Utilization of organic refuse compost for agricultural production on material recycling society

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Abstract

We estimated the amount of compost derived from livestock excreta, food refuse and sewage sludge as possible industrial organic resources, and the capacity of farmland to utilize these composts on national and regional scales in Japan in 2005. Japan could produce 11.9 Tg, 5.8 Tg and 2.0 Tg of livestock manure, food refuse compost and sewage sludge compost, respectively. The amount of manure required to maintain soil fertility was calculated as 40.0 Tg cattle manure. This capacity would mean that farmland could utilize all organic refuse compost on a national scale, although the variation among regions in potential compost production and utilization capacity means that not all regions would be able to utilize all of their organic refuse compost. The potential for refuse recycling in regions with intensive livestock farming and/or a large population would be quickly exhausted. To reuse valuable fertilizer ingredients, especially phosphorus, in organic refuse, other means, such as extracting phosphorus from incineration ash and during sewage processing, should be considered.
Keywords: livestock excreta, food refuse, sewage sludge, compost, farmland.

1 Introduction

Environmentally sound material cycling is one of the requirements of environmentally sound material cycling, and is one of the requirements of a sustainable society. Agriculture has a role to both utilize and produce organic refuse, such as livestock excreta, food refuse and municipal sewage sludge.

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Because these organic refuses come from food and feed, composting them and applying them to farmland would be an acceptable way of recycling. However, excessive application of organic refuse compost causes a load on the environment (for example, contamination and eutrophication of ground and surface water by nutrient constituents), damages soil (for example, excessive potassium, change in pH, undesirable enrichment by nutrients and organic matter) and crops (for example an excess of macro- and/or micro-nutrients, soil-borne damage or growth suppression), and affects humans and livestock (for example blue baby syndrome, acidosis, grass tetany). Therefore, it is important that organic refuse compost is applied appropriately for sustainable agricultural production, in the correct amounts in relation to the capacity of farmland to utilize such refuse.

The quantity of organic refuse, its nutrient content and the capacity for recycling this refuse on to farmland on a nutrient ingredient basis on a national scale have been discussed. However, the capacity for recycling on a regional scale on a fresh material basis has not been discussed or evaluated. In this paper, we estimate the capacity of farmland to utilize organic refuse compost on national and regional scales in Japan in 2005. To discuss productivity potential of organic refuse compost, all organic refuses are assumed to be composted for application to farmland.

2 Methods

2.1 Livestock excreta

Numbers of dairy and beef cattle, pigs, and poultry (layers and broilers) in Japan, nationally and by region, were derived from the Statistical Yearbook of the Ministry of Agriculture, Forestry and Fisheries [1]. Livestock phosphorus (P) excretion per head was derived from Tsuiki and Harada [2]. Total livestock P excretion, nationally and by region, was derived from head numbers of each kind of livestock and their P excretion.

2.2 Food refuse

Food refuse per capita was calculated from the total amount of food refuse produced in Japan [3] divided by the Japanese national population. The amount of food refuse produced by region was calculated from the regional population [4] and food refuse produced per capita. The amount of P in food refuse was calculated from the water and P content of food refuse and amount of food refuse.

2.3 Municipal sewage sludge

National and regional populations who use municipal sewage were calculated from the population [4] and the proportion served by a municipal sewage system [5]. Sewage sludge per capita was obtained from the amount of sewage sludge produced [5] and the national population served by a municipal sewage system.

The amount of sewage sludge by region was derived from the regional population served by municipal sewage system and sewage sludge per capita. The amount of P in sewage sludge was calculated from the water and P content of sewage sludge.

2.4 Estimation of compost amount

If P is not lost by composting, compost fresh weight can be calculated as follows,

$$FW = \frac{RMP \times 100}{P \times (100 - W)}$$

where FW is fresh weight of compost, RMP is P content of raw material, P is P content of compost, and W is water content of compost.

