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Long-Term Change in the Application Rate of On-Farm Organic Amendments in Japanese Upland Fields

Ai LEON, Kazunori KOHYAMA, Toshiaki OHKURA, Yusuke TAKATA and Hiroshi OBARA*

National Institute for Agro-Environmental Sciences (Tsukuba, Ibaraki 305-8604, Japan)

Abstract

In order to help maintain soil fertility, a national survey was conducted in Japan, beginning in 1979. Both soil samples and questionnaires given to farmers on agricultural management were collected. By using the dataset, we described the long-term application rates of on-farm organic amendments (which we denote as OA and consists of livestock waste compost (LWC), and "other OA" such as rice straw residue) that are crucial for maintaining soil fertility. Average LWC and "other OA" application rates (fresh weight, FW) decreased from 17.8 ± 0.5 and 3.2 ± 0.2 (1979-1983) to 12.1 ± 0.4 and 2.7 ± 0.4 (1994-1998) Mg Fw ha^{-1}, respectively. The long-term change in LWC application rate may be partly due to limited time and labor. The application rates were influenced by the type of crop, possession of livestock, and the part-time/full-time status of farmers. The differences in OA application may be partly due to the separation of crop and livestock farming. When data points were categorized by the joint influence of these factors, there was a difference of more than seven times between the largest and smallest LWC application rates. The largest application rate was achieved by the group with "feed and forage crops" (FFC, such as dent corn) along with full-time farmers possessing livestock, while the smallest rate was achieved by the group of full-time or part-time farmers with neither FFC nor vegetable cropping (e.g. potatoes), and with no possession of livestock.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: crop type, part-time/full-time status of farmers, possession of livestock

Introduction

Food production must be doubled in order to feed the world's growing population over the next 50 years[27]. Sustainable food security is closely linked with soil fertility[4]. Monitoring soil properties and agricultural management play crucial roles in maintaining and enhancing soil fertility. The application of organic amendments (OA) is one form of management used to maintain soil fertility. However, excessive application has caused environmental degradation[31].

The application rates of organic amendments vary both globally[15,16] and nationally[9] as influenced by certain factors[7,9,11,12,28] and over time[7,16]. The application rate has only been approximated based on the number of livestock[15], and sometimes together with the rates of utilized/non-utilized livestock excreta[9,16] based on available statistics. Moreover, in Japan, knowledge about the long-term OA application rate for wheat and barley is availabe[19], while such knowledge for other crops is derived from a one-off survey[23], or based on recommendations regarding OA application rate[30]. This knowledge is crucial to identify areas or crops with a high OA application rate. However, the knowledge is inadequate for understanding the changes in soil properties linked with OA application. To understand such changes in detail, a national soil survey has been underway in Japan since 1979[14] to collect both soil samples and questionnaire surveys on agricultural manegement. Given the growing concerns in recent years over climate change, such survey data have become more important than ever, as it allows us to evaluate the changes in soil organic carbon (SOC) in association with agricultural management, and estimate SOC changes by using Tier 3 methods[3]. By using the dataset, Mishima et al. (2012)[12] estimated the amount of manure produced from 1994 to 1997, while Leon et al. (2012)[7] reported the long-term change in on-farm OA application rates in paddy fields from 1979 to 1998, taking into account the joint influence of several factors. The long-term change in the OA application rate in upland fields has yet to be studied in detail. Given the fact that organic matter is depleted faster in upland fields than in paddy fields[5], this

*Corresponding author: e-mail obara@affrc.go.jp
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knowledge will presumably prove essential in monitoring soil fertility.

With this background, this paper aims to explore the differences and long-term changes in OA application rates associated with agricultural structure, and those changes in Japan.

Materials and methods

Activity data

We used the national soil survey data collected between 1979-1998 [5394 points in wave 1 (1979-1983); 5286 in wave 2 (1984-1988); 5283 in wave 3 (1989-1993); 4879 in wave 4 (1994-1998)]. We selected farmers that responded to the four consecutive surveys, and who continued the same land use (upland field, 4006 points). That is, even if farmers did not specify which crops they were growing, we still used their information in the analysis. In case neither the types nor the amounts of OA were described, we assumed that no OA was applied. We omitted those points that were missing the amounts of OA, but included the types (and vice versa, 15 points) and those points with extremely large application rates (greater than 400 Mg ha^{-1}, 8 points). As a result, we used 3983 points for each wave.

We described the OA application rates for the crop type, possession of livestock, and part-time/full-time status of farmers. As for the crop type, vegetables were divided into "leaf" [e.g. Chinese cabbage (*Brassica rapa var. glabra*)], "fruit" [e.g. tomato (*Solanum lycopersicum*)], "root" [e.g. carrot (*Daucus carota L.*)], and "other" [e.g. sweetcorn (*Zea mays convar*)] as per the "Agricultural Production Environmental Statistics"[23]. We grouped data points for growing "feed and forage crops" (FFC, crop 3), followed by data points for growing vegetables (crop 2) and the rest of the crops (crop 1). In case crop 1 and/or crop 2 were grown together with FFC, or crop 1 was grown together with crop 2, these data points were included in "FFC/others" and "vegetables/other," respectively. In case "leaf," "fruit," "root" and/or "other" vegetables were grown twice (or three times), we grouped these types as "vegetables/vegetables" (or "vegetables/vegetables/vegetables"). As for the possession of livestock, we assumed that farmers covered by the data points possessed livestock only if the numbers of dairy cattle (*Bos taurus*), beef cattle (*Bos taurus*), swine (*Sus scrofa domesticus*), poultry (*Gallus gallus domesticus*), and other farm animals were reported.

