

# Residue Management for Soil Improvement on Sloping Lands in Asia

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## INTRODUCTION

The management of soil organic matter is considered critical since it plays an important role in maintaining soil fertility and soil structure. Nutrients are stored at the exchange sites in soil organic matter (SOM) and on decomposition, the nutrients are released and made available to the plants. Hence, loss of fertility and subsequent soil degradation could occur as a result of the depletion of the organic matter.

The role of SOM is of great importance in the productivity of acid, infertile Ultisols and Oxisols. These soils are dominant in the uplands of humid tropical Southeast Asia where various forms of low-input agriculture are practised by the farmers. Recognizing the fact that such systems are not sustainable, efforts have been made to introduce improved cropping systems to the farmers to achieve higher productivity of their farms and eventually to improve food security.

The International Board for Soil Research and Management (IBSRAM) initiated a project to develop improved cropping systems and soil conservation technologies for sloping lands using the networking approach. With the ultimate objective of enhancing their adoption on a wide scale, the project has been implemented in seven countries in Southeast Asia. The process is to improve on available systems in the participating countries and later test them in on-farm trials. An important feature of the study is to introduce conservation cropping systems that protect the soils against erosion and subsequent degradation.

This paper presents the results of the project in four participating countries of the network, namely, Indonesia, Malaysia, Thailand, and Vietnam. It focuses on the effect of residue management on soil organic carbon, some soil properties, and its role in soil conservation.

## METHODOLOGY

The results of the *ASIALAND* Management of Sloping Lands network in Indonesia, Malaysia, Thailand, and Vietnam were reviewed and analyzed. Different cropping systems were evaluated in terms of their effect on soil organic carbon and on soil erosion. It should be noted that the network has conducted long-term experiments in these countries for more than 10 years already. Each country made use of available information and subsequently designed the cropping systems to best fit into the national agricultural policy requirements.

## Study sites

The sites represent different climatic regimes. Thailand and Vietnam have Ustic moisture regimes, with average annual total rainfall of <2,000 mm, and a pronounced seasonal distribution (IBSRAM, 1992). There is practically no dry season in Indonesia and Malaysia, with annual rainfall total of >2,000mm. These countries have Udic regimes with the potential for year-round cropping. The Thailand

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and Vietnam sites have peak rainfall around July and August while in Indonesia and Malaysia the maximum rainfall occurs in October and November. The soils at the trial sites are all Ultisols. The topsoil texture varies from sandy clay loam to clay loam. The general characteristics of the sites are presented in Table 1. Table 2 shows the chemical characteristics of representative soil profiles.

The site in Malaysia is the most depleted. For food crop production, the soil is constrained by high aluminium saturation (90% of the ECEC), low CEC, and low potassium reserves. Calcium and magnesium levels are higher at the sites in Thailand and Indonesia. This accounts for their relatively higher base saturation. In the case of Thailand, the soils are less acidic, with high amounts of organic carbon. In Vietnam, the soil contains high amount of organic carbon and the CEC is the highest. In general, all the soils are of low fertility and for food crop production, the application of external fertilizer inputs becomes inevitable.

**Table 1.** General characteristics of the ASIALAND sloping lands network sites in Indonesia, Malaysia, Thailand, and Vietnam.

Country	Soil	Topsoil texture	Annual rainfall (mm)	Cropping period
Indonesia	Kandiudult	Sandy clay loam	3,193	January-December
Malaysia	Kandiudult	Sandy clay loam	2,477	January-December
Thailand	Kandihumult	Clay loam	1,794	May-October
Vietnam	Palehumult	Clay loam	1,830	February-October

### Cropping systems

Alley cropping is the most common farming system that was tested (Table 3). The hedgerows consist of leguminous shrubs such as *Flemingia congesta* (Indonesia), *Leucaena* and pigeon pea (Thailand), and a combination of *Tephrosia candida* and *Crotalaria* (Vietnam). In Malaysia, a cover crop of *Puereria* and *Calapogonium* was established as an intercrop. The nonleguminous hedgerow plants include rubber in Malaysia, and bahia grass and coffee in Thailand. In all the cropping systems, the biomass from the respective alley crops and hedgerows was returned to the soils.

