Improvement of nitrogen balance (land budget) in South Korea in terms of livestock manure: a review

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Abstract. South Korea’s nitrogen (N) balance is the highest among OECD countries. However, this figure is likely to be overestimated. Besides, there is a lack of scientific logic to persuade stakeholders (i.e., fertilizer company, livestock farmer) when these numbers are used as a basis for the N reduction policy. N balance is the residual value after subtracting the amount of N flowing out of the specific boundary from the amount of N entering the boundary. The boundaries of N balance are divided into farm budget, soil budget, and land budget. OECD uses a land budget for N balance calculation. The N inputs consist of mineral fertilizers, organic fertilizers, livestock manure, crop residues, seed and planting materials, biological N fixation, and atmospheric deposition. The N content in the crops produced corresponds to the N output. The N balance method proposed by the OECD is based on a grazing farming system. This method derives from the agricultural environment in which livestock manure is directly deposited into farmland. However, most of the livestock manure in South Korea is not used directly in farmland but is converted to compost and liquid fertilizer. N loss occurs during composting and liquid fertilizer production, which means that the amount of N loaded on the actual soil can be significantly reduced. Another concern related to N from livestock manure is the source of the N content in the crop. N absorbed by crops is not distinguished from livestock manure N, chemical fertilizer N, or soil N. If policymakers intend to reduce N by limiting mineral fertilizers or livestock manure, the N use efficiency of crops based on N sources will play an important role. Therefore, this paper discusses two uncertainties (N loss rate and crop N uptake) related to N from livestock manure and suggests ways to improve N balance.

1. Introduction

According to the Organization for Economic Co-operation and Development (OECD) nutrient balance data, South Korea’s nitrogen (N) balance (222 kg ha⁻¹) ranks first among OECD countries [1]. N balance is the residual value after subtracting the amount of N flowing out of the specific boundary from the amount of N entering the boundary. The boundaries of N balance are divided into farm budget, soil budget, and land budget. The farm budget (or farm-gate budget) calculates the N balance of the farm boundaries. Both soil and land budgets are based on regional boundaries. However, the land budget takes into account atmospheric N surpluses and not the soil budget [2, 3]. OECD uses a land budget for N balance calculation. The N inputs consist of mineral fertilizers, organic fertilizers, livestock manure, crop residues, seed and planting materials, biological N fixation, and atmospheric...
deposition [4]. The N content in the crops produced corresponds to the N output. The N balance method proposed by the OECD is based on a grazing farming system. This method derives from the agricultural environment in which livestock manure is directly deposited into farmland. However, most of the livestock manure in South Korea is not used directly in farmland but is converted to compost and liquid fertilizer [5]. N loss occurs during composting and liquid fertilizer production, which means that the amount of N loaded on the actual soil can be significantly reduced [6, 7, 8, 9]. Therefore, the N balance reported to the OECD is likely to be overestimated. Besides, there is a lack of scientific logic to persuade stakeholders (i.e., fertilizer company, livestock farmer) when this N balance is used as a basis for the N reduction policy. The chemical fertilizer and compost industry are concerned that N balance will lead to a contraction in the industry through N regulation. Livestock farmers are concerned about the reduction in stocking density due to N restrictions. Crop farmers are concerned about the reduction of agricultural production due to the reduced N input. The Ministry of Environment (ME) intends to manage agri-environmental indicators, including the atmosphere through N balance. Ministry of Agriculture, Food and Rural Affairs (MAFRA) argues that the national security (self-sufficiency rate) of livestock and food crops should be preceded before N balance can be used systematically. Due to the complex involvement of N balance and multiple stakeholders, sufficient consent of each stakeholder is required before the N management policy is implemented. Another concern associated with manure N is the N use efficiency (NUE) in crops. N absorbed by crops is not distinguished from livestock manure N, chemical fertilizer N, or soil N. If policymakers intend to reduce N by limiting mineral fertilizers or livestock manure, the N use efficiency of crops based on N sources will play an important role. Therefore, this paper discusses two uncertainties (N loss rate and crop N uptake) related to N from livestock manure and suggests ways to improve N balance in South Korea.

