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Soil Carbon Dynamics of Forage Crop Fields with Different Applications of Slurry Barnyard Manure in a Warm and Rainy Region of Japan

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Summary

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Soil CO_2 efflux was measured at Miyakonojo Japan in forage crop fields fertilized with a slurry of barnyard manure in order to evaluate the carbon dynamics of intensive applications of cattle wastes on agricultural lands and potential environmental problems. The experimental site consisted of three fields with different slurry applications: 6, 15 and 30 kg m^{-2} for each growing season. Maize and Italian ryegrass are grown in rotation from April to August and from September to March. The same methods of growing and slurry application have been conducted for 18 years at this site. CO_2 efflux was measured by a closed chamber system during the daytime and the daily maximum was estimated for each day. In addition, soil CO_2 concentration was measured continuously at different depths by small solid-state CO_2 sensors to estimate the continuous soil efflux using a soil gas diffusion model. Daily maximum CO_2 efflux ranged from 12.6 to 36.6 μmol m^{-2} s^{-1} for one month immediately after the slurry application and then it decreased to 1.3 μmol m^{-2} s^{-1} during the winter. CO_2 efflux was greater in plots with high slurry applications. The peak CO_2 efflux during the first month after slurry application was caused, not only by the soil microbial decomposition of organic matter, but also by soil carbon oxidation because the pH of the soil was much lower than that of slurry. The long-term measurement of soil carbon content confirmed that the soil of the experimental plots accumulated very little organic carbon in spite of the intensive application of slurry. Based on the accumulated CO_2 efflux estimated by the gas diffusion model

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over an entire growing season, it is concluded that more than 60 % of the carbon from the slurry and the plant residual is released to the atmosphere and the remaining carbon is unaccounted for.

Introduction

Atmospheric greenhouse gas levels continue to enhance global warming greatly (IPCC 2001). The emissions of greenhouse gases from agricultural land contribute to this environmental problem (IPCC 2001). The emission of the greenhouse gases such as CH_4, N_2O and CO_2 from livestock is a large part of the total emission from agriculture and the storage of cattle wastes has been increasing (MINAMI & al. 1993). The appropriate disposal of cattle wastes has been required because cattle wastes pollute the atmosphere as well as the ground water if they are applied to agricultural lands (KOBAYASHI & al. 1985, MINAMI & al. 1993, NIIMI 2002).

In Japan, neither dumping of cattle wastes into unlined tanks nor field heaping are recommended and the disposal system has been improved recently in order to protect the environment. However, most of the slurry barnyard manure is directly applied to forage fields intensively. 14 % of the cattle wastes in Japan are produced in the southern part of Kyushu, and most of it is applied to a proportionally smaller field area (NIIMI 2002). The climate in Kyushu is temperate and rainy; the annual mean air temperature is above 17 °C and the annual rainfall is more than 2000 mm. In such regions, both autotrophic and heterotrophic respiration is large and the percolation of soil solution to deeper soil layers is greater than in other regions. The long term effect of slurry application, in a warm and rainy region, on the soil carbon content; and the effect of the application intensity on the soil CO_2 efflux from the forage field obtained by both the chamber method and the gas diffusion model were examined in this study.

Material and Methods

The experiment was conducted at a forage field in the Department of Upland Farming Research, National Agricultural Research Center for Kyushu Okinawa Region, Miyakonojo Japan (131 ° 18 E, 31 ° 45 N) from April 2002 to August 2004. The experimental site consisted of three plots with different slurry applications: 6, 15 and 30 kg m^{-2}. The slurry was 92.3 % water and the total carbon content was 2.92 %, which is relatively low compared with other manure (NIIMI 2002). The experimental plots were all 5m wide and 20 m long surrounded by closely-cut lawn to avoid surface run off. Maize was grown from May to August and Italian ryegrass was grown from October to March. The slurry was applied at the beginning of April and the beginning of September every year. Every plot remained bare for a month after the slurry application. These treatments have been conducted since 1985. The soil of the experimental plots consisted of Andisol. The bulk density and the porosity of the soil within the 0.15 m surface layer were 0.72 g m^{-3} and 70.1 %, respectively and no significant differences were found among the three experimental plots. The total carbon content of the soil was measured once a year (KOBAYASHI & al. 1995, NIIMI 2002). The relative gas diffusion coefficient of the soil cores that were sampled in 2003 was measured with a diffusion chamber (OSOZAWA 1987). The total carbon content of the soil, between the soil surface and the 0.15m deep layer, was measured at each experimental plot after every harvest of the Italian ryegrass (NIIMI 2002).

