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Nutrient production from dairy cattle manure and loading on arable land

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Objective: Along with increasing livestock products via intensive rearing, the accumulation of livestock manure has become a serious issue due to the fact that there is finite land for livestock manure recycling via composting. The nutrients from livestock manure accumulate on agricultural land and the excess disembogues into streams causing eutrophication. In order to systematically manage nutrient loading on agricultural land, quantifying the amount of nutrients according to their respective sources is very important. However, there is a lack of research concerning nutrient loss from livestock manure during composting or storage on farms. Therefore, in the present study we quantified the nutrients from dairy cattle manure that were imparted onto agricultural land.
Methods: Through investigation of 41 dairy farms, weight reduction and volatile solids (VS), total nitrogen (TN), and total phosphorus (TP) changes of dairy cattle manure during the storage and composting periods were analyzed. In order to support the direct investigation and survey on site, the three cases of weight reduction during the storing and composting periods were developed according to i) experiment, ii) reference, and iii) theoretical changes in phosphorus content ($\Delta P = 0$).
Results: The data revealed the nutrient loading coefficients (NLCs) of VS, TN, and TP on agricultural land were 1.48, 0.60, and 0.66, respectively. These values indicated that the loss of nitrogen and phosphorus was 40% and 34%, respectively, and that there was an increase of VS since bedding materials were mixed with excretion in the barn.
Conclusion: As result of nutrient-footprint analyses, the amounts of TN and TP particularly entered on arable land have been overestimated if applying the nutrient amount in fresh manure. The NLCs obtained in this study may assist in the development of a database to assess the accurate level of manure nutrient loading on soil and facilitate systematic nutrient management.

Keywords: Dairy Cattle Manure, Composting, Weight Reduction, Nutrient Loss, Nutrient Loading Coefficients

INTRODUCTION

Livestock industries have grown tremendously in recent decades to meet the demand from the increasing human population. Improved technologies are also adopted for feeding, breeding, and reproductive management to increase livestock production. A significant amount of manure is produced in addition to meat and milk, which directly relates to concerns of environment conservation. The current increases both quantitative and qualitative living standards have led to additional livestock breeding and the subsequent release of greenhouse gases from manure has contributed to climate change, which has received significant attention in the last decade. Livestock manure is largely composed of organic compounds including nitrogen (N) and phosphorus (P) which results in eutrophication of nearby streams when released without an appropriate treatment [1]. Both P and N enhance algal blooms in water bodies (rivers, lakes, and seas) worldwide, which reduce light penetration and available oxygen in these ecosystems, and globally has led to the death of aquatic organisms [2].

The nutrient balance in Organisation for Economic Co-Operation and Development (OECD) was calculated by the term of the gross N budget which takes into account the entire nutrients including the risk of air, soil and water pollution. This is corresponded with the term of land budget which is one of nutrient budget types including farm and soil budget suggested in nutrient budgets [3]. As per the explanation about nutrient budget, land budget facilitates the measurement of nutrients including all the influences to the nature using model calculations based on manure and fodder production. Farm budget is the most desirable method but has difficulties to survey each farm. Although soil budget requires also data collection, it is relatively available and meaningful to estimate nutrients on soil excluding N volatilized and describe nutrients in regional level. Further, the current OECD stat for nutrient balance may not be applicable for some specific countries with lack of grazing land for livestock breeding like Korea. The manure management is mostly separated where its production and application places are. The most part of manure is stored and treated for compost production by livestock farm and then those are applied to cultivated land. Therefore, data collection for soil budget may be relatively facilitated which can be more accurate and reasonable method for the measurement of nutrient balances.

Composting methods in solid and liquid phases play an important role in circulation of nutrients in manure and can affect as much as 88.7% of the total livestock manure produced in Korea [4]. The sustainable agriculture practices supported by the government ideally aim to obtain a balance of resources in nature through their circulation, whereby nutrients in livestock manure compost are applied to soil to enhance the growth of plants that fed to livestock. Thus, the ultimate goal is to sustainably recycle nutrients in the eco-system that are produced by agricultural practices [5].

Nutrient turnover in manure with or without bulking agents occurs during storage due to the microbial activity [6]. In particular, N exists in various forms (nitrite/nitrate, nitrous oxide, and nitrogen gas) and its concentration can vary due to ammonia volatilization, nitrification, and denitrification. During these processes, the nitrous oxide and N gas released to the atmosphere contributes to global warming. About 20% to 40% of the N in manure may be lost during the storage and composting processes through gaseous emission [6,7].