## RESULTS AND DISCUSSION

### Soil organic carbon (SOC)

The levels of soil organic carbon (SOC) after the initial establishment of the cropping systems in Indonesia were reduced drastically (Table 4). From the original content of 1.76%, the SOC was reduced to levels of 0.78 to 1.05% in 1990. This initial reduction in SOC content was reversed immediately the following year. Four years later, in 1997, the SOC levels again showed a decline in all cropping systems. The lowest decline from the original level by about 30% was recorded from the alley-cropping plots. The system of food crop and cover crop rotation showed SOC levels of 1.01 to 1.33%, a decline of 24 to 43% from the baseline level. The data also indicate that the incorporation of crop residue (T4) was not effective in maintaining SOC content, allowing the level to go down to less than 1% irrespective of fertilizer inputs. However, the most conspicuous decline occurred in the farmers' practice plots. The practice of burning crop residues (T1) resulted in SOC levels of 0.1%, indicating a management system that severely degrades the soil. The trend also showed that the SOC content in the alley-cropping system (T2) and in the cover crop rotation (T3) could be sustained with the application of fertilizers.

At the Malaysian site, the cropping systems did not exhibit any dramatic change in SOC levels (Table 5). The highest input system (T5) consistently showed SOC levels that were higher than the pre-cultivation value. This was also observed in the legume interrows (T2) and in the interrows with

Table 2. Chemical characteristics of the soil profiles at the network sites.

Country	Depth (cm)	pH (H2O)	Sandy ———(%)———	Clay ———(%)———	Org. C	N	Avail. P (mg kg <sup>-1</sup> )	Exchangeable cations					CEC	BS (%)
								Ca	Mg	K	Na	Al		
—————cmol {+} kg <sup>-1</sup> —————														
Indonesia	0-12	4.4	64.0	27.0	1.76	0.12	18	1.78	0.61	0.06	0.05	0.79	8.44	30
	12-30	4.2	58.0	32.0	0.87	0.07	2	0.61	0.24	0.04	0.10	1.24	4.91	20
	30-52	4.2	55.0	38.0	0.59	0.06	5	0.51	0.20	0.04	0.03	1.30	4.56	17
Malaysia	0-10	4.5	54.2	39.4	1.65	0.17	7	0.11	0.10	0.12	0.03	2.40	6.24	6
	10-45	4.6	47.8	45.8	0.85	1.00	6	0.08	0.07	0.07	0.02	2.24	4.93	5
	45-150	4.8	40.6	55.5	0.60	0.07	12	0.09	0.05	0.05	0.06	2.13	5.04	5
Thailand	0-15	5.3	-	30.0	2.14	-	4	2.00	1.00	0.25	-	-	9.40	23
	15-30	5.3	-	39.1	1.16	-	3	0.80	0.40	0.13	-	-	7.70	13
	30-70	5.4	-	43.9	0.64	-	3	0.40	0.20	0.14	-	-	6.60	10
Vietnam	0-8	4.1	30.5	27.8	3.14	0.21	13	2.20	0.26	0.34	0.08	-	21.20	14
	10-20	4.2	31.8	30.1	3.10	0.19	14	0.80	0.09	0.17	0.05	-	19.60	6
	22-40	4.2	32.4	34.4	3.08	0.16	13	2.40	0.11	0.04	0.08	-	18.80	14

Table 3. Improved cropping systems tested at the different sites.

