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Animal Waste Problems and Their Solution from the Technological Point of View in Japan

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Abstract

Intensive animal raising in limited areas such as in Japan results in a large accumulation of animal wastes which have been causing serious pollution problems. Animal farms are bound by strict regulations to control environmental pollution, especially water pollution and offensive odor evolution. Animal wastes which are taken out from the farm are classified into 3 types; solid, slurry and waste water. Solid wastes are treated by drying or composting. Dried wastes are used not only fertilizer but also as fuel for combustion to obtain energy. Compost is the main product from animal wastes in Japan. Slurry is treated by liquid composting or methane fermentation to produce biogas. But slurry spreading to the field is almost restricted to regions such as Hokkaido where is enough space to apply a large amount of slurry. Waste water is treated by the activated sludge process to obtain clean water or simplified aeration method to produce liquid fertilizer. The most appropriate techniques of animal waste management involve proper treatment followed by application of the treated wastes to cropland for agricultural use as organic fertilizer sources.

Discipline: Animal industry
Additional key words: drying, composting, broiler litter boiler, activated sludge process

Background

1) *Animal industry in Japan*

The animal industry in Japan has expanded rapidly, for the last few decades, with increasing demand for animal products by the Japanese people. The expansion of the animal industry is characterized by a drastic increase in the number of animals per farm. For example, the average number of pigs per farm in 1996 (618.8 head per farm) was about 86 times that in 1966 (7.2 head per farm) (Table 1). This kind of expansion of animal industry results in the accumulation of wastes in limited areas.

2) *Output of animal wastes*

The amount of animal wastes excreted in 1996 was estimated at 85,450,000 t per year (Fig. 1), an amount exceeding Japanese people night soil and domestic wastes. In 1966, cattle wastes accounted for 75% of the total wastes. The amount of pig and poultry wastes steeply increased during the 1970s and now it accounts for about 50% of the total. In recent years, the total amount of animal wastes has remained at around 90,000,000 t due to the small changes in the number of animals.

3) *Occurrence of animal waste pollution problems*

The number of complaints against animal waste pollution increased steeply until 1973 (11,676 per year) and then gradually decreased (Fig. 2). The number of complaints in 1996 decreased to 2,576 which is less than one fourth of the number in 1973. Apparently, it appears that the occurrence of

Table 1. Changes in the number of pigs, farms and the average number of pigs per farm

Items		1966	1971	1976	1981	1986	1991	1996
Number of farms	(1,000 farms)	714.3	398.3	195.6	126.7	74.2	36.0	16.0
Number of pigs	(1,000 head)	5,158	6,904	7,459	10,065	11,061	11,335	9,900
Average number of pigs per farm	(head/farm)	7.2	17.3	38.1	79.4	149.1	314.9	618.8