2.5 Application of compost to farmland

The scenario for annual application of compost to farmland was as follows. For paddy rice field, compost application is assumed to be equivalent to twice the amount of rice straw removal, except for northern districts. The amount varied from 0 to 5.62 Mg ha-1 according to district. Amount of removal was according to Rice Related Report [6]. In northern districts, compost is not applied to paddy fields because of the cool climate. Applications to upland field, orchard and forage field are assumed to be 10 Mg ha-1, 7.5 Mg ha-1 and 20 Mg ha-1, respectively [7–9]. These amounts are assumed to maintain farmland soil fertility and are assumed to be an acceptable amount for continued application annually, not as the maximum that could be utilized at a single year application of compost. These amounts are based on cattle manure: 1 Mg of pig manure is assumed to be equivalent to 2 Mg of cattle manure and 1 Mg of poultry manure, food refuse compost and sewage sludge compost are assumed to be equivalent to 2.64 Mg of cattle manure [7,8,10]. Later, the amount of compost is indicated as amount of fresh weight of cattle manure equivalent, unless otherwise stated.

3 Results

3.1 Amount of refuse and the compost

Results for livestock excreta, food refuse and sewage sludge and their composts material are shown in Tables 1 and 2.

3.1.1 Livestock excreta and manure

Total amount of livestock excreta was 89 Tg fresh weight. Cattle, pig and poultry excrete 14.2 to 44.2, 8.7 to 15.6 and 0.21 to 0.58 g of P per day; therefore they excrete 34 Gg, 40 Gg, and 42 Gg of P, respectively. Seventy percent of pig urine, equal to 15 Gg of P, was eliminated by disposal through sewage treatment. Cattle, pig and poultry manure contains 5.37%, 39.9% and 63.7% of water and 0.87%, 2.31% and 2.56% of P, respectively. When all of the rest was composted, the amount of cattle, pig and poultry manure would be 7.7 Tg, 2.1 Tg and 2.1 Tg

Table 1: Outline of statistics in Japan and its regions.

Region	Farmland*	Cattle**	Pig**	Poultry**	Population**	Sewage***
Japan	46,938	4,402,000	9,724,000	279,905	127,756,815	88,535,473
Hokkaido	11,687	1,305,200	535,400	12,142	5,627,424	4,912,741
Aomori	1,591	73,200	389,300	11,661	1,436,628	699,638
Iwate	1,566	160,800	395,700	20,788	1,385,037	639,887
Miyagi	1,380	124,900	238,300	6,682	2,359,991	1,725,153
Akita	1,522	29,330	243,700	1,982	1,145,471	583,045
Yamagata	1,249	52,200	170,100	1,221	1,216,116	783,179
Fukushima	1,532	103,600	230,900	5,959	2,091,223	890,861
Ibaraki	1,773	89,200	625,100	13,173	2,975,023	1,502,387
Tochigi	1,300	156,400	338,700	4,792	2,016,452	1,113,082
Gunma	785	112,900	607,300	7,233	2,024,044	882,483
Saitama	848	40,100	139,600	5,632	7,053,689	5,142,139
Chiba	1,334	88,500	541,700	11,703	6,056,159	3,857,773
Tokyo	83	3,830	5,190	144	12,570,904	12,369,770
Kanagawa	211	18,960	98,800	1,506	8,790,900	8,307,401
Niigata	1,771	26,400	222,200	5,219	2,431,396	1,291,071
Toyama	601	7,860	39,800	1,517	1,111,602	801,465
Ishikawa	445	9,140	37,100	1,627	1,173,994	685,612
Fukui	414	6,550	5,370	659	821,589	590,722
Yamanashi	259	13,210	24,200	940	884,531	625,363
Nagano	1,136	56,200	106,200	1,773	2,196,012	1,370,311
Gifu	591	44,340	104,500	6,975	2,107,293	1,083,149
Shizuoka	751	46,700	156,600	5,419	3,792,457	2,430,965
Aichi	840	96,100	378,900	10,875	7,254,432	2,720,412
Mie	633	37,400	133,000	6,354	1,867,166	1,174,447
Shiga	546	22,550	13,300	898	1,380,343	1,108,415
Kyoto	330	14,520	17,600	2,246	2,647,523	2,303,345
Osaka	145	3,750	8,860	196	8,817,010	7,847,139
Hyogo	773	87,000	27,300	7,952	5,590,381	5,484,164
Nara	233	8,680	12,500	896	1,421,367	967,951
Wakayama	370	4,940	3,530	1,862	1,036,061	148,157
Tottori	356	33,700	73,300	2,673	606,947	339,890
Shimane	395	45,900	37,900	1,335	742,135	253,810
Okayama	710	59,300	34,900	8,632	1,957,056	980,485
Hiroshima	605	41,500	61,700	8,675	2,876,762	1,846,881
Yamaguchi	515	23,590	26,200	4,289	1,492,575	795,542
Tokushima	324	38,620	42,000	4,264	809,974	93,147
Kagawa	328	26,900	40,100	8,237	1,012,261	370,488
Ehime	569	28,080	225,300	4,232	1,467,824	619,422
Kochi	289	11,990	42,200	593	796,211	224,532
Fukuoka	899	50,400	77,900	6,008	5,049,126	3,544,486
Saga	560	67,170	85,400	3,393	866,402	338,763
Nagasaki	513	102,100	195,700	3,854	1,478,630	780,717
Kumamoto	1,204	199,300	284,800	5,251	1,842,140	1,015,019
Ooita	604	84,500	134,500	3,584	1,209,587	485,044
Miyazaki	702	288,900	863,600	22,384	1,152,993	537,295
Kagoshima	1,255	370,400	1,378,000	30,277	1,753,144	641,651
Okinawa	393	84,820	269,900	2,109	1,360,830	845,075
	*:km^2	**:head, capita		***:population use sewage system		