Organic amendments were divided into two groups: Livestock waste compost (LWC) and "other organic amendments ("other OA")" to describe the OA application rate. LWC contained livestock waste compost (from cattle, swine, and other livestock) with/without sawdust. "Other OA" included rice straw compost, husks, sawdust or bark compost, green manure, wheat straw residue, city refuse compost, sewage sludge compost, waste from the food processing industry, and industrial waste.

Statistical method

We took a nonparametric approach to test for significant differences in distribution among several independent samples (using the Kruskal-Wallis test) or paired samples (using the Friedman test), as the medians of OA in many cases were 0 (Fig. 1). Consequently, the application rates of OA were described in terms of mean ranks derived from the tests, as well as the average. Fig. 2 shows one type of mean rank, while Figs. 3 and 4, and Tables 1 and 2 show two types of mean ranks [mean ranks (1) and (2)]. Mean rank (1) was used to test for differences (in OA application rate) between groups differing in livesotck possession (Fig. 3), between full-time and part-time farmers (Fig. 4), and among smaller groups as defined by combinations of these factors (Table 2) for each wave, using the Kruskal-Wallis test. Mean rank (2) was used to test for differences (in OA application rate) among the waves for each level of factors, using either the Friedman test for when observations were paired

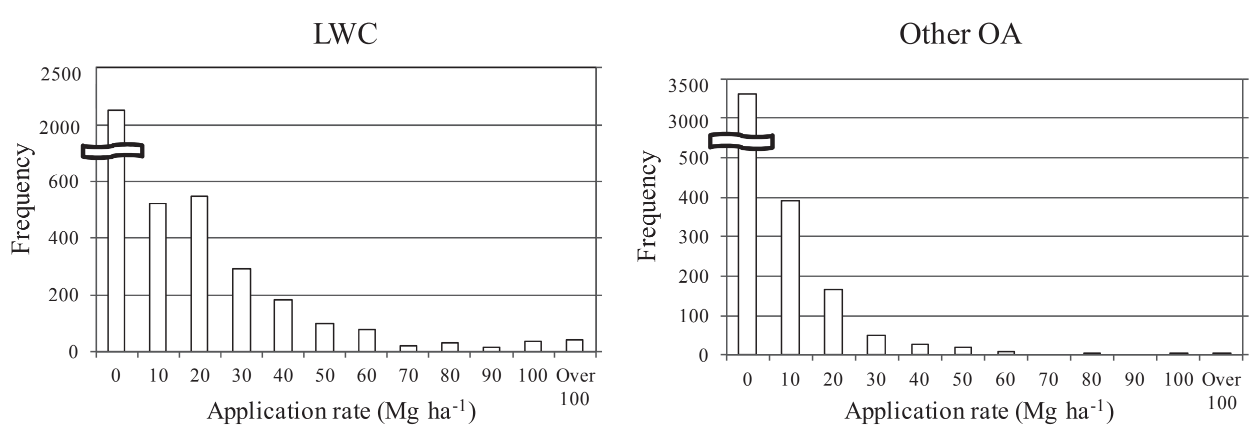

Fig. 1. Histograms of application rates of livestock waste compost (LWC, at left) and other organic amendments ("Other OA,"at right) in wave 3 (1989-1993)

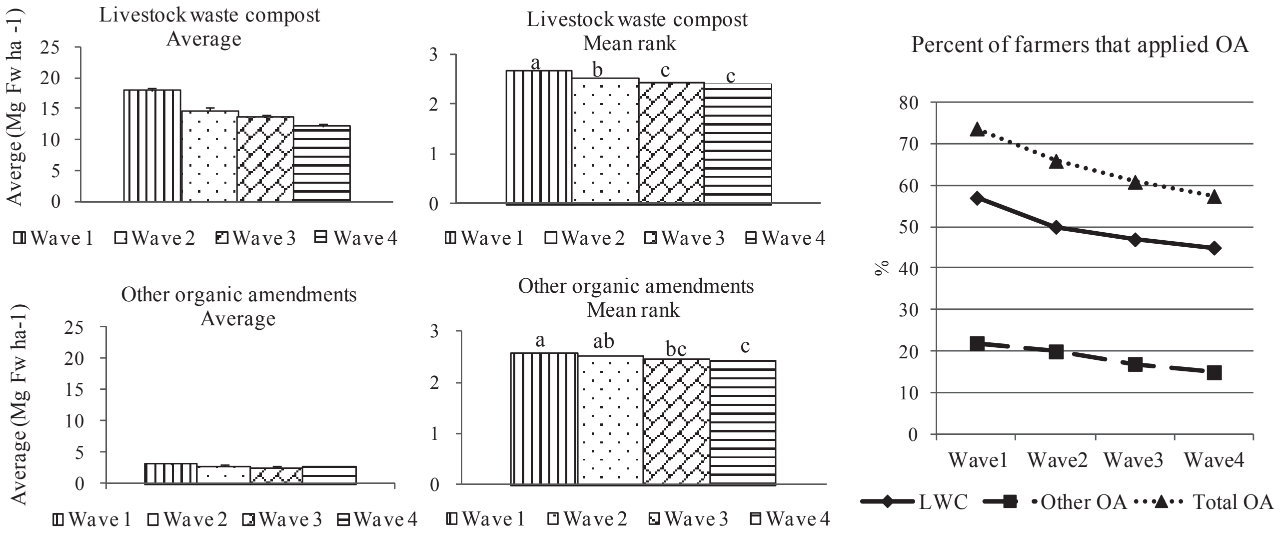

Fig. 2. Application rates of organic amendments in 1979-1998 in upland fields

Post hoc tests were conducted after the Friedman test revealed significant differences (in OA application rate $P<0.05$) among the waves. Two waves assigned with different lowercase letters indicate a significant difference between them ($P<0.05$). The error bar in Average shows the standard error of mean.