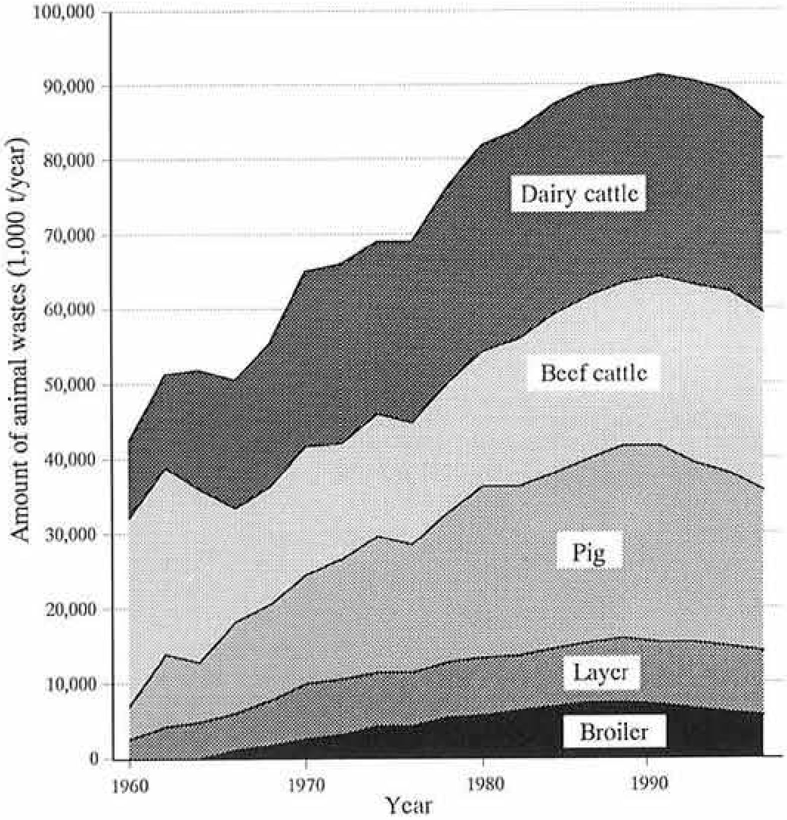

Fig. 1. Annual changes in animal wastes

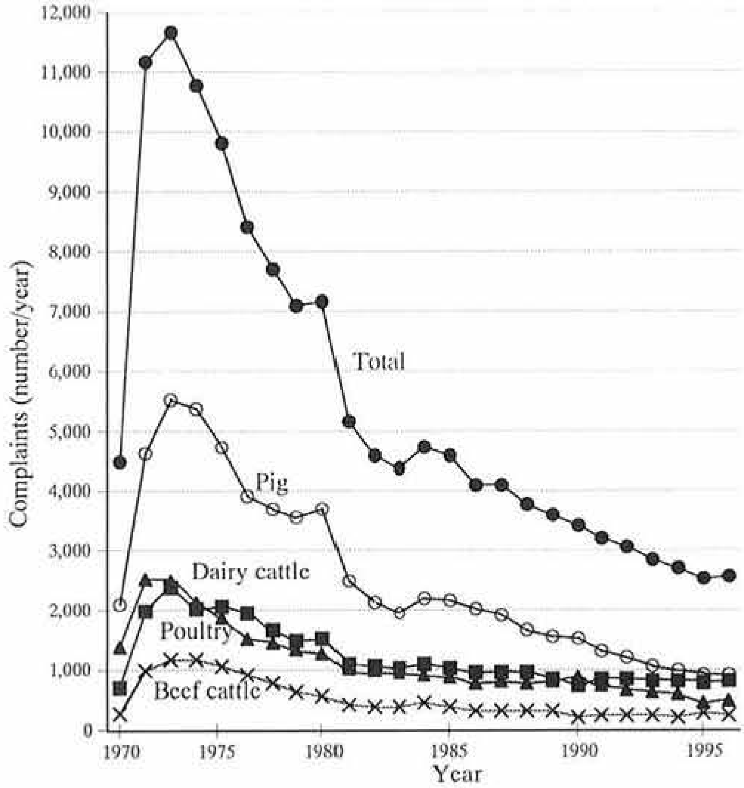

Fig. 2. Annual changes in the number of complaints about pollution problems by animal wastes

pollution problems is on the decrease. However, in the meantime, the decrease in animal farms is much more drastic while the number of complaints per farm has been rather increasing, suggesting that the problems are becoming increasingly more complicated and serious for each farm.

4) Legislation

(1) Legislation system

Animal farms are controlled by strict regulations (Fig. 3). Government legislation of environmental pollution control has been developed due to social needs around 1970. The enactment of the Basic Law for Environmental Pollution Control of 1967 was followed by the enactment of many other laws, namely the Water Pollution Control Law in 1970, the Waste Disposal and Public Cleansing Law in 1970, the Offensive Odor Control Law in 1971, etc. Recently, the Basic Law of 1967 has been fully revised into the Environment Basic Law of 1993 which involves the establishment of social systems for environmental conservation and introduces the concept of preservation of the global environment. Animal waste pollution problems are mainly related to water pollution and offensive odor evolution.