Country/site	Treatments	Practice	Alley crop
Indonesia (Kumang Kuning Unit IV)	T1 Farmers' practice	Crop residue burnt	Upland rice-peanut-mung bean
	T2 Alley cropping	Minimum tillage Hedgerow <i>Flemingia congesta</i> Hedgerow trimmings mulched Crop residue incorporated Conventional tillage	Upland rice-peanut
	T3 Covercrop-foodcrop	Mucuna in rotation	Upland rice-peanut-mucuna
	T4 Incorporate crop residue	Conventional tillage	Upland rice-peanut-mung bean
Malaysia (Gadong)	T1 Farmers' practice	Rubber hedgerows alley with Grasses and weeds	-
	T2 Low input	Rubber hedgerows alley with Legumes	-
	T3 High input I	Rubber hedgerows	Corn-peanut
	T4 High input II	Rubber Hedgerows	Pineapple
	T5 High input III	Rubber hedgerows	Pineapple with corn-peanut
Thailand (Chiang Rai)	T1 Farmers' practice	Planting up-and-down slope	Upland rice
	T2 Alley-cropping I	Hedgerow-leucaena+pigeon pea	Upland rice
	T3 Alley-cropping II	Hedge-coffee+grass strip	Upland rice
	T4 Hillside ditches	Coffee along ditches coffee with rice as intercrop	Upland rice
	T5 Agroforestry		
Vietnam (Dac Lac)	T1 Farmers' practice	Coffee without conservation practice	-
	T2 Ditching	Ditching between coffee rows	-
	T3 Bunding	Bunding around each coffee point	-
	T4 Intercropping	Corn-peanut intercropped with coffee	-
	T5 Alley cropping	Hedgerow- <i>Tephrosia candida</i> and <i>Crotalaria</i> <i>Urasamoyensis</i>	-
	T6 Intercropping	Vigna sinensis intercropped with coffee	Coffee
	T7 Bare plot		-

**Table 4.** Soil organic carbon (SOC) content (%) of soils under different cropping systems at Kuamang Kuning IV, Indonesia.

Year	Cropping systems (treatments)											
	T1-1	T1-2	T1-3	T2-1	T2-2	T2-3	T3-1	T3-2	T3-3	T4-1	T4-2	T4-3
1990	0.80	0.91	0.91	0.93	0.86	1.02	1.01	0.91	1.05	0.84	0.78	0.82
1991	1.56	1.60	1.64	1.32	1.52	1.58	1.68	1.38	1.76	1.47	1.62	1.56
1992	1.70	1.72	1.61	1.52	1.72	1.71	1.51	1.54	1.50	1.44	1.63	1.63
1993	1.39	1.35	1.37	1.50	1.41	1.74	1.37	1.39	1.29	1.17	1.20	1.33
1996	1.12	1.22	1.43	1.57	1.34	2.13	1.52	1.25	1.65	1.33	1.24	1.56
1997	0.10	0.11	0.11	1.21	1.26	1.25	1.33	1.01	1.14	0.98	0.97	0.96

T1 Farmers' practice (crop residue burnt)—upland rice-peanut-mung bean

T2 Alley cropping (*Flemingia congesta* hedgerows) with upland rice a peanut-mung beanT3 Food and cover crop rotation with upland rice-peanut-*Mucuna*

T4 Incorporation of crop residue-upland rice

1 No fertilizer

2 Low-input fertilizer

3 High-input fertilizer

peanut-corn rotation (T3). At 48 months in the cropping cycle (9), the SOC levels increased sharply in most of the plots. This is possibly due to active recycling processes as the rubber canopy closes. The added inputs comprised of rubber leaf litter and dead feeder roots in the topsoil. The rubber ecosystem is close to that of a forest ecosystem and could be an example of a nutritionally efficient self-sustaining plantation crop (Sivanadyan, 1995). The C/N ratio indicates active N mineralization in the topsoil (Zainol *et al.*, 1995). Hence, the overall SOC content indicates a steady-state level whereby, despite the addition of crop biomass residues to the soil, there is little indication of organic matter buildup.

**Table 5.** Soil organic carbon (%) under different intercrops between rubber rows at Gadong Jaya, Malaysia.

Intercropping systems (treatments)	Cropping cycle								
	1	2	3	4	6	7	8	9	
T1 (Farmers' practice)	1.25	1.21	1.23	1.24	1.30	1.28	1.16	1.12	1.41
T2 (Leguminous cover crop)	1.25	1.26	1.28	1.33	1.39	1.44	1.35	1.34	1.57
T3 (Corn/peanut rotation)	1.26	1.51	1.33	1.19	1.31	1.37	1.39	1.30	1.32
T4 (Pineapple)	1.20	1.34	1.18	1.28	1.23	1.21	1.22	1.06	1.33
T5 (Pineapple–corn/peanut)	1.32	1.36	1.43	1.38	1.35	1.36	1.48	1.26	1.38

