Microbial biomass and organic carbon stock in paddy soils in the lake Biwa basin, Japan

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Abstract
The Shiga prefectural government has been promoting environmentally conscious agriculture through a direct payment system in order to conserve water quality of the Lake Biwa, the largest lake in Japan. Furthermore, we target to halve the emission of greenhouse gasses by 2030 from the 1990 level. Therefore we have participated in the National Soil Survey Program for monitoring soil carbon content, and investigated microbial biomass carbon (B_C) and organic carbon stock in paddy soils as influenced by soil types and management practices at the long-term experimental fields for manuring and the farmers' fields designated for a monitoring purpose.The B_C values were affected by soil types and increased by organic matter applications, ranging from 200 to 1,168 mg C/kg. The B_C values in Brown Lowland soils were higher than those in Gray lowland soils. In contrast, the values of microbial biomass nitrogen (B_N) did not show any appreciable difference among the soil types. The B_C and B_N values corresponded to 1.1-5.8 and 1.7-5.1% of the respective values of soil organic matter. Similar tendencies were also observed in the farmers' fields for monitoring, the number of the fields being about 40. The average values of soil carbon stocks for the depth of 0-30 cm in lowland soil groups ranged from 47 to 63 Mg C/ha.

Key Words
Paddy soil, microbial biomass, soil organic carbon, carbon stock, organic matter application.

Introduction
Shiga prefecture is facing various problems including the issue of water quality in the Lake Biwa, the largest freshwater lake in Japan. It is surrounded by paddy fields, which occupy 92% of the total farmland area in Shiga. Hence, the prefectural government has been promoting environmentally conscious agriculture (ECA) through a direct payment system since 2004. The ECA practice for paddy rice extended to 10,117 ha in 2008, corresponding to 30% of the total rice cultivation area in Shiga, and the ratio was highest in Japan (Shibahara 2009). Furthermore, according to the vision for a sustainable society in Shiga towards 2030, we target to halve the emission of greenhouse gasses (GHGs) from the 1990 level. As agricultural management practice has received much interest recently as a source and a sink of GHGs, we have participated in the National Soil Survey Program for monitoring soil carbon content and soil management since 2008 (Leon *et al.* 2009).
Soil microorganisms and their activities are at the heart of several vitally important processes such as carbon sequestration and CO_2 release, the formation and destruction of trace GHGs and many transformations within the nitrogen cycle (Powlson 1994). Furthermore, changes in soil microbial biomass measured over relatively short periods can indicate trends in total organic matter content before these can be detected by chemical analyses (Powlson *et al.* 1987). Therefore, we investigated microbial biomass carbon and organic carbon stock in paddy soils as influenced by soil types and management practices at the long-term experimental fields for manuring and the farmers' fields designated for a monitoring purpose.

Materials and methods
Long-term experimental fields
The long-term field experiment for paddy rice cultivation was continued from 1975 to 2001 at Central Station of Azuchi (Gray lowland soils) and at Western Branch Station of Kosei region (Brown Lowland soils) in Shiga Prefecture Agricultural Technology Promotion Center. Soil samples of the plow layer were collected from the following plots: plot without organic matter application, rice straw compost plot, and rice straw plot. Microbial biomass carbon (C) and nitrogen (N) were determined by the fumigation-extraction method (Inubushi *et al.* 1991; Shibahara and Inubushi 1995, 1997). Several data sets of soil microbial biomass and soil organic matter determined during the last 10 years (the 16th-25th year period after the initiation) were averaged for calculating the balance sheet.

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Farmers' fields for monitoring
The soil survey program was applied to about 40 farmers' paddy fields that are designated for a long-term monitoring purpose in Shiga prefecture. Soil samples for measuring microbial biomass were collected from the plow layer (0 to 15 cm) under submerged conditions in 2001. Soil samples for measuring organic carbon stock were collected from a depth of 0-30 cm in 2008 and were subjected to determination by a dry combustion method and a core sampling method.

Results and discussion

Effects of long-term application of organic matter on soil microbial biomass and organic carbon
Microbial biomass C (B_C) and N (B_N) in paddy soils are shown in Table 1. The values of B_C were affected by the soil types and increased by organic matter applications, ranging from 200 to 1,168 mg C/kg. The B_C values in Brown Lowland soils were much higher than those in Gray lowland soils. In contrast, the values of B_N did not show any appreciable difference among soil types. The B_C and B_N values corresponded to 1.1-5.8 and 1.7-5.1% of the respective values of soil organic matter. These differences between the changes in the B_C and B_N values affected the B_C/B_N ratios, indicating that the composition of microbial biomass can be affected by the soil types and organic matter application. Furthermore, lower contents of total soil organic C (T-C) and lower B_C/T-C values in Brown Lowland soils suggests that a continuous application of organic matter is important to maintain soil organic C level and nitrogen fertility in well-drained soils.

