# Evaluation of Phosphorus Flows in Agricultural Sector of Thailand

Nuchnapa Prathumchai, Supawadee Polprasert and Chongchin Polprasert

***Abstract***— *Phosphorus (P) deficit in the near future has posed threat to global food security. Hence, mass balance analysis of P flows in agricultural activities of Thailand was carried out in this study so as to determine its current situation coupled with recovery and recycling potentials. The average 186,300 tons P per year of fertilizers are found totally imported from abroad to be used for cultivation in the country. These quantities are accounted for 59% of the total P applied on the agricultural plantations; while the other 41% come from recycling of agricultural processing wastes and animal manures. After harvested, P is mobilized through 5 channels: (a) export of agricultural products (28.7%), (b) domestic consumptions (26%), (c) production of animal feed (33%), (d) other plant products (5.2%), and (e) losses due to agricultural runoff (1.2%) and industrial processing (5.9%). After animal feeding, P is contained mostly in (a) manures (82%), of which 99% are recycled to cultivation fields, (b) animal products (meat, milk, and egg) (4.5%), (c) unidentified loss during husbandry (13%), (d) identifiable losses in husbandry and processing (0.4%), and (e) by-products produced from manure recovery and recycling (i.e. fish rearing) (0.1%). From the finding of this study, the overall P mass balance in Thailand's agricultural ecosystem exhibits annual loss of 45,422 tons P, which is accounted for 17% of the total P input into the country. Such these losses are believed to accumulate in landfills and in the sediment of various estuaries.*

***Keywords***— **agriculture, cultivation, livestock, manure, phosphorus flows.**

## 1. INTRODUCTION

During the last several decades, the agriculture sector of Thailand has been transforming from a small-scale, labor farming activity into a more commercial, large-scale, food industry for both export and domestic consumption. This transition is evident from the fact that only 37% of the country's labor force are presently employed in agriculture [1], compared to about 70% in 1980 [2]. However, Thailand is still an agricultural country, of which 47% of the total area were occupied predominantly by agricultural plantations. Main crops are rice, rubber, cassava, sugarcane and palm oil. Livestock and poultry are also important parts of farming [3]. In addition, agricultural products have not been produced for their own consumption but also being a major source of income from exporting. Currently, they constitute about 17% of the total export value and the country has become the world's leader of rice and Para rubber exporters [4].

To achieve a successful harvest, the country needs to import over 5 million tons of chemical fertilizers (N, P, and K) solely from aboard as to enable all agricultural cultivation mentioned above [5]. Of particular interest is Phosphorus (P) fertilizer mostly produced from phosphate rock, of which its commercial mining sources are predicted to diminish in the next 30 – 50 years [6–8]. In 2009, the reserves of phosphate rock were reported that China held 37% of reserves, Morocco and West Sahara 32%, South Africa 8%, and the US 7%, with some other countries holding less reserves [9]. These above show that in the near future Thai farmers will definitely encounter the problem of phosphorus shortage**,** ranging from higher price and eventual running-out of P stock.

Studies on P input-output have been conducted in a number of countries; i.e., Australia, China, and France [10–12]. But none is in Thailand. Depending on geographical locations, different countries exhibit different mass flows and transformation pathways of phosphorus movement. In France, P flows were monitored in the food processing industries and urban communities to evaluate P recycling efficiency [12]. P transforming processes (animal and plant productivities, household and industrial processing, consumption and waste handling) were examined in Linkoping, Sweden to determine the per-capita amounts of P consumed, lost, and recycled [13]. Contrastingly, material flow analysis of P in food consumption in two megacities in northern China indicated that P was accumulated in cities about 64% of the total inflow [14].

Hence, mass balance analysis of P flows in agricultural activities of Thailand was carried out in this study with the objectives to determine its current situation in the country's agricultural ecosystem coupled with recovery and recycling potentials. As it is the pioneering study of the country's phosphorus balance, the results of this work could hopefully help decision makers in drawing medium and long-term plans for sustainable agriculture so as to cope successfully with the future P deficit

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problems to come.