Table 2: Amount of refuse composted material and farmland capacity to receive.

Region	Compost(Gg)			Capacity	In cattle manure eq.(Gg)			Type*
	Livestock	Food	Sewage	(Gg)	Livestock	Food	Sewage	
Japan	11,902	5,803	1,988	40,036	17,415	15,272	5,232	A
Hokkaido	2,850	256	110	17,076	3,107	673	290	A
Aomori	276	65	16	1,067	492	172	41	A
Iwate	477	63	14	1,201	750	166	38	A
Miyagi	310	107	39	575	452	282	102	C
Akita	119	52	13	518	202	137	34	A
Yamagata	135	55	18	461	186	145	46	A
Fukushima	260	95	20	620	390	250	53	C
Ibaraki	412	135	34	1,341	738	356	89	A
Tochigi	400	92	25	1,058	544	241	66	A
Gunma	394	92	20	735	612	242	52	C
Saitama	151	320	115	571	254	843	304	C
Chiba	400	275	87	1,025	679	724	228	C
Tokyo	11	571	278	79	15	1,503	731	C
Kanagawa	82	399	187	192	126	1,051	491	C
Niigata	142	110	29	360	255	291	76	C
Toyama	38	50	18	149	72	133	47	C
Ishikawa	42	53	15	107	74	140	41	C
Fukui	18	37	13	129	30	98	35	B
Yamanashi	38	40	14	179	56	106	37	B
Nagano	145	100	31	819	188	263	81	A
Gifu	151	96	24	434	267	252	64	C
Shizuoka	167	172	55	512	277	453	144	C
Aichi	355	330	61	555	592	867	161	D
Mie	143	85	26	327	258	223	69	C
Shiga	47	63	25	295	63	165	66	A
Kyoto	52	120	52	154	90	316	136	C
Osaka	13	401	176	76	18	1,054	464	C
Hyogo	219	254	123	440	331	668	324	C
Nara	31	65	22	106	48	170	57	C
Wakayama	22	47	3	230	45	124	9	A
Tottori	90	28	8	199	132	73	20	C
Shimane	93	34	6	141	119	89	15	C
Okayama	189	89	22	270	316	234	58	D
Hiroshima	153	131	41	234	285	344	109	D
Yamaguchi	76	68	18	258	137	178	47	C
Tokushima	95	37	2	223	144	97	6	C
Kagawa	121	46	8	205	238	121	22	D
Ehime	131	67	14	376	235	175	37	C
Kochi	37	36	5	164	55	95	13	A
Fukuoka	160	229	80	860	258	604	209	C
Saga	133	39	8	623	184	104	20	A
Nagasaki	218	67	18	520	306	177	46	B
Kumamoto	418	84	23	1,194	539	220	60	A
Ooita	187	55	11	539	257	145	29	A
Miyazaki	712	52	12	982	1,108	138	32	D
Kagoshima	987	80	14	1,439	1,596	210	38	D
Okinawa	202	62	19	417	340	163	50	C

*: A; All compost, B; Livestock+food, C; Livestock, D; Part of livestock can be received

of each type of manure by fresh weight and 17.4 Tg in cattle manure equivalent on a national scale. The regions with the largest and the smallest amounts of manure were Hokkaido (3,107 Gg) and Tokyo (15 Gg), respectively. Hokkaido had the largest number of livestock and Tokyo the lowest number among the regions (Table 2).

