Practical use of anaerobically digested dairy slurry as a soil resource

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Summary

A practical and effective method of utilizing animal waste as a soil resource - such as fertilizer and soil conditioner - should be developed and promoted to conserve natural resources and reduce the risk of environmental pollution. The proper management and utilization of dairy manure is one of the most important topics in Hokkaido, Japan. The anaerobic digestion method would be a powerful and useful technique to transform dairy manure into an energy source; however, the practical use of digested dairy slurry as a soil resource still remains unseen. This study looks at the combination of digested dairy slurry with recycled dry chemical extinguishing agents, which are disposed as industrial waste but are rich in nitrogen and phosphate. Supplementation of dairy cattle slurry by mixing in ground dry chemical agents was found to be quite effective for increasing fertilizer efficiency, as testing on grasslands resulted in yields that nearly equaled or even exceeded those with the application of chemical fertilizers. On the other hand, a strategy for the application of digested dairy slurry in upland fields would help alleviate the need for chemical fertilizers. A combination of digested dairy slurry and chemical fertilizers led to higher yields of potato tubers than plots where only chemical fertilizers or chemical fertilizers and composted manure had been applied. These results suggest that not only the direct effects of macro-nutritional constituents in digested dairy slurry, but also the effects of other constituents as fertilizers and soil conditioners should be taken into consideration. We expect the role and function of dissolved organic matter in digested slurry is an important factor in helping achieve the goals of sustainable agricultural production and the practical use of livestock waste.

Keywords: digested dairy slurry, dissolved organic matter, field application, industrial waste, recycled dry chemical extinguishing agents

1. Introduction

Animal production can be described as a transformation of biomass, where livestock feed, which is the parent biomass, is converted into two types of biomass - stock farm products and animal waste. Animal waste includes animal excreta and animal by-products; however, animal excreta has been the main focus when referring to livestock waste. Although the livestock waste is disposed of and processed as industrial waste, it is still a valuable resource as a fertilizer and energy source. The recycling and recovering techniques of livestock waste are closely related to environmental conservation techniques.

Anaerobic digestion of animal waste by the biogas plant can produce methane, which can be transformed into heat and electricity, and can metamorphose animal excreta as a fuel resource. In Hokkaido, Japan, anaerobic digestion technologies are often applied to manage and process dairy cattle excreta, because the number of dairy cattle and the amount of dairy manure are both largest among livestock in Hokkaido (the number of dairy cattle is 853,700, pork 544,700, and laying hen 8,049,000; and the amount of dairy manure is 43,000, swine manure 3,000 and poultry manure 1,200 t/day). Anaerobically digested dairy slurry has a lot of advantages over other types of slurry such as raw slurry, stored slurry, and aerobically fermented slurry. These advantages include 1) Handling and management are easy due to its good fluidity. 2) The bad smell can be reduced (Nitrogen loss, leaching, and volatilization are scarce during fermentation.). 3) A number of pathogenic bacteria and harmful microorganisms can be suppressed, along with weed seeds and undesirable plants. 4) Digested slurry contains a lot of mineralized fertilizer nutrients. On the other hand, digested slurry has several disadvantages including 1) The anaerobic fermentation process cannot reduce the weight and volume of dairy cattle excreta, making it labor intensive. 2) The costs for construction of a Bio-Gas plant are extremely high. 3) The digested dairy slurry is rich in potassium, followed by nitrogen, and relatively poor in phosphate (Umetsu et al. 2002). 4) The effects of digested slurry application on soil properties, especially as an organic amendment, are not clear.

This paper presents information from our trials on the combination of recycled dry chemical extinguishing agents, which are an industrial waste, with the digested dairy slurry to supplement fertilizer efficiency upon application on grassland, and strategy for the application of the digested dairy slurry on upland fields.

2. Combination of digested dairy slurry with industrial waste

2-1. Recycled dry chemical extinguishing agent

Dry chemical extinguishing agents, which are packed in a fire extinguisher, are generally replaced in mandatory periodic inspections. Drawn agents have traditionally been disposed of as industrial sludge waste in reclaimed land. Major components of the most popular dry agents, which are commonly called ABC agents, are ammonium phosphate (MAP) and ammonium sulfate. Accordingly, the contents of water-soluble nitrogen (N) and phosphate (P_2O_5), which can be effectively used as plant nutrients, are extremely high, amounting to 15 % and 25 %, respectively. However, dry chemical powder is coated with hydrophobic silica to give a moisture-proof characteristic and avoid deliquescence in the container. They also show high fluidity and scatteration due to waterproofing. These characteristics make the agent undesirable for recycling as a fertilizer resource. Tani et al. (2004) developed a method to solve the problem, and has reported that a smashing and/or grinding procedure could eliminate the water- repellent property of the dry chemicals and make them water-soluble fertilizer (Jap. Pat. App. No. 2003-17665).

