Nutrient Loss and the On-site Cost of Soil Erosion under Different Land Use Systems

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Abstract

Nutrient loss and the on-site cost of soil erosion were evaluated in the MSEC study catchments in Indonesia, the Philippines, Vietnam, and Lao PDR. Nutrient loss by erosion was calculated from the production of sediment yield and nutrient concentration in the sediment. The on-site costs associated with nutrient loss were calculated as the equivalent cost of fertilizer materials that would be needed to replace the lost nutrients. In Indonesia, an additional study on nutrient lateral transport in a lowland rice system was conducted. Farmers' practice (45 kg N ha^{-1} $crop^{-1}$) and the improved technology (90 kg N, 40 kg P, and 50 kg K ha^{-1} $crop^{-1}$) were compared in terms of nutrient inputs (gains) and outputs (losses). Nutrient inputs included those coming from fertilizers, returned rice straw, and irrigation, while losses included crop removal and erosion. The changes of nutrients in the soil were not taken into account. Results show that in general high nutrient yield (especially N and K) was associated with intensive annual upland farming systems. Assuming that nutrient loss by erosion could be replaced with fertilizer application, the calculated cost of major nutrients was about US$27 per year as observed in the 0.9 ha sub-catchment planted to annual upland crops in the Philippines. The major proportion of nutrient loss in lowland rice farming was by crop removal as shown in the Indonesian case. Phosphorus and N were contained more in the rice grain while K was mostly in the rice straw. Except for P in the improved practice, the balances of N, P, and K were all negative, both in the farmers' practice and the improved technology. Recycling of a major portion (such as two-thirds) of the rice straw may solve the problem of K depletion.

Introduction

Over recent years, there has been improving awareness of the threat to agricultural sustainability and the general environment of soil erosion by water. Erosion by water, which is defined as the wearing away of the land by running water, has been a problem since time immemorial (Sys, 1989). Today, soil erosion threatens several million hectares of land in the world. In the Philippines, Lao PDR, Vietnam, and Indonesia, soil erosion has been identified as a major threat to sustainable agriculture in steep land areas (Agus *et al.*, 2001, 2002; Duque *et al.*, 2002; Phommasack *et al.*, 2002; Toan *et al.*, 2002). It causes negative on- and off-site environmental, economic, and social impacts.

On site, soil erosion reduces the chemical fertility of the soil through nutrient and organic matter depletion, and in some cases, could expose the acid subsoil. Erosion also damages the physical fertility by removing surface soil, reducing the soil depth, and decreasing water

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holding capacity. Ultimately, it reduces crop yields, farm incomes, and household nutrition (Agus *et al.*, 2002; Duque *et al.*, 2002; Phommasack *et al.*, 2002; Sukristiyonubowo *et al.*, 2001; Toan *et al.*, 2002).

Recognizing this problem, the Management of Soil Erosion Consortium (MSEC) initiated a collaborative project in Indonesia, Lao PDR, Nepal, the Philippines, Thailand, and Vietnam, with funding support from the Asian Development Bank (ADB). This paper reviews and discusses nutrient loss and costs as a consequence of water erosion in four countries, namely, Indonesia, the Philippines, Vietnam, and Lao PDR. It also presents the nutrient lateral transport in a lowland rice system in Indonesia.

Methodology

Measurement of Nutrient Loss and On-site Cost

In this project, soil loss or sediment yield represents the sum of bedload and suspended load, which are measured every rainfall event. Bedload was collected in the sediment trap with V-notch weirs, equipped with an automatic water level recorder and staff gauges. Since the sediments have different chemical composition due to different settling velocities, daily sampling of sediments for chemical analysis in the laboratory was done separately for the bedload and suspended load. In the case of Indonesia, selection was done taking into consideration rainfall amount and intensity and current farmers' activities. For other countries, nutrient contents in the bedload samples were determined periodically based on composite samples, but some countries like the Philippines were unable to take into account the soluble nutrient content in runoff water.