(2) Water pollution control

Table 2 shows the regulation standards of discharged water closely related to animal waste water. These criteria are governmental ones. Each prefecture can promulgate much stricter criteria depending on the local conditions, such as the presence of a national park, water catchment area, etc. Nitrogen and phosphorus were newly introduced in 1985 to cope with the eutrophication of lakes and sea. Limits until 2,000 for nitrogen and phosphorus contents in animal waste water are less than 140 mg/L (daily average 70 mg/L) and less than 34 mg/L (daily average 17 mg/L), respectively. In 1994, the concentration of substances with a trihalomethane forming

Table 2. Criteria of discharged water

Items	Units	Limits
pH	–	5.8~8.6
BOD	mg/L	160 (Daily average 120)
COD_{Mn}	mg/L	160 (Daily average 120)
SS	mg/L	200 (Daily average 150)
Coliform	number/mL	3,000
N	mg/L	120 (Daily average 60)
P	mg/L	16 (Daily average 8)

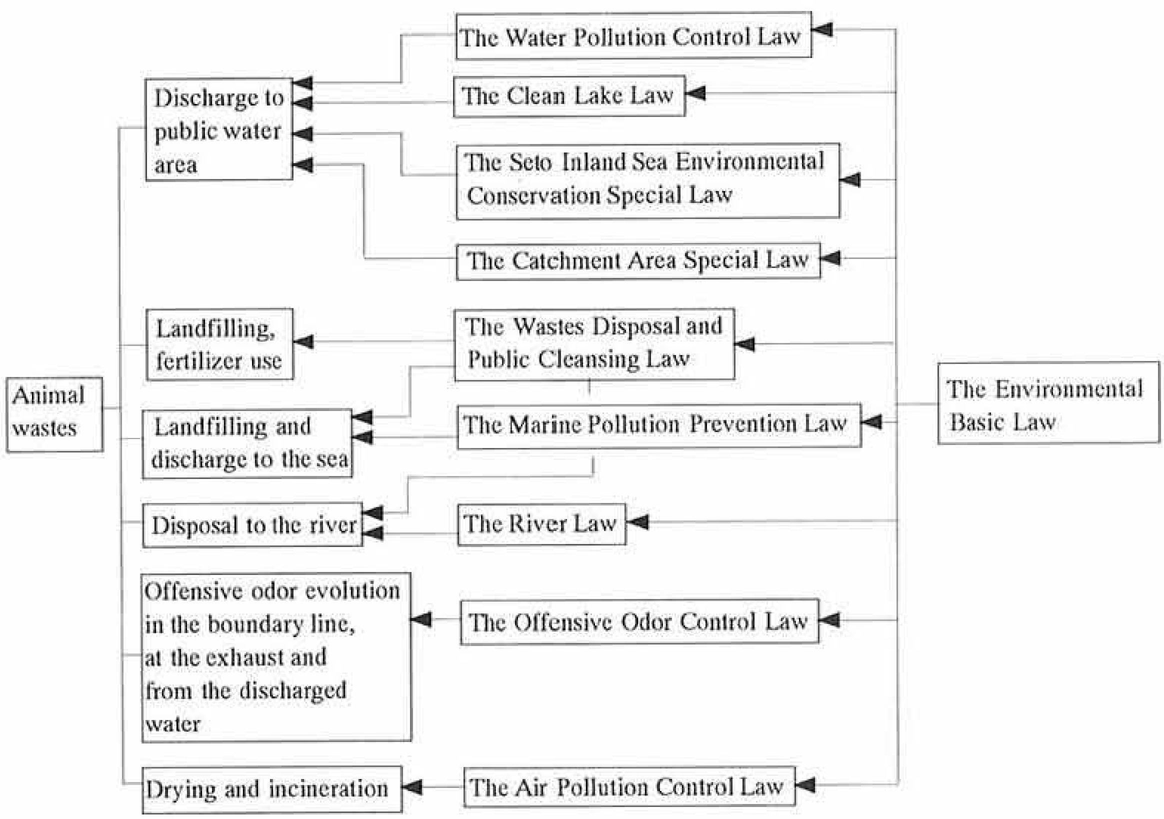

Fig. 3. Legal constraints related to animal wastes

potential (THMFP)[10] which are the precursors of trihalomethanes considered as carcinogens was regulated in various catchment areas. The criteria for animal waste water range from 1.3 to 5.2 mg/L.

