Nutrient Balances in a Rice–Vegetable System: A Case Study of an Intensive Cropping System in Ilocos Norte, the Philippines

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ABSTRACT

Sustaining soil fertility for economically motivated intensive agriculture is a challenge in the rainfed lowlands of Ilocos Norte, the Philippines. Many residual nutrients are left in the soil after the harvest of dry season crops such as sweet pepper, garlic, tomato, and tobacco. Some of these nutrients are prone to loss through leaching, denitrification, and fixation. Conservation and recycling of nutrients are essential for maintaining soil fertility and the resource base. Partial nitrogen (N) balances have indicated that the integration of a nutrient 'retention' crop during dry to wet season (DTW) transition reduced N losses by 39 to 59 percent. However, the introduction of a cash crop alone was not able to reduce the high N losses in the rainfed lowland system investigated. A positive P balance was observed, which ranged from 63 to 123 kg ha^{-1} (0-25 cm soil depth). A higher balance was observed in plots where nutrient 'retention' crops were grown and residues were incorporated. Nutrient 'retention' crops, especially indigo, improved the K balance in the soil by 34 to 67 percent. The K balance was positively correlated with K input. The C balance indicated a loss of about 600 kg ha^{-1} of labile C from the top 0–25 cm of the soil profile in the farmers' practice (keeping the land fallow) and a gain of up to 3,000 kg ha^{-1} with nutrient 'retention' crops grown during the transition period with residue incorporation before rice transplanting.

INTRODUCTION

Maintaining soil fertility is essential to meeting the food requirements of a rising population. Rice is the staple food of 2.4 billion people worldwide. Further, it is estimated that by 2050, this figure will have increased to 4.6 billion people. This means that more than one billion tonnes of rice must be produced just to maintain current per capita consumption. Irrigated rice ecosystems are already under severe stress and are not likely to expand. To meet the rice needs of the future, we must look to the less favorable, high-risk ecosystems of the rainfed lowlands.

The loss of nutrients from the soil is both an agricultural and environmental concern. The long-term sustainability of agricultural systems depends on maintaining the level of soil Organic Matter (OM) and associated nutrients. Understanding how ecosystems are altered by intensive agriculture, and developing new strategies that take advantage of ecological interactions within agricultural systems are crucial to the continuance of high-production sustainable agriculture (Matson et al., 1997).

The rainfed lowlands of northern Luzon, the Philippines, which exemplify high cropping intensity and input use, serve as a model system for intensified agriculture. The wet season rice followed

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by one or two dry season non-rice crops including sweet pepper, tomato, garlic, mungbean, corn, and tobacco are among the most common cropping systems. Alternate soil drying (aerobic) during the dry season and wetting (anaerobic) during the wet season are the main features of this system. The cropping system is input intensive. Farmers apply 394–698 kg N ha^{-1}, 64–213 kg P ha^{-1} and 88–347 kg K ha^{-1} (Sta Cruz et al., 1995; Tripathi et al., 1997; Shrestha, 1997). Irrigation and pesticide applied for dry season rice-rotation crops are estimated to be 18 times (Lucas et al., 1999) and 22 times (Shrestha, 1997), higher respectively as compared to the wet season condition. This has revolutionized the crop production system. Previously, Tripathi et al., (1997) reported large N losses of up to 550 kg ha^{-1} across a range of cropping patterns, with the largest occurring in the rice–sweet pepper system, which is the predominant cropping sequence in northern Luzon, the Philippines. The major pathway of N loss is NO_3^- leaching to the groundwater (Shrestha and Ladha, 1998). Groundwater utilized as drinking water contains NO_3^--N at concentrations > 10 mg l^{-1} and is considered unsafe for human consumption (Fletcher, 1991; Viets and Hagemen, 1971). Due to excess use of N fertilizer by farmers, other problems such as decline in soil OM and imbalances of other nutrients are rapidly emerging.