Sediment concentration was determined in the laboratory by oven drying a known volume of sediment samples and calculated by the following formula (Ciesiolka and Rose, 1998):

$$\textit{Sediment concentration} = \frac{\textit{Oven dry weight of sediment}}{\textit{Volume of sample (sediment + water)}}$$

Suspended load is then calculated as:

Suspended load = discharge x sedimentation concentration

Nutrient loss is calculated as the product of soil loss and concentration of nutrients in the sediment (Hashim *et al.*, 1998):

Nutrient loss = soil loss x nutrient concentration in sediment

The on-site costs associated with nutrient loss were calculated by determining the equivalent cost of fertilizer materials needed to replace the lost nutrients (Agus and Sukristiyonubowo, 2002). The fertilizer price referred to the current price of fertilizers in Indonesia.

Nutrient Balance in a Paddy Rice System

In this initial study, nutrient balance was calculated as the difference between inputs (nutrient gains) and outputs (nutrient loss). Nutrient inputs were counted from fertilizer addition, irrigation, and recycled rice straw, while nutrient losses were calculated from the soil loss by erosion and nutrient removal through harvest. The concentrations of N, P, and K were measured from rice grain and straw, soil, water, and suspended sediment samples and used in the nutrient balance estimates. The changes of nutrients in the soil were not taken into consideration.

Measurement of soil erosion was started from land preparation (plowing, harrowing, and puddling) to rice harvest. Since the study focused on soil and nutrient loss, samples of suspended sediment were taken from the main outlet, that is, the last terrace where the runoff went before flowing out to the river. A rating curve for the relationship of water level and water discharge of the inlet (where the water from the canal came to the first terrace) was determined as the product of water velocity (measured using the float method) and the cross-sectional area of the flowing water at the gauge. The discharge at the main outlet was determined using the tipping bucket method. During land preparation, suspended samples were taken every 10 minutes, starting from the first runoff flowing out of the V-notch of the main outlet until the color of suspension became almost the same as that of the water coming into the inlet. These samples were used to analyze the concentration of sediment. Selected suspended sediment and irrigation water samples were analyzed in the laboratory to determine the concentrations of N, P, and K. Selection was based on rainfall and farmers' activities. The daily water level was monitored three times, at 08.00, 12.00, and 16.00. Soil and nutrient loss were calculated using the formula mentioned above.

The estimate of nutrient balance was made for two simple treatments: farmers' practice, and improved technology. Most farmers in this village added only urea (about 45 kg N ha^{-1} $cropping^{-1}$). The improved technology considered the rate recommended by the Food Crop Institute at District Level which is 90 kg N, 40 kg P, and 50 kg K ha^{-1} $cropping^{-1}$. The study was conducted for two rice cropping seasons (31 October 2001 to 31 January 2002 and from 16 March to 1 July 2002). An estimate of the nutrient balance was also done for a system where 66 percent of the rice straw is recycled.

Results and Discussion

Profile of Selected Catchments

Table 1 shows some attributes of the catchments and sub-catchments in Indonesia, Lao PDR, the Philippines, and Vietnam. It also shows some runoff and erosion data in 2002.

Indonesia

The site in Indonesia is located in Ungaran sub-district, Central Java Province. The catchment is relatively close to urban development such that farming constitutes the second or third source of income. Annual rainfall of 3,800 mm in 2000/2001and 3,136 mm in 2001/2002 is considerably higher than that in other countries. Moreover, the rainfall amount was above the annual average of 2,800 mm. In spite of the high rainfall, the proportion of runoff relative to rainfall (runoff coefficient) was less than 14 percent (about 3-13 percent) indicating the high infiltration capacity of the soils at the site. Sediment yields in 2001/2002 were 0.2, 7.8, 10.2, and 6.1 t ha^{-1} $year^{-1}$ for Rambutan, Kalisidi, Tegalan, and Babon catchments, respectively. For the Tegalan sub-catchment, dominated by cassava, sediment yield in 2000/2001 was about 20 t ha^{-1} $year^{-1}$ and this was attributed to the relatively exposed surface soil, sparse litter cover, intensive tillage, steep slopes, and small catchment size. In 2001/2002, when about 60 percent of the area was planted to fodder grass (Benggala grass and King grass) and the rest to