## 2. MATERIALS AND METHODS

### *Scope of study and system boundary*

Two major components of Thailand's agriculture are cultivation and livestock systems. Starting from P fertilizers applied on plantation fields, which are derived from imported P materials in the form of Di-ammonium phosphate and/or Mono-ammonium phosphate, P is transferred from ground to plant biomass. After harvested, plant products are consumed either as food for human living or as feed in animal rearing. Emphasized in this work is P quantification in livestock system. Apart from animal products, which are exported and consumed in urban, P in manures is generally recycled to plantations again and again. In addition, P losses from agricultural ecosystem would be expected from different activities along the transformation pathways.

### *Cultivation system*

Thailand, one of the Southeast Asian countries, has a total land area of 51.31 million hectares. Of this total, 23.89 million hectares or 47% is engaged in the agricultural sector. In this regard, 11.19 million hectares or 22% are used for paddy area, and 12.70 million hectares or 25% for other croplands. Productivity from cultivation accounts for 60% of the total agricultural production [3]. Top-ten commodities based on annual productivity are listed in Table 1. Data information shown in Table 1 is used to compute the P input from fertilizers applied on plantations to cultivation crops. The P output includes those contained in the harvest and loss due to field runoff.

### *Livestock system*

The livestock system includes various types of agricultural farms either as specialized animal farms or as mixed with cropping activities. Previously, indigenous livestock had an important role in smallholder farms and local populations. Animal products and by-products was produced to meet household needs. But at present, livestock production has been switched from backyard systems to industrial husbandry. In parallel, the new technology is imported to improve the production performance for economically important traits.

Indigenous livestock was therefore gradually used for crossbreeding. It has finally been replaced completely by commercial breeds. Livestock industries such as meat and dairy are also significant parts of the Thai economy in terms of export products. In this study, top-five major livestock species in the country are selected based on annual productivity as listed in Table 2. Phosphorus flows in livestock system are computed from the animal feeds, which are produced from crop harvest and bio-residues left after milling. P outputs of animal farms range from meat, egg, milk, manures, and losses.

**Table 1. Top-ten crop commodities in Thailand.**

| Name | Area (million hectare) | Productivity[1] (Mt/y) | Domestic consumption[2] (Mt/y) | Export[2] (Mt/y) |
|---|---|---|---|---|
| 1. Sugarcane | 1.35 | 103.70 | 2.50 | 6.50 |
| 2. Rice | 12.36 | 36.84 | 16.32 | 10.00 |
| 3. Cassava | 1.35 | 30.02 | 8.64 | 10.46 |
| 4. Oil palm | 1.21 | 13.33 | 4.72 | 0.99 |
| 5. Maize | 2.76 | 5.06 | 0.55 | 3.80 |
| 6. Para rubber | 0.08 | 4.20 | 0.19 | 0.68 |
| 7. Pineapple | 0.66 | 1.94 | 1.77 | 0.30 |
| 8. Longan | 0.17 | 0.99 | 0.05 | 0.59 |
| 9. Durian | 0.09 | 0.63 | 0.22 | 0.41 |
| 10. Mangosteen | 0.07 | 0.29 | 0.09 | 0.19 |

Source: [15]

[1] Productivity is raw material harvested from plantation field.

[2] Domestic consumption and export are the produced or processed materials, excluding residues.

**Table 2 Top-five animal products in Thailand.**

| Name | Number of head (million head) | Productivity[1] (Mt/y) | Domestic consumption[2] (Mt/y) | Export[2] (Mt/y) |
|---|---|---|---|---|
| 1. Broiler | 228.82 | 1.66 | 1.09 | 0.57 |
| 2. Layer hen | 52.95 | 0.67[2] | 0.66[2] | 0.01[2] |
| 3. Swine | 9.50 | 1.03 | 0.97 | 0.02 |
| 4. Cattle | 4.31 | 0.14 | 0.18 | 0.01 |
| 5. Dairy cow | 0.51 | 1.07 | 1.03 | 0.13 |

Source: [15]

[1] Productivity, domestic consumption and export are the produced or processed materials, excluding residues.