(in Fig. 2), or the Kruskal-Wallis test when the Friedman test was not suitable, as the observations were unpaired in Figs. 3 and 4, and Tables 1 and 2. In case these tests detect groups that are significantly different (P<0.05), post hoc tests were conducted. Statistical analyses were conducted using PASW statistics 18. The technical details, including differences in the mean ranks, of the statistical analyses employed in this paper were previously described by Leon et al[7].

Results

Application rate of organic amendments in upland fields

Fig. 2 shows the average application rate of OA on the basis of fresh weight (FW) and mean rank values over time (between 1979-1998). The average application rate of livestock waste compost (LWC) was between four and six times higher than that of “other organic amendments (“other OA”).” Both the average and mean rank values of livestock waste compost (LWC) application rate decreased from wave 1 to wave 4 ($P<0.05$). That is, the average LWC and “other OA” application rates (fresh weight, FW) decreased from 17.8 ± 0.5 and 3.2 ± 0.2 (1979-1983) to 12.1 ± 0.4 and 2.7 ± 0.4 (1994-1998) Mg FW ha^{-1}, respectively. Thus, the changes in both the average and mean rank of “other OA” over time were much smaller than those of LWC.

Influence of crop type on the application rate of organic amendments

Table 1 lists the average OA application rates, mean rank (1) and mean rank (2). The application rate of LWC was lower for crop 1 than for crop 2 and crop 3. Among crop 1, the application rates (both mean rank (1) values and average) of LWC for “wheat and barley” and “pulses (e.g. *Glycine max*)” were likely to be lower than for other crops in crop 1, while it was higher for “flowers (e.g. *Cosmos*)” and “industrial crops (e.g. *Beta vulgaris* ssp. *vulgaris*).” As for crop 2, the application rate of LWC for single cropping (“leaf,” “root” and “other” vegetables), except for “fruit vegetables,” was lower than for multiple croppings (“vegetables/other,” “vegetables/vegetables” and “vegetables/vegetables/vegetables”). Among crop 3, the LWC application rates (average and mean rank (1) values) were the greatest for “FFC/FFC.” From wave 1 to wave 4, the average application rate of LWC decreased continuously for certain crops in crop 3 ($P<0.05$, “FFC” and “FFC/FFC”). Other crops did not change as per a single trend. As for “other OA,” the application rate was likely to be higher (both average and mean rank (1) values) throughout the survey waves for “vegetables/vegetables/vegetables” and “fruit vegetables,” and lower for “FFC” and “pulses.” The average application rate of “other OA” decreased continuously from wave 1 to wave 4 for potatoes and sweet potatoes ($P<0.05$).

Influence of possessing livestock on the application rate of organic amendments

Fig. 3 shows the mean ranks and average OA application rate for farmers with and without livestock. The mean rank (1) value for LWC was higher ($P<0.05$) for farmers with livestock than for those without livestock. In addition, farmers with livestock applied LWC more than twice as much, in terms of average, as did the farmers without livestock, who showed a significantly higher application rate of

Table 1. Application rates of organic amendments for crops in upland fields (livestock waste compost)

		Mean rank (1)				Mean rank (2)				Average (Mg FW ha^{-1})				Samples			
		Wave 1	Wave 2	Wave 3	Wave 4	Wave 1	Wave 2	Wave 3	Wave 4	Wave 1	Wave 2	Wave 3	Wave 4	Wave 1	Wave 2	Wave 3	Wave 4
						LWC appplication											
Crop 1	Potatoes and Sweet potatoes	1554	1550	1568	1561	701	654	661	682	7.3 ± 0.7	5.9 ± 0.7	6.0 ± 0.7	6.7 ± 0.7	351	346	308	344
	Pulses	1287	1495	1472	1306	434	453	449	421	4.2 ± 0.6	5.4 ± 0.7	5.1 ± 0.7	3.8 ± 0.6	248	221	216	193
	Industrial crops	1664	1699	1687	1683	884	841	839	870	8.6 ± 0.7	7.9 ± 0.6	7.9 ± 0.7	8.2 ± 0.6	461	460	414	381
	Upland rice	1622	1598	1442	1498	112	102	91	99	7.0 ± 1.4	4.5 ± 1.0	4.6 ± 1.7	5.3 ± 1.5	50	61	47	44
	Wheat and Barley	1363	1246	1227	1384	268 a	237 ab	232 b	261 ab	5.2 ± 1.1	3.1 ± 0.9	2.8 ± 0.6	6.3 ± 1.4	77	123	166	126
	Flowers	1719	1731	1547	1638	183	174	159	173	14.3 ± 5.0	10.1 ± 2.0	5.7 ± 1.2	8.9 ± 1.6	50	82	101	107
	Others	1803	1837	1782	1658	444	424	411	397	12.6 ± 1.7	10.3 ± 1.3	11.0 ± 1.6	8.8 ± 1.3	245	235	205	157
Crop 2	Fruit vegetables	2269	2050	2119	1753	450 a	385 bc	403 ab	340 c	21.5 ± 1.8	16.1 ± 2.0	17.2 ± 1.8	11.2 ± 1.4	238	175	175	205
	Leaf vegetables	1785	1845	1720	1729	676	656	615	642	11.1 ± 1.1	10.8 ± 1.0	9.6 ± 1.0	9.7 ± 0.8	250	300	355	383
	Root vegetables	1874	1880	1868	1842	643	608	607	622	12.7 ± 1.1	11.8 ± 1.2	11.0 ± 1.0	11.0 ± 0.9	294	278	307	360
	Other vegetables	1990	1876	1904	1756	443	398	406	389	17.4 ± 2.0	11.6 ± 1.2	13.0 ± 1.3	9.8 ± 1.1	154	187	242	229
	Vegetables/other crops	1977	2058	2076	1858	559	551	560	515	14.0 ± 1.0	13.0 ± 1.0	14.8 ± 1.5	12.9 ± 1.6	370	309	241	179
	Vegetables/Vegetables	2172	2066	2103	2029	1048 a	941 bc	969 b	965 b	20.4 ± 1.3	16.2 ± 1.2	17.0 ± 1.4	15.3 ± 1.1	613	544	443	369
	Vegetables/Vegetables/Vegetables	2322	2188	1984	2086	171	153	137	152	25.1 ± 3.4	17.2 ± 2.6	13.3 ± 2.2	17.5 ± 3.2	86	80	78	62
Crop 3	Feed and Forage crops	2849	2690	2514	2319	600 a	537 ab	507 b	485 b	36.3 ± 2.2	29.8 ± 1.9	28.9 ± 2.0	27.9 ± 2.2	208	243	295	305
	Feed and Forage crops/other crops	2690	2650	2597	2333	214	199	194	173	32.4 ± 3.2	29.4 ± 3.1	26.7 ± 3.0	25.4 ± 5.7	122	120	93	61
	Feed and Forage crops/Feed and Forage crops	3355	3332	3125	2806	331 a	319 ab	278 bc	238 c	82.7 ± 5.4	74.5 ± 4.9	60.6 ± 4.6	50.2 ± 4.3	158	155	132	141