The development of sustainable nutrient management systems that conserve and recycle nutrients is imperative for economic and environmental sustainability. A possible strategy is to grow a nutrient ‘retention’ crop during the transition period between the dry season and the wet season when the soil would otherwise have been left bare. It is envisaged that a nutrient ‘retention’ crop, apart from accumulating NO_3^--N, would preclude NO_3^- loss upon soil flooding and permit recycling of other macro- and micronutrients to the succeeding rice crop. Incorporation of the residue of the nutrient ‘retention’ crop grown during this dry to wet season transition period can also increase the quality and quantity of soil OM. Thereby, the use of a nutrient ‘retention’ may in large part reduce the demand for continued high fertilizer inputs. Residue mineralization can be expected to be high in the first year, but what is not mineralized will mineralize slowly over the succeeding year (Jensen, 1991; 1992). Residue recycling provides a greater buffering capacity for the soil with respect to nutrients and fertility attributes, namely C, N, P, and K.

Changes in the cropping system and residue utilization are likely to affect the quality and quantity of soil OM. The effect of a nutrient ‘retention’ crop on the soil OM status has not been studied in the context of an intensive system. The development of a sustainable agriculture system requires techniques that monitor changes in the amount of soil OM, especially the labile (active) pool, and accurately evaluate nutrient balances under different management systems. This paper describes the effect of selected nutrient ‘retention’ crops on partial nutrient (C, N, P, and K) balances in an intensive rice–vegetable system of Ilocos Norte, the Philippines.

NUTRIENT BUDGET MODEL

A partial nutrient budget model for C, N, P, and K was developed to assess nutrient stocks and flows. A partial C balance was obtained with the difference of initial and final labile C in the soil. Fertilizers added to the soil for all the crops were the sources of nutrient inputs; nutrients captured by all the crops grown in one year were sources of nutrient outputs. Input and output differences were used to calculate the apparent N, P, and K balance. The labile C balance was calculated for a 25 cm soil depth.

Nitrogen (N), Phosphorus (P), and Potassium (K) Balance

The mineral N balance was calculated to evaluate the effect of the nutrient 'retention' crop and wet season management on reducing N losses (Table 1). The N loss from the 100 cm soil profile ranged from 109 to 317 kg ha^{-1}. It was highest in the sweet pepper–fallow–rice system and lowest in the sweet pepper–corn–rice system where corn residue was incorporated in the rice field.

Table 1. System level partial N balance of a sweet pepper–rice cropping system at Magnuang, Philippines (average of 4 sites).

Treatments	**Nitrogen (kg ha^{-1})**		
	Input from fertilizer (A)	**Output from crop uptake** (B)	**Balance** (A-B)
Sweet pepper–fallow–rice (n=4?)	558	241	317
Sweet pepper–indigo–rice (n=4)	519	390	129
Sweet pepper–indigo + mungbean–rice (n=4)	519	358	161
Sweet pepper–corn–rice (n=4)	519	411	109

The efficiency of the nutrient 'retention' crop in decreasing N loss was in the order of corn > indigo > indigo + mungbean. Corn was more efficient in its ability to capture a soil N (177 kg ha^{-1}) as compared with indigo (151 kg ha^{-1}) and indigo + mungbean (118 kg ha^{-1}) (data not shown). The reduction in N loss due to the integration of a nutrient 'retention' crop during the DTW transition and incorporation of the residue prior to the rice cropping season ranged from 66 % (corn to 49 % (indigo + mungbean) of N losses associated with the traditional fallow. The inability of the nutrient 'retention' transition crops investigated to reduce N losses completely may in part be due to the high buildup of soil mineral N which for the treatments evaluated ranged from 227 to 626 kg ha^{-1}, 97 % of which is NO_3-N (data not shown). This indicates that the strategy of introducing a transitional nutrient 'retention' crop alone is not effective enough to create a closed system and prevent N loss. There is therefore an urgent need to explore other avenues, especially reducing the N fertilizer application rates to better match the N-requirement by dry season crops.