[2] Calculated from the average mass per egg [16]

### *Data collection*

The reliable data used in this study come from both primary and secondary sources. Primary data were obtained from site visits, sample collection, and laboratory analyses. Face-to-face interviews with animal farm owners were carried out, using questionnaires, to gather all relevant farm-operational records, including the quantities of feeds, chemicals, energy consumed, manure treatment and/or utilization, product marketing, and final waste disposal. Samples of wastewaters, manures, and sludges were collected and sent to the laboratory of Land Development Department, Ministry of Agriculture and Cooperatives, for analysis. For secondary data, statistical records of import and export of agricultural products were taken from official document, such as annual reports and bulletins posted in the webpage and/or published by concerned governmental offices. In addition, phosphorus contents in harvested crops, animal products, feeds, and manures were sought from literature. They are summarized in Table 3. Flow diagram of phosphorus transport in agricultural ecosystem of the country was then established to show step-by-step mass balance activities and pathways with the functional unit of ton phosphorus per year. Other sources of data are presented in Table 4.

## 3. RESULTS AND DISCUSSION

### *P flows in cultivation system*

Beginning with nutrients essentially used for promoting plant growth, Thailand's import of chemical fertilizers grew from 3.8 Mt/y in 2008 to 5.6 Mt/y in 2014, as illustrated in Figure 1. Of these quantities are phosphorus compounds, which are accounted for annual average of 201,156 tons P. These imported P (59%) combined with P contained in recycled manures and recovered agro-industrial residues (41%) are the total amount of 316,557 tons P per annum applied on plantations of the country. Being transferred from ground to plant biomass with total P-equivalent harvest of 295,311 tons P/y, about 6.2% of applied P are found lost via agricultural runoff. Most P-containing harvests (80%) are milled to produce commodities, which will be traded in markets for both export and domestic consumption, while the other (20%) are used directly for animal feeds. Details of P contents in harvest and products of selected plants are shown in Table 5. The schematic flow diagram of phosphorus in Thailand's agricultural ecosystem is shown in Figure 2.