Table 1. Characteristics of MSEC catchments in four countries in 2002

Catchment	Area (ha)	Rainfall (mm)	Runoff Coef.	Sediment yield	Soil order/ Subgroup	Land use/farming system	Dominant slope	Fertilizer application (kg ha^{-1})
INDONESIA								
Tegalan	1.1	3,136	5	10.20	Andic Eustropept	Cassava (40%), fodder grass (60%)	45-47	For fodder grass: 100 urea, 100 TSP and KCl
Rambutan	0.9	3,136	3	0.20	Andic Dystropept	Rambutan, shrub	22–55	406 urea; 420 TSP; 658 KCl[1)]
Kalisidi	13	3,136	13	7.80	Andic Dystropept	Rambutan	22–55	406 urea; 420 TSP; 658 KCl[1)]
Parshall flume	285	3,136	7	6.10	Typic Tropaquept	All + rice	0–55	For rice only 100 kg urea
PHILIPPINES								
MC 1	24.9	2,102	2	0.00	Ultisol	Falcata, bamboo, grassland (98%), vegetables, and root crops (2%)	15-20	2 bags chicken dung and 6 bags complete fertilizer 14-14-14
MC 2	17.9	2,102	7	0.08	Ultisol	Forest, grassland (85%), cropland, shrubs (10%)	10-25	2 bags chicken dung and 6 bags complete fertilizer 14-14-14
MC 3	8	2,102	4	0.00	Ultisol	Grassland (75%), cultivated (15%), settlement (10%)	15-20	2 bags chicken dung and 6 bags complete fertilizer 14-14-14
MC 4	0.9	2,102	-	24.70	Ultisol	Grassland, trees (60%) Cultivated and bare (40%)	10-15	2 bags chicken dung and 6 bags complete fertilizer 14-14-14
Whole	84.5	2,623	4.44	1.07	Ultisol	Grassland, bamboo, Eucalyptus, etc 80%; vegetable and root crop (20%)	15-20	2 bags chicken dung and 6 bags complete fertilizer 14-14-14

VIETNAM								
W 1	4.8	2,035		4.40	Ultisol	Cassava, grass	25-40	-
W 2	9.4	2,035		3.90	Ultisol	Cassava, *A. mangium*	30-35	-
W 3	5.2	2,035		2.90		Cassava, taro, *A. mangium*	40-45	-
W 4	12.4	2,035		1.60		Cassava, *A. mangium*, Secondary forest	35-40	-
MW	96.0	2,035		1.90		Cassava, arrow root, sec.	20-25	-
LAOS								
S0	1.3	1,651	8.7	0.58	Ultisols Alfisols	69% bush fallow 31% teak	25	-
S1	19.6	1,651	31.4	0.72	Ult, Alf, Ent	76% bush fallow, 14% forest and teak, 9% annual and 1% perennial crops	29	-
S2	32.8	1,651	39.8	0.59	Alf, Ult, Entisols	80% bush fallow, 15% forest and teak 2% annual and 3% perennial crops	27	-
S3	51.4	1,651	67.1	1.47	Alf, Ent, Ult	60% bush fallow, 10% forest and teak 20% annual and 10% perennial crops	25	-
S4	60.2	1,651	44.8	6.83	Alf, Ult, Ent	53% Bush fallow, 43% forest, teak 2% annual and 2% perennial crops	28	-

1) Fertilizer application for rambutan *(Nephelium lappaceum)* was stopped in 1999 until mid-2001 because of encroachment by villagers. In November 2001 the company resumed the fertilization and regeneration of some trees

cassava, the sediment yield was only 10.2 t ha^{-1} $year^{-1}$. This may be due to better soil protection by fodder grass, less intensive tillage, and less soil disturbance during grass cutting and cassava harvesting. For the Kalisidi sub-catchment, sediment yield was doubled compared to the previous year. The reason was that in 2001/2002, all the cassava planted in the lower 1-2 ha area of the sub-catchment had been harvested (Agus *et al.*, 2000; Agus *et al.*, 2002). (Cassava has been planted by the local villagers since 1999; they claim a right to the land dating back to the Dutch colonial era.)