Soil CO_2 efflux measurements were conducted once a week for one month after slurry application, then once a month, by the closed chamber method. The chamber was a plastic column that covered a soil surface area of 0.02 m^2 and was 0.2 m in height.. A fan, at the top of the chamber, mixed the air inside. The GMP 221 sensor of the infrared gas analyser was inserted through a hole of 20 mm diameter in the wall of the chamber and attached to a MI700 data logger (Vaisala Oyj, Helsinki, Finland). The bottom of the chamber was buried in the soil up to a depth of 20 mm when it was installed at the center of the plot. A set of measurements was conducted at 30-minute intervals during the daytime. At every interval, two measurements were made lasting between one and two minutes each. For each plot, CO_2 concentration at the soil surface and at 0.1, 0.3 m depths was measured directly by solid-state infrared gas analyser GMD20 (Vaisala Oyj, Helsinki, Finland)) from September 2003 to August 2004. This was used to estimate the soil CO_2 efflux by the gas diffusion model (HIRANO & al. 2000, TANG & al. 2003). From April 2002 to August 2003, soil moisture was measured at the depth of 0.1 m in the 30 kg m^{-2} application plot using the Theta Probe model ML2-X sensor (Delta-T Devices, Ltd., Cambridge, UK). This was only on days when the soil CO_2 efflux was measured by chamber. From September 2003 to September 2004, the soil moisture was measured continuously at the depths of 0.1 and 0.3 m using CS616 Time-domain reflectometry sensors (Campbell Scientific, Inc, Logan, UT, USA). Soil temperature was measured at depths of 0.02 and 0.1m by the copper-constantan thermocoupples. Because of the lack of instruments, continuous measurement of the soil moisture and the soil temperature were only conducted in the 30 kg m-2 plot. No significant differences in physical properties were found among the plots as described above, so that the soil moisture and the soil temperature that were measured at the 30 kg m^{-2} application plot were regarded as the same for all plots. Readings were collected every 30 minutes by data loggers CR10x (Campbell Scientific, Inc, Logan UT, USA) and LI1000, (LI-COR, Inc, Lincoln, NB, USA). All instruments that were installed in the soil of the experimental field, were removed for a few days before and after the plowing and slurry application took place. Other meteorological data from the Institute's weather station were used for the analysis.

Daytime maximum CO_2 efflux was determined from the chamber data for the entire period. Continuous measurement of CO_2 efflux was only conducted using the gas diffusion model from the winter season of 2003 to the summer of 2004. Regression analysis of the CO_2 efflux between the chamber based measurements and the gas diffusion measurements was used to determine daily total CO_2 efflux.

Results and Discussion

The daily maximum soil CO_2 efflux measured by chamber is shown in Fig. 1. The daily maximum of soil CO_2 efflux was greater in summer than in winter and the differences among the three application plots is not significant except immediately after the slurry application. The soil CO_2 efflux from May to August and October to March ranged from 0.8 to 18 µmol m^{-2} s^{-1} and the average was 7.9 µmol m^{-2} s^{-1}. The average soil CO_2 efflux obtained in our study corresponds to the annual maximum which was obtained for temperate forest (MIZOGUCHI & al. 2001) and it was more than four times greater than that of NAKADAI & al. 2002 which was measured in bare soil without organic matter application for four years. Comparing the FRANK & al. 2002 results obtained in northern semiarid grassland with the average daily maximum soil efflux excluding April and September when the direct effect of slurry application is dominant, our study's average daily maximum is 1.2 times greater than that of their annual maximum, and it is 15 times greater during the slurry dominated period. The annual total of the soil CO_2 efflux at our site was between 0.67 and 1.8 kg m^{-2} and was 1.8 times greater than the fallow field (OSOZAWA & HASEGAWA 1995) and was at least 1.3 times greater than the soybean field (OSOZAWA & HASEGAWA 1995). Thus, our result was relatively large compared to other studies. The average soil temperature at the depth of 0.1 m was 25.5 °C from May to August, 12.6 °C from October to March and 8.8 °C from December to February. It is higher than that of FRANK & al. 2002 and corresponds to that of NAKADAI & al. 2002 and OSOZAWA & HASEGAWA 1995. The mean annual precipitation was about 2400 mm at our study site, 1365.5 mm at NIAES, Tsukuba

