard deviation of the measured N₂O fluxes with three replicates.

The horizontal solid and dashed arrows show periods with the impermeate and perforated mulch films applied to the ridge soil, respectively.

Part of the data during the period with the impermeate mulch film is also shown in the report by Nishimura *et al.* (2012).

N_2O fluxes from the furrow were $205 \mu\text{g N m}^{-2} \text{h}^{-1}$ in the PM plots in 2010, and 594 and $408 \mu\text{g N m}^{-2} \text{h}^{-1}$ in the OF and PM plots, respectively, in 2011. Thereafter, the N_2O flux gradually decreased. These increases in the N_2O flux from the furrow soil surface are attributed to the horizontal diffusion of N_2O produced in the fertilized ridge soil to the adjacent furrow soil surface. In the OF plots in 2010, the N_2O flux from the furrow during the period with the impermeate mulch film in summer was remained low, of which the maximum was $30 \mu\text{g N m}^{-2} \text{h}^{-1}$, presumably because no fertilizer was applied to the plots.

The estimated N_2O flux by permeation through the black mulch film in winter was lower than that from the furrow soil surface, of which the maxima were 36 and $33 \mu\text{g N m}^{-2} \text{h}^{-1}$ in the OF and PM plots, respectively. In contrast, the N_2O flux by permeation through the transparent mulch film was extremely high in summer, of which the maxima reached 1230 in the PM plots in 2010, and 3120 and $2130 \mu\text{g N m}^{-2} \text{h}^{-1}$ in the OF and PM plots in 2011, respectively. In the OF plots in 2010, the N_2O flux by permeation was much lower than that in the PM plots, presumably because no fertilizer was applied, although it reached $169 \mu\text{g N m}^{-2} \text{h}^{-1}$ at maximum. In addition, a remarkably large diurnal fluctuation in the N_2O flux by permeation through the mulch film was found. This indicates a large diurnal variation in the flux according to the significant change in the gas permeance of the mulch film caused by a diurnal change in soil temperature. In the daytime on sunny days in summer, the soil temperature at 5 cm depth under the mulch film ranged mostly from 40 to 50°C (*cf.*, Nishimura *et al.*, 2012). The gas permeance of the mulch film significantly increased under an extremely high temperature below the mulch film, which caused the high N_2O flux by permeation.

Soil temperature during the period with the impermeate mulch film in winter was generally kept suitable for moderate progress of nitrification. Although soil temperature during the period with the impermeate mulch film in summer was quite high (with a daily maximum of $40\text{--}50^\circ\text{C}$), it still may not have been sufficient to cause significant inactivation of nitrification. Volumetric soil water content was kept stable (24–33 %) throughout the periods with the impermeate mulch film both in winter and in summer, which is also suitable for progress of nitrification. Oxygen concentration in the soil air did not become lower than

12 % for the entire experimental period, which did not indicate suitable condition for significant enhancement of denitrification. All of these environmental conditions indicated that the N_2O in the mulch-covered soil was mainly produced via nitrification, and that the contribution of N_2O production via denitrification was low. Specific data on these environmental factors and more detailed discussion on the processes of the N_2O production in the mulch-covered soil are also described in our previous report (Nishimura *et al.*, 2012).

During the rest periods without the mulch film or with the perforated mulch film, the N_2O flux from ridge soil was generally low. In the PM plots, however, a significant increase in the N_2O flux was observed from February to March 2010 during the lettuce cultivation, of which the maximum was $263 \mu\text{g N m}^{-2} \text{h}^{-1}$. Other slight and temporal increases in the N_2O flux after fertilization were occasionally observed throughout the experimental period.

In the OF plots, the soil $\text{NH}_4^+\text{-N}$ content increased during the winter lettuce cultivation periods, of which the maxima reached 199 and $127 \mu\text{g N g soil}^{-1}$ in 2010 and 2011, respectively. The increase in the soil $\text{NH}_4^+\text{-N}$ content during the carrot cultivation was less significant in summer than in winter. In the PM plots, the soil $\text{NH}_4^+\text{-N}$ content remained low throughout the two-year experiment. In the OF plots in 2010, the soil $\text{NO}_3^-\text{-N}$ content increased during the winter lettuce cultivation period and remained high (higher than $250 \mu\text{g N g soil}^{-1}$) until the harvest at the end of April. Furthermore, it was still remained high until June. From April to June 2010, the ridge soil was still covered with the perforated black mulch film even after the lettuce harvest. Therefore, the penetration of rainfall into the ridge soil was continuously suppressed, which may have resulted in the suppression of leaching of nitrate to the underground and thus kept the $\text{NO}_3^-\text{-N}$ content in the topsoil high. The soil $\text{NO}_3^-\text{-N}$ content in the PM plots was generally lower than that in the OF plots in 2010. In 2011, the seasonal courses of the soil $\text{NO}_3^-\text{-N}$ content in the OF and PM plots were similar, with binomial peaks around March and July. In the PM plots in 2010, both the soil NH_4^+ and $\text{NO}_3^-\text{-N}$ contents remained low during the winter lettuce cultivation period. Unexpectedly, a significant increase in the N_2O flux during this period was observed only in the PM plots with low soil NH_4^+ and $\text{NO}_3^-\text{-N}$ contents, whereas no such significant increase in the N_2O flux was