Fig. 1. Fire extinguisher

Fig. 2. Dry chemicals: raw materials (left) and processed materials (right)

2-2. Supplementation of fertilizer efficiency of anaerobically digested dairy slurry by recycled dry chemical extinguishing agents

Plant growth experiments in plots (1/5000 a) were conducted to evaluate methods to supplement the efficiency of fertilizer in dairy cattle slurry by dissolving recycled dry chemical extinguishing agents in the slurry (DC plot) and also by adding chemical fertilizers to slurry (CF plot) that is applied to grass ($N\text{-}P_2O_5\text{-}K_2O$ = 300-200-200 kg ha^{-1}) and vegetables ($N\text{-}P_2O_5\text{-}K_2O$ = 210-220-220 kg ha^{-1}). The yield and fertility efficiency of timothy and greens (*Komatsuna*) in the DC and CF plots were compared with those in a plot in which only chemical fertilizers were applied (CL plot). The experiments used four types of slurry (fresh, aerobically digested, anaerobically digested, and slurry stored at a dairy farm). The contents of total solid, nitrogen, phosphate, and potassium are shown in Table 1. As mentioned above, all types of the dairy cattle slurry were rich in potassium, followed by nitrogen, and poor in phosphate, irrespective of fermentation processes. The contents of inorganic nitrogen, extractable phosphate and potassium, and their extractability are shown in Table 2. The anaerobically fermented (digested) slurry was rich in ammonium compared to other types of dairy slurry and inorganic nitrogen amounted to 45 % of total nitrogen. Nitrate was not detected in the digested slurry and the stored slurry. The extractability of phosphate and potassium was higher than that of nitrogen, suggesting that these constituents existed as inorganic forms in the dairy slurry such as orthophosphate and potassium ions.

Table 1. Contents of total solid, nitrogen, phosphate and potassium in the dairy slurry.

	TS	N	P_2O_5	K_2O
	%		g kg^{-1}	
Raw (Not Fermented) Slurry	4.66	1.51	0.78	1.51
Aerobically Fermented Slurry	3.60	1.32	0.78	1.57
Anaerobically Fermented Slurry	5.47	2.71	0.96	3.02
Stored (Not Fermented) Slurry	10.5	3.66	1.65	3.79

Table 2. Contents of extractable nitrogen, phosphate and potassium in the dairy slurry, and their extractability.

	Inorganic Nitrogen		Extractable		Extractability		
	NH_4-N	NO_3-N	P_2O_5	K_2O	N	P_2O_5	K_2O
	g kg^{-1}		g kg^{-1}			%	
Raw (Not Fermented) Slurry	0.36	0.03	0.74	1.45	25.5	95.2	96.4
Aerobically Fermented Slurry	0.26	0.05	0.61	1.57	23.6	78.5	99.9
Anaerobically Fermented Slurry	1.23	ND	0.86	3.02	45.4	89.0	99.9
Stored (Not Fermented) Slurry	1.45	ND	1.49	3.72	39.5	90.1	98.1

Table 3. Fertilizer efficiency of timothy and Komatsuna in each plot.

	Timothy			Komatsuna		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
		(%)			(%)	
CL plot	33.9	8.74	50.3	26.7	6.15	49.2
CF plot	34.5	8.63	49.5	34.3	8.23	73.2
DC plot	32.9	11.2	50.7	33.9	9.28	75.7

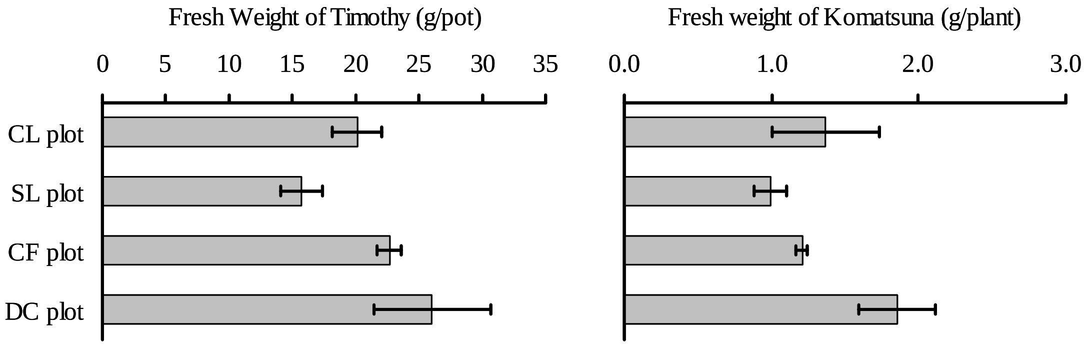

Fig. 3. Fresh weight of a) timothy (left) and b) Komatsuna (right) in each plot
CL plot: Chemical Fertilizer only, SL plot: Dairy Slurry only, CF plot: Dairy Slurry + Chemical Fertilizer, DC plot: Dairy Slurry + Dry Chemical