The Philippines

The Philippine catchment with an area of 85 ha is located in Mindanao Island. Annual rainfall was 2,907, 2,906, and 2,102 mm in 2000, 2001, and 2002, respectively. For the sub-catchments with an area of more than 8 ha, sediment yield was only 1 t ha^{-1} $year^{-1}$. Sub-catchment MC4 with an area of 0.9 ha and 40 percent cultivated or bare, had an annual sediment yield of 52, 29, and 25 t ha^{-1} in 2000, 2001, and 2002, respectively. These high values could be due to the close proximity to the sediment trap of the bare and cultivated area (Duque *et al.*, 2002). Otherwise, this value seems to be extremely high for catchment-scale measurement

Vietnam

The Vietnamese catchment has an annual rainfall of about 2,000 mm. It represents the typical cultivated mountainous uplands with slopes ranging from 15 to 60 percent. The altitude varies from 125 to 700 m above sea level. The main crops are cassava, taro, peanut, rice, maize, forest plantation such as eucalyptus, *Acacia mangium*, cinnamon, etc. Water from catchment streams is used for irrigation of 10 ha of paddy in Dong Cao village. With catchment sizes ranging from 4.8 to 45.5 ha, annual sediment yield ranged from 1.6 to 4.4 t ha^{-1} (Toan *et al.*, 2002).

Lao PDR

The MSEC study site in Laos is located in Luang Prabang Province, about 400 km north of Vientiane municipality. Luang Prabang is predominantly mountainous, consisting mostly of hills, steep and very steep slopes (8 to more than 55 percent) while the flat and gentle slopes (0 to 2 percent) represent less than 1 percent of the area and lie on the foothills, at the valley bottom. The elevation varies from 290 to 2,257 m above sea level. The most common soil order is Ultisols (*Soil Taxonomy*), which is found on slopes ranging from 8 to 50 percent. The province has a wet-dry monsoon tropical climate. The dry season (November to March) is cold and mostly dry, while the wet season (April to October) is hot and humid. The annual rainfall varies from year to year. In 2001, the annual rainfall was 2,153 mm but 1,661 mm in 2002. Sub-catchments of less than 1 ha and predominantly planted with annual crops yielded 2.5-5.7 t ha^{-1} $year^{-1}$ of sediments. Larger catchments ranging from 20 to 65 ha with annual upland crops and teak as their land use had sediment yield of 0.72-6.83 t ha^{-1} $year^{-1}$ (Phommasack *et al.*, 2002). This means that areas with annual crops, which are intensively farmed, tended to have high sediment yields.

Nutrient Loss by Erosion

Inherently, soil differs in fertility. However, human activities can easily manipulate and improve soil fertility through the addition of fertilizers, manure, amendments, and application of soil conservation measures. The amount of soil and nutrient loss could be an indicator of how effective the farmers manage their land.

The loss of nutrients was less in 2002 than in 2001 (Table 2). The most likely reason was the lower rainfall and soil loss in 2002 in all countries. In both 2001 and 2002, the highest N loss of 144 and 37 kg N ha^{-1} $year^{-1}$, respectively, was shown by MC-4 (the catchment planted to an annual upland crop) in the Philippines. As described earlier, this sub-catchment is less than 1 ha and intensively cultivated. The second highest loss was in the Tegalan sub-catchment in Indonesia. The N loss was 21 N ha^{-1} $year^{-1}$ in 2001 and 5 N ha^{-1} $year^{-1}$ in 2002. Incidentally, this is also a small sub-catchment and cultivated to annual upland crops.

Table 2. Nutrient losses from different MSEC catchments in 2001 and 2002

Catchment	**Nutrient loss (kg ha^{-1} yr^{-1})**					
	N		**P**		**K**	
	2000/01	**2001/02**	**2000/01**	**2001/02**	**2000/01**	**2001/02**
INDONESIA						
Tegalan	21.53	5.34	5.82	1.82	9.02	1.65
Rambutan	0.89	0.00	0.90	0.00	1.11	0.00
Kalisidi	9.24	0.03	0.21	0.13	5.97	0.08
Parshall flume	0.60	0.00	0.00	0.00	2.11	0.01
PHILIPPINES						
MC 1	0.50	0.00	0.00	0.00	0.50	0.00
MC 2	2.30	0.21	0.00	0.00	0.05	0.03
MC 3	4.80	0.00	0.00	0.00	0.19	0.00
MC 4	144.20	37.59	0.08	0.00	6.09	3.32
Whole	1.30	1.59	0.00	0.00	0.15	0.17
VIETNAM						
W 1	10.79	3.50	4.81	0.57	4.26	4.73
W 2	10.83	4.60	4.97	0.83	2.46	1.74
W 3	8.73	1.60	3.99	0.39	2.68	1.41
W 4	4.03	1.10	2.25	0.31	1.38	0.83
MW	3.55	0.90	1.94	0.22	2.58	0.75
LAOS						
S 0	0.03	0.00	0.00	0.00	0.00	0.00
S 1	4.74	1.25	0.90	0.20	0.82	0.12
S 2	5.12	0.06	0.93	0.01	0.79	0.00
S 3	12.51	3.31	1.91	0.15	0.76	0.01
S 4	16.27	2.58	2.73	0.12	0.98	0.07