Table 1. Microbial biomass C and N as influenced by soil types and organic matter application in paddy fields of the long-term manuring experiment.

Soil group, texture, (Clay content)	Plot	Application rate of organic matter (kg/ha)		Microbial biomass (mg/kg)			Soil organic matter (g/kg)		B_C/T-C (%)	B_N/T-N (%)
		O_C	O_N	B_C	B_N	B_C/B_N	T-C	T-N		
Gray Lowland soils, CL (24%)	NPK	–	–	200	29.3	6.8	18.7	1.73	1.1	1.7
	$NPKC_{20}$	1,210	61	386	57.7	6.7	23.5	2.05	1.6	2.8
	$NPKS_8$(Fp)	2,890	45	349	59.3	5.9	20.9	1.82	1.7	3.3
Brown Lowland soils, L (15%)	NPK	–	–	706	49.1	14.4	15.5	1.63	4.6	3.0
	$NPKC_{10}S_7$	3,430	77	1,168	94.1	12.4	20.3	2.41	5.8	3.9
	$NPKS_7$(Fp)	2,540	33	1,019	95.7	10.6	18.6	1.88	5.5	5.1

NPK, S_7 and S_8 indicate chemical fertilizer and rice straw applied at 7 and 8 (Mg/ha/y), while C_{10} and C_{20} as rice straw compost applied at 10 and 20 (Mg/ha/y), respectively.
Fp indicates soil improvement material consisting of calcium silicate and fused magnesium phosphate.
O_C and O_N indicate the average amounts of carbon and nitrogen per ha derived from organic matter application each year, respectively.
B_C and B_N indicate microbial biomass carbon and nitrogen, respectively.
T-C and T-N indicate total soil organic carbon and nitrogen, respectively.

Microbial biomass and organic carbon stock in the farmers' paddy fields
Microbial biomass data in the farmers' fields (sampled and measured in 2001) and soil carbon stocks (sampled and measured in 2008) are shown in Table 2. The average values of B_C in Brown Lowland soils were higher than those in Gray lowland soils and Gley Lowland soils. On the other hand, the average values of total soil organic matter content (T-C, T-N) and clay contents show an opposite tendency. These results are consistent with the changes of the microbial flora in soils and decomposition rates of soil organic matter. Soil carbon stock to the depth of 0-30 cm was much higher in an Andosol field (116 Mg C/ha) than in those of the other soil groups (35–63 Mg C/ha). Although there was only one Andosol sample in this study, similar values and trends have been obtained in the National Soil Survey Program (Leon *et al.* 2009). The average values of soil carbon stock did not show any appreciable difference among the lowland paddy soil groups (i.e., Gley Lowland soils, Gray Lowland soils and Brown Lowland soils) in this study. Further studies are required to estimate soil carbon stocks more accurately and their changes with soil types and manuring practice more quickly by means of microbial biomass measurements.

Table 2. Microbial biomass and organic carbon stock in various soil types among the farmers' paddy fields designated for monitoring purpose.

Classification of cultivated soils in Japan 3rd approximation	Soils collecetd from the plow layer in 2001						Soils collected from a depth of 0-30 cm in 2008	
	Number of sample (n)	B_C (mgC/kg)	B_N (mgN/kg)	T-C (gC/kg)	T-N (gN/kg)	Clay (%)	Number of sample (n)	T-C (Mg C/ha) (average±standard deviation)
Lowland Paddy soils	15	745	82	19.2	1.85	18.6	19	46.8±10.4
Gley Lowland soils	7	651	100	27.9	2.46	25.9	8	62.5±18.2
Gray Lowland soils	14	664	79	20.9	1.95	19.7	9	50.2± 8.2
Brown Lowland soils	4	1,023	102	21.8	2.10	17.0	3	56.3±23.1
Gray Upland soils	1	405	51	17.0	1.58	26.2	1	34.78
Andosols	1	1,653	137	58.4	4.36	17.4	1	116

Each value indicates the average for the respective soil group. B_C and B_N indicate microbial biomass C and N, respectively.

Conclusion

Microbial biomass and organic matter status in paddy soils of the long-term manuring experiment and the designated farmers' fields for monitoring were investigated to estimate organic carbon stocks in agricultural lands, especially paddy soils. Microbial biomass C was affected by soil types and increased by organic matter application. Soil carbon stocks for the depth of 0-30 cm in lowland soil groups ranged from 46.8 to 62.5 Mg C/ha. These results are consistent with the changes of the microbial flora in soils and decomposition rates of soil organic matter. Further studies are required to estimate soil carbon stocks more accurately and their changes more quickly.

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