observed in the OF plots with higher soil NH₄⁺ and NO₃⁻-N contents. Most of labile N in poultry manure compost is included as uric acid, which is often decomposed and lost prior to fertilization (Murakami *et al.*, 2011). The low NH₄⁺ and NO₃⁻-N contents in the PM plots during this period (Fig. 1) indicate significant loss of uric acid in the applied poultry manure compost prior to the fertilization. At the same time, N in other various forms was also included in the applied poultry manure compost. Nitrous oxide flux from soils amended with organic fertilizer is generally high and varies depending on the type of fertilizer, which indicates that various kinds of factors such as the availability of C and N in the applied organic manure are relat-

ed to N₂O production in the soil (Pelster *et al.*, 2012; Rochette *et al.*, 2008; Senbayram *et al.*, 2012). Therefore, in this study, some of the organic compounds other than uric acid in the poultry manure compost were presumably related to the marked enhancement of N₂O production during this period.

3.2 Cumulative N₂O emission

The cumulative N₂O emissions throughout the experimental period, including those from both the ridge and the furrow, are summarized in Fig. 2. The cumulative N₂O emission from the entire field including both the ridge and the furrow was highest (3.91 kg N ha⁻¹) in the PM plots in the first cropping cycle, where a significant increase in the N₂O flux from the ridge soil

Fig. 2. Cumulative N₂O emission from the field grown to lettuce and carrots from 09/12/17 to 11/01/10 (a, 1st cropping cycle) and from 11/01/11 to 12/01/16 (b, 2nd cropping cycle).

The emissions during the periods with the impermeable mulch film and other periods (without or with perforated mulch film) are shown separately for each cropping cycle.

The N₂O emission from the ridge during the periods with the impermeable mulch film is represented by the estimated emission by permeation through the mulch film.

was observed during the winter lettuce cultivation period. In other cases, the cumulative N₂O emissions in the OF and PM plots ranged from 1.41 to 2.20 kg N ha⁻¹ for the first and second cropping cycles.

The contribution of the N₂O flux during the period with the impermeate mulch film was lower in winter (from December 2009 to January 2010) than in summer, which ranged from 4 to 12 % of the cumulative emission. In contrast, when the soil was covered with the impermeate mulch film just after fertilization in summer, the contribution of the N₂O emission was high, which was 41 % (PM plots in 2010), 66 % (OF plots in 2011) and 48 % (PM plots in 2011) of the cumulative emissions over the cropping cycle. Among these, in particular, the flux by permeation through the mulch film had a significant contribution, which was 33 % (PM plots in 2010), 53 % (OF plots in 2011) and 38 % (PM plots in 2011) of the cumulative emissions. The contribution of the N₂O emission from the furrow soil surface was comparatively low but not negligible, ranging from 8 to 13 % of the cumulative emission.

An increase in soil temperature and a decrease in fluctuation of soil water content are the two major changes in environmental factors in soils caused by soil mulching. In this study, although increase in soil temperature may have temporally promoted progress of nitrification and the concurrent N₂O production in the soil, the N₂O production may have then rapidly decreased due to the rapid exhaustion of labile N in the soil available for N₂O production. On the other hand, soil water content remained relatively stable (24–33 %) throughout the periods with the impermeate mulch film both in winter and in summer because both the evaporation of soil water and the penetration of rain water into the soil were restricted by the mulch film. Although N₂O production by denitrification is often enhanced remarkably according to a marked increase in soil water content after heavy rain (Nishimura *et al.*, 2005), soil mulching may have effectively prevented such enhancement. However, unfortunately, we cannot conclude how the cumulative N₂O emission (or cumulative N₂O production) was changed by the introduction of soil mulching practice in this study, since we did not establish plots with no soil mulching practice for comparison. The cumulative N₂O emission obtained in this study should be evaluated again in future studies in comparison with the emission levels

from fields with no soil mulching practice.

In this study, the amounts of N fertilizer differed between the OF and PM plots, and also between the first and second cropping cycles. In addition, various types of N compounds were included in the applied organic fertilizers. Therefore, a detailed discussion on the comparison among the treatments or on the interannual variation in N₂O emission may not be possible in this study. The effects of various organic matter applications on N₂O emission should also be investigated in detail in future studies.

4. Conclusion

In a two-year experiment in a field grown to lettuce and carrots, we quantified N₂O emission during soil mulching practice and its contribution to the cumulative emission. When the soil was covered with an impermeate mulch film just after fertilization in summer, the N₂O emission during the practice had a significant contribution, ranging from 41 to 66 % of the cumulative emission. The N₂O flux by permeation through the mulch film had a particularly high contribution, ranging from 33 to 53 % of the cumulative emission. The N₂O flux from the furrow soil surface was comparatively low.

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