The yield of timothy, whether with the DC plot or CF plot, was almost always equal to or more than the yield of the CL plot (Fig. 3a). The digested slurry dissolved with dry chemicals led to the highest yield. The yield of *Komatsuna* in the DC plot was greater than that of the

CF plot or CL plot for all slurry types (Fig. 3b). The fresh weights of both plants were lowest in the SL plots, where only dairy slurry was applied as a nutritional source (Fig. 3 a and b), indicating that the fertilizer efficiency of dairy slurry was insufficient. The nitrogen and potassium efficiency of timothy differed little from plot to plot. The phosphate efficiency of the DC plot was remarkably higher than other plots. The fertilizer efficiency of *Komatsuna*, whether with the DC plot or CF plot, was higher than with the CL plot. Supplementation of fertilizer efficiency of dairy cattle slurry by the dissolution of recycled dry chemical extinguishing agents was found to be quite effective, as it sustained yields that nearly equaled or even exceeded those with the application of chemical fertilizers.

2-3. Dissolution of recycled dry chemical extinguishing agents in the anaerobically digested dairy slurry and field application

Grass growth experiments were conducted to evaluate the technique of dissolving recycled dry chemical extinguishing agents in digested dairy slurry. The digested slurry was mixed well with 1 % or 4 % (w/w) of the ground dry chemical agents to supplement the efficiency of nutritional constituents, especially phosphate and nitrogen (Fig. 3). In the orchard grassland, Shikaoi Town, Hokkaido, 20 Mg ha^{-1} of supplemented slurry dissolved with 1 % of dry chemicals (DC1 plot), 10 Mg ha^{-1} of supplemented slurry dissolved with 4 % of dry chemicals (DC2 plot), and 30 Mg ha^{-1} of the original slurry (SL plot) were spread to apply 90 kg ha^{-1} of nitrogen in the early spring (Fig. 4). The control plot (CL plot), where only chemical fertilizers were applied, was also prepared. After the first grass harvest, 10 Mg ha^{-1} of the supplemented slurry dissolved with 1 % of the dry chemicals was applied in the DC1 and DC2 plots, and 15 Mg ha^{-1} of the original slurry was applied in the SL plot. Additive chemical fertilizers were also applied in the CL plot.

The dry matter yield of orchard grass was largest in the DC2 plot, followed by CL plot and DC1 plot (Table 4). The differences among the CL plot, DC 1 plot, and SL plot were very small. In the CL plot, the dry matter yield of the second grass harvest was the smallest, while the first harvest was the largest. These results suggest that the practical technique of applying digested dairy slurry dissolved with recycled dry chemical extinguishing agents can be used in the fields in place of the application of chemical fertilizers.

Fig. 3. Mixing procedure

Fig. 4. Field application of the supplemented slurry

Table 4. Experimental design and yields of orchard grass in each plot.

	Chemical fertilizer	Slurry	Dry chemicals	Dry matter yields		
				First	Second	Total
		(Mg ha^{-1})	(kg ha^{-1})		(Mg ha^{-1})	
CL plot	Applied	None	None	5.53	2.11	7.64
SL plot	None	30	None	5.04	2.53	7.57
DC1 plot	None	20	200	5.27	2.32	7.60
DC2 plot	None	10	400	4.95	3.03	7.97

Additionally, the recycling of fertile resources from industry increases the efficiency of agricultural operations and practices, reduces labor, and reduces the costs of chemical fertilizers. The combination of agricultural waste, including animal waste, with industrial waste has significant potential for eliminating obstacles in both areas and complementing each other.

3. Application of digested dairy slurry in upland field

3.1 Strategy for the application of digested dairy slurry in upland field

The substitution of chemical fertilizers with digested dairy slurry dissolved with dry chemical agents can be employed in the grassland as mentioned above; however, it may be difficult to follow the same method in the upland field, because fertilizer standards are different and vary depending on crops, soil types, and climatic conditions. Digested dairy slurry should be used in the upland field, since a number of pathogenic bacteria and harmful microorganisms can be suppressed, and seeds of weeds and undesirable plants can also be reduced during anaerobic fermentation especially by thermophilic microorganisms. The strategy for the application of digested dairy slurry in upland fields would be a partial substitution for chemical fertilizers. Namely, the amount of chemical fertilizers applied in crop production can be suppressed to some extent by using digested dairy slurry at the same time, which contains nitrogen, phosphate, potassium, and other macro- and micro- nutrients for plant growth.