Post hoc tests were conducted after the Kruskal-Wallis test revealed significant differences (in OA application rate, $P<0.05$) among the waves. The different lowercase letters mean that the mean rank (2) values for each crop differed significantly between the survey waves ($P<0.05$). Average shows mean ± S.E. Mean rank values (1) are compared vertically; mean rank values (2) are compared horizontally.

Table 1. Application rates of organic amendments for crops in upland fields (continued, application of other organic amendments)

		Mean rank (1)				Mean rank (2)				Average (Mg FW ha^{-1})				Samples			
		Wave 1	Wave 2	Wave 3	Wave 4	Wave 1	Wave 2	Wave 3	Wave 4	Wave 1	Wave 2	Wave 3	Wave 4	Wave 1	Wave 2	Wave 3	Wave 4
						"Other OA" application											
Crop 1	Potatoes and Sweet potatoes	1912	1959	1835	1728	692 ab	702 a	661 ab	643 b	3.6± 0.6	2.6 ± 0.4	1.9 ± 0.4	1.7 ± 0.4	351	346	308	344
	Pulses	1794	1766	1832	1716	443	433	448	433	2.0± 0.6	0.7 ± 0.2	1.4 ± 0.3	1.4 ± 0.4	248	221	216	193
	Industrial crops	2145	2143	2088	1925	877	875	858	817	3.1± 0.3	3.8 ± 0.4	3.7 ± 0.4	3.7 ± 0.6	461	460	414	381
	Upland rice	1733	1975	2030	1848	93	105	108	101	0.8± 0.5	2.4 ± 1.0	1.9 ± 0.8	2.0 ± 1.0	50	61	47	44
	Wheat and Barley	1882	2026	1902	1926	238	255	240	252	0.7± 0.2	1.9 ± 0.5	1.8 ± 0.5	2.1 ± 0.5	77	123	166	126
	Flowers	2191	1962	1954	1745	193 a	172 ab	172 ab	158 b	3.2± 1.0	3.5 ± 1.5	2.7 ± 0.7	1.7 ± 0.7	50	82	101	107
	Others	2071	2041	1928	1877	438	428	405	407	2.9± 0.4	2.5 ± 0.5	2.4 ± 0.6	2.2 ± 0.6	245	235	205	157
Crop 2	Fruit vegetables	2141	2062	1955	2054	410	392	371	409	4.3± 0.7	4.3 ± 0.8	3.0 ± 0.8	6.2 ± 1.1	238	175	175	205
	Leaf vegetables	2150	2059	1985	1889	686 a	653 ab	632 ab	622 b	4.1± 0.6	4.2 ± 0.6	3.6 ± 0.5	4.2 ± 0.8	250	300	355	383
	Root vegetables	1940	1874	1874	1793	642	614	617	609	2.3± 0.4	2.3 ± 0.5	2.3 ± 0.4	2.5 ± 0.7	294	278	307	360
	Other vegetables	2000	2055	1865	1865	419	426	388	402	3.1± 0.8	3.5 ± 0.7	2.1 ± 0.5	3.9 ± 1.1	154	187	242	229
	Vegetables/other crops	2124	1956	1909	1763	592 a	541 ab	531 ab	504 b	4.8± 0.7	2.9 ± 0.6	3.5 ± 1.0	1.3 ± 0.3	370	309	241	179
	Vegetables/Vegetables	1985	1971	1972	1884	996	980	986	974	3.6± 0.5	2.7 ± 0.4	3.4 ± 0.5	4.4 ± 0.8	613	544	443	369
	Vegetables/Vegetables/Vegetables	2103	2095	2268	2059	149	149	164	153	3.0± 0.9	3.9 ± 1.0	6.7 ± 1.8	5.8 ± 2.0	86	80	78	62
Crop 3	Feed and Forage crops	1624	1678	1697	1596	522	528	534	520	1.2± 0.6	1.3 ± 0.4	1.5 ± 0.4	0.8 ± 0.3	208	243	295	305
	Feed and Forage crops/other crops	2012	1796	1822	1840	211	189	192	201	4.5± 1.1	2.0 ± 0.6	2.0 ± 0.7	4.2 ± 1.7	122	120	93	61
	Feed and Forage crops/Feed and Forage crops	1624	1717	1572	1626	293 ab	301 a	282 b	297 ab	1.2± 0.6	3.3 ± 1.2	0.0 ± 0.0	2.2 ± 1.0	158	155	132	141