Table 2. System level partial phosphorus balance of a sweet pepper–rice cropping system at Magnuang, the Philippines.

Treatments	**Phosphorous (kg ha^{-1})**		
	Input from fertilizer (A)	**Output from crop uptake (B)**	**Balance (A-B)**
Sweet pepper–fallow–rice	114	27	87
Sweet pepper–indigo–rice	127	42	85
Sweet pepper–indigo + mungbean–rice	127	38	89
Sweet pepper–corn–rice	127	48	79

The P balance was positive, ranging from 79–89 kg P ha^{-1} (Table 2). Incorporation of the indigo + mungbean nutrient ‘retention’ crops in the sweet pepper–indigo + mungbean–rice system gave a higher P balance as compared to indigo alone or the corn nutrient ‘retention’ crop with residue incorporation. The corn nutrient ‘retention’ had the least positive balance due to higher plant P uptake and removal losses.

Table 3. System level partial potassium balance of a sweet pepper–rice cropping system at Magnuang, the Philippines.

Treatments	**Potassium (kg ha^{-1})**		
	Input from fertilizer (A)	**Output from crop uptake (B)**	**Balance (A-B)**
Sweet pepper–fallow–rice	332	203	129
Sweet pepper–indigo–rice	357	318	39
Sweet pepper–indigo + mungbean–rice	357	303	54
Sweet pepper–corn–rice	357	467	-110

The K balance was positive for both the indigo and the indigo + mungbean treatments with crop residue incorporation. In contrast, corn residue incorporation resulted in a negative balance of -110 kg K ha^{-1} due to the large biomass and K uptake (467 kg K ha^{-1} for the sweet pepper–corn–rice system) as compared to indigo + mungbean (303 kg K ha^{-1} for the sweet pepper–indigo + mungbean–corn system) and indigo alone (318 kg K ha^{-1} for the sweet pepper–indigo–rice system). The balance was negative for the sweet pepper–corn–rice system as only 96 to 143 kg K ha^{-1} of K was returned to the soil out of 271 kg K ha^{-1} captured by the corn (data not shown). The balance was highly positive for the traditional sweet pepper–fallow–rice system as compared to the nutrient ‘retention’ crop treatments due to the absence of crop uptake during the DWT.

Nitrogen, Phosphorus and Potassium Recycling and Soil N-Status

Sweet pepper residue was incorporated in the sweet pepper–fallow–rice treatment whereas both sweet pepper and the respective nutrient ‘retention’ crop residues were incorporated in the nutrient ‘retention’ crop treatments (Table 4). The high amounts of residual soil N after the sweet pepper harvest result from excessive (500 kg N ha^{-1}) N–fertilizer application in the dry season sweet pepper crop. After the wet season crop of rice, residual soil N was significantly reduced. However, the incorporation of indigo residue increased residual soil N after the rice harvest as compared to the indigo + mungbean and corn treatments. This may in part be due to its deep rooting system.

Table 4. Recycling of residue N and soil N status in a sweet pepper– rice cropping system at Magnuang, the Philippines.

Treatments	**Soil residual N (kg ha^{-1})**		
	Residual N recycled	**Initial**	**Final**
Sweet pepper–fallow–rice	62	459	55
Sweet pepper–indigo–rice	137	459	61
Sweet pepper–indigo + mungbean–rice	134	459	56
Sweet pepper–corn–rice	127	459	56

Although recycled residue P was small (3–10 kg P ha^{-1}), the amount and type of nutrient ‘retention’ crop residue had an effect on soil P (Table 5). Incorporation of nutrient ‘retention’ crop residue maintained higher soil P as compared to the traditional sweet pepper–fallow–rice system without residue incorporation. Corn residue maintained higher soil P as compared to the other cropping systems investigated (Table 5).