1 Pretreatment

2 After harvesting peanut

3 After harvesting corn

4 After harvesting peanut

5 After harvesting peanut

6 After harvesting corn

7 After harvesting peanut

8 No intercrop

9 No intercrop (48 months after planting)

Fertilizer application enhanced the SOC content of the soil at the site in Thailand (Table 6). However, with time, the overall trend showed a decline in SOC levels from its original content in all cropping systems. The maximum decline occurred in the farmers' practice plot (T1) where drops of 66% and 56% were recorded in the unfertilized and fertilized plots, respectively. The lowest decline was shown by the agroforestry system, with the SOC levels decreasing by 19, to 32%. Higher decrease occurred in the unfertilized plots, thus emphasizing the role of fertilizers in enriching the soil carbon level. The hedgerow systems (T2 and T3) did not appear to contribute significantly to organic matter increase, especially in the unfertilized plots.

**Table 6.** Soil organic carbon content (%) under different cropping systems at Chiang Rai, Thailand.

Cropping system		1989	1992	1994	1995	1996
T1	- fertilizer	2.33	1.67	1.35	1.02	0.79
	+ fertilizer	-	2.21	2.15	1.42	1.02
T2	- fertilizer	2.19	1.82	1.65	1.36	1.10
	+ fertilizer	-	2.15	2.12	1.92	1.55
T3	- fertilizer	1.88	1.60	1.39	1.24	1.05
	+ fertilizer	-	1.86	1.89	1.74	1.51
T4	- fertilizer	2.12	1.79	1.56	1.30	0.99
	+ fertilizer	-	1.97	1.89	1.59	1.40
T5	- fertilizer	1.98	1.85	1.56	1.46	1.34
	+ fertilizer	-	2.00	2.09	1.76	1.61

- T1 Farmers' practice (planting up-and-down slope)  
 T2 Alley cropping 1 (leucaena and pigeon pea hedgerows)  
 T3 Alley cropping 2 (coffee and grass strip hedgerows)  
 T4 Hillside ditches (coffee on ditches)  
 T5 Agroforestry (coffee and upland rice)

Unlike the Thailand site, the decline in SOC content at the Vietnam site was not that dramatic (Table 7). The data indicated a buildup of organic matter, and a negligible decrease was recorded from the farmers' practice system (T1) and the bare plot (T7). Nitrogen mineralization was far more active at this site as compared to Malaysia and Indonesia. This can be attributed to the high amount of native organic matter and the less aggressive nature of the rainfall at the site. The role of the legume biomass is distinct in systems T5 and T6, maintaining SOC levels at more than 2.20%. The SOC level in the intercrops of coffee, corn, and peanut (T4) was just comparable to the farmers' practice (T1) and the bare plot (T7). This indicates that short-term crops may not be an effective proposition to sustain SOC levels.

**Table 7.** Changes in organic carbon and nitrogen content at Dac Lac site in Vietnam.

Cropping System	Org. carbon (%)		Nitrogen (%)	
	1992	1997	1992	1997
T1	1.86	1.69	0.17	0.17
T2	1.86	2.15	0.18	0.18
T3	1.90	1.98	0.19	0.18
T4	1.75	1.76	0.18	0.18
T5	2.26	2.32	0.18	0.19
T6	2.17	2.25	0.19	0.19
T7	1.78	1.71	0.14	0.14

- T1 Farmers' practice: coffee without soil conservation  
 T2 Ditching between coffee rows  
 T3 Bunding around coffee  
 T4 Intercropping of coffee and corn-peanut  
 T5 Alley cropping: *Tephrosia* and *Crotalaria* hedgerows  
 T6 Intercropping of coffee and *Vigna sinensis*  
 T7 Bare plot

## Biomass yields

The highest amount of biomass recorded at the Indonesian site came from the alley-cropping system (T2), accumulating a total of 24–43 t ha<sup>-1</sup> (Table 8). An amount of 12–35 t ha<sup>-1</sup> was accumulated in the system of incorporation of crop residues (T4). Lower but comparable amounts were observed in treatments T1 and T3. In all systems, the application of fertilizers increased the biomass yield. The application of high-input fertilizers increased the yield of upland rice straw by 75 to 237%. The increase in yield was also attributed to the effect of lime in the soils (Santoso *et al.*, 1997) where the high-input plots recorded the highest pH, Ca content, and base saturation. Despite the amounts of biomass returned to the soil, however, the SOC levels did not indicate a proportionate increase.