3.1.2 Food refuse and its compost

The amount of food refuse was 22 Tg on a national scale. It contained 80% of water and 0.6% of P, i.e., food refuse contained 26 Gg of P. Food refuse compost contained 1.22% of P and 62.7% of water. Therefore, if all food refuse was composted, the amount of food refuse compost would be 5.8 Tg on a national scale. Food refuse compost can be produced at 45.4 kg per capita. The region with the largest and was Tokyo (571 Gg as food refuse compost) and with the smallest budget was Tottori (28 Gg as food refuse compost) (Table 2), a difference that resulted from their different populations (Table 1).

3.1.3 Sewage sludge and its compost

The amount of sewage sludge was 75 Tg on a national scale. It contained 97% of water and 0.39% of P. Therefore it corresponded to 20 Gg P. Sewage sludge compost contained 52% of water and 2.12% of P. If all sewage sludge was composted, the amount of sewage sludge compost would be 2.0 Tg on a sewage sludge compost basis, which corresponds to 5.2 Tg of cattle manure equivalent. Sewage sludge had high water content (97%). However, water and organic matter loss during composting meant that the amount of sewage sludge compost was much smaller than that of sewage sludge, the raw material. Therefore, composting is an effective way of reducing the amount of compost. One sewage system user would produce 22.5 kg. Tokyo produced the greatest amount of sewage sludge compost (278 Gg in sewage sludge compost) and Tokushima the least (2 Gg in sewage sludge compost) (Table 2). The variation in amount of compost was a result of the differences in the population and the population served by the sewage system (Table 1).

3.1.4 Amount of compost in cattle manure equivalent

The amounts of all manures and composts were converted to cattle manure equivalents. The amounts of livestock manure, food refuse compost, sewage sludge compost and total refuse on a national scale were 17.4 Tg, 15.3 Tg, 5.2 Tg, and 37.9 Tg in cattle manure equivalents. The maximum was observed in Hokkaido (4,070 Gg cattle manure equivalent) and the minimum in Fukui (163 Gg cattle manure equivalent). Hokkaido had the largest number of livestock and Fukui the smallest of livestock, population and population served by a sewage system (Table 2).

3.2 The amount farmland receive compost

Japan had 1,702,000 ha, 1,337,870 ha, 314,500 ha and 1,030,000 ha of paddy rice field, upland field, orchard and forage field, respectively; these areas received 4.1 Tg, 13.4 Tg, 2.4 Tg and 20.1 Tg of compost, respectively. In total, Japanese farmland would be able to utilize 40.0 Tg of compost to maintain soil fertility (Table 2). The largest and the smallest utilization capacities were recorded in Hokkaido (17,076 Gg) and Osaka (76 Gg), respectively. Hokkaido has a large forage field area. Osaka is small region with a small area of farmland (Table 2).

The amount of compost applied to Japanese farmland exceeded the total production of organic refuse compost (37.2 Tg). However, uneven regional distribution of organic refuse compost meant that some regions could not fully utilize all compost produced. When livestock manure, food refuse compost and sewage sludge compost were applied to farmland, 14 regions utilized all compost (Type A), 3 regions utilized all of livestock manure and food refuse compost (Type B), 24 regions utilized all livestock manure (Type C), while 6 regions produced more livestock manure than they could utilize (Type D) (Table 2).

4 Discussion

Several estimates have been made of the amount of organic refuse produced in Japan and the capacity of farmland to utilize it.

Shiga [11] estimated in 1990 the amount of livestock nitrogen (N) excretion and the amount of excreta farmland can utilize on the basis of the amount of N, concluding that all livestock excreta would be utilized for maintaining soil fertility and could partly substitute for chemical fertilizer on a national scale in Japan. This estimation, which did not exclude N loss by composting, is one of the recent estimates of the relationship between the amount of livestock excreta and the capacity farmland to utilize it.

