# Soil Nutrient Balance in Farming Systems of the Agricultural Resource System Research Station, Chiang Mai, Using Plot Database for Rapid Assessment

Tupthai Norsuwan[1], Sittichai Lodkhew[1], Kularb Utasuk[1], Thakoon Panyasai[1] and Chanchai Sangchyoswat[2]

[1]Agricultural Resource System Research Center, Faculty of Agriculture, Chaing Mai University, Chiang Mai, Thailand
[2]Plant Science and Natural Resources, Faculty of Agriculture, Chiang Mai University, Chiang Mai, Thailand

## Abstract

The objective of this study was to assess the soil nutrient and organic carbon balances in a farming system of Agricultural Resource System Research Station, Chiang Mai, Thailand. According to FAO framework, quantification of key soil nutrient inputs and outflows by plant nutrient components and regression models were applied to evaluate soil nutrient and soil organic carbon balances by using the extracted data of 39 rice-based cultivated plots from the tailored plot database during July, 2014 and June, 2015. The assessment results indicated that 63.13 kg N and 40.52 kg K/ha/yr from crop residue and green manure sources (IN2) were needed for maintaining the balances. In order to maintain phosphorus balance, only phosphorus from IN2 was not possible, but needed to apply 65.03 kg P/ha/yr from mineral fertilizer and manure sources (IN1). At least 5,219 kg/ha/yr of organic carbon was required to recover the soil organic carbon balance, which in the cultivation implementation, incorporating one crop of green manure before rice cultivation should be considered.

**Keywords:** farming system, farm-plot database, soil nutrient balance

## 1. Introduction

In farming system research, productivity, stability and sustainability of the system were applied to describe the status of the system, which could be analyzed from the pattern of land use, timing and resource flows and decision [1, 2]. Macro nutrient flows in the system could be used to diagnose the consequences and to draw the suitable measurement to improve and maintain the agroecosystem [3]. Although the global positioning system and on-the-go soil sensors has been developed for site specific management of fertilizer input in production system, the technologies and tools are expensive for small farm in developing countries [4, 5].

Instead of direct measurements, quantitative assessment for soil fertility provides quick overview and awareness raising [6]. In order to trace soil nutrient balances of nitrogen phosphorus and potassium, key nutrient inputs and outputs were characterized and quantified as regression models in a bounced system [7, 8]. The approach was used to monitor at various scales based on

*Corresponding author: E-mail: tupthai.n@cmu.ac.th

estimation of existed database and soil nutrient-balance modeling [9]. However, the original regression models were developed from the limited data sets and lack of validation [10], which were lately re-estimated and integrated into land use map, soil map and climate database to evaluate spatial soil nutrient balance in West Africa [11].

Having been applied widely, the principle of data-driven decision supporting system is known as "Helping managers monitoring operational performance or gain intelligence from historical data" [12]. Data acquisition is the first step to support decision making [13]. In the experimental farm management, database manipulation of field-plots on day-to-day basis could be applied to track of resource utilization, which it is needed to analyze for making decision on farm resource allocation [14]. The objective of this study was to use farm-plot database, the identified key nutrient inputs and outputs, and the referred soil nutrient models, which were purposely to evaluate soil nutrient and organic carbon balances. The gaseous loss equations and organic carbon balance equation was additionally used to properly reflect a lowland rice-base production system of Agricultural Resource System Research Station, Chiang Mai University, Chiang Mai, Thailand. Sucharapid assessment case quantified the effect of nutrient input sources on soil nutrient balance and allow to draw the implementation for proper cultivations implementation.

## 2. Materials and Methods

The assessment was carried out on 39 plots, covering 5.2 ha of Agricultural Resource System Research Station, Chiang Mai University, Chiang Mai, Thailand (18º46'N, 98°55'E, 350 m a.s.l.) during July, 2014 and June, 2015. The soil is a loamy-skeletal, mixed, isohyperthermic Typic (Kandic) Paleustult, Mae Rim soil series. The average soil organic matter, available phosphorus and exchangeable potassium in the upper 30 cm of the soil from 20 plots in the research station were 1.5%, 36.7 mg/kg and 28.3 mg/kg, respectively. The plots were mainly used for crop production, including rice, corn and sun flower, and sunn hemp as green manure (Figure 1). Mineral fertilizers, 16-16-16, 16-20-0, 46-0-0 and 0-0-60, were applied regularly at various rates and amounts depending on planting crops and plot size. Chicken manure was applied to improve soil fertility in 80% of the total plot number.