The amount of corn and peanut residues after every cropping at the Malaysian site is shown in Table 9. The total residue amounted to 13.5 t ha<sup>-1</sup> after seven croppings under the pineapple-corn/peanut system (T5) while a total amount of 16.1 t ha<sup>-1</sup> was accumulated in the peanut-corn system (T4). Under the farmers' practice (T1) and the legume cover crop system (T2), the total amounts of biomass accumulated 51 months after planting rubber were 19.8 and 21.0 t ha<sup>-1</sup>, respectively (Table 10). These included the litter and other vegetation found in the alleys. At 51 months, there was a reduction by

50% from the first sampling in the farmers' practice plots (T1) and 49% in the legume cover crops plot (T2). The dominant vegetation in the farmers' practice plot was *Paspalum conjugatum*, *Mikania cordata*, and *Asystasia spp.* Under both systems, there was a persistence of grasses and weeds despite increasing shading of the interrow crops.

**Table 8.** Biomass yields of food crops and legumes at Kuamang Kuning IV, Indonesia (1990–1997).

Cropping Systems (treatments)	Soil org. C (%)	Mung bean	Upland rice	Peanut (t ha <sup>-1</sup> )	<i>Flemingia congesta</i>	Total biomass
T1-1	0.10	0.71	5.10	5.96		11.77
T1-2	0.11	0.85	6.27	6.47	-	13.59
T1-3	0.11	2.00	11.65	9.70	-	23.35
T2-1	1.21	1.45	9.53	8.49	5.50	24.97
T2-2	1.26	1.64	9.58	8.66	4.20	24.08
T2-3	1.25	3.74	16.72	12.77	9.90	43.13
T3-1	1.33	-	5.49	6.02	-	11.51
T3-2	1.01	-	6.16	6.09	-	12.25
T3-3	1.14	-	12.79	9.73	-	22.52
T4-1	0.98	0.88	5.53	5.29	-	11.70
T4-2	0.92	1.00	5.78	7.02	-	13.80
T4-3	0.96	2.64	18.65	13.77		35.08

Biomass yield of *Mucuna* not available.

T1 Farmers' practice (crop residue burnt)—upland rice-peanut-mung bean

T2 Alley cropping (*Flemingia congesta* hedgerows) with upland rice-peanut-mung bean

T3 Food and cover crop rotation with upland rice-peanut-*Mucuna*

T4 Incorporation of crop residue—upland rice

1 No fertilizer

2 Low-input fertilizer

3 High-input fertilizer

**Table 9.** Amount of peanut and corn residues returned to the soil at the site in Malaysia.

Interrow treatment	Residue of peanut (kg ha <sup>-1</sup> )				Corn yield (kg ha <sup>-1</sup> )		
	1	2	3	4	1	2	3
T3 Corn/peanut	2,824	1,189	2,251	2,755	2,818	3,974	327
T5 Pineapple peanut/corn	2,765	753	1,698	1,950	3,297	2,685	347

**Table 10.** Dry matter yield (kg ha<sup>-1</sup>) of the nonintercropped plots at the Malaysian site.

Interrow treatment	21 months		33 months		51 months	
	Total	Litter	Total	Litter	Total	Litter
T1 Farmers' practice	10,010	3,548	4,777	2,986	5,047	2,312
T2 Legume cover crops	9,792	4,709	6,208	3,386	4,993	2,198



With the exception of the agroforestry system (T5), addition of fertilizers increased the upland rice straw yield twofold at the Thailand site (Table 11). However, despite the high yield, the mulch produced did not have any effect in maintaining the SOC level. In Vietnam, the amount of residues obtained varied from 25 to 76 t ha<sup>-1</sup>.