2. Livestock manure production and treatment methods in South Korea
The amount of livestock manure in South Korea treated with compost, liquid fertilizer, and purification was shown in table 1. About 85% of livestock manure is converted to compost and liquid fertilizer (including private company), and 15% is purified and discharged to water bodies [10]. The amount of pig manure was 19 million tons (39.5% of total livestock manure production), followed by beef cattle and chickens (data not shown).

| Total amount (ton d⁻¹) | Compost (ton d⁻¹) | Liquid fertilizer (ton d⁻¹) | Self purification (ton d⁻¹) | Public Purification (ton d⁻¹) | Private company a (ton d⁻¹) |
|------------------------|------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| 176,434 (100%)         | 119,091 (67.5%)  | 8,017 (4.5%)                | 8,691 (4.9%)                | 17,415 (9.9%)                | 23,220 (13.2%)              |

a Private company that produces compost and liquid fertilizer

2.1. Manure treatment methods by livestock type
Depending on the type of livestock, the treatment of livestock manure can vary. Most beef cattle farmers in South Korea operate small-scale bedded pack barns, resulting in the production of solid manure. Most beef cattle farmers store their livestock manure in a self-composting shed and supply it to nearby farmland. Farmers should take into account adequate environmental factors (e.g., compost duration, temperature, moisture, C/N ratio) for the aerobic microorganisms involved in composting. If immature (unfinished) composts are used or stacked in nearby cropland, odors and pests can occur. Dairy cow manure, like beef cattle, is mostly composted because it is in the form of solids from bedded pack barn. However, since the washing water is generated during the milking process, the
purification method is also operated in parallel. Pig housing forms mostly consist of slurry pit. A slurry pit is a structure that makes a pit-shaped storage space under the slatted floor and stores pig’s urine and feces in the pit for a while. Due to this unique structure, it becomes a liquid slurry mixed with pig feces and urine. Treatment of pig slurry generally begins with the solid-liquid separation process that separates solids and liquids [7]. The solid is then composted, and the liquid is treated with liquid fertilizer or purification. Pig slurries have a small amount of solids and have high moisture content, so they are mainly treated with liquid fertilizer, and the purification method is also gradually increasing in South Korea [11]. The types of chicken housing in South Korea are primarily divided into cage and cage-free. Chicken manure is managed in various ways such as scrapers, conveyors and bedded packs. Chicken manure is low in moisture so that it can be composted on the farm or commissioned by a private company. Chicken manure is the preferred compost material for composting companies. The low moisture content of the chicken manure reduces the use of bulking agents such as sawdust and rice husks, resulting in lower operating costs. Besides, the N in chicken manure is four times more than that of other livestock manure [12].

2.2. **Odor (Nitrogen) reduction process**
In South Korea, urban residents tended to move to rural areas, and at the same time, complaints of livestock odor increased rapidly. Livestock farmers that cannot control odors are no longer able to operate farms. To improve the livestock odor complaints, MAFRA has been carrying out the ‘Regional Livestock Odor Improvement Project’ since 2016. The project aims to efficiently manage odors by switching from supporting local farms to supporting local units (city, county or village, livestock complexes). The government provides livestock farmers with consulting on odor reduction and subsidizes the costs of setting up odor reduction facilities such as biofilters and wet-air scrubbers. In order to maintain the livestock industry, installation, and operation of odor reduction facilities are inevitable. Since the ammonia removal rate of odor reduction facilities is high [21, 22, 23, 24], it is necessary to estimate N balance by excluding it from atmospheric surplus N.

3. **Problems with nitrogen balance in land budget system and improvement**
The OECD’s land budget determines N input based on livestock manure production. N loss in livestock manure treatment in South Korea was not considered. If the N balance is calculated to account for N losses in livestock manure processing, there are still concerns. Land budget is an N balance system that manages agri-environmental indicators such as soil, water, and atmosphere [1]. Thus, the volatile N produced in the compost and liquid fertilizer processes belongs to the atmosphere N. Even the amount of N collected by odor abatement facilities (such as biofiltration, wet air scrubbing) can be attributed to the atmosphere, resulting in excessive production of atmospheric N. N input to cropland is reduced by the amount of volatile N, but excessively estimated atmospheric N (surplus) may weaken the livestock industry in the future. In South Korea, the livestock industry is a major target of malodorous complaints, and the fact that ammonia volatilization in the livestock sector contributes to the production of PM2.5 [35] will continue to undermine the livestock industry. The N flow in a modified land budget is given in figure 1.
Another problem with the land budget is that the effect of N forms (mainly livestock manure N and mineral fertilizer N) on the crop’s N recovery was not taken into account. N surplus should be reduced to maintain a sustainable agricultural environment and increase NUE. The way to lessen N surplus is to reduce the amount of input N or increase the amount of output N. For proper N management, the effects of each N source (such as mineral fertilizer N, compost N, liquid fertilizer N) on excess N should be considered. Implementing an N management policy without a scientific basis could lead to a constant debate among stakeholders.

