**Supplementary material**

**Table S1.** Equations for nitrogen budget model

| | Entry | Methodology |
|---|---|---|
| Input | N1* | ∑i [Sale of the i mineral fertilizer (ton/yr) × N content of i mineral fertilizer (%)] |
| | N2-1* | ∑i [Head of i livestock (head) × Unit of generation and discharge from i livestock (L/head/d) × Share from manure to manure treatment (%) × Coefficients of N conversion of i livestock manure (%)] |
| | N2-2* | ∑i [Head of i livestock (head) × Unit of generation and discharge from i livestock (L/head/d) × Share from manure to solid composting (%)× Coefficients of N conversion of i livestock manure (%)] |
| | N2-3* | ∑i [Head of i livestock (head) × Unit of generation and discharge from i livestock (L/head/d) × Share from manure to liquid composting (%)× Coefficients of N conversion of i livestock manure (%)] |
| | N3* | ∑ij {[Amount of import i solid composting from livestock manure (ton/yr) × Coefficients of N conversion of i solid composting (%)] + [Amount of import j liquid composting from livestock manure (ton/yr) × Coefficients of N conversion of j liquid composting (%)]} - ∑kz {[Amount of import k solid composting from livestock manure (ton/yr) × Coefficients of N conversion of k solid composting (%)] + [Amount of export z liquid composting from livestock manure (ton/yr) × Coefficients of N conversion of z liquid composting (%)]} |
| | N4* | ∑i [Sale of the i organic fertilizer (ton/yr) × N content of i organic fertilizer (%)] |
| | N5* | ∑i [Cropped area of i legume (ha) × Coefficients of N fixation of i legume (kg/ha)] |
| | N6* | ∑i [Area of paddy and upland (ha) × Coefficients of N deposition (kg/ha)] |
| | N7* | ∑i [Cropped area of i seed (ha) × Coefficients of N conversion of i seed (kg/ha)] |

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|---|---|---|
| | N8 | Total inputs Nitrogen = sum(N1, N2-1, N2-2, N2-3, N3, N4, N5, N6, N7) |
| Output | N9* | ∑i [Cropped area of i crop (ha) × Coefficients of N conversion of i crop (kg/ha)] |
| | N10* | ∑i [Cropped area of i fodder crop (ha) × Coefficients of N conversion of i fodder crop (kg/ha)] |
| | N11 | Total outputs = sum(N9, N10) |
| | NS | Surplus (NS) = N9 – N11 |
| Surplus | aNS* | ∑jkz{[Amount of N loss at j livestock manure treatment plant (LMTP) (ton/yr)]+[Amount of N loss during composting at k solid compositing facility (SCF) (ton/yr)]+[Amount of N loss during composting at z liquid compositing facility (LCF) (ton/yr)]}<br>○ Amount of N loss at j LMTP (j= Public, Individual, Communal)<br>= ∑ij [Head of i livestock (head) × Unit of generation and discharge from i livestock (L/head/d) × Share from manure to manure treatment at j LMTP (%) - [Amount of input at j LMTP (m3/d) x N concentration of treated manure at j LMTP (mg/L)]<br>○ Amount of N loss at k SCF (k= Recycling business, Individual, Communal)<br>= ∑ik〔{[Head of i livestock (head) × Unit of generation and discharge from i livestock (L/head/d) × Share from manure to solid composting at k SCF (%) + [Quantity of sawdust bedding in k SCF (kg/head/d)]} × [Coefficients of N conversion of i solid compositing at k SCF (%)]〕<br>○ Amount of N loss at z LCF (z= Recycling business, Individual, Communal)<br>= ∑z [Amount of evaporation during composting at z LCF (m3/d) × Coefficients of N conversion of liquid compositing at z LCF (%)] |
| | hNS | hydrospheric Nitrogen Surplus(hNS) = NS - aNS |

