Sustainability Analysis of Existing Land-use Systems in Northeast Thailand

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ABSTRACT

Agricultural systems in Northeast Thailand have been developed on marginal sandy soils within an undulating landscape. Agricultural productivity has declined considerably under the currently adopted land use systems as indicated by declining crop yields and an increasing dependency on chemical fertilizers. This has resulted in skepticism with regards the sustainability of the current the land-use systems of the region.

From 1999-2001 researchers at Khon Kaen University conducted research to evaluate the sustainability of currently adopted land-use systems using a nutrient balance model. The project was funded by the National Research Council of Thailand (NRCT) and the Thailand Research Fund (TRF). The specific objectives of the project were to investigate nutrient inputs and outputs from selected land-use systems in a micro-watershed area; investigate changes in land use and management as affected by socioeconomic and cultural factors; model the characteristics and dynamics of land degradation in a micro-watershed, and to identify factors affecting land degradation. It is envisaged that knowledge gained from this project will lead to the development of sustainable land use and management for Northeast Thailand.

A micro-watershed at Ban Khummuang village, Khao Suan Kwang District, Khon Kaen Province, was selected as the study site. Nutrient balances were determined for the major land uses in the area, and for the entire micro-watershed under investigation. Specific studies relating to the different input and output parameters were also conducted. These include studies on (1) ground cover and placement of surface structures under current land uses in relation to soil erosion, (2) rainfall-runoff relationships, (3) sediment transport, (4) unconfined groundwater hydraulics, (5) subsurface flows of nutrients, (6) estimation of the water table in paddy systems, and (7) soil organic matter build up and dynamics under the selected land-use systems. A summary of the nutrient balance studies is presented in this paper. It should be noted that the nutrient balance analysis did not include nutrient loss from leaching; nutrient gain and loss from accumulated moisture and runoff or wind erosion; and nutrient gains from capillary water in the soil, and weathering of parent materials, N fixation, and livestock manure. The results represented in this paper can therefore only be considered as an incomplete and estimated nutrient balance for the agricultural systems evaluated.

INTRODUCTION

From 1999-2001 researchers at Khon Kaen University conducted research to evaluate the sustainability of currently adopted land-use systems using a nutrient balance model. The specific objectives of the project were to investigate nutrient inputs and outputs from selected land-use systems in a micro-watershed area; investigate changes in land use and management as affected by socioeconomic and cultural factors; model the characteristics and dynamics of land degradation in a micro-watershed, and to identify factors affecting land degradation.

MATERIALS AND METHODS

A micro-watershed at Khummuang village, Khao Suan Kwang District, Khon Kaen Province, was selected as the study site. A rapid rural appraisal was conducted to obtain information on landuse, and land management practices. Nutrient balances were determined for the major land uses in the area, and for the entire micro-watershed under investigation.

Specific studies relating to the different input and output parameters were also conducted. These include studies on (1) ground cover and placement of surface structures under current land uses in relation to soil erosion, (2) rainfall-runoff relationships, (3) sediment transport, (4) unconfined groundwater hydraulics, (5) subsurface flows of nutrients, (6) estimation of the water table in paddy systems, and (7) soil organic matter build up and dynamics under the selectedt land-use systems.

The land-use patterns investigated comprise eight subsystems of sugarcane planted at the end of the rainy season; cassava planted at the end of the rainy season; and rainfed paddy rice. The sugarcane subsystems used a combination of different chemical fertilizer rates, burning or not burning of leaves before harvesting, and planting on the upper or lower parts of upland fields. Chemical fertilizer applications were the primary source of nutrient inputs to the sugarcane subsystems., Rainfall data including N, P and K concentrations were obtained from secondary sources. Information on nutrient losses via eroded soil particles was obtained from secondary data derived from erosion plots located under similar agro-systems in Khummuang village. Nutrient outputs were determined on removed crop products, burned leaves, and eroded soil particles.

RESULTS AND DISCUSSION

Nitrogen (N), phosphorous (P) and potassium (K) showed positive balances for all sugarcane subsystem investigated (Tables 1-8). This infers that the current rates of fertilizer application are excessive. Further, increasing the rate of fertilizer application resulted in increasingly positive nutrient balances. In the case of the burned stubble, a significant amount of N was lost through burning but the nutrient balance for this element was still highly positive (Tables 2, 4, 6 and 8). There were no significant differences in the macronutrient balances for sugarcane grown on upper and lower upland fields (Tables 1-8).

Table 1. Nutrient balance of a sugarcane subsystem: Upper field with high fertilizer rate (stubble, not burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	93.75	40.91	77.81
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Total input	98.51	42.11	83.34
Outputs			
Sugarcane stems	22.62	1.78	32.24
Eroded soil particles	1.14*	0.07	3.06
Total output	23.76	1.85	35.30
Balance	74.75	40.26	48.04

* Estimated from erosion plots located under similar agro-systems Khummuang village.