The Tegalan sub-catchment in Indonesia showed the highest loss of P in both years. There was a loss of about 6 kg P ha^{-1} $year^{-1}$ in 2001 and 1.8 kg P ha^{-1} $year^{-1}$ in 2002. Considering that no external P input had been applied before the introduction of the fodder grass in late 2001 and the area was intensively cultivated with cash crops (maize, peanut, and cassava) that require high P, this level of loss may quickly deplete soil P.

The highest K loss in 2002 was in W1 sub-catchment in Vietnam at 4.7 kg K ha^{-1} $year^{-1}$. In 2001, this occurred in the Tegalan sub-catchment in Indonesia with a loss of 9 kg K ha^{-1} $year^{-1}$. The loss of K almost corresponds to the soil and N losses in the four countries. Interestingly, the pattern was almost the same as in 2001. Higher soil loss results in higher N and K losses.

On-site Cost of Soil Erosion

On-site cost as an end result of erosion varies among the countries. It depends on the total nutrient loss and the price of fertilizer. In 2002, the MC4 sub-catchment in the Philippines which had the highest N and second highest K loss presented the highest on-site cost of erosion (Table 3). This was followed by W1 of Vietnam, which had the biggest K loss, and then Tegalan of Indonesia, which had the highest P loss and the second highest N loss. The on-site cost was US$27.13, 9.50, and 8.48 ha^{-1} $year^{-1}$ for the Philippines, Vietnam, and Indonesia respectively. These values mean that the farmers must pay as much as US$27, 10, and 8 ha^{-1} $year^{-1}$ to replace the nutrients lost due to erosion. These costs were lower than those in 2001 which were about US$12 to 68 ha^{-1} $year^{-1}$ (Agus and Sukristiyonubowo, 2002). The cost in 2002 was lower by 21 to 51 percent of the cost in 2001.

Table 3. Nutrient loss and on-site cost of erosion at different MSEC catchments in 2002

Catchment	**Soil loss**	**Nutrient loss (kg ha^{-1} yr^{-1})**			**On-site cost**
	(t ha^{-1} yr^{-1})	**N**	**P**	**K**	**(US$)**
INDONESIA					
Tegalan	10.20	5.34	1.82	1.65	8.48
Rambutan	0.20	0.00	0.00	0.00	0.01
Kalisidi	7.80	0.03	0.13	0.08	0.34
Parshal flume	6.10	0.00	0.00	0.01	0.02
PHILIPPINES					
MC 1	0.00	0.00	0.00	0.00	0.00
MC 2	0.08	0.21	0.00	0.03	0.16
MC 3	0.00	0.00	0.00	0.00	0.00
MC 4	24.70	37.59	0.00	3.32	27.10
Whole	1.07	1.59	0.00	0.17	1.18
VIETNAM					
W 1	4.40	3.50	0.57	4.73	9.54
W 2	3.90	4.60	0.83	1.74	6.53
W 3	2.90	1.60	0.39	1.41	3.55
W 4	1.60	1.10	0.31	0.83	2.31
MW	1.90	0.90	0.22	0.75	1.93
LAOS					
S 0	0.58	0.00	0.00	0.00	0.00
S 1	0.72	1.25	0.20	0.12	0.44
S 2	0.59	0.06	0.01	0.00	0.02
S 3	1.47	3.31	0.15	0.01	0.95
S 4	6.83	2.58	0.12	0.07	0.76

From these data, it can be concluded that except in MC4 in the Philippines, nutrient loss and on site-cost were relatively smaller under the no or little fertilizer input. However, the data of soil loss signalled that MC4 in the Philippines, W1 of Vietnam, and Tegalan of Indonesia have soil loss higher than the permissible value of 2-11 t ha^{-1} $year^{-1}$ for agricultural lands (El-Swaify, 1989). Improved catchment management including additions of fertilizer and application of soil conservation measures should therefore be given priority to improve land productivity. Sediment yield from catchments of less than 1 ha and intensively planted to annual crops also reminds us of the importance of soil conservation to maintain better land productivity.