3.2 Effect of digested dairy slurry application on the yield of potato tuber

A field experiment was conducted to evaluate the effects of the combined application of chemical fertilizers and digested dairy slurry on the yields of potato tubers in 2002 and 2003. Experimental design for the application of chemical fertilizers, digested slurry, and composted dairy manure, which was chosen as a typical soil organic conditioner, in each plot is shown in Table 5. In the design, the fertilizer efficiency of the digested dairy slurry was assumed to be approximately 100 %. The applied amounts of chemical fertilizer (ammonium sulfate, super phosphate, and potassium sulfate were used as nitrogen, phosphate, and potassium sources, respectively) and the digested slurry was calculated by following the standard application rate of fertilizer for potato production in the Tokachi district, Hokkaido, to give 80 kg ha^{-1} of nitrogen (as N), 200 kg ha^{-1} of phosphate (as P_2O_5), and 120 kg ha^{-1} of potassium as (K_2O).

A distinct difference in the growth of potatoes among the plots was not observed as shown in Fig. 5. The yield of potato tubers was lowest for the CF plot both in 2002 and 2003 (Table 6). The application of composted manure could increase the yield of potatoes, suggesting manure could play an important role in supporting the growth of potatoes, such as by releasing micronutrients and other constituents. Among the combined slurry plots, the SS plot, where a small amount of the digested slurry was applied, showed the highest yield in 2002, while the SL plot, where a large amount of the digested slurry was applied, showed the highest yield in 2003. The yields of potato tubers increased with an increase in the amounts of the digested dairy slurry applied in 2003. The combined digested slurry plots showed higher yields than the applied composted manure plots both in 2002 and 2003.

Table 5. Designs for fertilizer application in the experimental plots (Mg ha $^{-1}$).

	Plots	Digested slurry	Ammonium sulfate	Super phosphate	Potassium sulfate	Composted manure
CF	Fertilizer	—	0.38	1.11	0.24	—
1M	Fertilizer + Manure 10 Mg ha $^{-1}$	—	0.38	1.11	0.24	10.0
2M	Fertilizer + Manure 20 Mg ha $^{-1}$	—	0.38	1.11	0.24	20.0
SL	Fertilizer + Large Amounts of Slurry	26.7	0.00	0.96	0.08	—
SM	Fertilizer + Medium Amounts of Slurry	20.0	0.10	1.00	0.12	—
SS	Fertilizer + Small Amounts of Slurry	13.3	0.19	1.04	0.16	—

These results suggest that not only the direct effects of macro-nutritional constituents in digested dairy slurry as fertilizers but also the effects of other constituents as fertilizers and soil conditioners should be taken into consideration. The digested dairy slurry would contain dissolved organic matter, micronutrients, and microorganisms, as well as macronutrients. Yasui et al. (2004) reported that digested dairy slurry and aerobically fermented dairy slurry were richer in humic substances than raw dairy slurry and less fermented slurry. The dissolved organic matter in the manure and slurry can compete with the soil colloids to suppress adsorption and retention of phosphate through ligand exchange reaction (Dravid and Biswas 1996). Results of phosphate efficiency shown in Chapter 2 might be related to the function of digested dairy slurry. We still need to make the critical functions of digested dairy slurry clearer.

Fig. 5. Growth of potato in flowering stage at the CF plot (left), 1M plot (center), and SL plot (right)

Table 6. Yield of potato tuber in 2002 and 2003 (Mg ha $^{-1}$).

	Plots	Potato yield in 2002	Potato yield in 2003
CF	Fertilizer	17.6	14.4
1M	Fertilizer + Manure 10 Mg ha $^{-1}$	18.9	15.0
2M	Fertilizer + Manure 20 Mg ha $^{-1}$	21.6	16.8
SL	Fertilizer + Large Amounts of Slurry	20.8	20.1
SM	Fertilizer + Medium Amounts of Slurry	19.6	18.5
SS	Fertilizer + Small Amounts of Slurry	22.2	17.2

4. Conclusion

Livestock waste, especially animal excreta, can be converted to splendid and unique soil resources (fertilizers and soil conditioners) for agricultural production, by combining industrial and/or nonagricultural waste. The combination of livestock waste and industrial waste is complementary. The principles, which were found in the studies, can lead to the ideal management and utilization of livestock waste. We expect the role and function of *dissolved organic matter* in digested slurry will become a keyword for the solution of sustainable agricultural production and the practical use of livestock waste.

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