**Table 11.** Rice straw yields with and without fertilizers at the Chiang Rai site in Thailand.

Fertilizer input	T1	T2	T3	T4	T5	Mean
	t ha <sup>-1</sup>					
- Fertilizer	0.73	1.34	0.90	0.90	0.85	0.94
+ Fertilizer	2.70	2.53	2.06	1.87	1.28	2.09

### Nutrients from plant residues

Since residue management is an integral feature of the agronomic inputs during intercropping, the nutrients available through decomposition of the organic matter are of major importance in nutrient cycling. This important aspect of organic residue management is an additional benefit, apart from its role as a surface mulch during the early growth of the next crop.

The potential returns of nutrients from the litter of the farmers' practice (T1) and legume cover crops (T2) in Malaysia are shown in Table 12. Based on tissue analysis, the leguminous litter can potentially return higher amount of nutrients than the farmers' practice. With time, the decreasing amount of litter had a direct influence on the levels of nutrients in both plots. The data suggested that there was greater mobilization of nitrogen by legumes.

**Table 12.** Nutrient content of litter from the nonintercropped plots in Malaysia.

Interrow treatment	Time (month)	Nutrient content (kg ha <sup>-1</sup> )				
		N	P	K	Ca	Mg
T1 Farmers' practice	21	45.4	2.8	30.9	11.4	8.9
	33	46.9	1.8	16.7	14.4	4.9
	51	34.9	1.2	4.4	22.0	3.7
	<b>Total</b>	127.2	5.8	52.0	47.8	17.5
T2 Legume cover crops	21	143.2	7.1	21.7	60.3	15.5
	33	81.9	4.3	31.8	28.5	6.4
	51	40.9	1.8	10.3	27.9	3.5
	<b>Total</b>	266.0	53.2	63.8	116.7	25.4

In the high-input interrow system (T3), the amount of N returned from the peanut residues was relatively constant, except for the depressed yield experienced during the second crop (Table 13). Phosphorus and Mg showed lower variability than K and Ca. In the highest input system (T5), the lower N returns were due to reduced planting density as a result of establishing the pineapple hedgerows. However, despite a lower planting density, a high amount of K was mobilized.

The sharp decrease in biomass yield of corn led to depressed levels of N and K. The decrease was more pronounced in the N levels. Apart from the lower planting density in the corn-pineapple system, the environmental conditions had limited the N returns from the second and third corn crops by 61% and 95% of the first crop, respectively.

**Table 13.** Nutrient content of peanut and corn residues in the corn-peanut (T3) and pineapple-corn/peanut (T5) systems in Malaysia.

Interrow treatment	Crop no.	Nutrient content (kg ha <sup>-1</sup> )					
		N	P	K	Ca	Mg	
T3 (Corn-peanut)	Peanut	1	55.4	2.5	57.3	35.9	15.2
		2	19.7	1.7	32.2	11.3	6.7
		3	51.1	3.4	66.0	17.3	9.7
		4	55.4	4.1	92.0	31.7	12.4
	Total		181.6	11.7	247.5	96.2	44.0
T3 (Corn-peanut)	Corn	1	86.2	7.3	84.3	11.8	6.8
		2	49.3	7.2	83.5	11.1	6.8
		3	5.1	1.1	9.4	0.8	0.5
	Total		140.6	15.6	177.2	23.7	14.1
T5 (Pineapple-Corn/peanut)	Peanut	1	55.3	2.8	58.6	37.6	14.9
		2	11.9	0.9	21.3	6.6	3.8
		3	40.8	3.2	48.1	15.3	7.1
		4	42.5	3.1	65.1	24.6	8.8
	Total		150.5	10.0	193.1	84.1	34.6
T5 (Pineapple-Corn/peanut)	Corn	1	105.5	9.9	103.9	14.5	7.9
		2	41.6	5.1	53.2	9.4	5.6
		3	5.3	0.9	8.4	0.8	0.7
	Total		152.4	15.9	165.5	24.7	14.2

Under high-input interrow management, there was a considerable potential for nutrients that can be recycled by allowing the biomass to act as a mulch cover as soon as harvesting is completed. Greater returns of K were achieved in both the peanut and corn systems. However, peanut tended to mobilize a higher amount of K than corn. For Ca, the returns from peanut were three to four times those from corn, while the Mg returns from peanut were two to three times more than the returns from corn.