Since the calculation of nutrient loading from livestock manure has been achieved based on OECD stat using the number of animals and the excretion coefficients, nutrient application from livestock manure on arable land has been overestimated with respect to soil budget due to neglecting to account for the loss of nutrients during the composting or storing periods. Thus, the practical nutrient loading on soil may be required for accurate and systematic management of livestock manure.

According to the OECD report in 2008, the N and P amounts of 224.6 and 44.4 kg/ha has been accumulated, respectively, in Korean arable land, which was the highest level among the OECD countries. The N loading in Korea was 583,000 tonnes, of which chemical fertilizer contributed 45% and livestock manure 49% in 2009. Chemical fertilizer and livestock manure contributed 42% and 58% to the total P loading of 107,000 tonnes, respectively. Based on OECD stat, implementing a nutrient-quota production and limiting the number of animal heads on farms have been proposed and estimated based on the environmental capacity [8] which threats livestock industry.

As mentioned above, N and P resources for crop cultivation come mainly from chemical fertilizer and livestock manure compost and their flux in agricultural sector is illustrated (Figure 1). Different from N, P flux mostly comes from phosphate rock and also P content from livestock manure is originated from feedstock in which P source is provided by phosphate rock. Nutrients provided from livestock manure for crop cultivation can be released to air for N and soil and water for P during the storing or composting period.

Although such a nutrient loss may vary dependent on the

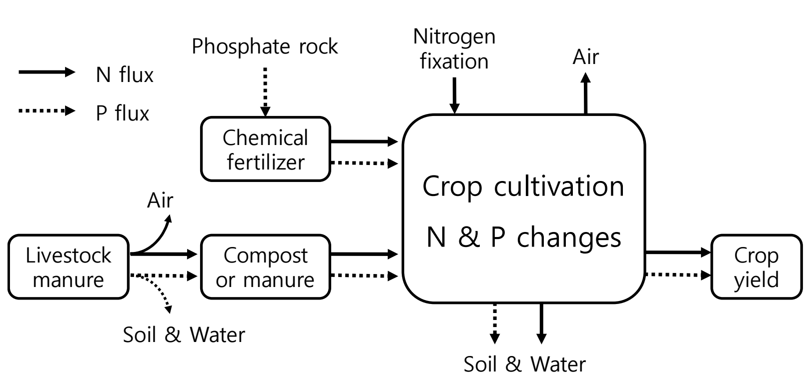

Figure 1. Nutrient (N and P) flux in agricultural sector. N, nitrogen; P, phosphorus.

traditional manure management, regional climate condition in each region, and livestock categories, quantifying and building up database of soil budget for nutrient may support the systematic management of nutrient and the environmental protection.

Therefore, this study was carried out to investigate the status of dairy cattle manure management and calculate the nutrient loading coefficients (NLCs) with consideration of nutrient loss during the composting or storing of manure. At the same time, the practical nutrient loading on soil from dairy cattle manure was estimated in order to assist in database construction account for nutrient loss from livestock manure, which supports the measurement of soil budget.

MATERIALS AND METHODS

Farm survey and sample collection

In order to collect samples and information from dairy farms, basic information was obtained in person regarding breeding heads, bedding materials, excretion structure and the amount of manure production after the 41 farms in Korea was investigated and the contents of N and P in those samples were measured. Methods of manure management were also investigated with detailed information recorded. Samples were collected from fresh manure and compost prior to application. For sampling on site, 20 L bucket was used for collection of fresh manure. However, compost samples were collected in 20 L bucket from vertical trisection of compost pile with 1 to 1.8 m of height.

Analytical methods

Collected samples were stored at −4°C until analysed. For total nitrogen (TN) and phosphorus (TP), samples were mixed with strong acid and heated in the block digester (BD40, LaChat, Milwaukee, WI, USA) at 320°C. Then, the analyses were conducted using the auto water analyser (QuikChem 8500, LaChat, Loveland, CO, USA). Total solids were determined by comparison of the sample weight before and after drying oven at 105°C overnight. The determination of volatile solids (VS) as organic matter was carried out after a high temperature muffle furnace at 550°C for over 4 hours [9]. The bulk density of the samples was weight per unit volume, which was measured with 18-L of bucket on site following the methods of Cooperband [10].