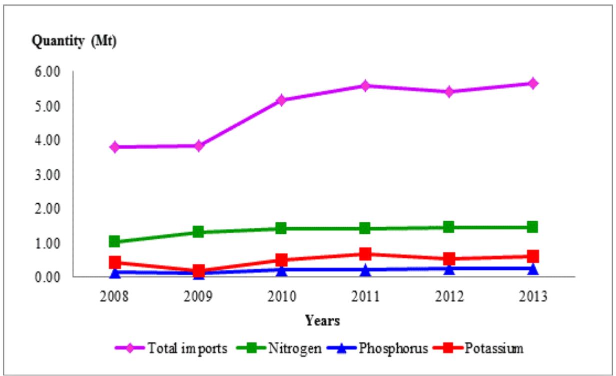


**Fig. 1. The imported quantities of chemical fertilizers by fertilizer template type**

**Table 3. P content in agricultural products.**

| Items | Unit | Value | Reference |
|---|---|---|---|
| **Field crops** | | | |
| Paddy | mg P/kg | 3,330 | [17] |
| Rice | mg P/kg | 1,150 | [17] |
| Maize | mg P/kg | 4,200 | [17] |
| Soybean | mg P/kg | 7,040 | [17] |
| **Energy crops** | | | |
| Cassava | mg P/kg | 270 | [17] |
| Sugar | mg P/kg | 40 | [17] |
| Oil palm | mg P/kg | 1,400 | [17] |
| **Horticulture** | | | |
| Para rubber | mg P/kg | 24,800 | [17] |
| Coffee | mg P/kg | 3,030 | [17] |
| Pineapple | mg P/kg | 80 | [17] |
| Longan | mg P/kg | 210 | [17] |
| Durian | mg P/kg | 390 | [17] |
| Mangosteen | mg P/kg | 80 | [17] |
| Potato | mg P/kg | 570 | [17] |
| Orchid | mg P/kg | 24,800 | [17] |
| **Livestock and Products** | | | |
| Broiler | mg P/kg | 1,830 | [17] |
| Hen egg | mg P/kg | 1,513 | [17] |
| Egg product | mg P/kg | 1,980 | [17] |
| Swine | mg P/kg | 2,000 | [17] |
| Cattle | mg P/kg | 3,240 | [17] |
| Milk and product | mg P/kg | 1,230 | [17] |
| **Feedstuffs** | | | |
| Grasses | %P* | 0.2 | [18] |
| Rice bran | %P* | 1.4 | [18] |
| Soybean meal | %P* | 0.5 | [18] |
| Cassava chip | %P* | 0.1 | [18] |
| Broken rice | %P* | 0.1 | [18] |
| Fish meal | %P* | 3.8 | [18] |
| **Manures** | | | |
| Cattle | %P** | 5.0 | [19] |
| Dairy cow | %P** | 5.0 | [19] |
| Swine | %P** | 2.0 | [19] |
| Broiler | %P** | 4.5 | [19] |
| Layer hen | %P** | 4.5 | [19] |

**Remark:** * %P dry weight; ** %P by weight

Note that no data information is available for human wastes recycled to plantation, but this quantity is believed to be very small because food grown with human-wastes-derived fertilizer is not socially acceptable yet, at present, and most of P-containing wastes are intercepted via sanitary treatment processes and finally end up in landfills or discharges into rivers and ocean, resulting in P loss from the country's ecosystem.

By-products from milling (formerly, mill's wastes) are processed and transformed into animal feeds. However, some bio-residues; such as rice husk, bagasse,

**Table 4. Sources of data used in this study**

| Sector | Details | Data sources |
|---|---|---|
| Fertilizers | Imported phosphorus fertilizer [1] | [5] |
| | Exported phosphorus fertilizer | [17] |
| Cultivation | Fertilizer application in agricultural plantations | Calculation |
| | Agricultural production, exports and domestic consumption (tons/y) [2] | [3] |
| | Imported agricultural products P in agricultural production (tons P/y) | [18] |
| Livestock | Number of animals (head) [3] | [19] |
| | P in animal feed broken down by animal type (tons P/y) | [20–21] |
| | Animal production, exports and domestic consumption (tons/y) | [3] |
| | P in animal production (tons P/y) | [18] |
| | The amount of animal manure (tons/y) | [22] |
| P losses | P in animal manure broken down by animal type (tons P/y) | [23] |
| | Agricultural runoff | [24] |
| | Industrial processing | Calculation |
| | Unidentified loss during animal husbandry | Calculation |
| | Identified loss in husbandry and processing | Calculation |

**Remark**

(1) Normally, phosphorus fertilizer was imported in the form of $P_2O_5$, but in this study, phosphorus in the form of P [$P = 0.44 \times P_2O_5$] is used.

(2) Using a sample group of 10 species of the major economic crops in the country.

(3) Using a sample group of 5 species of the major economic animals in the country, consisting of cattle, dairy cows, swine, layer hens, and broilers.

However, some bio-residues, such as rice husk, bagasse, and others, are used as fuel to operate steam power plants to generate electricity. After that, P contained in the ash is lost from the ecosystem as it finally stays in the landfills. These quantities are estimated to be 19,654.7 tons P/y or 8% of P inputs to the mills.

***P flows in livestock system***

Animal productions in Thailand are operated, using feeds containing total P of 159,028.8 tons P/y. As shown in Figure 2, in addition to biomass grown in the country, imports from aboard are used to make feeds for animal husbandry, ranging from ready-to-use feeds, minerals and vitamins blended to the feeds, and other additives. Moreover, imports of livestock and meat products also add up P to the total animal products of 7,405.4 tons P/y. After all, the resulting animal products (meat, milk, and egg) contain 4.5% of P. In rearing, 82% of P input are found in manures, of which 99% are returned to cultivation fields. Details of P content in animal products are summarized in Table 6. In some circumstances, manures are not only used as fertilizer applied on land for plant growth, but also as feed to anaerobic digester to produce biogas, which can be kept as gaseous fuel for further utilization. P-containing sludge wasted from the digester is used to apply on land for plant cultivation again. Examples of these manures are swine waste and cow dung. Other manures, like those from layer hen farm, are fed directly to fish pond. In this study, P-equivalent fish reared with manures are estimated to have a productivity of 384.4 tons P/y.