**Figure 1.** Plots and planted crops in Agricultural Resource System Research Station between July, 2014 and June, 2015

The cultivation activities of the research station were recorded to tailored forms operated in MS Access, which were used to transfer into database tables on daily basis. Firstly, crop field form (Figure 2) consisted of plot ID, planting crop, crop cultivar, planting date, cultivated area, harvest date, harvest component, yield in a square meter, residue materials, residue in a square meter and incorporation percentage of crop residue. Secondly, fertilizer application form (Figure 3) consisted of plot ID, application date, current planted crop, plot area, application area, fertilizer material, and application rate.

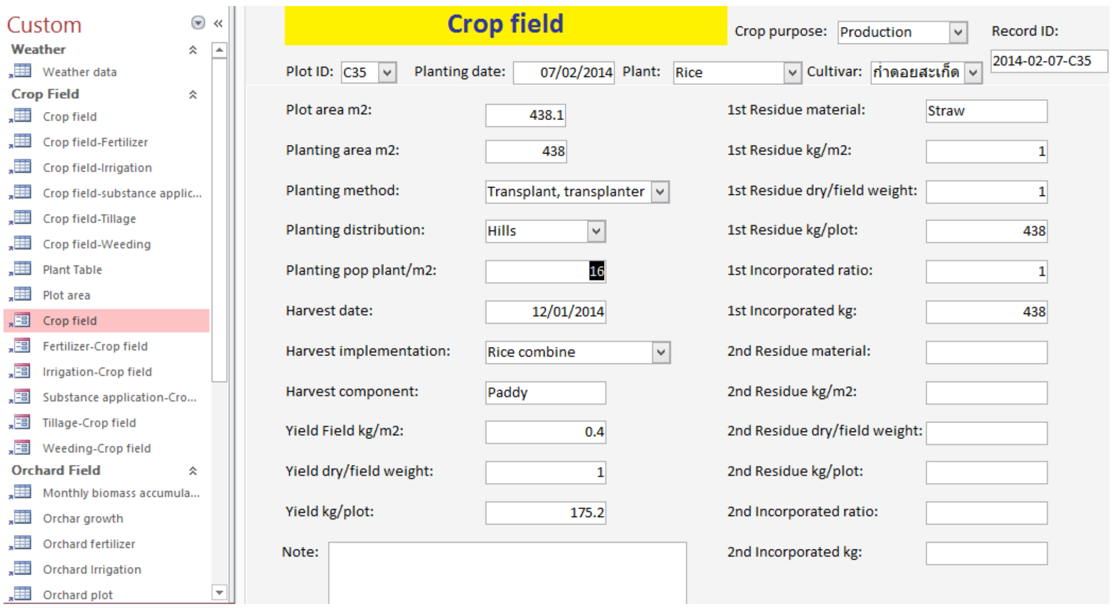


**Figure 2.** Tailored crop field form operated in MS Access

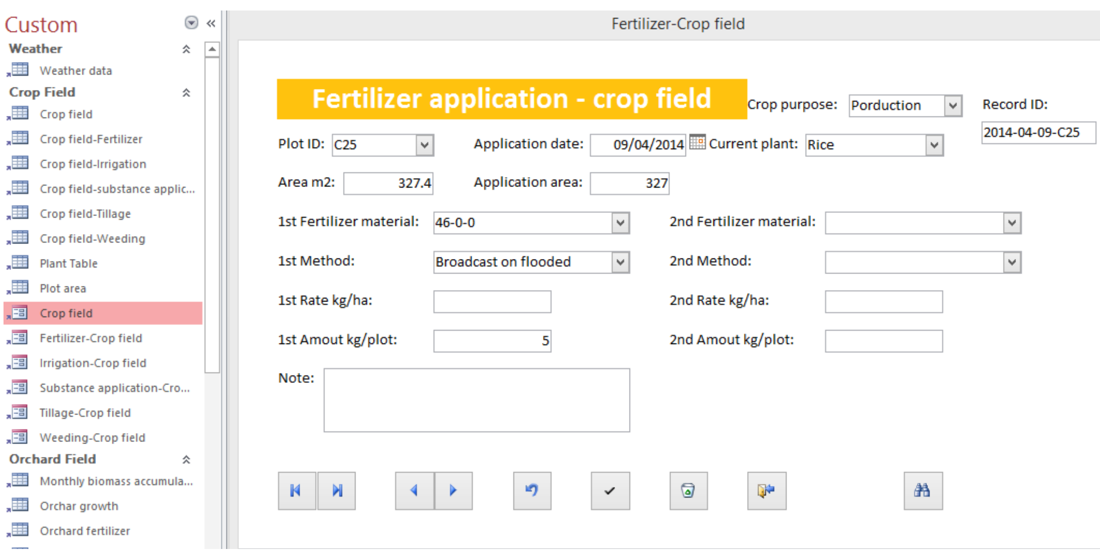


**Figure 3.** Tailored fertilizer application form operated in MS Access

Two replications of one-squire meter of planting crop's above ground components were set up aiming to quantify dry weight of yields, residues and green manure, and applied amount of mineral fertilizer, including manure and incorporation percentage of crop residue. Tracked material flows (Table 1) were allocated for soil organic carbon, nitrogen, and phosphorus and potassium dynamics in the plots. Assessment method of soil nutrient balances was mainly based on FAO Fertilizer and Plant Nutrition Bulletin 14 [9]. Soil organic carbon content was added into the assessment. Nitrogen, phosphorus and potassium balances and soil carbon content were monitored in each plot separately (eq.1).