Calculation of nutrient loading from dairy cattle manure

The nutrient loading refers to the nutrients from dairy cattle manure that released into the environment, specially soil and streams. However, livestock manure passes through a composting or storing period prior to land application. Through the composting or storing period, the oxidation of organic matter and N stripping or transformation occurs, which leads to a loss of nutrients. Hence, the amount of nutrient loading can be calculated by multiplying the total nutrients in manure with NLCs, which are considered to account for nutrient loss during the composting or storing period. Hence, NLCs as a dimensionless number represent the opposite of nutrient loss ratio.

Nutrient loading amount (kg VS, N, P/head/yr)
= Nutrient con. in manure (kg/t)
×Manure amount (t/head/yr)×NLCs

Where above, NLCs represents nutrient loading coefficients.

The nutrient loss rate during the composting or storing period can be calculated by dividing the nutrient quantities in compost by those of manure.

$$\text{Nutrient loss rate (\%)} = \frac{\text{Nutrients in compost (VS, N, P)(mg)}}{\text{Nutrients in manure (VS, N P)(mg)}} \times 100$$

$$= \frac{\text{Compost product (kg)} \times \text{Conc. of nutrients in compost (mg VS, N, P/kg)}}{\text{Manure product (kg)} \times \text{Conc. of nutrients in manure (mg VS, N, P/kg)}} \times 100$$

Construction and application of the experiments

In order to obtain nutrient quantities in compost and manure, the concentrations of VS, TN, and TP were multiplied by the amount of manure and compost, respectively, but the whole quantities of manure could not be measured directly on site. Thus, the value from Ministry of environment displays of 37.7 L/head/d for Holstein was used for NLC calculation [11].

Regardless, the measurement of compost production was not feasible directly on site. Hence, the amount of compost production was assessed after consideration of three different cases to understand nutrient loading after manure production. The first experimental operations were carried out to obtain the weight reduction during the composting or storing period (case I) and were conducted at the research and development ranch of Kangwon National University, South Korea (39°56'N, 127°46'E) for 4 months. First, the floors of 3 barns were covered by 15 cm of sawdust to prevent the cattle from being affected by the cold and also to remove moisture, simulating conditions widely implemented in over 90% of dairy farms for the management of manure and cattle in Korea. A total of 12 Holstein in growing, milking, or dry stages (429±112 kg of initial body weight) were selected and allocated to barns. Each barn had 4 Holstein, allowing for 6.4, 13.5, and 16.5 m2/head of stocking density for growing, milking and dry stages, respectively, in order to meet national standard for sustainable livestock management [12]. The mixture of manure and sawdust was stepped on and turned over by cows for 3 months, after which the mixture was retrieved from the barns and stored in a compost lot for 1 month. According to the Korean Rural Development Administration, the daily manure production of Holstein was determined to account for 5.6%, 6.5%, and 10.3% of body weight in the growing, milking, and dry stages, respectively, values that were adopted for the calculation of case I. Case II was the reference experiment to determine volume reduction during the composting period. Finally, case III was calculated based on the amount of P. One of the important components in nutrients, P, should theoretically not change during the composting period. Practically, however, P loss during the composting period occurs via run-off and leachate [13], which is additional nutrient loading to the environment, whereby constant amount of P amount before and after composting can be counted. The concentrations of each nutrient in the manure and compost samples were collected and directly analysed and the amount of P in manure calculated using the total amount of manure produced based on the documents from Ministry of Environment. The total compost produced was based on the amount and concentration of P found after analysis of compost samples. Thus, manure production from Ministry of Environment was combined with the results from case II and III in order to calculate NLCs on land.

RESULTS

Investigation of dairy farms

The main livestock categories in Korea are beef and dairy cattle, pig, broiler, and layers which produced manure of 44.8 million m^3/yr in 2013. Ministry of Environment in Korea announced the excretion coefficients in each livestock categories in 2008 and a head of dairy cattle produces manure of 37.7 L/d. The number of dairy cattle occupied only 3% of four major livestock categories (Hanwoo, dairy cattle, pig, and chicken) in Korea (the number of chicken was counted in thousandfold) but its manure production contributed 12.9%. In addition, the daily nutrient production of N and P in dairy cattle manure are the highest of 161.8 and 56.7 g/head over the other livestock categories and the yearly nutrient production based on the dairy cattle numbers were 8.0% and 7.0% of the N and P production from the entire livestock in Korea.

