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Nutrient Balances and Sustainability of Sugarcane Fields in a Mini-Watershed Agroecosystem of Northeast Thailand

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Abstract

Large areas of undulating terrain in Northeast Thailand are dominated by farming systems based on rainfed upland crops and lowland rice. Evidence of a substantial decline in land productivity from current land uses and management points out the need for a more detailed assessment on land-use sustainability of the region. The present study evaluated nutrient balances of different types of sugarcane fields as an indicator of land-use sustainability. The crop is currently the most widely grown field crop in the region, and its production practices involve high fertilizer inputs and considerable soil disturbances. Kham Muang village in Khon Kaen province was selected as a study site. Four types of sugarcane subsystems were recognized based on their differences in nutrient input and output parameters. These included combinations of two rates (high and low) of fertilizers and two practices of field burning prior to harvesting (burned and not burned). Sources of nutrient inputs and outputs were identified for the individual subsystems. Amounts of major nutrients (N, P and K) were determined for the individual sources, based primarily on actual field measurements in farmers' fields in Kham Muang and adjacent villages and in a mini-watershed in Kham Muang village. Nutrient balances were then calculated for the full three-year cycle of the individual subsystems and at three yield levels (high, moderate and low). The results showed that N balances were mostly positive but P and K balances were negative for all subsystems. Positive balances of N were high at the high fertilizer rate and low yield level, declined at the low fertilizer rate and higher yield levels, and became negative when the field was burned. Negative P and K balances increased as yield level increased and when the low rate of fertilizer was applied. Field burning caused significant losses for all three nutrients, making negative balances even higher for P and K in burned field; the amounts were quite substantial in all subsystems. Excess N is likely to be lost through water flow, but continuation of current practices can cause P and K depletion in the long run. Measures to adjust the balances of these two nutrients are needed to improve land-use sustainability of sugarcane production in the region.

Keywords: nutrient balance, nutrient cycling, nutrient budget, sugarcane, agroecosystem, land degradation, land-use sustainability, Northeast Thailand

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I Introduction

Agricultural systems in Northeast Thailand have been developed on rather marginal poor sandy soils of the undulating terrain. The development of agricultural land use was through forest clearing for production of rice and commercial upland crops [Vityakon 2002; Vityakon *et al*. 2004]. The gently undulating terrain dominates the region's landscape forming a "mini-watershed" agroecosystem in which paddy rice occupies the lowlands and various field crops as well as remnants of dipterocarp forest are in the uplands. The dominant field crop has changed from monoculture of kenaf to cassava, and most recently to sugarcane. Continuous cultivation of these crops has resulted in a substantial decline in land productivity as indicated by declining crop yields and an increasing dependency on chemical fertilizers to obtain satisfactory yield levels [Limpinuntana 1988]. Previous studies also have shown a general decline in fertility of upland soils as indicated by a decline in soil nutrients and soil organic matter [Limpinuntana *et al*. 2000]. The situation creates skepticism regarding land-use sustainability of the region. A more detailed assessment of land-use sustainability under current practices is needed. Currently, sugarcane is the most widely grown upland crop in the region, occupying both the upland and the upper lowland of the undulating terrain. Its cultural practices involve high fertilizer inputs and considerable soil disturbances [Wongwiwatchai and Paisancharoen 2001]. Some farmers also burn the cane fields prior to harvesting to facilitate the stem-cutting operation [Wongchantra 2002], causing a significant loss of certain nutrients. Land-use sustainability of the system is unclear and warrants an in-depth analysis. The system is of more general interest because it represents a relatively high-input extensive commercial cash crop production in a rather low-productivity sandy soil in a semi-arid tropic environment.

Analysis of nutrient balances is a simple and useful methodology to assess the sustainability of agricultural land-use systems. The method has been used as a tool for assessing the sustainability of many land-use systems in various parts of the world, including Africa and Europe [Janssen 1999; Oenema and Heinen 1999; Smaling *et al*. 1999], Asia [Manaligod and Cuevas 1998; Patanothai 1998; Polthanee *et al*. 1998; Vien 1998] and America [Jordan 1985]. In relating nutrient balance to long-term sustainability of land productivity, the basic assumption is that a negative balance of any nutrient would indicate a loss of the nutrient from the system. Long-term continuation of such a situation will result in a degradation of land quality and consequently a decline in productivity and sustainability. A high positive balance of certain nutrients may also adversely affect land-use sustainability if these nutrients are accumulated to a level that could create a plant nutrient imbalance or toxicity or even excess export from the system [Patanothai 1998]. Our previous study on nutrient balances of sugarcane fields in Northeast Thailand with different field positions, fertilizer rates and field burning practices [Polthanee *et al*. 1998] indicated positive balances for all three major nutrients (N, P and K) in all types of fields. However, in that study, the analysis was based mainly on secondary data. The present study also investigated nutrient balances of different types of sugarcane fields, but the analysis was based primarily on primary data obtained from field measurements in a study site representing a mini-watershed agroecosystem in Northeast Thailand. The objectives were (1) to determine the amount of nutrients in various sources of inputs and outputs for different types of sugarcane fields, and (2) to determine the balances of major nutrients in these fields as an indicator of land-use sustainability.

II Methodology

II–1 *The Study Site*

The site chosen for this study was Kham Muang village in Khon Kaen province in Northeast Thailand (latitude 16˚ 48'–16˚ 49' north and longitude 102˚ 52'–102˚ 53' east), approximately 45 km north of Khon Kaen city. The general landscape of the area is undulating terrain, typical of a mini-watershed agroecosystem in the region. Soils are coarse textures (loamy sand to sandy loam) classified as Oxic Quartzipsamment. The rainy season is from April to October, with annual rainfall approximately 1,200 mm. Crops grown in the area are sugarcane, cassava and rice, with sugarcane and cassava occupying the upland areas and rice occupying the lowland areas.