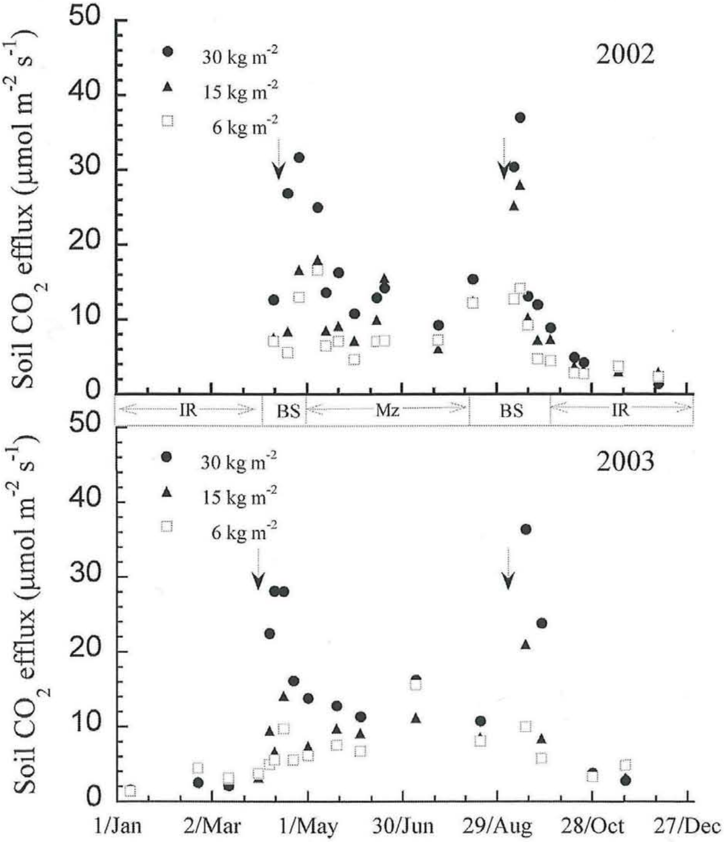

Fig. 1. Soil CO_2 effluxes over forage fields with different applications of slurry. The upper graph shows the results from 2002 and the lower shows the results from 2003. Arrows show the date when the slurry was applied and Mz, IR and BS indicate Maize, Italian ryegrass and Bare Soil periods, respectively.

(NAKADAI & al. 2002) and 404 mm at the site of FRANK & al. 2002, thus our experimental site received much more rainfall than the other sites described above. The average volumetric water content of the soil measured at our site from September 2003 to August 2004 was 43.6 % corresponding to 100 cm H_2O of matric potential. Comparing with other research, this value was relatively high. In general, most of the easily decomposable organic matter in farmyard manure decomposes over time in the process of composting; however, the slurry already included the decomposed organic matter at the time it was applied. It was supposed that the relatively high CO_2 efflux observed at our site was caused mainly by the warm soil and high soil moisture condition, but it was also affected by heavy application of easily decomposable organic matter contained in the slurry.