$$\text{Soil nutrient balance} = \Sigma \text{ nutrient input} - \Sigma \text{ nutrient outflow} \quad (1)$$

Soil nutrient inputs of phosphorus and potassium were multiplied by recovery efficiencies because of soil desorption and sorption between soil solution, and Fe/Al oxides and clay mineral, respectively. The reviewed recovery efficiency of phosphorus and potassium for irrigated rice across Asia ranged from 0.22 to 0.35 and 0.35 to 0.66 kg/kg, respectively [15]. Mean of the range were adopted for the assessment, which were 0.29 kg/kg for phosphorus and 0.51 for potassium recovery rate of mineral fertilizer and manure application, and residue and green manure.

Plot-input and outflow material weights, known as, chemical fertilizer and manure application, yield and crop residues and green manure were converted to a certain amount of soil organic carbon and nutrient contents in the form of plant carbon and nutrient contents percentage in the crop components, which referred to literature reviews (Table 2).

**Table 1.** Input and outflow list and nutrient contribution

| Nutrient balance | Flow list | Nutrient contribution | Calculation method |
|---|---|---|---|
| Input | Mineral fertilizer and manure application | SOC, N, P, K | Component percentage |
| | Residue and green manure | SOC, N, P, K | Component percentage |
| | Atmospheric decomposition | N, P, K | Regression model |
| Outflow | Harvest | N, P, K | Component percentage |
| | Leaching | N, K | Regression model |
| | Gaseous losses | N | Likelihood model |
| | Organic carbon mineralization | SOC | Regression model |

**Table 2.** Percentage of organic carbon and nutrient content in crop components and materials obtained from literature reviews