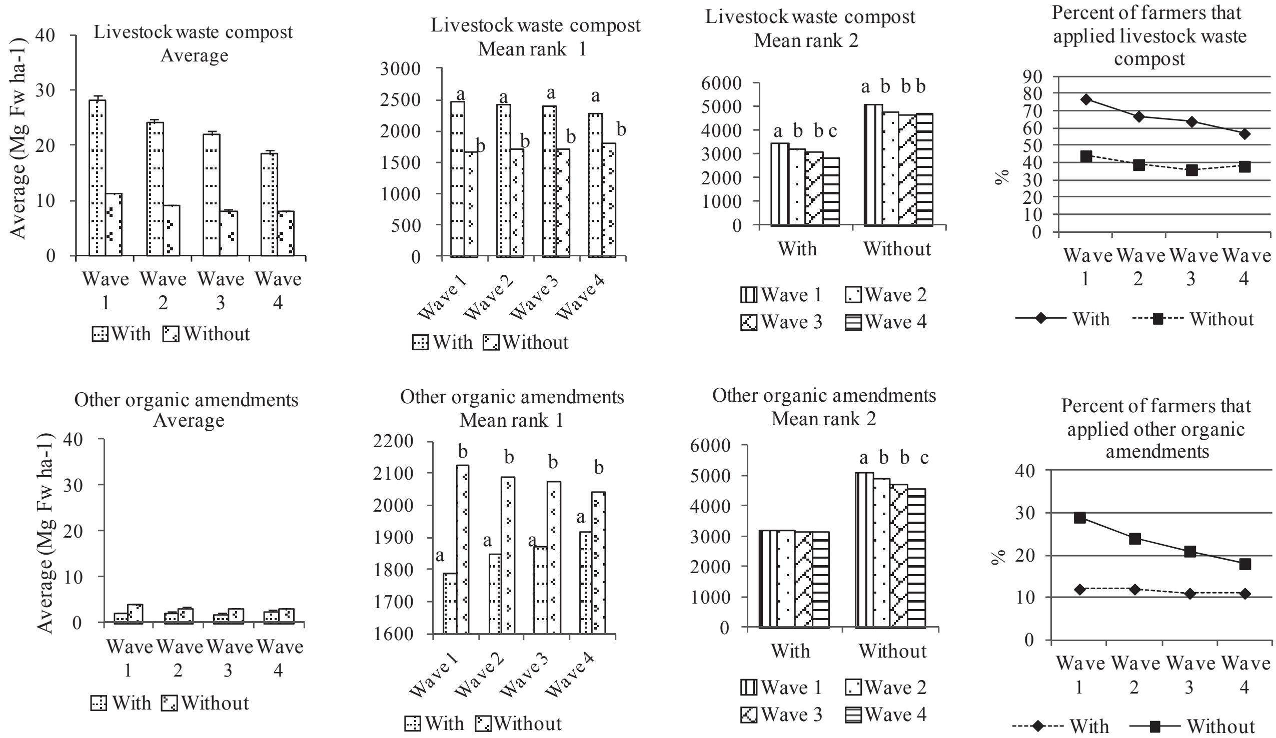

Fig. 3. Application rates of organic amendments by farmers with/without the possession of livestock in upland fields

Post hoc tests were conducted after the Kruskal-Wallis test revealed significant differences (in OA application rate, $P<0.05$) between the groups possessing and not possessing livestock, and differences among the waves. The different lowercase letters mean that the mean rank (1) values in a wave differed significantly among farmers possessing livestock and those not possessing livestock, and that the mean rank (2) values for each group of farmers differed significantly between the survey waves ($P<0.05$). The error bar in Average shows the standard error of mean. (No. of samples with the possession of livestock: 1572, 1557, 1600, and 1580 in waves 1, 2, 3, and 4, respectively; No. of samples without the possession of livestock: 2411, 2426, 2383, and 2403)

"other OA" than farmers with livestock.

During the survey waves, the differences between the farmers in terms of LWC and "other OA" application rates became smaller. That is, although both farmer groups reduced the LWC application rate ($P<0.05$), farmers with livestock reduced the rate more than did farmers without livestock. Conversely, the application rate of "other OA" did not differ significantly over time for farmers with livestock ($P>0.05$), but decreased significantly for farmers without livestock.

Influence of the part-time/full-time status of farmers on the application rate of organic amendments

Fig. 4 shows the mean ranks and average OA application rate for part-time/full-time farmers. Throughout the survey waves, full-time farmers applied a significantly greater amount of LWC ($P<0.05$) than did part-time farmers. As for "other OA," which is different from LWC, no significant difference was noted between farmers in either of the first two waves. The mean rank (1) value for "other OA" was higher for part-time farmers than for full-time farmers, while the opposite held true for average, except in wave 4. This could be attributed to some full-time farmers applying a greater amount of "other OA." The application rates of LWC and "other OA" decreased for both farmer groups over time ($P<0.05$).

Joint influence of several factors on OA application rate

Table 2 lists the joint influence of the factors that we explored in previous sections on LWC and "other OA" application rates, except for the farming status (i.e. part-time/full-time status) for crops 1 and 2, as no significant difference was observed when data points were categorized in terms of the farming status of farmers and their possession of livestock regarding these crops ($P>0.05$, except for crop 2 in wave 3). Throughout the survey waves, the average application rate of LWC was largest in group 8, followed by groups 6, 4, 3, 2, and 1 (each having a group size at least greater than 79, except groups 5 and 7 where the maximum group size was 44). Such a small number of samples made long-term change in the average LWC and other OA appli-