The soil CO_2 efflux for both 2002 and 2003 increased greatly just after the slurry application and remained high for a couple of weeks. CO_2 efflux ranged from 12.0 to 37.0 μmol $m^{-2\ -1}$ for the 30 kg m^{-2} plot; from 7.4 to 28.0 μ mol m^{-2} s^{-1} for the 15 kg m^{-2} plot and from 4.5 to 14.1 μ mol $m^{-2}s^{-1}$ for the 6 kg m^{-2} plot for the period just after slurry application to just before the sowing of seed, which is approximately one month. In this period, the CO_2 efflux was greater for higher application intensity and the difference among plots was significant, however the difference between the 15 kg m^{-2} plot and the 6 kg m^{-2} plot was not great in April but was in September. The mean soil temperature was 17.9 °C in April and 27.3 °C in September through the entire experimental period. It is supposed that the warmer soil condition promoted decomposition greatly. The large increase of CO_2 efflux was only found in April and September just after the slurry application. It is concluded that this increase was induced by the slurry itself and it is a unique characteristic of the slurry applied field. ROCHETTE & al. 2000 did not observe a large increase in a plot enriched with a mineral fertilizer but a significant increase similar to our result was observed in a plot with pig slurry application. It is supposed that most of the organic matter contained in the slurry decomposed within a month after the application. CO_2 can also be released from the slurry by chemical processes. CO_2 is produced in slurry during storage by the hydrolysis of urea and the anaerobic decomposition of volatile fatty acids (SOMMER & HUSTED 1995). The CO_2 in the solution forms pH-dependent chemical equilibriums with other species such as NH_3 (SOMMER & HUSTED 1995). The pH of the slurry in our study was 7.44 (NIIMI 2002) while that of the surface soil was 5.20 in the 6 kg m^{-2} plot, 5.62 in the 15 kg m^{-2} plot and 5.69 in the 30 kg m^{-2} plot. These values are lower than the threshold below which ammonium carbonates are dissociated and CO_2 is released. GENERMONT 1996 reported very large carbonate-induced CO_2 emissions following application of cattle slurry and ROCHETTE & al. 2000 also concluded that the large CO_2 efflux after the pig slurry application was induced by the carbonate.

According to the regression analysis between the soil CO_2 efflux measured by the chamber and that estimated by the gas diffusion method, the coefficient of determination was 0.61 for the 6 k gm $^{-2}$ plot, 0.75 for the 15 kg m^{-2} plot and 0.86 for the 30 kg m^{-2} plot and the regression coefficient was 0.33 for the 6 kg m^{-2} plot, 0.60 for the15 kg m^{-2} plot and 0.50 for the 30 kg m^{-2} plot. Based on these results, accumulated soil carbon from CO_2 effluxes (CO_2-C effluxes) for the peak period (slurry dominant period) and for the entire growing period (including the peak period) were calculated as listed in Table 1. The accumulated CO_2-C efflux of the Maize field during the peak period was greater in 2002 than in 2003. The peak period was 31 days from April 12 to May 13 in 2002 and 20 days from April 2 to 22 in 2003. The main reason for the difference in accumulated CO_2-C efflux between these two years was difference in length of the peak periods. However, the average of soil CO_2 efflux during the peak period for the 6 kg m^{-2} plot and 15 kg m^{-2} plot was 37 to 69 % greater in 2002. The mean air temperature (15.6 °C in 2002 and 15.6 °C in 2003) and the total rainfall amount (214 mm in 2002 and 207.5 mm

Table 1. Accumulated soil carbon effluxes during the peak period (A) and during the entire growing period (B) and the ratio of effluxes A and B to total added carbon as shown in Table 2. Mz and *IR* indicate Maize and Italian ryegrass growing seasons, respectively as shown in Fig.1. Numbers in parenthesis indicate days of each period.

Year	Plot	Peak (A) kg m^{-2}		Entire (B) kg m^{-2}		A/added C		B/added C	
		Mz	IR	Mz	IR	Mz	IR	Mz	IR
2002	6 kg m^{-2}	0.13	0.07	0.40	0.27	0.73	0.38	2.26	1.56
	15 kg m^{-2}	0.25	0.20	0.91	0.55	0.58	0.47	2.08	1.26
	30 kg m^{-2}	0.37	0.27	1.11	0.58	0.42	0.31	1.26	0.66
		(31)	(50)	(144)	(210)				
2003	6 kg m^{-2}	0.06	0.06	0.46	0.23	0.36	0.34	2.08	1.29
	15 kg m^{-2}	0.10	0.22	0.91	0.58	0.23	0.49	1.31	1.33
	30 kg m^{-2}	0.26	0.35	1.15	0.65	0.30	0.40	1.56	0.74
		(20)	(48)	(159)	(209)				