| Crop and input material | Crop component | Percentage by dry weight | | | |
|---|---|---|---|---|---|
| | | Organic carbon | Nitrogen | Phosphorus | Potassium |
| Rice | Paddy | - | 1.15[16] | 0.12[16] | 0.30[16] |
| | Straw | 40.3[17] | 0.86[16] | 0.09[16] | 2.80[16] |
| Corn | Ear | - | 0.50[18] | 0.30[19] | 0.73[19] |
| | Stover | 49.4[20] | 0.40[18] | 0.12[19] | 1.23[19] |
| Soybean | Pod | - | 6.33[21] | 0.57[19] | 1.84[19] |
| | Straw | 48.0[20] | 1.81[21] | 0.13[19] | 1.80[19] |
| Sunflower | Head | - | 2.41 [22] | 0.96[22] | 0.89[22] |
| | Stover | 50.5 [20] | 1.30 [22] | 0.09[22] | 1.54[22] |
| Sunn hemp | Straw | 54.8[23] | 2.90[24] | 0.24[25] | 1.23 [25] |
| Chicken manure | - | 25.0[26] | 1.1[27] | 0.8[27] | 0.5[27] |
| Mineral fertilizer | | | | | |
| 16-16-16 | - | - | 16 | 16 | 16 |
| 16-20-0 | - | - | 16 | 20 | 0 |
| 46-0-0 | - | - | 46 | 0 | 0 |
| 0-0-60 | | | 0 | 0 | 60 |

### 2.1 Atmospheric deposition

Nitrogen deposition in the research station was 10.3 kg/ha, which was quantified from 0.009 kg/m$^3$ of $NH_4^+$ and $NO_3^-$ in urban area in Chiang Mai [28] and 1,148 mm/yr of precipitation in Chiang Mai from 2010 to 2014 [28]. Regression functions were used to quantify phosphorus and potassium deposition (eqs.2 and 3) [8].

$$Pd = 0.023 \times p^{0.5} \quad (2)$$

$$Kd = 0.092 \times p^{0.5} \quad (3)$$

where Pd = phosphorus deposition (kg P/ha/yr)
Kd = potassium deposition (kg K/ha/yr)
p = annual precipitation (mm/yr)

### 2.2 Leaching

Leaching nitrogen and potassium were monitored by the regression models (eqs.4 and 5) based on literature review to estimate the amount of the leached nitrogen and potassium in wide range of soil and climates [29]. The input parameters of the equation were adopted from "Characterization of Established Soil Series in the North and Central Highland Region of Thailand Reclassification" [30]. Bulk density, clay content and cation exchange capacity (CEC) of Mae Rim soil series at 0-30 cm depth were 1.63 g/cm$^3$, 14.5% and 3.8 cmol/kg, respectively. Applications of chemical fertilizer and manure were transferred to mineral and organic fertilizer of nitrogen and potassium by percentage of mineral content (Table 1). Decomposition rate was referred as 0.03 kg/ha/yr based on rice-base production system of 53 plots in KhonKaen, Thailand during the dry season of December to April 2005 [31]. The average soil organic matter percentage and bulk density value were used for the calculation of actual amount of soil organic matter and later was converted into the amount of nitrogen, using 1:0.05 ration between soil organic matter total nitrogen [32].

Nitrogen uptake in crop was estimated from dry weight of yield and residue multiplied by percentage of nitrogen content in crop components.

$$Nl = (0.0463 + 0.0037 \times (P / (C \times L))) \times (F + D \times NOM - U) \quad (4)$$

where
Nl = nitrogen leaching (kg N/ha/yr)
P = annual precipitation (mm)
C = clay%
L = layer thickness (m)
F = mineral and organic fertilizer of nitrogen (kg N/ha)
D = decomposition rate
NOM = amount of nitrogen in soil organic matter (kg N/ha)
U = nitrogen uptake by crop (kg N/ha)

$$Kl = -6.87 + 0.0117 \times P + 0.173 \times F - 0.265 \times CEC \quad (5)$$

where
Kl = phosphorus leaching
P = annual precipitation (mm)
F = mineral and organic fertilizer of potassium (kg K/ha)
CEC = cation exchange capacity (cmol/kg)

## 2.3 Gaseous losses

Denitrification of $N_2O$ and NO, and volatilization of $NH_3$ were determined according to "the Global estimation of gaseous emissions of $NH_3$, NO and $N_2O$ from agricultural land" [33]. Likelihood model (eq.6) were applied to predict NO and $N_2O$ emissions separately, and $NH_3$ (eq.7). The selected determining factor classes (n) consisted of fertilizer type and rate, crop type, soil texture, soil organic carbon content%, soil drainage, soil pH, CEC and climate.