II–2 *Determination of Nutrient Inputs and Outputs and Field Types*

To determine sources of nutrient inputs and outputs, field surveys and farmer interviews were conducted in Kham Muang and neighbouring villages. A Rapid Rural Appraisal (RRA) was used in gathering information on current practices for sugarcane production in the area and variations among farmers in production practices. Information obtained from the interviews included variety grown, planting date and method, kind and rate of fertilizer applied, time and method of weeding, harvesting date and method, and plant parts removed from and retained in the field.

Major sources of nutrient input into a sugarcane field identified were planting materials, chemical fertilizers, rainfall, in-coming eroded sediments and run-in water from adjacent upper fields, and run-in subsurface water. Major nutrient outflows were harvested canes, losses through field burning before harvesting, out-going eroded sediments and run-off water to a lower field, leaching, and run-out subsurface water (Fig. 1). No manure was normally applied to the crop, and not many leguminous weeds were found, thus, manure and nitrogen fixation were omitted from the input sources. Other gaseous losses were considered minor and were also omitted. Weeds were left in the field after weeding, and sugarcane leaf litter and leaves were retained in the field if not burned. These were considered recycled plant parts and were not included in the nutrient balance analysis.

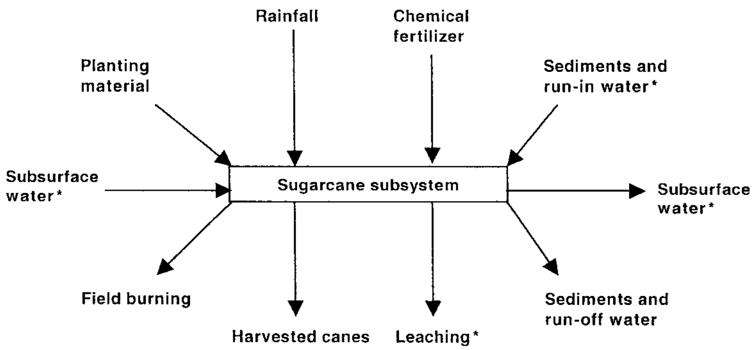

Fig. 1 Major Nutrient Flows for a Planted-sugarcane Field in a Mini-watershed in Northeast Thailand
*not measured

In Northeast Thailand, a cycle of sugarcane planting consists of three years, corresponding to a planted crop, a ratoon crop and a fallow period. The cycle begins with the planted crop, which is normally planted at the end of the rainy season in October to November and harvested about 14–16 months later in December to March, the operating season of sugar factories. The field is then left for ratooning, and the ratoon crop is harvested in the following December to March. After that the field is generally left fallow throughout the rainy season until the next planting in the following October to November. Some plowing are also done during the rainy season as a part of field preparation for end-of-season planting. In this study, nutrient balance analyses were done for the full cycle (three years) of sugarcane planting system. Sources of nutrient inflows and outflows indicated in Fig. 1 were applicable to the planted crop, and also to the ratoon crop but with the omission of planting material. As sub-surface flows and in-coming eroded sediments and water were not measured, the only nutrient inflow during the fallow period was rainfall and the nutrient outflows were only out-going sediments and run-off water.

Variations among fields for sources of nutrient flows were found to reflect three main factors. Fields located at different positions along the sloping landscape would differ in eroded sediments and water coming in and going out of the fields. Farmers who were quota holders from a sugar factory applied the 15–15–15 fertilizers at a high rate (625 kg/ha) as they received credits for production inputs from the factory. Non-quota holders normally applied the same kind of fertilizer but at a lower rate (312.5 kg/ha). Some farmers burned their sugarcane fields prior to harvesting to facilitate the harvesting operation but others did not. Nutrient losses from burning would be different between burned and unburned fields. In the classification of field types (subsystems) for nutrient balance analysis, however, field position was not included in the criteria as it was difficult to determine the amounts of deposition of in-coming eroded sediments and water before leaving the field. Based on differences in fertilizer application and field burning practices, four field types (subsystems) of sugarcane were recognized. These included combinations of two rates (high and low) of fertilizer application and two practices of field burning prior to harvesting (burned and not burned). Subsequent quantity determinations of nutrient inflows and outflows were done for each sugarcane subsystem.

II–3 *Quantification of Nutrient Inflows and Outflows*

Amounts of major nutrients (N, P and K) for various sources of nutrient inputs and outputs for the individual sugarcane subsystems were mainly done by actual field measurements in farmers' fields in Kham Muang and two adjacent villages and in a mini-watershed in Kham Muang village. The selected mini-watershed covers an area of 14 ha. The topography is gently undulating with an average slope of 2.8% and elevation ranging from 190 to 208 m above mean sea level. The soils are Oxic Quartzipsamment with loamy sand to sandy loam texture. Land uses are typical for the area, i.e. forest on top slope, field crops (sugarcane and cassava) in upper and lower upland fields and in upper paddies on lower slope, while rice is grown in lower paddies on the foot slope. An automatic weather meter with data logger was installed at the site, and run-off plots were set up at key positions to measure sediments and run-off water from different land uses.

In this study, the inputs of nutrients to a sugarcane subsystem that were included in the nutrient balance analysis were rainfall, chemical fertilizers and planting material. The outputs were harvested canes, loss through burning, outgoing sediments and run-off water. Flows of nutrients in and out of the field by subsurface water and leaching loss, though considered important, were not included in the analysis as their measurement was rather difficult. Procedures for determining mineral nutrients (N, P and K) in different sources of inputs and outputs that were taken into account in this study are as follows:

1) *Rainfall*

Amounts of daily rainfall from 1991 to 2002 were recorded by an automatic weather meter (Unidata Australia with Starlog model 6301B) installed at the study mini-watershed. Total rainfall for the planted crop, the ratoon crop and the fallow periods was determined in accordance with the corresponding periods for sediments and run-off water determination (see more details in later section). N, P and K contents of rain water from a previous study [Polthanee *et al.* 1998] were used in the calculation of amounts of N, P and K brought in by rainfall for the individual periods.