3.1. Nitrogen loss by treatment methods
Previous studies have shown that the loss of N during the conversion of livestock manure to compost and liquid fertilizer ranges from 5-88% (table 2). The difference in N loss occurs depending on the substrate type and the specific treatment method. A broad range of N loss means that it is challenging to apply N loss coefficient to N balance in land budget. However, considering the treatment rate of livestock manure in South Korea (Table 1), it is necessary to generalize the N loss coefficient under particular assumption such as classification of treatment facility based on standard design. The amount of N loss in odor reduction facilities was found to be from 54% to 100% (table 2).

### Table 2. Nitrogen loss during composting, liquid fertilizer production and odor reduction process

| No. | Process and substrate                                      | N loss (%) | Reference |
|-----|------------------------------------------------------------|------------|-----------|
| 1   | Co-composting of solid wastes and liquid pig manure        | 30 – 66    | [9]       |
| 2   | Organic fertilizer production from olive mill              | 15         | [13]      |
| 3   | Co-composting of solid wastes and liquid manure            | 30 – 66    | [9]       |
| 4   | Composting of animal manure                               | 5 – 60     | [14]      |
| 5   | Compost bedding on a dairy farm                            | 11 – 17    | [15]      |
3.2. Nitrogen uptake by crop

Previous studies showed that N recoveries by plants in feces N and compost N were relatively small, ranging from 8 to 10% [27, 30]. On the other hand, urine N and mineral fertilizer N had high NUE with 29-47% N recovery [27, 31]. N uptake of manure N (including feces N, urine N, bedding material N) ranged from 8% to 56% [26, 28, 29, 30]. Martõñez-Alcañiz et al. [25] reported that no significant differences were observed in Citrus tree NUE between organic fertilizer N (vegetal or animal-based liquid fertilizer) and mineral fertilizer N. Jensen et al. [26] reported that 56% of the total manure N applied (immediate incorporation) was recovered in barley. Proper use of urine N and mineral fertilizer N with high NUE may help to improve N balance in land budget. However, increasing the use of urine N and mineral fertilizer N to improve N balance can cause more problems. Mineral fertilizers and manure compost contain ammonium (NH\(_4^+\)) and nitrate (NO\(_3^-\)) N, which can be used by crops. However, manure compost takes time before the fertilizer effect appears (slow-release N) because mineralization is required. Compared with mineral fertilizers, manure compost has characteristics of improved soil physical properties (such as humus production, aggregation and pore space formation), and activation of soil microorganisms. Mineral fertilizer N is released quickly into the soil, but it means that N leaching can occur easily. As mineral fertilizer N needs to be added as much as leaching and runoff, there is a possibility of excessive fertilization of N due to long-term use, resulting in adversely affects [34]. Liquid fertilizers, composts and mineral fertilizers should be used in consideration of tradeoffs regarding N loss and conservation due to soil type, application timing (season) and application methods [36].

| No. | N source                     | Application method | Application season | Plant species | N uptake (%) | Reference |
|-----|------------------------------|--------------------|--------------------|---------------|--------------|-----------|
| 1   | Sheep urine                  | Incorporation      | Spring             | Wheat         | 37           | [27]      |
| 2   | Sheep feces                  | Incorporation      | Spring             | Wheat         | 10           | [27]      |
3. Dairy cow manure Incorporation Spring Maize 14-16 [28]
4. Sheep manure Immediate incorporation Spring Barley 56 [26]
5. Dairy manure Incorporation Spring Corn 10-22 [29]
6. Composted manure Incorporation Autumn Winter Wheat Pasteur 8 [30]
7. Cow urine - May 29-39 [31]
8. Liquid fertilizer + mineral fertilizer application Spring, Fall Rice 8-9 [32]
9. Mineral fertilizer (ammonium sulfate) Surface application September Pecan tree 10-21 [33]
10. Mineral fertilizer (ammonium nitrate) Incorporation Spring Wheat 47 [27]
11. Mineral fertilizer (ammonium sulfate) Surface application Spring, Fall Rice 15 [32]

4. Conclusion
N losses in composting and liquid fertilizer process should be considered in the N balance of the land budget. The volatilized N in the process is estimated to be atmosphere N, except the amount of N trapped in the odor reduction system. A scientific basis for the effects of mineral fertilizer N, compost N, and liquid fertilizer N on atmospheric N, soil N, and crop N should be presented to improve the N balance. Further studies on the effects of mineral fertilizer N, compost N, and liquid fertilizer N on atmospheric N (NH$_3$, NO$_x$, NO, N$_2$O, N$_2$), soil N (N recovery), and crop N (NUE) are required.

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