In total 41 dairy farms were selected to investigate manure management and nutrient loading on land as well as farm animal databases. The head of cattle ranged from 12 to 140 with an average of 64, which was less than the average of 75 for all of Korea [14]. All dairy farms used sawdust as the bedding material with the number of time which was replaced ranging from 1 to 8/yr (average 3.2/yr), and the average consumption of bedding materials per head was 1.03 kg/d (Table 1). The thickness of the bedding material was 15 cm and it was replaced when it reached 60% to 70% moisture as determined by the farmers. In relation to composting methods, only 12% of the entire dairy farms conducted turning using a skid-loader or tractor while the remaining ones heaped simple static piles without any air-supply.

Table 1. Methods of manure management and characteristics of 41 dairy farmsinvestigated

Contents	Range	Average
The number of head per farm	12–140	64.0 ± 26
Exchange rate of bedding materials (turn/yr)	1–8	3.2 ± 1.6
Daily bedding material used (kg/d)	4–175	66.3 ± 40.1
Daily bedding material used per head (kg/head/d)	0.19–2.11	1.03 ± 0.52
Composting methods (%)		
Turning	12	
Simple static pile	88	

Characteristics of dairy cattle manure and compost

The samples of manure and compost collected from the 41 dairy farms were analysed to determine the total VS, TN, and TP and to calculate the amount of each nutrient in each (Table 2). The TN concentration (5,086 mg/kg) in manure was close to that from Ministry of Environment (5,203 mg/kg), while the TP concentration was much lower (1,289 mg/kg) than the Ministry of Environment value (1,823 mg/kg). On the other hand, a much higher concentration of TN (8,897 mg/kg) and TP (2,186 mg/kg) was found in samples collected from the composting lot. The VS content of 10.8% in manure increased to 21.4% when manure was housed in the barn and composting. This was probably because the bedding materials such as sawdust and rice husk mostly counted as VS were mixed with manure even though the VS was degradable during the storage and composting periods.

Assessment of weight reduction cases during the composting period

As previously described, the cases for weight reduction of dairy manure were calculated. In order to obtain practical values for Case I, the measurements were conducted in two stages; i.e., the excretion from cattle was housed in the barn and rolled with bedding materials for 3 months, after which point the mixture

Table 2. Nutrient concentrations of dairy cattle manure and compost according to on farm investigation and the reports from the Ministry of Environment in Korea

Source of values	Concentration (mg/kg)			Moisture content (%)	Bulk density (kg/m^3)
	VS (%)	TN	TP		
ME[1)]	-	5,203	1,823	-	-
Fresh manure[2)]	10.8 ± 1.4	5,086 ± 1,743	1,289 ± 457	81.6 ± 4.6	998.7 ± 74.8
Compost	21.4 ± 5.1	8,897 ± 4,947	2,186 ± 1,383	69.0 ± 10.1	791.0 ± 207.0

VS, volatile solids; TN, total nitrogen; TP, total phosphorus
[1)] ME, the values from Ministry of Environment in Korea.
[2)] The sample was collected from the barn avoiding bedding materials.

Table 3. Experimental weight reduction of dairy cattle manure in dairy cattle barn and composting lot after 4 months

Stall number	Manure production (kg) (A)	Bedding materials (kg) (B)	Mixture weight (kg) (C)	Weight loss-1[1] (%)	Mixture weight (kg) (D)	Weight loss-2[2] (%)	Total weight loss[3] (%)
1	5,880	667	2,476	62.2	1,960	23.0	70.9
2	7,150	667	3,423	56.2	2,644	22.7	66.2
3	4,964	667	2,372	57.9	1,840	22.4	67.3
Average	5,998	667	2,757	58.8	2,130	22.7	68.1

[1] Weight loss-1 (%) by (1–[C/{A+B}]) × 100 for 3 months staying in the barn.
[2] Weight loss-2 (%) by (1–D/C) × 100 for 1 month storing in the composting lot.
[3] Total weight loss by (1–[D/{A+B}]) × 100 for 4 months including both periods.

was stored in a composting lot for 1 month. The total reduction in weight was measured for 4 months, for which 3 months the manure was in the barn and 1 in the composting lot (Table 3). A final value of mixture weight loss of 58.8% was observed while the mixture of dairy cattle manure and bedding materials left in cattle barns for 3 months. For this experiment, the entire mixtures of manure and bedding materials were weighed from cattle barns, after which point the mixture was stored in a composting lot for 1 month, resulting in weight loss of 22.7%. The overall weight loss of the mixture was 68.1% for 4 months.