2) *Chemical Fertilizers*

The kind and amounts of chemical fertilizers applied to sugarcane fields were obtained by interviewing sugarcane growers in the study village and two adjacent villages. Nutrient contents of the applied fertilizer (15–15–15) were used in calculating the amounts of N, P and K brought in by chemical fertilizer at a high (625 kg/ha) and a low (312.5 kg/ha) rate.

3) *Planting Materials*

In determining nutrient input from planting material, a sample of 10 canes was taken from a farmer's field which was being planted. Individual canes were measured for length and fresh weight. They were then oven-dried to obtain dry weight, and means were calculated for length and dry weight of a cane. Sugarcane is normally planted in furrows spaced 1 m apart, and planted canes are laid linearly in the furrows with overlapping ends of the two consecutive canes. Lengths of overlapping ends of planted canes were measured in 4 fields, each with 10 spots. The average values for length of overlapping end and for length and dry weight per cane were used in computing the number of canes used for planting a hectare and its corresponding dry weight. Average nutrient contents of harvested canes obtained from yield measurements in 14 fields (described below) were used in determining the amounts of N, P and K brought in by planting material.

4) *Harvested Canes*

Harvested cane yields were measured in 14 farmers' fields in Kham Muang and two adjacent villages in 1999–2000. Crop cuttings were done in 5 quadrates of 2×2 m^2 in 2 fields and in 4 quadrates in 12 fields. In a quadrate, all sugarcane stems were cut at soil surface and leaf litter was collected from the ground. Leaves (including leaf litter and tops) were separated from stalks, and the two parts were separately weighed. Samples were taken for oven drying to determine their moisture contents, one form each quadrate for leaves and a composite sample from all quadrates for stalks. Dry weights per hectare were then calculated for stalks and leaves. After drying, a composite sample was taken from each part and analyzed for N, P and K contents. Nutrient content analyses were done for 13 fields, of which 9 were burned fields and 4 were not burned fields. In nutrient balance analyses, three yield levels were set as scenarios. Averages for nutrient contents of stalks over all 13 fields were used in determining the outflow amounts of N, P and K through harvested canes at different yield levels. Averages for nutrient contents of leaves were calculated separately for burned and not-burned fields. These were used in determining the amounts of nutrient losses through field burning before harvesting and nutrient recycled through leaves remaining in the field.

5) *Losses of Nutrients from Field Burning*

Losses of nutrients from field burning were determined as the differences between total nutrients in all leaves and nutrients remained in unburned leaves and ash. Total dry weight of leaves at a certain yield level was calculated from the corresponding cane dry weights using a percentage of dry leaf weight to dry cane weight derived from means for cane and leaf yields of 4 fields that were not burned. Among the 14 fields harvested for yield determination, 2 were actually the same field but a part was burned and the other part was not. The 2 parts were harvested separately and were considered as 2 fields. Percentage of leaf weight loss from field burning was determined from average dry weights of leaves of these 2 fields. Percentage of leaf weight remaining as ash after burning was taken from a previous study [*ibid.*] in which leaf samples were actually burned and weights of ash were measured. Nutrient contents of ash from the same study were also used in the calculation of nutrients retained in the ash from field burning.

6) *Sediments Outflow and Run-off Water*

Five erosion plots were constructed at different positions along the toposequence in the mini-watershed. One was in the forest, two were in upper and lower cassava fields and two were in sugarcane fields. Each plot consisted of 5 ridges and 4 furrows, with a sediment tank setting up at the lower end. The amounts of erosion materials were determined by measuring the height of liquid in the sediment tank in the morning following each rainstorm. Liquid in the tank was also sampled for separation of sediments and run-off water and subsequently analyzed for their N, P and K contents. These were used in calculating amounts per hectare of nutrient losses through sediments and run-off water of individual erosion plots. Data were collected from August 1999 to December 2002, and the details are described in Vityakon and Trelo-ges [2003].

In one erosion plot (the middle upland plot), the crop in 1999 was ratoon sugarcane, followed by a fallow period in 2000, then by cassava that was planted in October 2000 and harvested in September 2001. Afterward, sugarcane was planted in October 2001 and harvested in early-2003. Data collected from this plot were used in estimating the outflows of nutrients through sediments and run-off water in the different periods in the cycle of sugarcane planting system. Data from the year 2002 were used to represent nutrient losses from sediments and run-off water for the planted crop period, and those from the year 2000 were used for the fallow period. As data for ratoon sugarcane in 1999 were available only from August, they were combined with data from January–July 2000 when the field was under cassava to get the estimate of nutrient losses through sediments and run-off water for the entire ratoon crop period.

II–4 *Chemical Analysis of Soil, Plant and Water Samples*

For sediment samples, total N was determined by micro Kjeldahl method, and total P and K were obtained by nitric perchloric acid digestion. P was determined by molybdenum blue method (Murphy and Riley), while K was determined by flame photometric method.

For plant samples, total N was determined by micro Kjeldahl method, and total P and K were obtained by dry ashing method. P and K were determined in the same way as those for sediment samples.

For water samples, total N was determined by sulfuric acid digestion of micro Kjeldahl method. For P and K determination, water samples were digested by mixture of sulfuric acid and nitric acid, and P was determined by the molybdenum blue method (Murphy and Riley) and soluble K was measured by flame photometer.

II–5 *Nutrient Balance Analyses*

Nutrient balance analyses were done for all four sugarcane subsystems, i.e. high fertilizer rate–field not burned, high fertilizer rate–field burned, low fertilizer rate–field not burned and low fertilizer rate–field burned. For each subsystem, analyses were done for the full cycle (three years) of sugarcane planting system and at three yield levels (high, medium and low, equal to 40, 30 and 15 tons/ha of dry cane or 129.6, 97.2 and 48.6 tons/ha of fresh-cane).