The results indicated that the high-input system of peanut and corn rotation had a greater potential of nutrient cycling than the highest input system (pineapple-peanut/corn). In the former system, the concentration of nutrients was in the order of 322.2 kg ha<sup>-1</sup> N, 27.3 kg ha<sup>-1</sup> P, 424.7 kg ha<sup>-1</sup> K, 119.9 kg ha<sup>-1</sup> Ca, and 58.1 kg ha<sup>-1</sup> Mg from seven croppings. In the highest input system, the levels were 302.9, 25.9, 358.6, 108.8, and 48.8 kg ha<sup>-1</sup> for the respective nutrients.

Results from Vietnam also showed large amounts of nutrients that are contained in the biomass (Table 14). Overall, the amount of nutrients from the plant residues added back to the soil from 1992 to 1996 was calculated at 44 to 247 kg N, 8 to 29 kg P, and 26 to 80 kg K ha<sup>-1</sup>.

**Table 14.** Biomass yields and amount of nutrients returned (1992–1996), Dac Lac, Vietnam.

Crops	Cumulative Fresh biomass (t ha <sup>-1</sup> )	Nutrient content (kg ha <sup>-1</sup> )		
		N	P	K
T2 Peanut	24.9	44	8	26
T4 Peanut	75.5	135	25	80
T5 Crotalaria	74.2	247	29	65
T6 Vigna sinensis	45.9	167	19	44

## Soil properties

With regard to soil structural characteristics, the establishment of the cropping systems in general increased the bulk density and decreased the porosity of the soil in Indonesia (Table 15). It should be noted, however, that the practice of mulching and incorporating residues (T2, T3 and T4) resulted in relatively lower bulk densities and higher porosity than the system of burning crop residues (T1).

**Table 15.** Changes in bulk density and porosity of soils at Kuamang Kuning IV, Indonesia.

Cropping Systems	Bulk density (g cm <sup>-3</sup> )		Total porosity (%)	
	1989	1997	1989	1997
T1-1	1.29	1.43	51.2	46.1
T1-2	1.29	1.46	51.3	45.0
T1-3	1.30	1.58	50.9	40.5
T2-1	1.28	1.24	51.6	53.3
T2-2	1.36	1.45	48.6	45.3
T2-3	1.25	1.49	53.0	44.0
T3-1	1.30	1.32	50.8	50.3
T3-2	1.33	1.47	53.1	44.6
T3-3	1.21	1.44	54.2	45.7
T4-1	1.23	1.43	53.5	45.9
T4-2	1.25	1.33	52.7	49.9
T4-3	1.32	1.39	50.0	47.7

T1 Farmers' practice (crop residue burnt)—upland rice-peanut-mung bean

T2 Alley cropping (*Flemingia congesta* hedgerows) with upland rice-peanut-mung bean

T3 Food and cover crop rotation with upland rice-peanut-*Mucuna*

T4 Incorporation of crop residue-upland rice

1 No fertilizer

2 Low-input fertilizer

3 High-input fertilizer

On cultivation, a loss of aggregation occurred and the loss is apparent in the fine-size fraction (<0.10 mm) (Zainol and Mahmud, 1993). In this size range, the cumulative aggregation of the original soil was 55.6% while in the cultivated plots, the size fraction constituted less than 30% of the total aggregates. However, there is a corresponding increase in the formation of coarser water-stable aggregates. Additionally, the water infiltration and retention characteristics are not adversely affected by the intercropping systems. The lowest infiltration capacity was recorded in the pineapple plots where the surface is partially bare.