(3) Offensive odor control

Table 3 shows the regulation standards of 22 offensive odor substances which correspond to an odor intensity of 2.5 to 3.5. Among them, 9 substances, such as ammonia, methyl mercaptan, hydrogen sulfide, dimethyl sulfide, dimethyl disulfide, propionic acid, n-butyric acid, n-valeric acid, and isovaleric acid are closely related to animal waste odor. Each prefecture can set up an initial criterion between the governmental ranges listed in Table 3 depending of the local conditions. In April 1996, a new regulation of odor index between 11 to 20 based on sensory tests was enacted additionally.

Table 3. Criteria of offensive odors

Unit: ppm (mL/m^3)

Items	Range
1. Ammonia	1 ~ 5
2. Methylmercaptan	0.002 ~ 0.01
3. Hydrogen sulfide	0.02 ~ 0.2
4. Dimethyl sulfide	0.01 ~ 0.2
5. Dimethyl disulfide	0.009 ~ 0.1
6. Trimethylamine	0.005 ~ 0.07
7. Acetaldehyde	0.05 ~ 0.5
8. Propionaldehyde	0.05 ~ 0.5
9. n-Butyraldehyde	0.009 ~ 0.08
10. Isobutyraldehyde	0.02 ~ 0.2
11. n-Valeraldehyde	0.009 ~ 0.05
12. Isovaleraldehyde	0.003 ~ 0.01
13. Isobutanol	0.9 ~ 20
14. Ethyl acetate	3 ~ 20
15. Methyl isobutyl ketone	1 ~ 6
16. Toluene	10 ~ 60
17. Styrene	0.4 ~ 2
18. Xylene	1 ~ 5
19. Propionic acid	0.03 ~ 0.2
20. n-Butyric acid	0.001 ~ 0.006
21. n-Valeric acid	0.0009 ~ 0.004
22. Isovaleric acid	0.001 ~ 0.01

The-state-of-the-art of animal waste management

Animal wastes which are taken out from the farm are classified into 3 types; solid, slurry and waste water (Fig. 4). Solid wastes are treated by drying or composting. Dried wastes are used not only as fertilizer but also as fuel for combustion to obtain energy. Slurry is treated by liquid composting or methane fermentation. Waste water is treated by the activated sludge process to obtain clean water or simplified aeration method to produce liquid fertilizer. The most appropriate techniques of animal waste management should involve proper treatment prior to the application to land. Drying, composting, energy production and waste water treatment are popular and well-studied in Japan.

Drying

Raw wastes with a high water content are dirty, offensive, putrescible and troublesome in handling. Reduction of water content is necessary for convenience in handling of animal wastes. Drying in a greenhouse with solar heating is superior to that with oil heating, because expenses can be reduced and energy saved. The evaporation power by the greenhouse system is 4.5 ~ 5 L/m^2 in summer and 1.5 ~ 2 L/m^2 in winter in Japan[4]. The area of greenhouse required for construction can be easily estimated based on the evaporation power and the amount and water content of animal wastes to be dried.

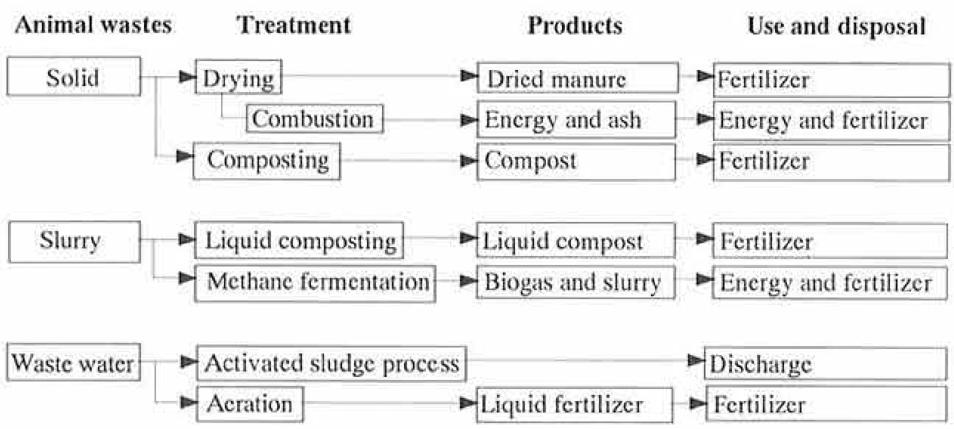

Fig. 4. Methods generally used for animal waste management in farms

Composting

Compost is the main product from animal wastes in Japan. The objectives in composting are to stabilize the biodegradable organic matter (BOD) in raw wastes, to reduce offensive odors, to kill weed seeds and pathogenic organisms, and finally, to produce a uniform organic fertilizer suitable for land application.