III Results and Discussion

Dry cane yields of the 14 farmers' fields harvested ranged from 13.9 to 41.0 tons/ha with an average of 28.4 tons/ha (Table 1). Yield differences could not be discerned between fields receiving high and low rates of fertilizer, or between fields with different burning practices, as well as between planted crop and ratoon crop. For example, fields with high rate of fertilizer had cane yields ranging from 13.9 to 41.0 tons/ha while fields with low fertilizer rate gave yields from 28.4 to 40.7 tons/ha. These could be accounted for by confounding effects of the above three and other factors as the numbers of fields for different categories were unequal and these fields were scattered in different places around the three study villages. These results indicated a naturally high variation in sugarcane yield among farmers' fields

Table 1 Means for Dry Cane and Dry Stubble Yields in Farmers' Fields in 1999–2000 at Ban Kam Moung, Khon Kaen, Thailand

Field no.	Farmer's Name	Fertilizer Rate[1]	Field Burning	Crop Year	Dry Cane Yield (kg/ha)[2]	Dry Stubble[3] (kg/ha)[2]	Dry Stubble[3] (%)[4]
1	Mr. Boonlert	Low	Yes	Ratoon	40,138	3,996	9.93
2	Mr. Boonlert	Low	No	Ratoon	32,209	8,335	25.62
3	Mr. Sanit	High	Yes	Ratoon	40,956	2,849	7.16
4	Mr. Sompong	High	Yes	Ratoon	24,613	2,845	11.70
5	Mr. No	Low	No	Ratoon	28,408	8,361	28.90
6	Mr. Boonmee	High	Yes	Planted	23,182	1,966	8.64
7	Mr. Sak	High	Yes	Planted	23,253	–	–
8	Mr. Paitoon	High	Yes	Planted	34,229	–	–
9	NA	NA	Yes	NA	23,075	–	–
10	Mr. Sawai	NA	Yes	NA	26,606	–	–
11	Mr. Boama	High	No	Planted	13,922	–	–
12	Mr. Somkid	Low	Yes	Planted	40,734	–	–
13	Mr. Tongsan	NA	No	Ratoon	31,453	6,569	20.94
14	Mr. Tawatchai	NA	No	Ratoon	15,131	5,493	35.60
	Overall mean				28,422	5,052	18.56
	Mean		Yes				9.36
	Mean		No				27.76

[1] Low = 312.5 kg/ha and high = 625 kg/ha of 15–15–15 compound fertilizer.
[2] Means from 5 replicates for Field nos. 1 and 2, others were from 4 replicates.
[3] Including leaves and tops; for burned fields, these were remaining unburned parts.
[4] Percent of dry cane yield.

Table 2 Nutrient Input from Rainfall and Nutrient Losses through Sediments and Run-off Water in the three-year Cycle of Sugarcane Planting in Northeast Thailand

Category	Amount	Nutrient (kg/ha)		
		N	P	K
Year 1 (Planted crop)				
Rainfall	1,312 mm	2.95	1.61	2.14
Sediments	16,800 kg/ha	3.30	1.24	2.21
Run-off water	253.9 mm	0.23	5.31	17.90
Year 2 (Ratoon crop)				
Rainfall	1,203.8 mm	2.71	1.48	1.96
Sediments	13,570 kg/ha	2.71	0.95	1.76
Run-off water	184.0 mm	0.17	3.85	12.97
Year 3 (Fallow)				
Rainfall	1,246 mm	2.80	1.53	2.03
Sediments	20,420 kg/ha	8.17	1.15	3.27
Run-off water	116.4 mm	0.66	1.87	30.13
Total 3 years				
Rainfall		8.46	4.62	6.13
Sediments and runoff		15.24	14.37	68.25

even with the same management practice. For this reason, three yield levels within the range in this study were used as scenarios in the analysis of each sugarcane subsystem. The high, moderate and low yield levels were set at 40, 30 and 15 tons/ha of dry-cane yields (equal to 129.6, 97.2 and 48.6 tons/ha of fresh-cane yields), respectively. Average yield of sugarcane in Northeast Thailand in 2001–02 was 18.1 tons/ha dry weight or 58.6 tons/ha fresh weight [OAE 2003].

The four subsystems analyzed included high fertilizer rate-field not burned, high fertilizer rate–field burned, low fertilizer rate–field not burned and low fertilizer rate–field burned. Each was analyzed for the full three-year cycle covering the planted crop, the ratoon crop and the fallow period, and with three yield levels (high, moderate and low). The same amounts of nutrient inflows by rainfall and planting material were used for all subsystems at all yield levels, as were nutrient outflows by sediments and run-off water. Table 2 shows the amounts of N, P and K brought in by rainfall and going out by sediments and run-off water in the individual years of the planting cycle. Their nutrient concentrations are given in Table 3. Nutrients brought in by rainfall were small and insignificant, the amount over the 3-year period being 8.46, 4.62 and 6.13 kg/ha for N, P and K, respectively. Although the amounts of out-going sediments and run-off water were quite considerable, totaling 50.7 tons/ha for sediments and 554.3 mm for run-off water, the amount of nutrient losses through these two sources were not great. Combined amounts from both sources over the three-year period were 15.24, 14.37 and 68.25 kg/ha for N, P and K, respectively. This was because soils at the study site were quite poor in fertility, as shown by low nutrient concentrations for both sediments and run-off water (Table 3).

As expected, soil erosion was lower in the ratoon-crop year than in the planted-crop year due to better ground cover (Table 2). Soil erosion was more serious during the fallow period

Table 3　Nutrient Concentration of Input and Output Components

Component	Nutrient			Source
	N	P	K	
Rainfall (ppm)	0.225	0.123	0.163	A previous study[1]
15–15–15 fertilizer (%)	15.000	6.546	12.450	
Planting material (%)	0.133	0.377	0.328	Means of 13 fields
Dry cane (%)	0.133	0.377	0.328	Means of 13 fields
Dry leaves (%)	0.436	0.573	1.024	Means of 3 fields
Dry unburned leaves (%)	0.582	0.824	0.961	Means of 7 fields
Leaf ash (%)	0.000	0.110	0.240	A previous study[1]
Sediments, years 1 and 2 (%)	0.020	0.007	0.013	Yearly average[2]
Sediments, year 3 (%)	0.040	0.006	0.016	Yearly average[2]
Run-off water, years 1 and 2 (ppm)	0.091	2.091	7.050	Yearly average[2]
Run-off water, year 3 (ppm)	0.567	1.607	25.885	Yearly average[2]

[1] Unpublished data from our earlier study [Polthanee *et al.* 1998].
[2] Concentrations at different periods in the season were used in the calculation.

as there were soil disturbances by plowing and less ground cover during the period of heavy rainfall. A much higher K concentration in run-off water during the fallow period than in the cropping period (Table 3) also made K loss through run-off water during the fallow period substantially higher. The amounts of sediments and run-off water for the ratoon-crop year might have been overestimated as the amounts for the early part of the season were taken from the period under a cassava crop which probably had less ground cover than ratoon sugarcane. However, with such low nutrient concentrations of both sediments and run-off water, this should not make much difference in terms of nutrient losses.