Nutrient Balance in Paddy Fields in Indonesia

Table 4 shows the total dry matter production (grain and straw) from two cropping seasons of rice under the farmers' practice and improved technology. Compared to the farmers' practice, the use of improved technology gave higher yields of rice grain and straw even if the second cropping was attacked by pests. The data also indicate that the improved technology increased the N, P, and K contents of grain and straw (Table 5). This information could be useful in evaluating the potential of recycling the rice straw to improve the nutrient balance in the soil.

Table 4. Rice grain and straw yield from the first cropping (February to March 2002) and second cropping (April to May 2002) at Babon Catchment, Indonesia

Production (t ha^{-1})	**Treatment**			
	Farmers' practice		**Improved technology**	
	1st crop	2nd crop	1st crop	2nd crop
Rice grain				
4.6	4.5	5.7	3.7*)	
Rice straw fed to cattle	2.7	2.6	4.1	5.2
Rice straw recycled	4.7	4.5	3.4	4.1

*) Pest attacks: rats and stink bugs (walang sangit)

Table 5. N, P, K content of the rice grain and straw under the farmers' practice and the improved technology

Component	**Nutrient content (%)**					
	Farmers' practice			**Improved technology**		
	N	**P**	**K**	**N**	**P**	**K**
Rice grain						
1.44	0.22	0.23	1.55	0.24	0.25	
Rice straw fed to cattle	1.02	0.08	1.91	1.09	0.13	1.88
Rice straw recycled	0.79	0.06	0.81	0.82	0.05	0.84

Nitrogen balance

In both the farmers' practice and improved technology, the N balance was in the negative, -71 and -93 kg N ha^{-1} $year^{-1}$, respectively (Table 6). This means that the N gain was less than the N loss. For the farmers' practice, the amount of added fertilizer urea was considered low (only

50 kg ha^{-1}). According to Wade *et al.* (1988), 100 kg urea or 45 kg N must be applied to satisfy the nutrient requirement of rice. Of the total N loss, about 91 percent was due to crop removal (68 percent to the grain and 32 percent to the rice straw used as cattle feed). The total N gains in the improved technology was higher than in the farmers' practice, but the N loss was much higher bringing a larger negative balance. Of the total N loss, about 93 percent was taken out by the crop harvest (about 59 percent in the rice grain and 41 percent in the straw fed to cattle). Of the total rice straw produced, about 45 to 63 percent had been used to feed the cattle. It follows that about the same percentage of N in the straw is lost in each harvest.

Table 6. Nitrogen balance of lowland rice fields based on two rice crops (October 2001 to June 2002)

Component	**Nitrogen balance (kg ha^{-1} yr^{-1})**	
	Farmers' practices	**Improved technology**
Gains:		
1. Fertilizer	45	90
2. Irrigation	22	22
3. Rice straw	73	62
Total gains	140	174
Losses:		
1. Removal by harvest:		
- Grain	131	146
- Rice straw	61	102
2. Soil Loss:		
- Suspended load	19	19
- Bedload	-	-
Total losses	211	267
Balance	- 71	- 93

Phosphorus balance

The addition of 100 kg TSP per season improved the balance of phosphorus. A positive 10.4 kg P ha^{-1} year^{-1} was estimated for the improved technology compared to the -18.82 kg P ha^{-1} year^{-1} for the farmers' practice (Table 7). The P gain in the improved technology was mainly due to the addition of fertilizer. Since the grain component has the highest P concentration and all is consumed, addition of P fertilizer becomes necessary to maintain soil fertility.

Potassium balance

As for N, both the farmers' practice and improved technology gave a negative K balance, –53 and –65 kg K ha^{-1} year^{-1}, respectively (Table 8). The use of rice straw as feed for cattle may have largely contributed to K loss. An equivalent amount of 103 and 171 kg K ha^{-1} year^{-1} was lost as cattle feed in the farmers' practice and improved technology, respectively. Because of the high K content of the rice straw, the K loss by crop removal was relatively high. Total input in the farmers' practice was mainly from irrigation and recycled straw (which was quite low). In the case of the improved technology, input from fertilizer addition did not improve the balance of K in the soil. Losses, especially through harvesting, were 193 kg K ha^{-1} year^{-1} (most of which was through rice straw removal) while the total gain was lower at 139 K ha^{-1} $year^{-1}$. Recycling of most, if not all of the rice straw, and application of manure or KCl fertilizer may improve the K balance in the soil.