1) Conditions for composting

Controlled conditions are important for composting, to distinguish it from other natural biological decomposition processes such as rotting and putrefaction[2]. Animal wastes contain a sufficient amount of nutrients (biodegradable organic matter) for microorganisms and an adequate number of microorganisms to enhance the composting process. However, the water content of raw wastes is too high to supply oxygen to the microorganisms. Moisture control of the raw wastes at around 65% by the addition of dry materials such as sawdust, rice hull and dried compost or by pre-drying in greenhouses is necessary to achieve suitable composting. The active degradation of organic matter by the microorganisms under controlled conditions leads to heat generation during composting. The high temperature (higher than 60°C) contributes to the killing of weed seeds and pathogenic organisms, to the evaporation of water and production of sanitary compost for convenience in handling. With occasional turning of the compost pile, the complete composting process requires a few months.

2) Facilities of composting

Various types of composting facilities are available in Japanese farms and compost centers jointly used by several farms[2]. Facilities can be classified into 5 types; the pile type, the box type, the rotary kiln type, the enclosed vertical type and the open elongated type with turning device (Fig. 5). For cattle wastes, the pile type and the open elongated type are generally used. For swine and poultry

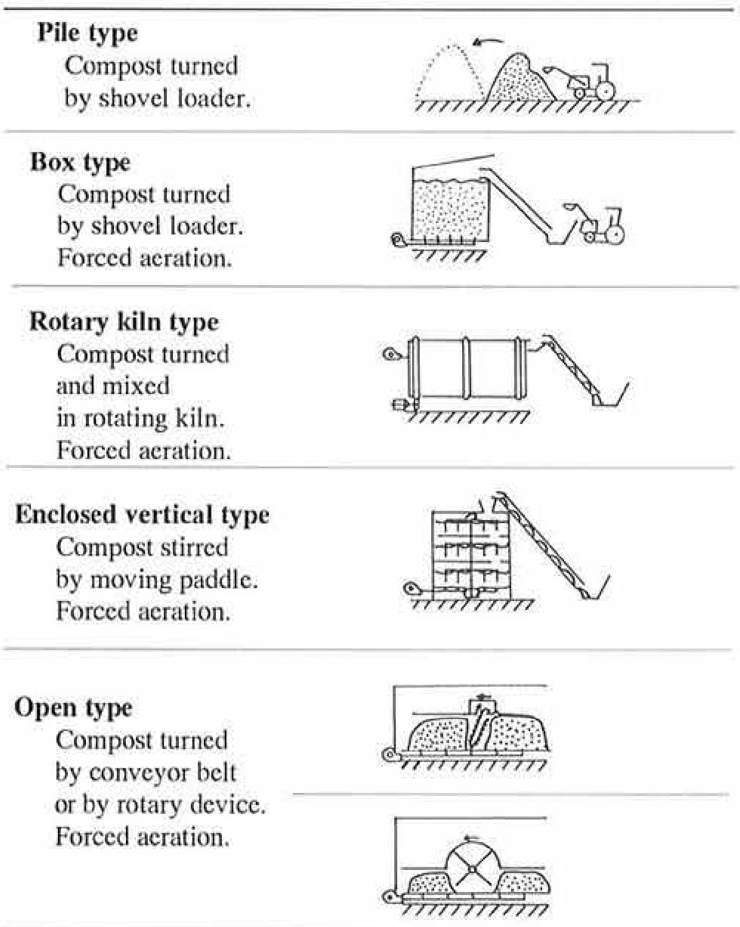

Fig. 5. Composting facilities for animal wastes[7]

Table 4. Recommended quality index of animal waste compost

A. Items to be indicated		B. Items not to be indicated	
Items	Standard	Items	Standard
Organic matter	more than 60% DW	Moisture	less than 70% FW
Carbon-nitrogen ratio	less than 30	Electric conductivity	less than 5 mS/cm
Total N	more than 1% DW		
P_2O_5	more than 1% DW		
K_2O	more than 1% DW		

1) As, Cd and Hg contents should be less than 50, 5 and 2 mg/kg DW, respectively.
2) Abnormal growth should not be observed for the Komatsuna (*Brassica rapa*) seedling test.
3) Cu and Zn contents should be less than 600 and 1,800 mg/kg DW, respectively.
4) DW: Dry weight, FW: Fresh weight.

wastes, the open elongated type and the enclosed vertical type are popular.