$$\text{Ln (Emission)} = \sum \text{Factor class value (n)} \quad (6)$$

$$\text{Ln (Loss fraction of } NH_3) = \sum \text{Factor class value (n)} \quad (7)$$

where
Emission = emission amount $N_2O$ and NO separately (kg/ha)
Loss fraction of $NH_3$ = the loss fraction of urea-N application

## 2.4 Organic carbon mineralization

The soil organic carbon content was monitored by considering as homogenous content with regarding its decomposition rate (eq.8) [34]. Soil organic carbon in the first year was 26,120 kg/ha. It was calculated from the average soil organic content and bulk density value of the soil while soil organic carbon content was converted from the amount of organic matter using the equation; total soil organic carbon = soil organic matter/1.724 [35]. The organic carbon balance was calculated in rice-planted plot based on the reviewed mineralization rate of the organic matter referred to soil condition of rice-base cropping system.

$$C_1 = C_0 e^{-K2t} + mc_r K1 (1 - e^{-K2t}) / K2 \quad (8)$$

where
$C_1$ = net total soil organic carbon content at the end of year ($10^3$ kg/ha)
$C_0$ = soil organic carbon content at the first year ($10^3$ kg/ha)
K2 = mineralization rate of the organic matter (0.03 kg/ha/yr) [31]
T = year number
M = the amount of organic dry matter supplied ($10^3$ kg/ha)
$c_r$ = the carbon content of the residue
K1 = iso-humic coefficient (rice straw was fixed at 0.15)

### 2.5 Regression analysis

Regression analysis was performed to determine coefficient of mineral fertilizer and manure application (IN1), and residue and green manure (IN2), which contributed to monitoring soil nutrient balance and soil organic carbon balance. Thirty four cultivated plots which were affected by harvested nutrient removal and 39 rice cultivated plots were selected for regression analysis of soil nutrient and soil organic carbon balances, respectively.

## 3. Results

### 3.1 Plant nutrient removals

Crop nutrient contributions were calculated from dry weight of above ground of the crop allotted to residues (straw and stover) and yield (paddy, ear and head) in one square meter multiplied by the percentage of plant nutrients in crop components (Table 3). Organic carbon mainly originated from crop residues, green manure and manure input incorporated in plots during land preparation before planting. The wide range of organic carbon from rice straw (± 913 kg/ha) obtained from the 37 rice-planted plots that have been planted six cultivars of rice in a given year. Also, cultivated rice and the incorporation of rice straw consequently provided the substantial amount of 244.8 ± 63.4 kg K/ha/yr (Table 3); thus, removing rice straw from the plot resulted in a negative impact on the nutrient balance.

### 3.2 Plant nutrient contribution in plots

Plot nutrient balances were calculated from inputs and outflows (Table 4) in 34 plots, where planting crops were harvested. Nitrogen balance ranged from -18 to 194.3 kg N/ha/yr, 5 from 34 plots were below zero (Figure 4A). Phosphorus balance ranged from -19 to 17 kg P/ha/yr under recovery coefficients 0.29 kg/kg, whereas 15 from 34 plots were in deficit (Figure 4B). Potassium balance ranged from -35 to 132 kg K/ha/yr under the recovery coefficient 0.51 kg/kg, while 1 from 34 plots was in deficit (Figure 4C).

Regression analysis between monitored soil nutrient balances and 2 different nutrient input sources; mineral fertilizer and manure (IN1) and crop residue and green manure (IN2) (Table 4) displayed that 85% of variability in nitrogen and potassium balance could be explained by the regression models. In the case of nitrogen, IN2 coefficient had very strong relationship with monitored soil nitrogen balance ($p \leq 0.01$). Partial effect of IN2 indicated that 1 kg N/ha from IN1 source provided 0.809 kg N/ha/yr to soil nitrogen balance in a given year.