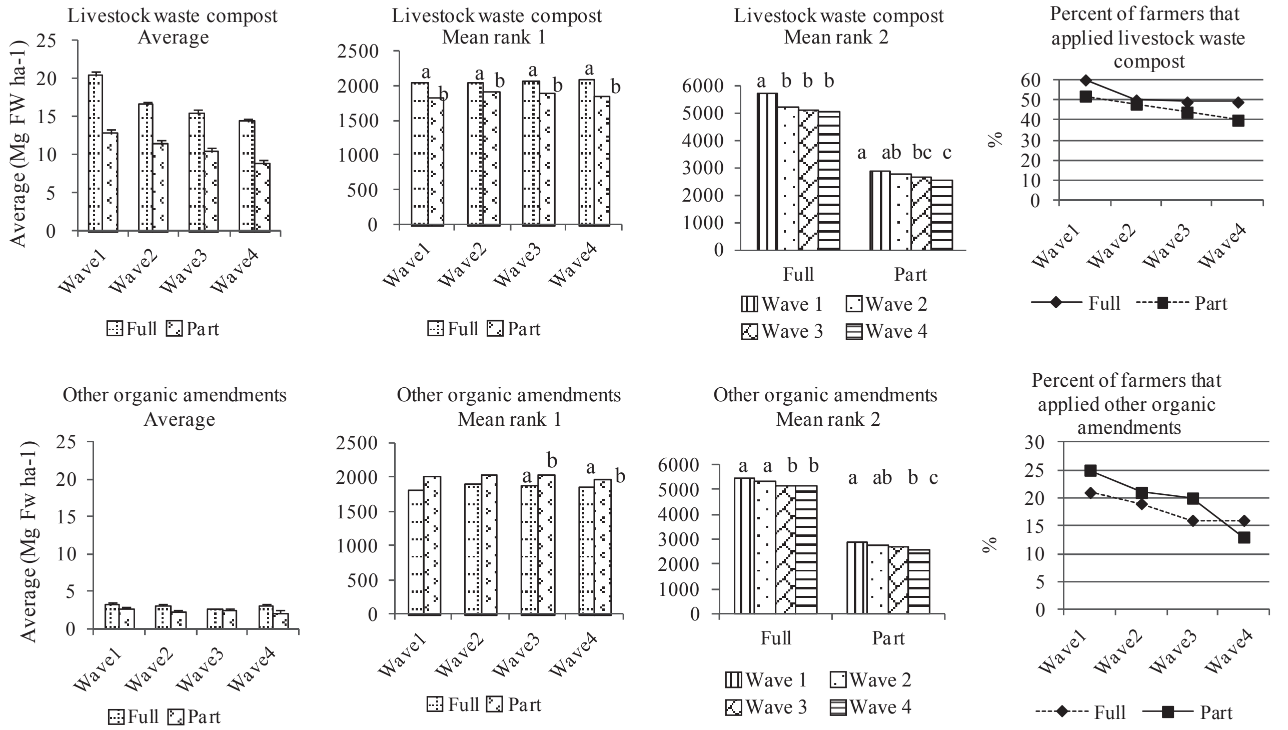

Fig. 4. Application rates of organic amendments by part-time/full-time status of farmers in upland fields

Post hoc tests were conducted after the Kruskal-Wallis test revealed significant differences (in OA application rate, $P<0.05$) between full-time/part-time farmers, and differences among the waves. The different lowercase letters mean that the mean rank (1) values in a wave differed significantly between full-time/part-time farmers, and that the mean rank (2) values for each group of farmers differed significantly between the survey waves ($P<0.05$). The error bar in Average shows the standard error of mean. (No. of samples by full-time farmers: 2717, 2737, 2569, and 2465 in waves 1, 2, 3, and 4, respectively; No. of samples by part-time farmers: 1206, 1245, 1406, and 1500)

cation rates unclear, and made a comparison of average values among the groups less certain as 95% confidence intervals were set wide due to a large standard error of mean). There was a difference of about seven to ten times between the smallest (group 1) and largest LWC application rates (group 8). For example, in wave 4, there was a difference of about seven times between the largest (39.7 ± 2.5 Mg FW ha^{-1}, group 8) and smallest (5.5 ± 0.4 Mg FW ha^{-1}, group 1) LWC application rates. The possession of livestock had a great influence on increasing the LWC application rate among the same crop types (e.g. groups 1 and 2 in case of crop 1), but crop types might have a greater influence than possessing livestock (e.g. groups 2 *vs.* 3). Conversely, the "other OA" application rate was likely to be high in groups where the LWC application rate was low. That is, it was lower in groups 8 and 6 than in other groups, except for group 6 in wave 1.

How the application rate of organic amendments changed from 1979 to 1998

Table 2 shows that rate of change in average OA application over a 20-year period varied among the groups. The largest rate of decrease in average LWC application was seen in group 4 followed by group 8, but fluctuated in groups 1 and 6. As for "other OA," the largest rate of decrease in average application rate was seen in group 1 ($P<0.05$).

According to average, both the LWC and "other OA" application rates decreased continuously in some groups (i.e. groups 2, 3 and 8 for LWC, group 1 for "other OA") ($P<0.05$). The change in application rate between waves 1 and 4 was partly explained by a change in the percentage of data points that applied OA (Table 2). The rate decreased between 6% and 18% for LWC, and 10% for "other OA," in groups where a significant difference was observed.