***P losses***

As shown in Figure 2, overall P losses from agricultural ecosystem are found to be 45,422.4 tons P/y, accounted for 17% of total P import. Such the losses are tabulated in Table 7. Significant P loss in the cultivation system is from milling process because bio-residues produced from milling are further used as fuel fed to power plant and finally left as P-containing inert material in landfills. Meanwhile, the other significant P loss in livestock system is from animal husbandry. As most rearing farms are located in rural area, wastes discharged from these farms might not be properly treated, thereby resulting in P losses due to deposit in landfill and/or discharge into rivers/ocean.

## 4. CONCLUSION AND RECOMMENDATION

P flows in Thailand's agricultural ecosystem were analyzed as to quantify its current situation and find ways to improve its recovery and recycling potentials. The results of this study have shown that the country is heavily dependent on imported P fertilizer of about 201,156 tons P per annum, which are accounted for 76% of the total P inputs being used to drive both plant and animal productions. P exports in the form of fertilizer and agricultural products are amounting to 110,528.1 tons P/y equivalent to 42% of the total P inputs. About 41% are food consumed in the country and 17% lost from the ecosystem. P in such the losses is believed to accumulate in landfills and in sediment of various estuaries.

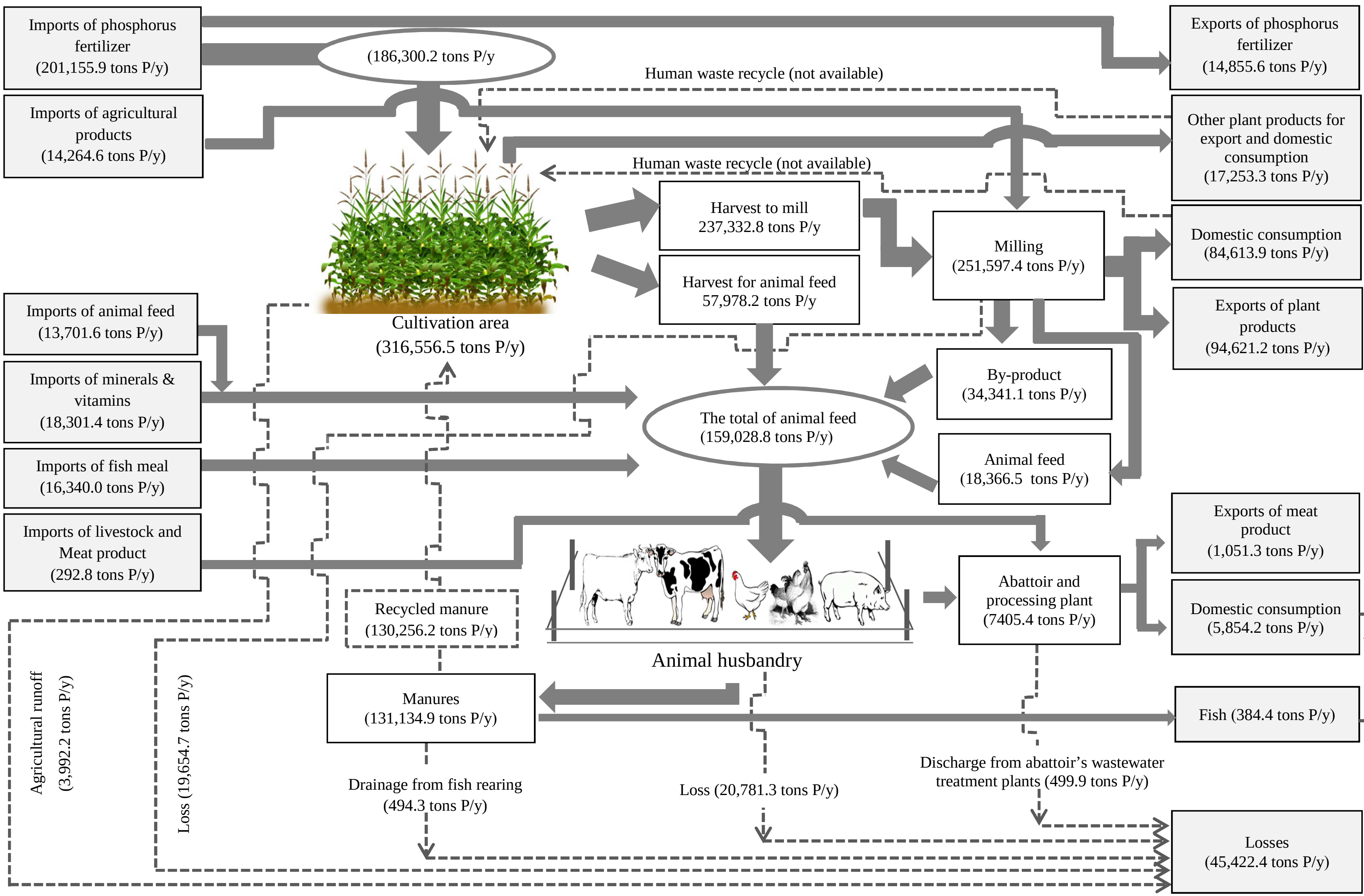