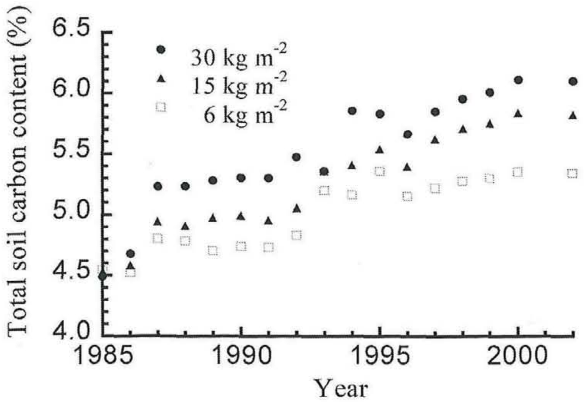

Fig. 2. Inter-annual changes of total carbon content in soil of forage fields with different applications of the slurry.

Table 2. Total Carbon from the slurry and the plant residual which was added to the soil and the increase of soil carbon (ΔCs) for 17 years since the beginning of the slurry application (1985), the ratio of ΔCs to the total added carbon and the plant carbon by assimilation assuming the carbon percentage was 40 % of the dry matter weight (NIIMI 2002).

Plot	Added C to soil (kg m^{-2})			ΔCs	ratio*	Plant C
	Slurry	Residual	Total	(kg m^{-2})	(%)	(kg m^{-2})
6 kg m^{-2}	5.27	3.08	8.35	0.79	9.42	10.54
15 kg m^{-2}	13.13	3.65	16.82	1.27	7.58	12.75
30kg m^{-2}	26.35	4.20	30.55	1.58	5.17	14.79

in 2003) differed very little between those years. However, the rainfall on the day before the slurry application was 18 mm in 2002 and 77.5 mm in 2003 and there was 27.5mm of rainfall after the slurry application in 2003. Unfortunately there was no continuous soil moisture data during those periods but data from other periods show the soil moisture at the depth of 0.1 m was above the field water capacity (52.6 %) and lasted longer than 8 hours when there was more than 50 mm of rain. It is supposed that drainage of the field was promoted in 2003 so that both organic and inorganic carbon in the slurry, which would produce CO_2-C efflux, might have been partly drained away with the gravitational water flow. The difference of accumulated CO_2-C efflux during the peak periods was not significant between Maize and Italian ryegrass; however, the accumulated CO_2-C efflux for the entire growing period was greater in the Maize crop than that of Italian ryegrass crop. Because the averaged soil temperature at the depth of 0.1m was higher in the Maize growing period than that of the Italian ryegrass growing period as described above, it is supposed that both root respiration and the microbial respiration were greater in the Maize field through out the growing season even though the growing period was longer for the Italian ryegrass. The ratio of accumulated CO_2-C in the peak period to the total added carbon ranged from 0.23 to 0.73, which suggested that the slurry induced carbon loss was a large part of the total carbon loss. The accumulated CO_2-C efflux (B) throughout the entire growing period exceeded the total added carbon, suggesting that carbon loss from the root respiration of plants increased with plant growth. Fig. 2 shows the change of the total carbon content of the soil between the surface and the 0.15m deep and Table2 shows the carbon balance of the soil for 17 years between 1985 and 2002. The total carbon content of the soil was approximately the same among the plots when the application began in 1985. For all the plots, the total carbon content of the soil increased and the degree of increase was directly related to the slurry application intensity.. Assuming that total soil weight down to the 0.15 m deep layer is 97.5 kg m^{-2}, the difference in soil carbon between the 30 kg m^{-2} and 6 kg m^{-2} application plots, in 2002, was 0.742 kg m^{-2} at the greatest. However this accounts for only 3.34% of the difference of the total added carbon up to 2002 and the ratio of the increase in soil carbon to the total added carbon for those 17 years is less than 10%. These results suggest that the accumulation of soil carbon was quite small compared to the amount of carbon that was added to the soil. In addition, the carbon assimilation by the plant was even smaller than the carbon efflux B (Table 1). Therefore, it is concluded that a large part of the carbon that was added to experimental plots was lost by soil respiration and this was enhanced by the warm and rainy climate of southern Kyushu region in Japan.

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