In this study, the run-in water and sediments from a higher field was not taken into account. However, the erosion plot in which the data were collected had a closed upper end. The amounts obtained would represent the out-going sediments and run-off water for the field with no erosion inflow. These amounts also should not be much different from the balances between the inflows and outflows if there were run-in water and sediments (upper end of the plot opened). In such a case, the amounts of run-out water and sediments should have been higher than those obtained in this study.

Losses of nutrients from field burning before harvesting are presented in Table 4. Significant losses were shown for all three nutrients, particularly at the high yield level. K losses were much greater than those of N and P as leaves had higher K content than N and P (Table 3). Losses from burning at the low yield level were 7.87, 9.45 and 15.05 kg/ha of N, P and K, respectively, and increased to 21.00, 25.21 and 40.14 kg/ha of N, P and K at the high yield level.

Quite considerable amounts of nutrients, particularly K, were recycled back to the field when the field was not burned (Table 4). At the high yield level, recycled nutrients amounted to 51.86 kg/ha for N, 68.84 kg/ha for P and 97.27 kg/ha for K. Even when the field was burned, a large proportion of leaves and tops were unburned, retaining more than half of their nutrients in the field. However, the losses also were considerable, and no field burn-

Table 4 Nutrient Losses from Field Burning before Harvesting Sugarcane and Nutrients Recycled from Leaves at Three Yield Levels

Category	Amount (kg/ha)		
	N	P	K
Loss from burning			
High yield level (40 tons/ha)	21.00	25.21	40.14
Moderate yield level (30 tons/ha)	15.75	18.91	30.10
Low yield level (15 tons/ha)	7.87	9.45	15.05
Recycled nutrients			
Field not burned			
High yield level (40 tons/ha)	51.86	68.84	97.27
Moderate yield level (30 tons/ha)	38.87	51.61	72.92
Low yield level (15 tons/ha)	19.45	25.82	36.48
Field burned before harvesting			
High yield level (40 tons/ha)	30.86	43.63	57.14
Moderate yield level (30 tons/ha)	23.15	32.73	42.85
Low yield level (15 tons/ha)	11.57	16.36	21.43

Table 5a Nutrient Balances for Sugarcane Subsystems in Northeast Thailand: Category I—High Fertilizer Rate, Field not Burned

Component	High Yield Level			Moderate Yield Level			Low Yield Level		
	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Planted Crop									
Fertilizer (15–15–15)	93.75	40.91	77.81	93.75	40.91	77.81	93.75	40.91	77.81
Rainfall	2.95	1.61	2.14	2.95	1.61	2.14	2.95	1.61	2.14
Planting material	5.19	14.70	12.79	5.19	14.70	12.79	5.19	14.70	12.79
Total input	*101.89*	*57.23*	*92.74*	*101.89*	*57.23*	*92.74*	*101.89*	*57.23*	*92.74*
Sugarcane-stem	53.20	150.80	131.20	39.90	113.10	98.40	19.95	56.55	49.20
Sediments-out	3.30	1.24	2.21	3.30	1.24	2.21	3.30	1.24	2.21
Run-off water	0.23	5.31	17.90	0.23	5.31	17.90	0.23	5.31	17.90
Total output	*56.73*	*157.35*	*151.31*	*43.43*	*119.65*	*118.51*	*23.48*	*63.10*	*69.31*
Balance Year 1	45.16	–100.12	–58.57	58.46	–62.42	–25.77	78.41	–5.87	23.43
Ratoon Crop									
Fertilizer (15–15–15)	93.75	40.91	77.81	93.75	40.91	77.81	93.75	40.91	77.81
Rainfall	2.71	1.48	1.96	2.71	1.48	1.96	2.71	1.48	1.96
Total input	*96.46*	*42.39*	*79.77*	*96.46*	*42.39*	*79.77*	*96.46*	*42.39*	*79.77*
Sugarcane-stem	53.20	150.80	131.20	39.90	113.10	98.40	19.95	56.55	49.20
Sediments-out	2.71	0.95	1.76	2.71	0.95	1.76	2.71	0.95	1.76
Run-off water	0.17	3.85	12.97	0.17	3.85	12.97	0.17	3.85	12.97
Total output	*56.08*	*155.60*	*145.93*	*42.78*	*117.90*	*113.13*	*22.83*	*61.35*	*63.93*
Balance Year 2	40.38	–113.21	–66.16	53.68	–75.51	–33.36	73.63	–18.96	15.84
Fallow									
Rainfall	2.80	1.53	2.03	2.80	1.53	2.03	2.80	1.53	2.03
Sediments-out	8.17	1.15	3.27	8.17	1.15	3.27	8.17	1.15	3.27
Run-off water	0.66	1.87	30.13	0.66	1.87	30.13	0.66	1.87	30.13
Balance Year 3	–6.03	–1.49	–31.37	–6.03	–1.49	–31.37	–6.03	–1.49	–31.37
Balance 3 Years	79.51	–214.81	–156.09	106.11	–139.42	–90.49	146.01	–26.32	7.91

Table 5b Nutrient Balances for Sugarcane Subsystems in Northeast Thailand: Category II—High Fertilizer Rate, Field Burned