Table 5. Recycling of residue P and soil-P status in a sweet pepper–rice cropping system at Magnuang, the Philippines.

Treatments	Soil residual P (kg ha^{-1})		
	Residual P recycled	Initial	Final
Sweet pepper–fallow–rice	3	78	63
Sweet pepper–indigo–rice	9	78	69
Sweet pepper–indigo + mungbean–rice	10	78	79
Sweet pepper–corn–rice	10	78	81

Residue incorporation increased soil K in all residue-incorporated fields as compared to the traditional sweet pepper–fallow–rice system without residue incorporation (Table 6). The increase ranged from 42 kg K ha^{-1} for the indigo treatment to 140 kg K ha^{-1} for the corn treatment. The highest increase in recycled K was associated with the sweet pepper–corn–rice system due to the greater amount of K added in the form of corn residue.

Table 6. Recycling of residue K and soil-K status in a sweet pepper–rice cropping system at Magnuang, the Philippines.

Treatments	Soil residual K (kg ha^{-1})		
	Residual K recycled	Initial	Final
Sweet pepper–fallow–rice	41	699	679
Sweet pepper–indigo–rice	80	699	741
Sweet pepper–indigo + mungbean–rice	110	699	798
Sweet pepper–corn–rice	166	699	839

Labile Carbon Balance

A gain in the labile C (C_L) pool ranging from 1,901 to 2,853 kg C_L ha^{-1} in the sweet pepper–rice system was observed with as a result of the incorporation of nutrient 'retention' crop residue. In comparison, a loss of 249 kg C_L ha^{-1} was observed in the traditional fallow transition period and fields without the incorporation of residue (Table 7). Indigo either alone or mixed with mungbean had a higher C_L balance as compared to the sweet pepper–corn–rice and traditional sweet pepper–fallow–rice systems.

Table 7. Labile soil C (C_L) balance for 0–25 cm soil depth as a result of the treatments evaluated.

Treatments	**soil C_L (kg ha^{-1})**		
	Before nutrient ‘retention’ crop (A)	**Residual soil C_L after rice harvest (B)**	**A-B**
Sweet pepper–fallow–rice	6,071	6,075	4
Sweet pepper–indigo–rice	6,192	8,353	2,161
Sweet pepper–indigo + mungbean–rice	6,107	8,960	2,853
Sweet pepper–corn–rice	6,107	8,008	1,901

Irrespective of the nutrient ‘retention’ crop grown during the dry to wet season transition period incorporation of crop residue produced a significant gain in soil C_L. In comparison, the traditional sweet pepper–fallow–rice system was associated with a mean (n=4) soil C_L of 4 kg C_L ha^{-1}.

CONCLUSIONS

The prevention of further degradation of soil fertility and the rehabilitation of already degraded land are challenges that must be addressed if agricultural productivity is to be improved and sustainably maintained. Rice–vegetable cropping systems involving rice in the wet season and one or two rotation crops in the dry season are practiced under high-input (N, P, K fertilizer; irrigation; pesticide; increased tillage) conditions in many parts of the rainfed lowlands of the tropics. A high cropping intensity with high inputs, especially for vegetable crops, affects crop production economics, soil fertility, and environmental quality.

Lowland agriculture in Ilocos Norte, Philippines, exemplifies high cropping intensity and input use. Farmers' use of excessive amounts of inputs because of the high economic returns from these cash crops is leading towards an unsustainable system. Therefore there is an urgent need to identify the factors that contribute to poor input efficiency. The crop's water and nutrient requirements for a given yield potential should be examined and appropriate recommendations for timing, amount, and sources to match the demand and supply of nutrients should be developed. The strategies for growing nutrient ‘retention’ crops during the dry-to-wet transition period in cropping systems, in fields which would otherwise be left fallow, should be promoted to capture and recycle nutrients, and thereby decrease the need for excessive nutrient inputs.

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