* N1: Amount of nitrogen of mineral fertilizers, N2-1: Amount of nitrogen from manure to livestock manure treatment, N2-2: Amount of nitrogen from to manure to solid composting, N2-3: Amount of

nitrogen from to manure to liquid composting, N3: Amount of nitrogen of solid and liquid composting import/export, N4: Amount of nitrogen of other organic fertilizer, N5: Amount of nitrogen of biological nitrogen fixation, N6: Amount of nitrogen of atmospheric nitrogen deposition, N7: Amount of nitrogen of seed and planting material, N9: Amount of nitrogen of crop production, N10: Amount of nitrogen of fodder production, aNS: Amount of nitrogen of atmospheric nitrogen surplus

**Table S2.** Parameters for calculating the nitrogen budget model

| Index | Parameter | Unit | Coefficient | | | References |
|---|---|---|---|---|---|---|
| Manure | Livestock excreta unit in South Korea | L/head/d | Solid | Min. | 0.09 | [74] |
| | | | | Max. | 19.2 | |
| | | | Slurry | Min. | 1.7 | |
| | | | | Max. | 10.9 | |
| | Nutrient excretion coefficients of livestock in South Korea | % | N | Min. | 0.3 | |
| | | | | Max. | 1.4 | |
| Manure fertilizers | Nutrient content of manure fertilizers | % | Solid | N | 1.7 | |
| | | | Slurry | N | 0.3 | |
| Biological nitrogen fixation | Annual rates of biological nitrogen fixation | kg/ha/yr | Soya bean (average) | | 20–135 (77.5) | [75] |
| | | | Adzuki beans (average) | | 24–125 (74.5) | |
| Atmospheric nitrogen deposition | Coefficients of atmospheric nitrogen deposition | $g/m^2/yr$ | 2005–2014 (average) | | 1.29–3.31 (2.41*) | [76, 77] |
| Seed and planting material | Annual nitrogen coefficients of seed input | kg/ha/yr | N | | 0.4–8.6 (3.9) | [75] |
| Crop production | Fertilizer recommendation guidelines for crops | kg/10 a | N | Min. | 0.0 | [78] |
| | | | | Max. | 60.0 | |
| Fodder production | | | Pasture grass/ Forage corn | N | 21.0 | |
| Livestock manure | Effluent water quality | mg/L | N | Individual | 250.0 | [79] |
| | | | | Communal | 60.0 | |

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| treatment plant (LMTP) | | | | | | |
| Solid composting from livestock excreta | Weight loss percentages of livestock excreta during solid composting | % | | Beef | 42.3–98.0 (78.5) | [80–84] |
| | | | | Dairy cow | 46.0–80.0 (61.5) | |
| | | | | Swine | 27.0–69.0 (66.3) | |
| | | | | Layer | 64.0–78.0 (65.5) | |
| | | | | Broiler and duck | 86.0 | |
| | Nutrient coefficients of livestock excreta during solid composting | % | N | Min. | 0.4 | |
| | | | | Max. | 1.6 | |
| Liquid composting from livestock excreta | Amount of evaporation during liquid composting in South Korea | $m^3/d$ | | 0.4 | | [85] |
| Nitrogen emission | Ammonia emission during application of fertilizers in cropland | kg $NH_3$/ tn N | Mineral fertilizer | Urea | 141.5 | [77 ,86] |
| | | | | Complex | 75.2 | |
| | | % | Manure fertilizer | $NH_3$ contents | 3.0 | |
| | | | | Loss of $NH_3$ | 66.0 | |

**Table S3.** Data and investigating organizations for nitrogen budget components

| Entry | Category | Data | Sources |
|---|---|---|---|
| Livestock manure composting input | N 1 | Sale of mineral fertilizer | Korean Statistical Information Service (KOSIS) |
| | N 2 | Livestock head and manure to solid and liquid composting rate | Water Emission Management System (WEMS) |
| | N 4 | Sale of other organic fertilizers | National Agricultural Cooperative Federation (NACF) |
| | N 6 | Cultivated area of leguminous crops | Agricultural Integrated Information Excellent System (AGRIX) |
| | N 7, 9, and 10 (N 5) | Area of paddy and upland | |
| | | Cropped area of seeds | |
| Output | | Cultivated area of crops | |
| | | Cultivated area of fodder crops | |