**Figure 2**. Diagram of P flows in Thailand's agricultural ecosystem.

**Table 5. Evaluation of phosphorus in plant production**

| Items | Average value (tons P/y) | | | |
|---|---|---|---|---|
| | Harvest | Domestic consumption[1] | Export[1] | Import[1] |
| **Field crops** | | | | |
| - Rice | 116,593 ± 9,557.0 | 54,064.9 ± 3,284.8 | 10,157.8 ± 1,891.4 | - |
| - Maize | 19,566 ± 1,838.0 | 18,048 ± 1,345.7 | 1,854.0 ± 1711.8 | 1,110 ± 578.9 |
| - Soybean | 875.0 ± 420.2 | 13,828.6 ± 1,303.7 | 16.1 ± 12.2 | 12,953.6 ± 492.9 |
| **Energy crops** | | | | |
| - Cassava | 7,300.4 ± 1,053.9 | 2,090.9 ± 189.8 | 2,131.7 ± 433.6 | - |
| - Sugar | 361.1 ± 68.2 | 90.5 ± 9.6 | 231.0 ± 36.6 | 0.2 ± 0.2 |
| - Oil palm | 2,446 ± 507.2 | 1,992 ± 361.1 | 436.0 ± 197.6 | 60.7 ± 21.4 |
| **Horticulture** | | | | |
| - Para rubber | 88,217.1 ± 13,734.9 | 11,797.7 ± 1,452.1 | 78,899.4 ± 11,651.1 | - |
| - Coffee | 136.6 ± 21.1 | 191.9 ± 23.3 | 17.6 ± 7.9 | 84.9 ± 39.1 |
| - Pineapple | 173.0 ± 21.2 | 15.6 ± 5.8 | 58.5 ± 11.3 | - |
| - Longan | 141.9 ± 56.2 | 8.4 ± 1.9 | 99.3 ± 28.8 | - |
| - Durian | 228.6 ± 22.9 | 102.2 ± 37.6 | 211.2 ± 29.3 | - |
| - Mangosteen | 18.5 ± 4.4 | 7.6 ± 3.5 | 10.9 ± 4.6 | - |
| - Potato | 69.9 ± 9.5 | 124.1 ± 11.8 | 1.0 ± 0.4 | 55.2 ± 10.8 |
| - Orchid | 1,204.9 ± 135.2 | 617.9 ± 102.8 | 586.8 ± 41.4 | 0.1 ± 0.04 |
| **Total** | **237,332.8 ± 2,532.6** | **102,980.4 ± 485.7** | **94,621.2 ± 2,060.7** | **14,264.6 ± 363.0** |