**Table 3.** Average plan nutrient contribution by planted crops

| Crop | Crop component | Nutrient contribution (kg/ha) | | | |
|---|---|---|---|---|---|
| | | Organic carbon | Nitrogen | Phosphorus | Potassium |
| Rice(n=39) | Paddy | | 71.6± 16.2 | 7.5± 1.7 | 18.7± 4.2 |
| | Straw | 3,523± 913 | 75.2± 19.2 | 7.9± 2.0 | 244.8± 63.4 |
| Corn (n=4) | Ear | | 26.5 ± 8.2 | 15.9 ± 3.4 | 38.7 ± 10.2 |
| | Stover | 3,112 ± 445 | 25.2 ± 12.4 | 7.6 ± 1.9 | 77.5 ± 23.8 |
| Sun flower (n=1) | Head | | 250.6 | 99.8 | 92.6 |
| | Stover | 2,020 | 52.0 | 3.6 | 61.6 |
| Sunn hemp (n=10) | Straw (green manure) | 4,224± 361 | 171.4± 14.7 | 13.7± 1.2 | 149.0± 12.8 |

This table displayed mean ± Standard deviation. Mineral fertilizers were applied regularly, the return amount of nutrients were depended on incorporation percentage of the given crop residues.

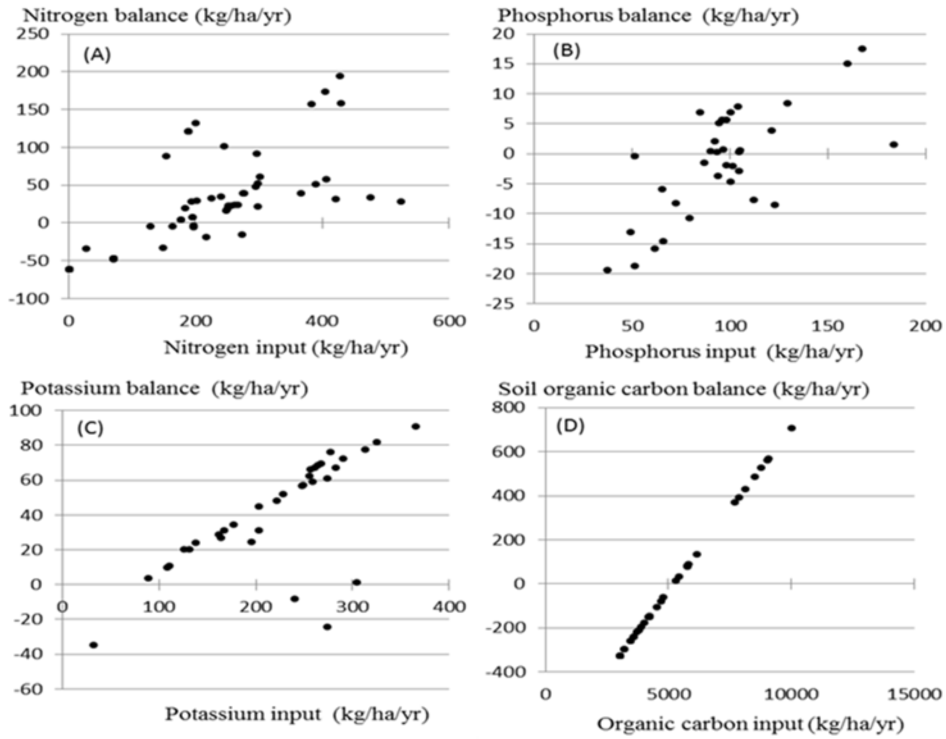


**Figure 4.** Input nutrients and calculated nutrient balances; nitrogen (A), phosphorus under recovery coefficient 0.29 (B), potassium under recovery coefficient 0.51 (C) and soil organic cabon (D)

The regression model of monitored soil potassium balance covered 66% of the variability. Both IN1 and IN2 significantly showed significant balance ($p \leq 0.01$). However, partial effect of IN2 was 1.56 times (0.459/0.293) higher than that of IN1, indicating that monitored potassium balance was sensitive to IN2 source rather than IN1 source. In case of phosphorus, 61% of the variability on phosphorus balance were explained by IN1 and IN2 variables in the regression model. The IN1 coefficient significantly related to the monitored balance ($p \leq 0.01$). The IN2 coefficient was not statistical significant ($p > 0.05$) and displayed inverse variation on the phosphorus balance.