Component	High Yield Level			Moderate Yield Level			Low Yield Level		
	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Planted Crop									
Fertilizer (15–15–15)	93.75	40.91	77.81	93.75	40.91	77.81	93.75	40.91	77.81
Rainfall	2.95	1.61	2.14	2.95	1.61	2.14	2.95	1.61	2.14
Planting material	5.19	14.70	12.79	5.19	14.70	12.79	5.19	14.70	12.79
Total input	*101.89*	*57.23*	*92.74*	*101.89*	*57.23*	*92.74*	*101.89*	*57.23*	*92.74*
Sugarcane-stem	53.20	150.80	131.20	39.90	113.10	98.40	19.95	56.55	49.20
Loss from burning	21.00	25.21	40.14	15.75	18.91	30.10	7.87	9.45	15.05
Sediments-out	3.30	1.24	2.21	3.30	1.24	2.21	3.30	1.24	2.21
Run-off water	0.23	5.31	17.90	0.23	5.31	17.90	0.23	5.31	17.90
Total output	*77.73*	*182.56*	*191.45*	*59.18*	*138.56*	*148.61*	*31.35*	*72.55*	*84.36*
Balance Year 1	24.16	–125.33	–98.71	42.71	–81.33	–55.87	70.54	–15.32	8.38
Ratoon Crop									
Fertilizer (15–15–15)	93.75	40.91	77.81	93.75	40.91	77.81	93.75	40.91	77.81
Rainfall	2.71	1.48	1.96	2.71	1.48	1.96	2.71	1.48	1.96
Total input	*96.46*	*42.39*	*79.77*	*96.46*	*42.39*	*79.77*	*96.46*	*42.39*	*79.77*
Sugarcane-stem	53.20	150.80	131.20	39.90	113.10	98.40	19.95	56.55	49.20
Loss from burning	21.00	25.21	40.14	15.75	18.91	30.10	7.87	9.45	15.05
Sediments-out	2.71	0.95	1.76	2.71	0.95	1.76	2.71	0.95	1.76
Run-off water	0.17	3.85	12.97	0.17	3.85	12.97	0.17	3.85	12.97
Total output	*77.08*	*180.81*	*186.07*	*58.53*	*136.81*	*143.23*	*30.70*	*70.80*	*78.98*
Balance Year 2	19.38	–138.42	–106.30	37.93	–94.42	–63.46	65.76	–28.41	0.79
Fallow									
Rainfall	2.80	1.53	2.03	2.80	1.53	2.03	2.80	1.53	2.03
Sediments-out	8.17	1.15	3.27	8.17	1.15	3.27	8.17	1.15	3.27
Run-off water	0.66	1.87	30.13	0.66	1.87	30.13	0.66	1.87	30.13
Balance Year 3	–6.03	–1.49	–31.37	–6.03	–1.49	–31.37	–6.03	–1.49	–31.37
Balance 3 Years	37.51	–265.24	–236.37	74.61	–177.24	–150.69	130.27	–45.22	–22.19

Table 5c Nutrient Balances for Sugarcane Subsystems in Northeast Thailand: Category III—Low Fertilizer Rate, Field not Burned

Component	High Yield Level			Moderate Yield Level			Low Yield Level		
	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Planted Crop									
Fertilizer (15–15–15)	46.88	20.46	38.91	46.88	20.46	38.91	46.88	20.46	38.91
Rainfall	2.95	1.61	2.14	2.95	1.61	2.14	2.95	1.61	2.14
Planting material	5.19	14.70	12.79	5.19	14.70	12.79	5.19	14.70	12.79
Total input	*55.01*	*36.77*	*53.84*	*55.01*	*36.77*	*53.84*	*55.01*	*36.77*	*53.84*
Sugarcane-stem	53.20	150.80	131.20	39.90	113.10	98.40	19.95	56.55	49.20
Sediments-out	3.30	1.24	2.21	3.30	1.24	2.21	3.30	1.24	2.21
Run-off water	0.23	5.31	17.90	0.23	5.31	17.90	0.23	5.31	17.90
Total output	*56.73*	*157.35*	*151.31*	*43.43*	*119.65*	*118.51*	*23.48*	*63.10*	*69.31*
Balance Year 1	–1.72	–120.58	–97.47	11.58	–82.88	–64.67	31.53	–26.33	–15.47
Ratoon Crop									
Fertilizer (15–15–15)	46.88	20.46	38.91	46.88	20.46	38.91	46.88	20.46	38.91
Rainfall	2.71	1.48	1.96	2.71	1.48	1.96	2.71	1.48	1.96

Table 5c—Continued

Component	High Yield Level			Moderate Yield Level			Low Yield Level		
	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Total input	*49.59*	*21.94*	*40.87*	*49.59*	*21.94*	*40.87*	*49.59*	*21.94*	*40.87*
Sugarcane-stem	53.20	150.80	131.20	39.90	113.10	98.40	19.95	56.55	49.20
Sediments-out	2.71	0.95	1.76	2.71	0.95	1.76	2.71	0.95	1.76
Run-off water	0.17	3.85	12.97	0.17	3.85	12.97	0.17	3.8	12.97
Total output	*56.08*	*155.60*	*145.93*	*42.78*	*117.90*	*113.13*	*22.83*	*61.35*	*63.93*
Balance Year 2	–6.50	–133.66	–105.06	6.81	–95.96	–72.26	26.76	–39.41	–23.06
Fallow									
Rainfall	2.80	1.53	2.03	2.80	1.53	2.03	2.80	1.53	2.03
Sediments-out	8.17	1.15	3.27	8.17	1.15	3.27	8.17	1.15	3.27
Run-off water	0.66	1.87	30.13	0.66	1.87	30.13	0.66	1.87	30.13
Balance Year 3	–6.03	–1.49	–31.37	–6.03	–1.49	–31.37	–6.03	–1.49	–31.37
Balance 3 Years	–14.24	–255.73	–233.90	12.36	–180.33	–168.30	52.26	–67.23	–69.90