## Soil loss

The cumulative soil loss and runoff measured from the plots in Malaysia are presented in Table 16. The legume plots (T2) generate the least amount of soil loss and runoff. The pineapple plots gave a high amount of soil loss, but in combination with annuals, the loss was greatly reduced. Frequent tillage (peanut-corn) without pineapple hedgerows also generated high amounts of soil loss. The data indicated that soil loss can be minimized under the introduced cropping systems. The pattern of runoff paralleled that of soil loss. About 4% of rainfall contributed to runoff in the legume plots, indicating that the permanent vegetative cover has induced better structural properties and higher infiltration capacity.

**Table 16.** Cumulative soil loss and runoff under different intercropping systems at Gadong Jaya, Malaysia.

Intercropping system	Soil loss(t ha <sup>-1</sup> ) (t ha <sup>-1</sup> )	Runoff	
		mm	% rainfall
T1 Farmers' practice	37.4	501	10
T2 Legume cover	17.6	209	4
T3 Peanut-corn	74.7	870	17
T4 Pineapple	182.3	888	17
T5 Pineapple-peanut/corn	53.7	616	12

In Thailand, the soil loss recorded from 1989 to 1997 for the unfertilized plots showed that the average soil loss was highest (164 t ha<sup>-1</sup>) in the farmers' practice plot (T1) (Rachadawong, 1997). The least was observed in the hillside ditch treatment (T4) at 18 t ha<sup>-1</sup>. The soil loss in the alley-cropping systems ranged from 20 to 23% of that in the farmers' practice plot (T1). The agroforestry system (T5) generated a loss of 97 t ha<sup>-1</sup> or 59% of the T1 plot.

The addition of fertilizers had a profound effect on soil loss. Due to better crop growth, soil loss was reduced greatly. The highest soil loss occurred in the farmers' practice (73 t ha<sup>-1</sup>), followed by the agroforestry system (47 t ha<sup>-1</sup>). The other systems generated a soil loss of 17 to 29% of that from the farmers' practice plot. The data indicate that proper fertilizer use could reduce soil loss by as much as 50% (T1 and T5 systems). This is pertinent for the agroforestry system, where the loss of SOC could be further reduced with proper management practices.

The highest soil loss in Vietnam was recorded from the bare plot (T7) and treatment without conservation practice (Phien *et al.*, 1998). The amount recorded from these plots was between 52 and 55 t ha<sup>-1</sup>. Intercropping of corn-peanut and coffee (T4) generated a loss of 42 t ha<sup>-1</sup>. This explains the relatively low level of SOC at the site.

Alley cropping (T5) was not as effective in reducing soil loss as ditching (T2) and bunding (T3). Low runoff occurred in the T2 and T3 plots, and the soil loss was about 30 to 40% of the farmers' practice (T1) system. The soil loss generally was not high when compared to the other wetter sites of the network.

## CONCLUSION

Residue management and fertilizer use have a strong effect on soil organic carbon dynamics, soil physical and chemical attributes, and on soil loss. In Indonesia, fertilizer application increased biomass yields and soil organic carbon. Alley cropping, cover crop rotation, and incorporating crop residues maintain SOC levels between 1 and 2%. The farmers' practice of burning the crop residues induced a sharp decline in SOC to negligible levels, and was characterized by stronger soil compaction.

The intercropping systems under rubber in Malaysia generally maintain SOC levels between 1–1.5%. The leguminous cover induced larger aggregation and provided the best means of soil conservation. The introduced cropping systems reduced soil loss and runoff with time. Peanut and corn biomass returned between 141 to 182 kg ha<sup>-1</sup> N, 10 to 16 kg ha<sup>-1</sup> P, and 166 to 248 kg ha<sup>-1</sup> K.

Soil loss and runoff were reduced with fertilizer application in Thailand. The amount of SOC declined sharply with time. The highest decline occurred under farmers' practice while the agroforestry system showed the least decline.

In Vietnam, the soils are endowed with high organic matter. Minimal changes were detected in SOC and nitrogen content. The leguminous biomass returned 44 to 247 kg ha<sup>-1</sup> N, 8 to 29 kg ha<sup>-1</sup> P, and 26 to 80 kg ha<sup>-1</sup> K.

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