Table 7. Phosphorus balance of lowland rice fields based on two rice crops (October 2001 to June 2002)

Component	**Phosphorus balance (kg ha^{-1} yr^{-1})**	
	Farmers' practices	**Improved technology**
Gains:		
1. Fertilizer	-	40.0
2. Irrigation	6.1	6.1
3. Rice straw	5.5	4.7
Total gains	11.6	50.8
Losses:		
1. Removal by harvest:		
- Grain	20.1	22.2
- Rice straw	4.3	12.1
2. Soil Loss:		
- Suspended load	6.0	6.1
- Bedload	-	-
Total losses	30.4	40.4
Balance	- 18.8	+ 10.4

Table 8. Potassium balance of lowland rice fields based on two rice crops (October 2001 to June 2002)

Component	**K-balance (kg ha^{-1} yr^{-1})**	
	Farmers' practices	**Improved technology**
Gains:		
1. Fertilizer	-	50
2. Irrigation	11	11
3. Rice straw	75	78
Total gains	86	139
Losses:		
1. Removal by harvest:		
- Grain	26	22
- Rice straw	103	171
2. Soil Loss:		
- Suspended load	10	11
- Bedload	-	-
Total losses	139	204
Balance	- 53	- 65

Recycling the rice straw

The nutrients contained in the rice straw can alter their balance if they are returned back to the soil. This can also substitute for even a small portion of chemical fertilizer requirement for rice, which is not subsidized by the government. The proposed recycling of 66 percent of the total rice straw produced can improve the balance of these nutrients in the soil. The expected gains from this system would be about 110 kg N, 11.2 kg P, and 166 kg K ha^{-1} year^{-1} for the improved technology and 88 kg N, 6.6 kg P, and 111 kg K ha^{-1} year^{-1} for the farmers' practice. The nutrient loss would be 45 kg N, 5.6 kg P, and 83 kg K ha^{-1} year^{-1} for the improved technology and about 44 kg N, 3.3 kg P, and 55 kg K ha^{-1} year^{-1} for the farmers' practice (Table 9).

Table 9. Estimated nutrient gains and losses with 66% of rice straw yield recycled

Component	Farmers' practices (kg ha^{-1} yr^{-1})			Improved technology (kg ha^{-1} yr^{-1})		
	N	P	K	N	P	K
Gains:						
Recycled rice straw	88	6.6	111	110	11.2	166
Losses:						
Removed rice straw	44	3.3	55	45	5.6	83

Using the nutrient gains from fertilizers and irrigation and the nutrient losses from rice grain removal and soil loss, recycling of 66 percent of the straw produced would yield a balance of +12 kg N, +23 kg P, and +112 kg K ha^{-1} year^{-1} for the improved technology and –39 kg N, +17 kg P, and +30 kg K ha^{-1} year^{-1} for the farmers' practices (Table 10). In terms of economics, this would save the farmers about US$120 (with the price of urea at about US$0.27, TSP US$0.33, and KCl US$0.33 kg^{-1}). Thus, recycling at least 66 percent of the rice straw combined with the addition of inorganic fertilizer at the recommended rate can be a good strategy to improve and maintain soil fertility.

Table 10. Estimated balance of nutrients in lowland rice fields with 66% of rice straw yield recycled

Treatment	Nutrient balance (kg ha^{-1} yr^{-1})		
	N	P	K
1. Rice straw is used for cattle feed:			
- Farmers' practice	- 71	- 18.8	- 53
- Improved technology	- 93	+ 10.4	- 65
2. 66% of rice straw recycled:			
- Farmers' practice	- 39.3	- 16.7	+ 30
- Improved technology	+ 12.4	+ 23.4	+ 111

Conclusion

High nutrient yield (especially of N and K) in general is associated with intensive annual upland farming systems. Assuming that nutrient loss with erosion will be replaced with fertilizer application, the cost of replacing the loss of the major nutrients could be as high as US$27 per year. This was observed in a small sub-catchment planted to annual upland crops in the Philippines.