The amount of P before and after composting should not change theoretically without the leachate occurrence or run-off since all of the P remains in the compost pile in the form of ortho- or poly-phosphate in addition to other organic compounds. Thus, the weight reduction can be calculated as is described below and the weight loss of 60% on average was derived based on the constant P content as was revealed by case III (Table 4). It was found that weight loss was higher in the field study (68%) compared to the database from the Ministry of Environment (55%) or where P loss was zero (60%).

$$\text{Weight loss (\%)} = \left[1 - \frac{[\mathrm{P}]_{\text{in mixture of manure \& bedding materials}}}{[\mathrm{P}]_{\text{in compost}}}\right] \times 100$$

Where [P] indicates the concentration of P.

Calculation of nutrient loading coefficients

According to the data from cases related to weight reduction, the NLCs for VS, TN, and TP were calculated based on the nutrient concentrations from sample analyses (Table 5). The NLCs refer to the nutrient amount from the manure to be loaded on land and nutrient loss is the opposite means of NLCs as previously described.

According to case II, higher NLCs were found for VS (1.92), TN (0.78) and TP (0.84) whereas, the values of NLCs in case I were 1.48, 0.60, and 0.66 for VS, TN, and TP, respectively. The values of NLCs based on a reference based weight reduction might be overestimated compared to the practical investigation of this experiment. Considering agricultural land excluding N emission to atmosphere, case III could be a reasonable value to determine the impacts of nutrients from dairy cattle manure in Korea. However, with respect to the nutrient loading only on agricultural land as soil budget for nutrients, the values of NLCs in case I would be reasonable.

Table 4. Weight reduction of dairy cattle manure during storing and composting periods according to three cases

Cases	Weight reduction (%)
I[1]	68 ± 10
II	55 ± 12
III	60 ± 16

[1] Weight reduction cases: I, Experiment; II, Reference; III, ΔP = 0 before and after composting.

DISCUSSION

Characteristics of dairy cattle manure and compost

Since we found that the average moisture contents of cattle manure and bedding materials were approximately 81.6% and 20.0%, respectively, 11.5 kg bedding material/head/d is required to obtain an optimal moisture content for composting (approximately 65%) assuming an average daily manure production of 37.7 kg/d as obtained from the Ministry of Environment document [15,16]. However, most dairy farmers used only 1.03 kg/head/d of bedding materials on average across the existing management practices. Assuming that there were no other factors affecting the mixture, such as ambient drying and the addition of water, the moisture content in the mixture

Table 5. The nutrient loading coefficients for VS, TN, and TP from dairy cattle manure according to three cases

Cases for weight loss during the composting or storing period	Nutrient loading coefficients		
	VS	TN	TP
I[1]	1.48	0.60	0.66
II	1.92	0.78	0.84
III	2.29	0.87	-
Average	1.90	0.75	0.75

VS, volatile solids; TN, total nitrogen; TP, total phosphorus.
[1] Weight reduction cases: I, Experiment; II, Reference; III, ΔP = 0 before and after composting.

was predicted to be 79.7% with the investigated amount of bedding materials used (1.03 kg/head/d). This highly moistened condition inhibited oxygen dispersal and thereby dead zones (anaerobic condition) were formed in the static piles [17]. Composting piles under anaerobic conditions take longer to decompose and a temperature of 55°C cannot be reached for pathogen destruction, which results in lower compost qualities [18]. The moisture content decreased naturally in the cattle barn; however, it was not possible to reach the optimal moisture level of 65% only with ambient drying and the amount of bedding materials investigated. In order to perform composting normally on dairy farms, sufficient bedding materials are required with the sufficient budget. Thus, frequent turning of the composting pile may help decrease the moisture content. Higher concentrations of TN, TP, and VS in dairy cattle manure after storage and composting might be due to the reduction in moisture content and the components that were condensed with weight loss [19,20]. Sommer [7] also found a higher TP concentration (34%) in cattle manure after 132 days of composting. This might have occurred due to moisture reduction and organic matter degradation during composting.