**Table 4.** Regression analysis of monitored nutrient balance

| Variable | Coefficient of nutrient contribution (kg/ha/yr) | | | |
|---|---|---|---|---|
| | **Nitrogen** | **Phosphorus** | **Potassium** | **Organic carbon** |
| Constant | -51.075** (4.885) | -14.762** (3.602) | -22.730 (12.296) | -772.278** (0.091) |
| Mineral fertilizer and manure (IN1) | 0.021 (0.018) | 0.227** (0.033) | 0.293** (0.089) | - |
| Crop residue and green manure (IN2) | 0.809** (0.023) | -0.173 (0.121) | 0.459** (0.063) | - |
| (IN1) + (IN2) | - | - | - | 0.148** (0.008) |
| $R^2$ | 0.85 | 0.61 | 0.66 | 0.99 |
| No. plots | 34 | 34 | 34 | 39 |

Considering organic carbon as homogeneous content, standard errors are reported in parentheses.
*, ** significantly correlated at p≤0.05 and p≤0.01 probability levels, respectively

Organic carbon balance (Figure 4D) was calculated in 37 rice-planted plots excluded the rests because reviewed mineralization rate of the organic matter only referred to rice-base cropping system. Organic carbon balance ranged from -326 to 706 kg/ha/yr and, 28 from 37 plots were below zero. The deduction of organic carbon was strongly affected by the removal of residue materials because in some plots, rice straw was removed to use the area for different purposes. Considering organic carbon as a homogenous matter, the coefficients of IN1 and IN2 sources were merged together. Input of organic carbon had a positive relationship with the balance in soil. Incorporating 1 kg/ha/yr of organic carbon provided 0.148 kg/ha/yr to the balance.

### 3.3 Implementation from finding

The amount of N from IN2 source to maintain the balance (nitrogen balance = 0 N kg/ha/yr) could be calculated from the following regression model, nitrogen balance = -51.075 + 0.021 (IN1) + 0.809 (IN2) when nitrogen balance and IN1 = 0. From this calculation, nitrogen from IN2 source needs to be incorporated 63.13 kg N/ha/yr (51.075 / 0.809) (Table 5). Application of nitrogen fertilizer was exempt from maintaining the balance because coefficient value of IN1 was insufficient less than IN2 38.52 times (0.809/0.021). According to partial effects, 65.03 kg P/ha/yr and 77.56 kg K/ha/yr were from IN1 source were sufficient to maintain the balances. Phosphorus from IN2 was not considered to maintain the balance because of negative coefficient value. Combined effects between IN2 and IN1 input sources, 5,218 kg/ha/yr of organic carbon was required.

According to the partial effects, applied input nutrients from IN2 source had gained more advantage. Total balance of yearly incorporation of a sun hemp crop were 87.5 kg N; -51.075 + (171.4 x 0.809), 45.6 kg K and -147.1 kg/ha/yr of soil organic carbon without applying mineral fertilizer to the crop. In comparison, to gain 45.6 kg K/ha/yr in the total balance, 233.4 kg K/ha/yr; (45.6 + 22.77) / 0.293 from IN1 source equaling to 389.0 kg/ha of 0-0-60 mineral fertilizer was required. Referring to rice production in research station, 16-20-0 and 46-0-0 were normally applied, which equaled to 96.9 kg N and 31 kg P/ha/yr. The incorporation of rice straw provided 75.2 kg N, 7.9 P kg and 244.8 kg K/ha/yr in average. The total nutrient balance of rice cultivation were 11.79 kg N; -51.075 + (96.9 x 0.021) + (75.2x0.809), 89.63 kg K/ha/yr, and -250.87 kg/ha/yr of organic carbon. The monitored balance indicated that organic carbon lost 250.87 kg/ha under the cultivation of rice crop year by year. Therefore, organic carbon 1,696 kg/ha/yr; 5,219-3,523 had to be added to maintain the balance, which it could be compensated by incorporating sunn hemp.