For paddy rice farming, based on the Indonesian evaluation, the major proportion of nutrient loss was through crop harvesting. Nitrogen and P were higher in the rice grain while the rice straw contained high K. This means that while fertilizer input for K could be alleviated by recycling the rice straw, P and N loss through crop removal needs to be replaced with fertilizer or organic matter application.

References

Agus, F.; Sukristiyonubowo; Vadari, T.; Hermiyanto, B.; Watung, R.L.; and Setiani, C. 2002. Managing soil erosion in Kaligarang catchment of Java, Indonesia. MSEC-Indonesia Country Report. In *Integrated catchment management for land and water conservation and sustainable agricultural production in Asia.* CD-ROM (one CD). IWMI. 2002.

Agus, F.; and Sukristiyonubowo. 2002. Nutrient loss and on site cost of soil erosion under different land use systems in South East Asia. In *Integrated catchment management for land and water conservation and sustainable agricultural production in Asia.* CD-ROM (one CD). IWMI. 2002.

Agus, F.; Sukristiyonubowo; Vadari, T.; and Setiani, C. 2001. Catchment approach to managing soil erosion in Kaligarang Catchment of Java, Indonesia. In Maglinao, A. and R.N. Leslie (eds.), *Soil erosion management research in Asian catchments: methodological approach and initial results.* Proceedings of the 5th MSEC Assembly. IWMI, Thailand.

Agus, F.; Bricquet, J.P.; Sukristiyonubowo; Vadari, T.; and Enters, T. 2000. Managing soil erosion in Kaligarang catchment of Java, Indonesia. Paper presented at ISCO meeting. Beijing, 7-13 May 2000.

Ciesiolka, C.A.A.; and Rose, C.W. 1998. The measurement of soil erosion. In Penning de Vries, F., F. Agus and J. Kerr (eds). *Soil erosion at multiple scales: principles and methods for assessing causes and impacts.* CABI Publishing in association with IBSRAM: 287-302.

Duque, C.M., Snr.; Ilao, R.O.; Tiongco, L.E.; Quita, R.S.; Carpina, N.V.; Santos, B.; and de Guzman, T. 2002. Management of Soil Erosion Consortium: An innovative approach to sustainable land management in the Philippines. MSEC-Philippines Annual Report. In *Integrated catchment management for land and water conservation and sustainable agricultural production in Asia.* CD-ROM (one CD). IWMI. 2002.

El-Swaify, S.A. 1989. Monitoring of weather, runoff, and soil loss. In *Soil management and smallholder development in the Pacific Islands.* IBSRAM-Thailand. Proceedings no. 8: 163-178.

Hashim, G.M.; Coughlan, K.J.; and Syers, J.K. 1998. On-site nutrient depletion: An effect and a cause of soil erosion. In Penning de Vries, F., F. Agus and J. Kerr (eds), *Soil erosion at multiple scales: principles and methods for assessing causes and impacts.* CABI Publishing in association with IBSRAM: 207-222.

Phommasack, T.; Chanthavongsa, A.; Sihavong, C.; Thonglatsamy, S.; Valentin, C.; de Rouw, A.; Marchand, P.; and Chaplot, V. 2002. An innovative approach to sustainable land management in Lao PDR. MSEC-Lao PDR Annual Report. In *Integrated catchment management for land and water conservation and sustainable agricultural production in Asia*. CD-ROM (one CD). IWMI. 2002.

Sukristiyonubowo; Vadari, T.; and Agus, F. 2001. Nutrient loss and onsite cost at different land use system in Babon Meso Catchment, Indonesia (Unpublished).

Sys, C. 1989. Land evaluation and land use planning, with special reference to steep lands. In *Soil management and smallholder development in the Pacific Islands.* IBSRAM-Thailand. Proceedings no. 8: 77-95.

Toan, T.D.; Phien, T.; Phai, D.D.; and Nguyen, L. 2002. Managing soil erosion for sustainable agriculture in Dong Cao Catchment. MSEC-Vietnam Annual Report. In *Integrated catchment management for land and water conservation and sustainable agricultural production in Asia*. CD-ROM (one CD). IWMI. 2002.

Wade, M.K.; Gill, D.W.; Subagjo, H.; Sudjadi, M.; and Sanchez, P.A. 1988. Overcoming soil fertility constraints in a transmigration area of Indonesia. *TropSoil Bull.,* 88-01. North Carolina State Univ., Raleigh, North Carolina.