Table 5d Nutrient Balances for Sugarcane Subsystems in Northeast Thailand: Category IV—Low Fertilizer Rate, Field Burned

Component	High Yield Level			Moderate Yield Level			Low Yield Level		
	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Planted Crop									
Fertilizer (15–15–15)	46.88	20.46	38.91	46.88	20.46	38.91	46.88	20.46	38.91
Rainfall	2.95	1.61	2.14	2.95	1.61	2.14	2.95	1.61	2.14
Planting material	5.19	14.70	12.79	5.19	14.70	12.79	5.19	14.70	12.79
Total input	*55.01*	*36.77*	*53.84*	*55.01*	*36.77*	*53.84*	*55.01*	*36.77*	*53.84*
Sugarcane-stem	53.20	150.80	131.20	39.90	113.10	98.40	19.95	56.55	49.20
Loss from burning	21.00	25.21	40.14	15.75	18.91	30.10	7.87	9.45	15.05
Sediments-out	3.30	1.24	2.21	3.30	1.24	2.21	3.30	1.24	2.21
Run-off water	0.23	5.31	17.90	0.23	5.31	17.90	0.23	5.31	17.90
Total output	*77.73*	*182.56*	*191.45*	*59.18*	*138.56*	*148.61*	*31.35*	*72.55*	*84.36*
Balance Year 1	–22.72	–145.79	–137.61	–4.17	–101.79	–94.77	23.66	–35.78	–30.52
Ratoon Crop									
Fertilizer (15–15–15)	46.88	20.46	38.91	46.88	20.46	38.91	46.88	20.46	38.91
Rainfall	2.71	1.48	1.96	2.71	1.48	1.96	2.71	1.48	1.96
Total input	*49.59*	*21.94*	*40.87*	*49.59*	*21.94*	*40.87*	*49.59*	*21.94*	*40.87*
Sugarcane-stem	53.20	150.80	131.20	39.90	113.10	98.40	19.95	56.55	49.20
Loss from burning	21.00	25.21	40.14	15.75	18.91	30.10	7.87	9.45	15.05
Sediments-out	2.71	0.95	1.76	2.71	0.95	1.76	2.71	0.95	1.76
Run-off water	0.17	3.85	12.97	0.17	3.85	12.97	0.17	3.85	12.97
Total output	*77.08*	*180.81*	*186.07*	*58.53*	*136.81*	*143.23*	*30.70*	*70.80*	*78.98*
Balance Year 2	–27.50	–158.87	–145.20	–8.95	–114.87	–102.36	18.89	–48.86	–38.11
Fallow									
Rainfall	2.80	1.53	2.03	2.80	1.53	2.03	2.80	1.53	2.03
Sediments-out	8.17	1.15	3.27	8.17	1.15	3.27	8.17	1.15	3.27
Run-off water	0.66	1.87	30.13	0.66	1.87	30.13	0.66	1.87	30.13
Balance Year 3	–6.03	–1.49	–31.37	–6.03	–1.49	–31.37	–6.03	–1.49	–31.37
Balance 3 Years	–56.24	–306.15	–314.18	–19.14	–218.15	–228.50	36.52	–86.13	–100.00

ing would be superior in term of nutrient management.

Results of nutrient balance analyses for the four sugarcane subsystems are shown in Tables 5a, 5b, 5c and 5d. It was quite evident that fertilizer was the only major source of nutrient input and cane yield was the major source of nutrient output. Burning losses also constituted another main output when the field was burned. In the first year (planted crop), nutrient losses through out-going sediments and run-off water could be sufficiently compensated by the nutrient inflows through rainfall and planting material. However, for the ratoon crop in the second year, there was no planting material and nutrient input from rainfall alone was not sufficient to compensate for the erosion losses. Consequently, a slight deficit in K (11 kg/ha) was observed. Essentially, for the two cropping years, balances of nutrients depended on the amounts brought in by fertilizer and the amount taking out by cane yield plus the losses from burning in case of burned field. For the fallow year, negative balances were shown for all three nutrients, but the amount was significant only for K (–31.37 kg/ha).

Table 6 summarized balances of N, P and K at three yield levels in the different years of the individual sugarcane subsystems. Since balances of all three nutrients were rather small in the third year (fallow period), balances for the first two cropping years largely determined the total balances of all subsystems. At the high fertilizer rate, N balances in the first two years were positive at all yield levels, more so when the field was not burned, but decreased when yield level increased. P balances, on the other hand, were negative at all yield levels, and more negative when the field was burned and when the yield level declined. For K, the balances were negative at high and moderate yield levels, but slightly positive at the low yield level. At the low fertilizer rate, positive balances for N during the first two years were much reduced, and became negative at the low yield level, and even at the moderate yield level when the field was burned. Negative P balances increased at all yield levels and the amounts were considerable even at the low yield level. K balances also increased negatively and became negative at all yield levels.

Balances of nutrients for the full three-year cycle followed the same trend as those of the first two years (Table 6). At the low yield level, N were positive in all subsystems, but the amounts were significant only at the high fertilizer rate (130–146 kg N/ha). P and K were all negative except K was slightly positive at the high fertilizer rate and field not burned. The amounts were significant at the low rate of fertilizer (–67 to –86 kg/ha for P and –70 to –100 kg/ha for K). At the moderate yield level, positive N balances declined, while negative balances for P and K increased to a considerable extent (–139 to –218 kg/ha for P and –90 to –229 kg/ha for K). Positive N balances declined further at the high yield level and became negative at the low fertilizer rate. P and K balances were more negative at the high yield level, and the amounts were quite substantial in all sugarcane subsystems (–215 to –306 kg/ha for P and –156 to –314 kg/ha for K).