Table 2. Nutrient balance of a sugarcane subsystem: Upper field with high fertilizer rate (stubble, burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	93.75	40.91	77.81
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Total input	98.51	42.11	83.34
Outputs			
Sugarcane stems	20.84	1.64	29.70
Losses from burning	4.47	0.58	0.55
Eroded soil particles	1.14*	0.07	3.06
Total output	26.45	2.29	33.31
Balance	72.06	39.82	50.03

Table 3. Nutrient balance of a sugarcane subsystem: Upper field with low fertilizer rate (stubble, not burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	46.88	20.46	38.91
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Total input	51.64	21.66	44.44
Outputs			
Sugarcane stems	16.67	1.31	23.76
Eroded soil particles	1.14*	0.07	3.06
Total output	17.81	1.38	26.82
Balance	33.83	20.28	17.62

Table 4. Nutrient balance of a sugarcane subsystem: Upper field with low fertilizer rate (stubble, burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	46.88	20.46	38.91
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Total input	51.64	21.66	44.44
Outputs			
Sugarcane stems	14.49	1.14	20.65
Losses from burning	12.52	2.38	3.21
Eroded soil particles	1.14*	0.07	3.06
Total output	28.15	3.59	26.92
Balance	23.49	18.07	17.52

Table 5. Nutrient balance of a sugarcane subsystem: Lower field with high fertilizer rate (stubble, not burned)

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	93.75	40.91	77.81
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Eroded soil particles (from upper fields)	15.44*	0.07	3.06
Total input	113.95	42.18	86.40
Outputs			
Sugarcane stems	23.42	1.84	33.37
Eroded soil particles	0.81	0.07	3.06
Total output	24.23	1.91	36.43
Balance	89.72	40.27	49.97

Table 6. Nutrient balance of a sugarcane subsystem: Lower field with high fertilizer rate (stubble, burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	93.75	40.91	77.81
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Eroded soil particles (from upper fields)	15.44*	0.07	3.06
Total input	113.95	42.18	86.40
Outputs			
Sugarcane stems	22.42	1.77	31.96
Eroded soil particles	0.81	0.07	3.06
Losses from burning	19.40	3.69	4.98
Total output	42.63	5.53	40.00
Balance	71.32	36.65	46.40

Table 7. Nutrient balance of a sugarcane subsystem: Lower field with low fertilizer rate (stubble, not burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	46.88	20.46	38.91
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Eroded soil particles (from upper fields)	15.44*	0.07	3.06
Total input	67.08	21.73	47.50
Outputs			
Sugarcane stems	16.87	1.33	24.04
Eroded soil particles	0.81*	0.07	3.06
Total output	17.68	1.40	27.1
Balance	49.40	20.33	20.4

Table 8. Nutrient balance of a sugarcane subsystem: Lower field with low fertilizer rate (stubble, burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	46.88	20.46	38.91
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Eroded soil particles (from upper fields)	15.44*	0.07	3.06
Total input	67.08	21.73	47.50
Outputs			
Sugarcane stems	16.07	1.27	22.91
Eroded soil particles	0.81*	0.07	3.06
Losses from burning	13.80	2.63	3.54
Total output	30.68	3.97	29.51
Balance	36.40	17.76	17.99

For cassava production, N and K showed negative balances while the balance for P was slightly positive (Table 9). This indicates that the current rates of fertilizer application are inadequate and further research is required to determine optimum rates of fertilizer application in relation to maximizing crop production. For rice production, N and P had positive balances while the balance for K was highly negative as the farmers did not add K fertilizer (Table 10). Apparently, K input is insufficient to cover the losses incurred from plant removal in the cassava and rice production systems investigated. All macronutrient balances were higher for sugarcane when compared to cassava and rice as the sugarcane received a higher fertilizer rate.

Table 9. Nutrient balance of cassava crop planted at the end of the rainy season.

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	28.13	12.27	23.34
Rainfall	1.78	0.97	1.29
Planting material	1.47	0.20	2.67
Total input	31.38	13.44	27.30
Outputs			
Cassava roots	31.88	4.39	58.00
Cassava stems	15.69	1.33	12.63
Eroded soil particles	6.42*	0.07	3.06
Total output	53.99	5.79	73.69
Balance	-22.61	7.65	-46.39

Table 10. Nutrient balance for rainfed rice planted in a paddy field.

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
16-20-0 (N: P_2O_5: K_2O) fertilizer	25.00	13.64	0.00
Rainfall	1.78	0.97	1.29
Planting material	0.31	0.07	0.49
Total input	27.09	14.68	1.78
Outputs			
Rice grain	15.00	1.68	41.81
Rice straw	12.28	0.50	19.44
Total output	27.28	2.18	61.25
Balance	-0.19	12.50	-59.47

However, it should be noted that the nutrient balance analysis did not include nutrient loss from leaching; nutrient gain and loss from accumulated moisture and runoff or wind erosion; and nutrient gains from capillary water in the soil, weathering of parent materials, N fixation, and livestock manure. The results represented in this paper can therefore only be considered as an incomplete and estimated nutrient balance for the agricultural systems evaluated.

It has been hypothesized that the total nutrient loss from the whole watershed might not be equal to the sum of the loss from individual farm plots. Observation of the surface structures within the agricultural systems investigated indicates that a proportion of the potential nutrient loss associated with surface runoff (soil particles and water) may be retained before reaching the next plot thus preventing complete loss from the system. Such surface structures include tillage generated furrows and small scale surface depressions caused by weeding, natural and/or man made levees/dikes, and grass strips.

Visual observation of the ground cover and amount of soil loss generated by erosion suggested that cassava planted in the middle of the rainy season lost more soil particles, implying more nutrient losses, as opposed to cassava or sugarcane planted at the end of the rainy season (observations not quantified by field derived data).

CONCLUSIONS

Discussions with farmers revealed that they were aware of the influence of nutrient inputs and outputs on soil fertility. To a certain extent, farmers address nutrient balance components to maintain soil fertility through the use of chemical fertilizers.. However, due to land-use pressure, farmland in Northeast Thailand is increasingly associated with declining soil fertility that is currently addressed by the excess application of chemical fertilizers. The maintenance of farmland soil fertility requires higher costs or an extended fallow period for the land to recover. The incomplete estimated nutrient balances presented in this paper indicated that further studies are required to determine optimum rates of fertilizer application in relation to maximizing crop production.