Ikumo et al. [12] noted the balance between the amount of livestock excreta N and the utilization capacity of farmland in each of the 47 regions of Japan, and indicated the surplus or deficiency of livestock excreta N. Although their estimated level of livestock excreta application to farmland was near to our estimation, the number of regions showing a deficiency differed. This difference was caused by the difference in N estimated on a fresh weight basis, weighting the amount of excreta according to type of livestock, whether or not excreta was applied to farmland, including N disappearance during composting in spite of N basis estimation, and so on.

The Japan Organic Resource Association [13] estimated nutrient constituents in various kinds of organic refuse on a national scale in Japan, and made a trial calculation in which all nutrients derived from organic refuse substituted chemical fertilizer. Although this is the most comprehensive nutrient budget estimation on organic refuse in Japan, it did not take into account uneven distribution of organic refuse among regions.

The Ministry of Agriculture, Forestry and Fisheries (MAFF) initiated a study on the lowest possible application of compost to farmland needed to maintain soil organic matter and fertility [14]. This study suggested that paddy field rice, upland field, vegetable field, and orchard should receive 3, 5-25, 10-25, 10-15 Mg ha-1 of cattle manure, respectively [14]. On the basis of this study, our rough estimation suggests that 42.3 Tg of cattle manure would be needed to maintain soil organic matter and soil fertility. This level of manure application is near to our estimation, assuming compost is applied every year to sustain soil fertility. The MAFF did not estimate a compost budget for Japan and did not take into account the variation in compost requirements among regions.

Our estimate of the amount of compost has a high level of uncertainty. For example, livestock manures have a 95% confidence range of 50-60% against mean P content [15], i.e., the amount of manure would have a 95% chance of varying by 50-60% on a fresh weight basis against our estimation. The amounts of compost that farmland can utilize per year also range widely, for example upland field can utilize 5-15 Mg ha^{-1} of cattle manure. We included in our calculations only livestock manure, food refuse compost and sewage sludge compost, because their raw materials are abundant on livestock farms and in waste and sewage treatment centres, and are therefore easy to compost on an industrial scale. Although human waste is also a valuable organic refuse resource, it is dispersed. However our estimates had uncertain and limiting the item of organic refuses, this will be one of the test estimations and one of the proposal plans for distributing to utilizing organic refuse resource in regional native farmland or to terminal disposal processing.

Livestock manure is relatively easy to obtain and use, is an acceptable material for crop farmers to use, and is also accepted socially and industrially. However, 6 regions were categorized as Type D (only part of livestock manure can be utilized by farmland) (Table 2). Because livestock farms do not always use much local land and are independent of crop farms, an excess of livestock manure is available. In these circumstances, some restriction on livestock farming or an expansion of farmland for livestock farming would be needed for all livestock manure to be utilized. The other 24 regions can utilize all livestock manure (Type C, Table 2), which means the amount of manure produced and utilized is in balance.

Gaining acceptance for the application of food refuse compost to farmland will be the next step. Some independent organizations or food-related companies make food refuse compost for local farms or on contract to farms, to reduce waste disposal and to create an environmentally sound recycling system. However, the relationship between the organic refuse budget and farmland utilization capacity needed to maintain soil fertility needs further study. The nutrient ingredient or fresh material budget approach would be important and would be needed to explain the rationale of these activities. Type B (all livestock manure plus food refuse compost can be utilized) includes 3 regions with low populations.

Utilization of sewage sludge compost has been discussed in the past. However, it is not yet an accepted agricultural practice in Japan because sewage sludge is contaminated by high concentrations of heavy metals, because of acidification or alkalinization of farmland soil with large applications, and because people reject the concept. Type A (livestock manure plus food refuse compost and sewage sludge compost can be utilized) includes 14 regions with large areas of farmland and low populations.

Organic refuse disposal causes problems in regions with high populations, especially with small areas of farmland in relation to population. Utilizing compost for food and feed production in agriculture is not always environmentally sound and the potential for recycling would be quickly exhausted. However, P in organic refuse is very valuable. Extracting P from incineration ash of food refuse and sewage sludge and from sewage processing would be one way of utilizing P in such refuse.

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