The results of this study were somewhat different from those of our previous study [Polthanee *et al.* 1998] in which positive balances were found in all sugarcane subsystems. However, in that study, the analyses were done only for the planted crop year and cane

Table 6 Summary of Nutrient Balances for Sugarcane Subsystems in Northeast Thailand at Three Yield Levels

Category/ Period	N Balance (kg/ha)			P Balance (kg/ha)			K Balance (kg/ha)		
	High Yield	Moderate Yield	Low Yield	High Yield	Moderate Yield	Low Yield	High Yield	Moderate Yield	Low Yield
Category I: High fertilizer rate, field not burned									
Year 1	45.16	58.46	78.41	–100.12	–62.42	–5.87	–58.57	–25.77	23.43
Year 2	40.38	53.68	73.63	–113.21	–75.51	–18.96	–66.16	–33.36	15.84
Year 3	–6.03	–6.03	–6.03	–1.49	–1.49	–1.49	–31.37	–31.37	–31.37
3 Years	79.51	106.11	146.01	–214.81	–139.42	–26.32	–156.09	–90.49	7.91
Category II: High fertilizer rate, field burned									
Year 1	24.16	42.71	70.54	–125.33	–81.33	–15.32	–98.71	–55.87	8.38
Year 2	19.38	37.93	65.76	–138.42	–94.42	–28.41	–106.30	–63.46	0.79
Year 3	–6.03	–6.03	–6.03	–1.49	–1.49	–1.49	–31.37	–31.37	–31.37
3 Years	37.51	74.61	130.27	–265.24	–177.24	–45.22	–236.37	–150.69	–22.19
Category III: Low fertilizer rate, field not burned									
Year 1	–1.72	11.58	31.53	–120.58	–82.88	–26.33	–97.47	–64.67	–15.47
Year 2	–6.50	6.81	26.76	–133.66	–95.96	–39.41	–105.06	–72.26	–23.06
Year 3	–6.03	–6.03	–6.03	–1.49	–1.49	–1.49	–31.37	–31.37	–31.37
3 Years	–14.24	12.36	52.26	–255.73	–180.33	–67.23	–233.90	–168.30	–69.90
Category IV: Low fertilizer rate, field burned									
Year 1	–22.72	–4.17	23.66	–145.79	–101.79	–35.78	–137.61	–94.77	–30.52
Year 2	–27.50	–8.95	18.89	–158.87	–114.87	–48.86	–145.20	–102.36	–38.11
Year 3	–6.03	–6.03	–6.03	–1.49	–1.49	–1.49	–31.37	–31.37	–31.37
3 Years	–56.24	–19.14	36.52	–306.15	–218.15	–86.13	–314.18	–228.50	–100.00

yields were comparable to the low yield level in this study. Nutrient contents of canes were also less than those of this study particularly P and K contents, and losses from sediments and run-off water were not included in the analyses. Since measurements of input and output components in this study were done in more replicates and some also covered a number of fields, data obtained should be more reliable than those of the previous study.

The above results raise some concern about land-use sustainability of the undulating landscapes in the Northeast Thailand. Positive N balance should not be a problem since N is soluble and is likely to be lost through water flow both laterally and vertically. Negative balances for P and K are of considerably more concern, as the amounts were substantial, particularly at moderate to high yield levels. These yield levels were not exceptional since they were obtained from actual measurement in farmers' fields. Continuation of the current practices would certainly threaten the sustainability of land productivity in the long run. Means to adjust the balances of these two nutrients should be sought to sustain the long-term productivity of the land. Nutrient losses through burning could be avoided by giving up the practice of burning the field before harvesting. Fortunately, field burning also causes a reduction in sugar content, and sugar factories are currently buying canes from burned fields at a lower price. This is a good incentive for farmers to give up the field burning practice. Attempts have also been made to grow legumes during the fallow period to replenish nutrients in the soil. Several legumes could be used including grain legumes (particularly peanut), green manure legumes and forage legumes. Rotating sugarcane with other field crops also might better maintain nutrient balances. Fully replenishing the negative balances of nutrients with chemical fertilizers might have to be done if there is no other alternative.

Under existing cultural practices, maintaining nutrient balances in the sugarcane fields are largely dependent on the farmers being able to purchase fertilizer inputs. In the four subsystems of sugarcane production investigated, the major nutrient input was chemical fertilizer while the major nutrient loss is harvested sugarcane stems. Thus, nutrients removed from the soil through yields are replenished by application of chemical fertilizers. A large proportion of sugar produced is exported while chemical fertilizers used in Thailand are imported. This is a case in which significant nutrient flows are occurring across national boundaries. With low crop price and increasing price of chemical fertilizers, it is questionable whether the farmers will earn sufficient income to be able to fully replenish the nutrient removed in the cane with imported chemical fertilizer. This would pose a major threat to land-use sustainability of the sugarcane production system in Northeast Thailand. What is happening in the sugarcane production system in Northeast Thailand might also be occurring in other high input commercial cash crop systems in low fertility soils in the semi-arid tropics.

IV Conclusions

Results of nutrient balance analyses of four sugarcane subsystems in a mini-watershed agroecosystem in Northeast Thailand indicated that land-use sustainability of these subsystems is under a threat from high negative balances of P and K from current practices. In all the subsystems, the major source of nutrient input was chemical fertilizer and that of the output was cane yield. Nutrient losses from field burning before harvesting were also quite considerable, and were an additional significant output for the subsystems with burned field. Although the amounts of eroded sediments and run-off water were substantial, resulting nutrient losses were rather small and could largely be compensated by nutrients brought in by rainfall and planting material. Nutrient balances in all the subsystems were, thus, largely determined by the amounts brought in by fertilizers and the amounts removed by cane yield. At the yield level of 15 tons/ha of dry cane (48.6 tons/ha of fresh cane), negative balances for P and K were low at the high fertilizer rate and would not be much of a problem. However, the amounts became significant when a low rate of fertilizer was used. At yield levels of 30 tons/ha of dry cane (97.2 tons/ha of fresh cane) and above, negative balances for these two nutrients were quite substantial even at the high fertilizer rate. If such a condition continues, P and K would be depleted in the long run, posing a threat to long-term productivity of the land. Means to adjust these balances are needed to improve their land-use sustainability.

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