Discussion

Influence of individual factors on OA application rate

Similar to previous studies, the LWC application rate differed with crop[11] and livestock excreta production[9,28], and the part-time/full-time status of farmers[7,12]. The difference in LWC application rate between farmers with/without livestock might be partly due to the separation of crop and live-

Table 2. Joint influence of several factors on livestock waste compost (LWC) and "Other OA" applications in upland fields

Crop type	Part/full-time farmers	Livestock possession	Group	Mean rank (1)				Mean rank (2)				Average (Mg FW ha^{-1})				% of farmers that applied Organic amendments				Samples			
				Wave 1	Wave 2	Wave 3	Wave 4	Wave 1	Wave 2	Wave 3	Wave 4	Wave 1	Wave 2	Wave 3	Wave 4	Wave 1	Wave 2	Wave 3	Wave 4	Wave 1	Wave 2	Wave 3	Wave 4
LWC application																							
Crop 1	—	Without	Group 1	1320^{A}	1431^{A}	1406^{A}	1439^{A}	1790	1786	1754	1855	5.5 ± 0.6	4.9 ± 0.5	4.5 ± 0.4	5.5 ± 0.4	28	28	26	31	897	947	907	838
		With	Group 2	1986^{B}	1921^{B}	1850^{B}	1749^{B}	1222^{a}	1110^{b}	1071^{b}	1049^{b}	12.3 ± 0.6	10.6 ± 0.6	10.2 ± 0.7	9.6 ± 0.7	65	53	49	47	585	581	550	514
Crop 2	—	Without	Group 3	1881^{B}	1842^{B}	1803^{B}	1753^{B}	2908^{a}	2696^{b}	2649^{b}	2678^{b}	14.3 ± 0.6	11.2 ± 0.6	10.9 ± 0.5	10.4 ± 0.5	54	47	45	48	1469	1382	1328	1294
		With	Group 4	2506^{C}	2389^{CD}	2355^{C}	2085^{C}	1126^{a}	1024^{b}	1014^{b}	895^{c}	24.6 ± 1.3	20.7 ± 1.1	20.7 ± 1.2	15.7 ± 0.9	80	69	70	62	536	491	513	493
Crop 3	Part-time	Without	Group 5	2035^{ABC}	2530^{BCDE}	1819^{ABC}	1552^{ABC}	31	37	27	23	15.7 ± 5.4	26.4 ± 7.8	11.2 ± 4.8	5.7 ± 2.5	55	71	47	40	11	14	17	15
		With	Group 6	2757^{CD}	2647^{D}	2717^{D}	2273^{CD}	245^{a}	221^{ac}	230^{a}	189^{bc}	32.1 ± 3.0	27.8 ± 2.9	30.4 ± 2.5	24.4 ± 3.6	81	75	81	66	79	95	135	128
	Full-time	Without	Group 7	2041^{BC}	1919^{ABC}	1645^{ABC}	2045^{BCD}	65	60	52	67	22.4 ± 6.0	19.4 ± 6.2	8.1 ± 3.0	23.8 ± 6.1	48	48	35	52	27	44	20	31
		With	Group 8	3115^{D}	3064^{E}	2773^{D}	2609^{D}	784^{a}	746^{a}	658^{b}	633^{b}	57.3 ± 2.9	50.7 ± 2.6	41.8 ± 2.5	39.7 ± 2.5	90	86	77	75	371	364	348	332
"Other OA" application																							
Crop 1	—	Without	Group 1	2080^{A}	2066^{A}	1982^{AC}	1841^{AC}	1867^{a}	1841^{ab}	1770^{bc}	1693^{c}	3.2 ± 0.3	3.1 ± 0.3	2.5 ± 0.2	2.1 ± 0.2	28	26	22	18	897	947	907	838
		With	Group 2	1859^{B}	1905^{BD}	1875^{AB}	1792^{A}	1115	1129	1115	1101	2.2 ± 0.3	2.0 ± 0.3	2.3 ± 0.3	2.7 ± 0.4	16	17	16	14	585	581	550	514
Crop 2	—	Without	Group 3	2137^{A}	2042^{A}	1997^{C}	1902^{C}	2879^{a}	2730^{b}	2681^{b}	2640^{b}	4.1 ± 0.3	3.3 ± 0.2	3.5 ± 0.3	3.9 ± 0.4	30	24	22	21	1469	1382	1328	1294
		With	Group 4	1809^{BC}	1842^{BDC}	1817^{BE}	1811^{AC}	1012	1016	1006	1035	2.6 ± 0.5	2.9 ± 0.5	2.4 ± 0.5	3.6 ± 0.6	13	13	13	15	536	491	513	493
Crop 3	Part-time	Without	Group 5	2272^{ABC}	1841^{ABC}	2355^{ACE}	1528^{ABC}	33^{ab}	26^{ab}	34^{a}	23^{b}	4.9 ± 2.9	1.6 ± 1.4	5.7 ± 2.7	0.0 ± 0.0	36	14	41	0	11	14	17	15
		With	Group 6	1712^{BC}	1663^{CD}	1678^{BD}	1558^{B}	226	219	221	213	2.5 ± 1.2	1.8 ± 1.1	1.1 ± 0.5	0.4 ± 0.3	8	4	5	2	79	95	135	128
	Full-time	Without	Group 7	2530^{A}	2151^{AB}	2075^{ABCD}	1891^{ABC}	72	60	59	56	13.9 ± 4.6	5.6 ± 1.6	4.8 ± 2.3	5.5 ± 2.9	44	27	25	19	27	44	20	31
		With	Group 8	1648^{C}	1673^{C}	1636^{D}	1643^{B}	710	708	697	717	1.0 ± 0.3	1.7 ± 0.5	0.8 ± 0.3	1.7 ± 0.5	5	5	3	6	371	364	348	332

Post hoc tests were conducted after the Kruskal-Wallis test revealed significant differences (in OA application rate, $P<0.05$) between the groups, and differences among the waves. The different uppercase letters mean that the mean rank (1) values in a wave differed significantly between the groups; the different lowercase letters mean that the mean rank (2) values for each group differed significantly between the survey waves ($P<0.05$). Mean rank values (1) are compared vertically; mean rank values (2) are compared horizontally.

stock farming that began in the 1960s[13], when many Japanese farmers possessed livestock for labor and manure purposes before that separation. Under this condition, as shown in Fig. 3 and Table 2, farmers with livestock utilized readily available livestock waste, while farmers without livestock applied "other OA" partly due to the difficulty of getting LWC. This difficulty might be due to the limits imposed by the high cost of long-distance LWC transport[26], thereby resulting in LWC being mainly distributed within a prefecture[32].