[1]Product quantity, excluding residues

**Table 6. Evaluation of phosphorus in animal production**

| Items | Average value (tons P/y) | | | |
|---|---|---|---|---|
| | Product | Domestic consumption | Export | Import |
| **Livestock and Products** | | | | |
| - Broiler | 2,542.7 ± 304.1 | 1,686.7 ± 183.0 | 856.0 ± 135.6 | - |
| - Hen egg | 903.8 ± 77.3 | 886.1 ± 84.0 | 17.7 ± 10.9 | - |
| - Egg product | - | - | 7.0 ± 0.9 | 3.2 ± 0.5 |
| - Swine | 1,978.9 ± 83.9 | 1,886.6 ± 81.2 | 25.0 ± 6.0 | 30.4 ± 6.1 |
| - Cattle | 509.1 ± 42.0 | 585.1 ± 1.2 | 15.4 ± 14.9 | 28.2 ± 22.8 |
| - Milk and product | 1,178.3 ± 142.9 | 809.8 ± 527.5 | 130.2 ± 14.4 | 31.1 ± 33.3 |
| **Total** | **7,112.6 ± 103.8** | **5,854.2 ± 207.2** | **1,051.3 ± 51.8** | **292.8 ± 14.4** |

**Table 7. The quantity of P loss in all agricultural sectors**

| Activities | P loss (tons P/y) | Loss (%) |
|---|---|---|
| **Cultivation** | | |
| - Agricultural runoff | 3,992.2 | 8.8 |
| - Industrial processing | 19,654.7 | 43 |
| **Livestock** | | |
| - Unidentified loss during husbandry | 20,781.3 | 46 |
| - Drainage from fish rearing | 494.3 | 1.1 |
| - Discharge from abattoir’s wastewater treatment plant | 499.9 | 1.1 |
| **Total losses** | **45,422.4** | **100** |

Based on the finding of this study, attention should be paid on three points of interest to minimize P losses from the ecosystem. Firstly, appropriate technology for P recovery and recycling of final residues (usually, ashes) from milling processes should be sought out. If so, this will bring about 19,654.7 tons P/y back to cultivation field, thereby reducing 43% of P losses. Secondly, on-site animal waste management should be thoroughly upgraded so that P in all farm wastes can be recycled most efficiently. Finally, in order to save costs from P import and increase food security of the country, research and development for P recovery and recycling of urban wastes should be supported as to find the best available technologies for implementation. In addition, food grown with P fertilizer produced from recovered human's wastes should be promoted so as to gain more public acceptance.

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## REFERENCES

[1] OAE (Office of Agricultural Economics), 2012. Report to the population number of the agricultural sector in 2012. Office of Agricultural Economics, Ministry of Agriculture and Cooperatives (MOAC), Bangkok, Thailand.

[2] ODI (Overseas Development Institute), 2011. Thailand's progress in agriculture: Transition and sustained productivity growth. ODI publications, London, UK.

[3] OAE (Office of Agricultural Economics), 2013. Annual Report: Basic information of Agricultural Economics. Office of Agricultural Economics, Ministry of Agriculture and Cooperatives (MOAC), Bangkok, Thailand.

[4] The Customs Department. Products exported of Thailand, 2015. Ministry of Finance, Bangkok, Thailand. Retrieved January 15, 2015, from http://www2.ops3.moc.go.th/.

[5] OAR (Office of Agriculture Regulation), 2013. Chemical fertilizers import of Thailand. Office of Agricultural Economics, Ministry of Agriculture and Cooperatives (MOAC), Bangkok, Thailand.

[6] Cordell, D., J.-O. Drangert and S. White, 2009. The story of phosphorus: Global food security and food for thought. Global Environmental Change; 19(2): 292-305.