**Table 5.** Amount of nutrient contribution to maintaining soil nutrient balance by sources of nutrient input

| Nutrient input source | Nutrient contribution (kg/ha/yr) | | | |
|---|---|---|---|---|
| | Nitrogen | Phosphorus | Potassium | Organic carbon |
| Mineral fertilizer and manure (IN1) | - | 65.03 | 77.56 | - |
| Crop residue and green manure (IN2) | 63.13 | - | 49.52 | - |
| IN1 +IN2 | - | - | - | 5219 |

The amount of nutrientswas calculated from coefficient values of constant and nutrient input sourcesin Table 4; the amount = - constant / IN, when, nutrient balance = 0 kg/ha/yr

## 4. Discussion

Tailored farm-plot database provided the substantial database of varied cultivations of plots. Assessment of soil nutrient and soil organic carbon balance reflected an annual consequence of land use in farming system instead of direct measurements. The preliminarily rapid findings from the assessment indicated potential problems and led to draw the farm-based implementation to improve soil nutrient balance in the production system. The assessment results could be applied in both plot-specific and entire farm measurements.

However, the conventional experiments on site and critical direct measurement methods were necessary to validate the assessment results and to develop the accuracy of the regression model in the specific soil condition of the farm system. In order to improve instant assessment results, the concept of labile, stable and inert nutrient pools could be adapted into the regression models [36]. Nitrogen from irrigation water and biological fixations were discarded in this assessment. The previous study showed that irrigation water and biological fixations portioned around 0.035 and 0.082 of nitrogen balance in rice-base production system, respectively [37]. In comparison with this assessment, the recovery coefficients of added phosphorus and potassium in the soil were in a wide range and dependent on other factors, for instance, from 0.31 to 042 and 0.57 to 0.78, respectively. Those did not just only depend on soil type and clay content, but also the input rates applied [38].

In the previous study of rice production system, available soil phosphorus reduced overtime due to insufficient phosphorus inputs under various fertilizer practices [39, 40]. In this assessment, 0.90 of total uptake potassium in rice were in the straw; hence, potassium balance was negative because of rice straw generally not being incorporated into the soil. This finding was correspondent with previous studies [41, 42]. Potassium from irrigation water was not accounted for the balance in this study. However, potassium from irrigation water could contribute 0.36 of the potassium balance of intensive rice-farming systems [37]. A coefficient in phosphorus from IN2 showed negative value. This was possibly due to portion of phosphorus from IN2related to phosphorus in OUT1 positively, which the greatest portions of IN2 and OUT1 were rice straw and rice yield, respectively. Comparatively, some study showed that phosphorus accumulation in yield was greater than phosphorus accumulation in incorporated straw [43]. Phosphorus accumulation in yield was positively correlated with yield, whereas phosphorus accumulation in straw was negatively correlated with yield [44].

In this assessment, soil organic carbon was considered as homogenous matter and adopted a certain decomposition rate at a reviewed rice field condition. Correspondingly, reginal scale evaluation of carbon sequestration in rice fields of Thailand using 6,422 soil nutrient testing results displayed the similar decomposition rate as 0.03 of total soil organic carbon [45]. However, first-order process or process-oriented model was suggested to distinguish decomposition rate of different soil organic compartments under various air temperature [46]. In China, rice-wheat rotation by 0.15 of above-ground crop residue and livestock wastes were incorporated to soil, which equal to 97 to 102 kg/ha/yr added to the system at 0-30 cm soil depth [47]. In comparison with this farming system, entire incorporation of rice-corn residue provided positive balance of organic carbon around 80 to 392 kg/ha/yr.

## 5. Conclusions

This study provided preliminary insight quantification of crop nutrient balance under lowland rice cultivation using extracted farm-plot database. The results could be used for guidance to maintain crop nutrient balance on site annually. Further study, rice yield and growth gaps within the heterogeneous nutrient balances of different plots are needed to investigate and to compare with monitored nutrient balances, which could be more supportive for site-specific management.

## 6. Acknowledgements

The authors would like to thank Prof. Dr. Attachai Jintrawet for his advice in writing guideline for this paper. The authors thanks to the Center for Agriculture Resource System Research, Faculty of Agriculture, Chiang Mai University for providing field staff and facilitation in the assessment.

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