Construction of weight reduction cases during the composting period

The previous case II from the study by Cooperband [10] revealed that volume reductions of 55%, 73%, and 55% of cattle manure occurred when utilizing the composting methods of simple static pile, windrow or turning, and aeration, respectively. In the present study, 36 farms used the simple static and 5 utilized the turning pile method and the weight reduction of each farm was calculated from the volume reduction using the bulk density of the samples. Weight reduction occurred due to moisture loss and microbial degradation during the composting period. Although the majority of the existing management practices followed a simple static pile method (88%), aerobic turning was also used (12%), and in the instances where there was a higher weight reduction (68%) than expected, it could have been due to low humidity, temperature, or other environmental causes. Average organic matter degradation was measured to be 53.3% of the total in each experiment during the 4 months of storage and composting and might be due to processes, including CO_2, CH_4, and N_2O emission, as well as NH_3 volatilization, nitrification, and denitrification due to the action of microbes. Further, complex compounds in manure were transformed into their most simple and stable forms during the composting process.

Calculation of nutrient loading coefficients

The larger values of NLCs for VS (1.48 to 2.29) were produced by the addition of bedding materials. The lower TN (0.60 to 0.87) values indicated that 13% to 40% of this element was reduced, presumably by ammonia volatilization, nitrous oxide, N gas emission and leachate [6,21-23]. Except for in case III, where no change in P concentration was observed, the reduction of TP was 34% and 16% in cases I and II, respectively. Theoretically, changes in P concentration occur if there is leachate or run-off. In this regard, case III may be the best for the calculation of total nutrient loading only excluding nutrient emission to atmosphere. However, the TN reduction in case III was only 13%, which indicates that most of the TN is retained in compost and ultimately imparted to the land. Inactive composting might cause such a low reduction of TN, which meant that no turning had taken place or there was insufficient addition of bedding material. The nutrient reduction via composting dairy cattle manure was previously reported as VS values from 29% to 81% and TN from 5% to 43%, although it was dependent upon the regional climate and composting methods [24-27]. Therefore, the values of NLCs obtained (VS, 1.48; TN, 0.60; TP, 0.66) from Case I experiment may accurately reflect the nutrient loading on agricultural land. Combining these derived NLCs with the data from the statistical report in Korea, the amounts of TN and TP from dairy cattle to agricultural land would be 15,262 and 5,882 tons per year, respectively, based on a dairy cattle population of 430,678 heads [14]. However, without considering nutrient loss during composting or storage, the nutrient values in manure would be directly applied to the yearly production of nutrients resulting in 25,437 tons of TN and 8,912 tons of TP, which are values 1.6 and 1.5 fold higher, respectively.

Although in the present study, we took into account the characteristics of manure and compost, utilization of bedding materials, and weight reduction during the storage and composting periods, and found that cattle manure is often mixed with insufficient amounts of bedding materials, then stacked in the composting lot without proper handling or even sufficient time before being applied to land as fertilizer, which causes an increased nutrient loading on soil and unpleasant odour in the surrounding areas. It has been proven that cattle manure needs a longer time for decomposition compared to pig or poultry due to the presence of large amount of fibrous materials [28]. Less usage of bedding material lowers the porosity in the composting pile, leading to an insufficient air supply and microbial degradation of the mixture during composting, and ultimately in high moisture in the dairy cattle manure compost in Korea. Addition of sufficient bedding materials in the dairy barn and longer composting periods along with aeration and turning are necessary to increase the compost quality of dairy cattle manure, which may ensure lower NLCs. Thus, it is mandatory and urgent to improve the management of dairy cattle manure in Korea.

Consequently, to calculate the amount of nutrients with respect to soil budget which are being loaded on agricultural land, it is desirable to use the NLCs values, [VS, 1.48; TN, 0.60; TP, 0.66] obtained from this experiment regarding soil N budget.

The NLCs developed here may be helpful for manure handling practices and beneficial for their application in agricultural land management as well as for the accurate calculation of nutrient in soil budget.

Further, when compared with animal heads in livestock categories, the number of dairy cattle occupies only 3% but 12.9% in the contribution of manure production as previously mentioned, which indicates dairy cattle produces the highest amount of manure per head as previously mentioned. The management of dairy cattle manure is more difficult than for the manure of other livestock categories due to its high moisture content. This is paradoxical since swine manure is characterized by higher moisture content than dairy cattle manure. However, most swine farms in Korea have solid and liquid separators while dairy farms do not, which results in relatively higher cost for purchasing bedding materials on dairy farms. Thus, the development of methods or protocols to decrease the moisture content in dairy cattle manure for proper composting is necessary and utilization is required in the near future.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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