[7] Cordell, D., A. Rosemarin, J. J. Schröder and A. L. Smit, 2011. Towards global phosphorus security: A systems framework for phosphorus recovery and reuse options. Chemosphere; 84(6): 747-758.

[8] Schröder, J. J., Smit, A. L., Cordell, D., Rosemarin, A., 2011. Improved phosphorus use efficiency in agriculture: A key requirement for its sustainable use. Chemosphere; 84(6): 822-831.

[9] Smit AL, Bindraban PS, Schröder J, Conijn J &Van der Meer H., 2009. Phosphorus in agriculture: global resources, trends and developments. Report to the Steering Committee Technology Assessment of the Ministry of Agriculture, Netherlands, Wageningen.

[10] Cordell, D., M. Jackson and S. White., 2013. Phosphorus flows through the Australian food system: Identifying intervention points as a roadmap to phosphorus security. Environmental Science & Policy; 29(0): 87-102.

[11] Wu, H., Z. Yuan, Y. Zhang, L. Gao and S. Liu., 2014. Life-cycle phosphorus use efficiency of the farming system in Anhui Province, Central China. Resources, Conservation and Recycling; 83(0): 1-14.

[12] Senthilkumar, K., A. Mollier, M. Delmas, S. Pellerin and T. Nesme., 2014. Phosphorus recovery and recycling from waste: An appraisal based on a French case study. Resources, Conservation and Recycling; 87(0): 97-108.

[13] Schmid Neset, T.-S., H.-P. Bader, R. Scheidegger and U. Lohm., 2008. The flow of phosphorus in food production and consumption — Linköping, Sweden, 1870–2000. Science of The Total Environment; 396(2–3): 111-120.

[14] Qiao, M., Y.-M. Zheng and Y.-G. Zhu., 2011. Material flow analysis of phosphorus through food consumption in two megacities in northern China. Chemosphere; 84(6): 773-778.

[15] OAE (Office of Agricultural Economics)., 2015. Annual Report: Situation of agricultural product and trends 2015. Office of Agricultural Economics, Ministry of Agriculture and Cooperatives (MOAC), Bangkok, Thailand.

[16] Royal Thai Government Gazette., 2010. Thai agricultural standard TAS 6702-2010. Published in the Government Gazette, Volume 127, Part 150, Special Issue, Dec. 28, 2010.

[17] The Customs Department. Chemical fertilizers export of Thailand, 2014. Ministry of Finance, Bangkok, Thailand 2012-2014. Retrieved January 12, 2015, from http://www2.ops3.moc.go.th/.

[18] USDA (United States Department of Agriculture)., 2014. National Nutrient Database for Standard Reference Release26. Retrieved November 1, 2014, from http://ndb.nal.usda.gov/ndb/foods.

[19] Information and Communication Technology center. Number of animals in Thailand. Department of Livestock Development, Ministry of Agriculture and Cooperatives (MOAC), Bangkok, Thailand

2014, Retrieved November 1, 2014, from http://ict.dld.go.th/th2/index.php/th/report.

[20] Planning Division. Report to the minerals in animal feed., 1996. Department of Livestock Development, Ministry of Agriculture and Cooperatives (MOAC), Bangkok, Thailand.

[21] TFMS (Thai Feed Mill Association). The quantity of animal feed consumption in Thailand. Retrieved December 22, 2014, from http://www.thaifeedmill.com/tabid/56/Default.aspx.

[22] Werner, U., Stöhr, U., & Hees, N., 1989. Biogas plants in animal husbandry. GATE, a Divisio of the GTZ GmbH.

[23] DOA (Department of Agriculture)., 2006. Report to the quantity of nutrient in animal manure. Department of Agriculture, Ministry of Agriculture and Cooperatives (MOAC), Bangkok, Thailand.

[24] PCD (Pollution Control Department)., 2011. The situation of water pollution from rice field and management. Retrieved January 9, 2015, from http://infofile.pcd.go.th/water/water_rice.pdf.