Long-term change in OA application rate

The global trend in the application rate of manure (including slurry, in terms of phosphorus) over time remained almost constant before 1990, and then started to increase, although it varied among continents and regions[16]. Manure production was high in the Northern Hemisphere, especially in areas with intensive crop land use and high livestock densities[15]. Despite the global trend, the on-farm LWC application rate as well as non-zero application data points decreased over time in Japanese upland fields (Fig. 2).

Possible reasons for the decrease in LWC application rate are (1) restricted labor and time, (2) aging farming communities, (3) lower water content in cattle manure compost, and (4) complaints about offensive odor. With regard to reason (1), during the survery period, persons engaged in farming decreasd by more than 30% at the national level (from 12.5 million in 1980[20] to 8.6 million in 2000[24]). Moreover, the number of livestock per household increased (from 16.8 head per livestock farming household in 1979[17] to 49.7 head in 1998[21] for dairy cattle, and from 5.5[17] to 21.3[21] head for beef cattle), while working hours per head of livestock decreased 30% to 44% (e.g. from 177 hours in 1979[18] to 122 hours in 1998[22] for dairy cattle, from 41 hours[18] to 23 hours[22] for fattening male dairy cattle). This kept farmers with livestock as busy[6] or even busier than before. A similar trend was also observed in our study. About a third of farmers increased the head of livestock on average by 2.6 times (in terms of average animal unit[25] from 13.2 head in wave 1 to 33.7 in wave 4), while average labor in their households remained constant over time (2.9 persons). Under this condition, the LWC application rate decreased from 31.5 in wave 1 to 22.8 Mg Fw ha^{-1} in wave 4, despite the fact that the number of livestock increased to an extent that could have increased the LWC application rate by more than double (up to 81.9 Mg Fw ha^{-1} or the product of the wave 1 value of 31.5 Mg Fw ha^{-1} times 2.6). That is, the actual application rate of LWC (22.8 Mg Fw ha^{-1}) was about a quarter of the expected rate (81.9 Mg Fw ha^{-1}). This suggests that a great amount of LWC was not applied to the soil, which might partly contribute to the increase in non-utilized livestock waste[9]. With regard to reasons (2), (3) and (4), the present dataset lacked the necessary information, but these factors could help to explain the decrease in LWC application. At the national level, the number of persons aged 65 or older engaged in farming increased by 1.5 times (from 1.9 million in 1980[20] to 3.0 million in 2000[24]). For these farmers, applying manure may pose a great physical effort. As for reason (3), the water content in cattle manure compost decreased by 10%[10] between 1979 and 1998. Without such water content change, the LWC application rate in wave 4 shown in Fig. 2 might have been about 1 Mg Fw ha^{-1} higher. With respect to reason (4), MAFF reports showed a decrease in the proportion of complaints about offensive odor related to livestock farming from 75% to 61% (there were 4552 cases related to odor complaints in 1980[1] and 1582 cases in 1998[2]), though these complaints may not be always related to the application of LWC into soil, but such complaints may influence LWC production[32].

The basic guidelines under the Soil Fertility Enhancement Act[8] recommend the application of between 15 and 30 Mg ha^{-1} of compost in upland fields. This was mostly satisfied throughout the survey waves by many groups listed in Table 2 when we summed both average LWC and "other OA," except for groups 1 and 2. However, note that between 25% of farmers (in wave 1) to 40% of farmers (in wave 4) who did not apply OA [i.e. percentage of farmers that applied total OA (sum of LWC and "other OA")] decreased from 74% to 57% in Fig. 2. Conversely, between 13% (in wave 4) and 20% (in wave 1) of the total data points were greater than recommended. Since OA application is crucial to maintain and enhance soil fertility, this result indicates that soil carbon—one basis of soil fertility—may be lost in the first case above, while excessive application may have caused environmental degradation in the latter case (e.g. degraded water quality).

A comparison with a one-off published statistics

Table 3 compares the OA application rates for vegetables in the current study with those given in the "Agricultural Production Environmental Statistics[23]." The average LWC application rate at the points without the possession of livestock in our study was slightly lower than the value shown in the statistics, but was higher at the points with livestock. Conversely, the application rate of "other OA" (i.e. sum of sawdust or bark compost, husks, rice straw compost) in our study tended to be higher than in the statistics[23]. This might be attributed to the type of farmers participating in our study, who tended to be enthusiastic about maintaining or enhancing soil fertility, for which OA application was one of the recommendations[29].

Table 3. Comparison of OA application rates for vegetables in the current study with those shown in Agricultural Production Environmental Statisics[23]

Current study		LWC	Other OA	Samples
	Without livestock	8.9 ± 0.6	2.9 ± 0.4	827
	With livestock	13.9 ± 0.9	3.3 ± 0.8	350
Agricultural Production Environmental Statistics		9.1	1.1	5797

In order to draw a comparison with the Agricultural Production Environmental Statistics[23], we calculated the average application of LWC for vegetables (fruit, leaf, root and other vegetables).

Conclusions

The main purposes of this study were to obtain detailed information on long-term OA application rates in upland fields. Similar to paddy fields, OA application rates in upland fields decreased from 1979 to 1998. When data points were simply divided by such individual factors as crop type or the possession of livestock (e.g. possessing livestock as opposed to not possessing livestock), the average LWC application rates of each crop or with/without the possession of livestock were clearly different. However, even in the same crop, there were differences depending on the possession of livestock, which was observed when the data points were categorized in terms of crop type and the possession of livestock (e.g. vegetable cropping with livestock vs. vegetable cropping without livestock). The present results will be useful in calculating OA application rates at the national level in the near future, and in exploring the influence of land management on SOC stock changes over the 20-year period of this study.

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