3) Quality of compost

Chemical nutrients in composts vary with the type of animals producing manure and the type of additional materials used[4]. Many methods have been proposed to estimate the degree of maturity of composts from animal wastes[6]. Only a few methods, however, are easy to use and reliable. Recommended quality index of animal waste composts was temporarily presented as shown in Table 4 in 1993.

Energy production

Animal feces contain a large amount of organic matter (around 80% of dry matter) and have a high value as energy source. Five methods of energy recovery from animal wastes[3], such as combustion, pyrolysis gas, oil conversion, heat recovery from compost and biogas can be applied.

1) Heat of combustion

Dried wastes have a fuel value of about 3,000 kcal/kg. For example, broiler litter taken out from a farm has been dried to a moisture content of about 30%. Since broiler farms need energy for floor heating with hot water, it is effective to recycle this dried litter as fuel for a broiler litter boiler and use it for heating purposes. This method enables to save 70 to 80% of the conventional energy consumption[3]. The residual ash can be used as inorganic fertilizer rich in phosphorus and calcium.

2) Biogas

Biogas can be produced from animal waste slurry by the action of microorganisms in a methane fermenter[1]. To achieve efficient methane fermentation, it is necessary to provide favorable conditions to these microorganisms in the fermenter. These conditions include anaerobic conditions, mesophilic temperature (about 35°C), neutral pH (6 to 8), appropriate organic matter loading (about 3 kg of organic matter/m^3·d) and proper retention time (10 to 20 days). For example, 150 to 250 L of biogas are produced from one head of pig per day, and the capacity of a fermenter required for a pig is about 150 L[3]. The biogas produced contains 60% of methane and 40% of carbon dioxide, and has a fuel value of about 5,500 kcal/m^3. It can be used not only as domestic fuel but also for many other purposes, such as agriculture and power generation.

Waste water treatment

Activated sludge process is one of the typical treatments of animal waste water to secure strict regulations of the effluent[5]. The process consists of a 4-stage cycle, namely sedimentation, discharge, charge and aeration. Fig. 6 shows the time chart of conventional, limited and intermittent aeration methods. The shortcoming of the conventional activated sludge process is the low capacity to remove nitrogen and phosphorus. In the limited aeration method, aeration stops just after charge for several hours[8]. Although most of the nitrogen remains as nitrate nitrogen in the conventional aeration method, most of nitrate nitrogen is removed under anaerobic conditions in the limited aeration method.

The intermittent aeration method[9] is considered to be more effective to remove nitrogen, because in the intermittent method the limited process is repeated several times a day. Fig. 7 shows the changes in pH, DO (dissolved oxygen) and TOC (total organic carbon) values by the intermittent aeration process. Intermittent increase and decrease

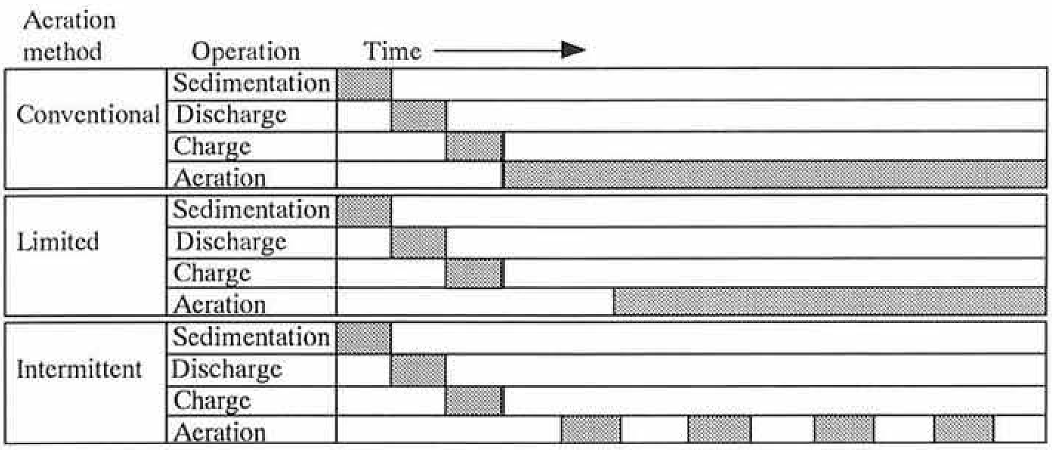

Fig. 6. Time chart of conventional, limited aeration and intermittent aeration methods

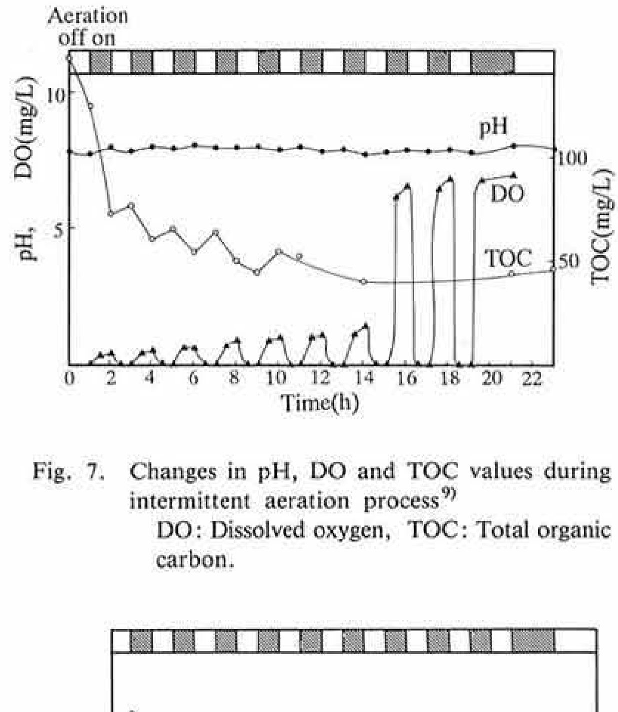

Fig. 7. Changes in pH, DO and TOC values during intermittent aeration process[9]
DO: Dissolved oxygen, TOC: Total organic carbon.

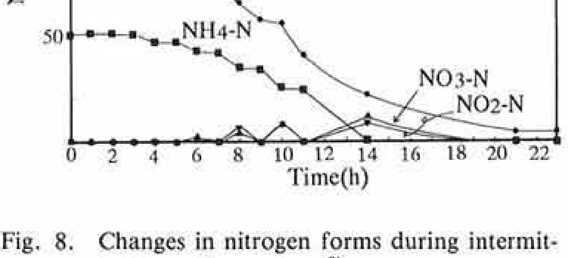

Fig. 8. Changes in nitrogen forms during intermittent aeration process[9]

of DO values were observed. Nitrification and denitrification occurred intermittently and the efficiency of nitrogen removal increased (Fig. 8). Phosphorus was also removed and accumulated in the microorganism body. In conclusion, limited and intermittent aeration methods were found to be effective in removing not only nitrogen but also phosphorus. These methods could be performed with minimal improvement of conventional facilities and may enable to achieve the objective at a low cost and with a high efficiency.

Conclusion

Agricultural use of animal wastes as compost is presently mainly recommended in Japan. Total amounts of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) contained in animal wastes are estimated to be 680,000, 450,000 and 550,000 t per year, respectively. These amounts of nutrients are nearly equal to those of chemical fertilizers applied to arable land in Japan. Environmentally friendly use of both animal wastes and chemical fertilizer is recommended. It is difficult to use slurry (liquid wastes) in Japan, except for a part of Hokkaido. Insufficient treatment and/or illegal dumping of excess animal wastes cause serious pollution problems. Then, recycling of animal wastes without any environmental pollution will be closely related to the development of sustainable agriculture with organic fertilizer in Japan.

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