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Erosion Control on a Steep Sloped Coffee Field in Indonesia with Alley Cropping, Intercropped Vegetables, and No-Tillage

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Abstract : In a hilly area in Lampung State, the southern end of Sumatra Island in Indonesia, coffee is commonly cultivated on hillsides with steep slopes and soil erosion affects sustainable coffee production. A field experiment on coffee cultivation was conducted for 4 years to evaluate the effects of alley cropping and no-tillage on the seed production of coffee and on erosion control in a steep slope area in this region. The cultivation of intercropped vegetables, red peppers, tomatoes, and long beans was introduced into the coffee fields when the coffee plants were small. No significant differences in the yields of either the coffee plants or the intercropped vegetables were noted among the treatments. Coffee shoot fresh weight, however, was slightly increased by no-tillage treatment. Soil erosion was reduced by 37% as a result of no tillage and by 64% with alley cropping. The amount of soil erosion for local farmers practice, tillage & no-alley, was more than four times that in no-tillage and alley treatment. These results indicate that alley cropping and no-tillage are effective for erosion control on coffee fields on steep slopes and that yield is not affected by these practices. The introduction of intercropped vegetables is beneficial in terms of farm economy, especially when the income from coffee cultivation is limited.

Key words : Alley cropping, *Coffea arabica*, Coffee, Erosion control, *Gliricidia sepium* (Jacq.) Walp., Intercropped vegetables, No-tillage, Red acid soil.

On steep slopes in Lampung State at the southern end of Sumatra Island, Indonesia, coffee is the main cash crop at altitudes above 700 m. Coffee is commonly cultivated on steep slopes, however, bare ground is visible on some of the slopes as a result of soil erosion. The soil in this region is classified as a red acid soil (Acrisol), which is known to rapidly lose fertility after they are opened to cultivation (Lumbanraja et al., 1998; Iijima et al., 1999). Most of the coffee plants are randomly planted on slopes. Coffee fields are recommended to be cultivated by hoe for weed control, and intertillage is often practiced even on steep slopes. These random plantings and intertillage cause soil erosion, thus the productivity of coffee plants grown on steep slopes quickly declines as fertile topsoil is lost. After that, the resulting infertile slopes are no longer worth cultivating. Furthermore, the loss of arable land may lead to further clearing of tropical rain forests for cultivation of coffee crops.

Alley cropping is an effective and inexpensive cultivation technique for the reduction of soil erosion on steep slopes (Craswell et al., 1998; Paningbatan et al., 1995; Renaud et al., 1998). In alley cropping, arable crops are grown between hedgerows of woody shrubs and tree species. The system is a bush-fallow system with improved management (Kang et al., 1986). The eroded soil accumulates on the upper side of the hedgerows of perennial shrubs and can be used to create terraces. Another technique to reduce soil erosion on slopes is no-tillage cultivation. For example, recent studies show that no-tillage effectively reduced soil erosion under crop rotation of maize (*Zea mays* L.)/cowpea (*Vigna unguiculata* (L.) Walp.) in Nigeria (Lal, 1997), pineapple (*Ananas comosus* (L.) Merr.) on Ishigaki Island, Japan (Sugahara et al., 2001), and winter and spring crops in central Croatia (Basic, et al., 2001). The combination of alley cropping and no-tillage has also been tested, for example, in maize+cassava (*Manihot esculenta* Crantz) in southern Cameroon (Hulugalle and Ndi, 1993; Hauser et al., 2000); however, the system has not been thoroughly tested for coffee cropping in Indonesia.

In some regional coffee fields, vegetable crops are planted among coffee plants, especially in the relatively flat fields near farmhouses. Local coffee farmers plant them for additional food and/or for commercial purposes. Intercropping annual food crops and vegetables in coffee fields was economically evaluated at several coffee research stations in Kenya (Njoroge and Kimemia, 1995 a and b; Njoroge et al., 1993). Some species, such as potato, tomato, and bean (Njoroge et al., 1993; Njoroge and Kimemia, 1995 b) and carrots and

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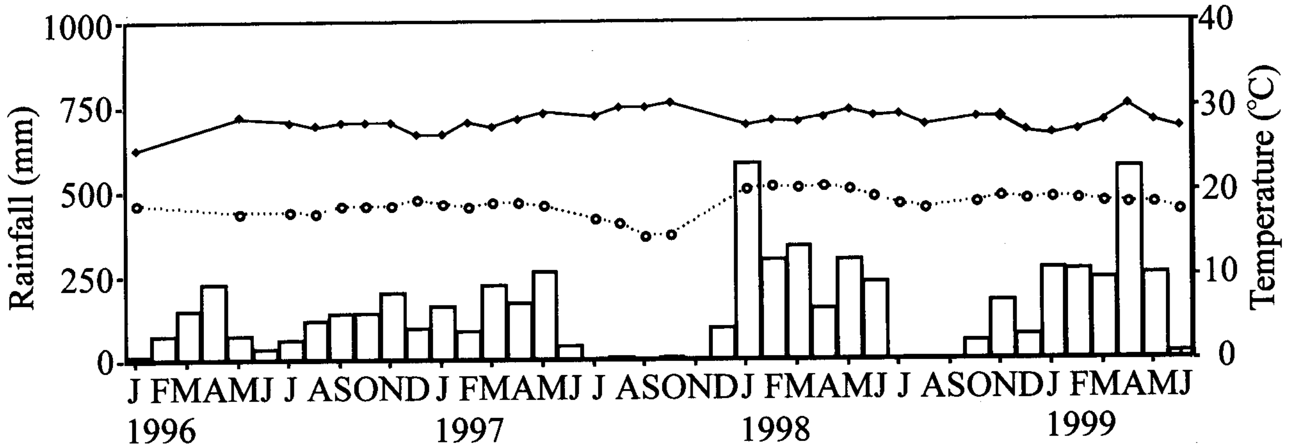

Fig. 1. Monthly rainfall and average values of daily maximum and minimum temperature at the experimental site (Sumberjaya, Indonesia) during the experiment.

Table 1. Soil properties of the experimental field. Values are the average of 12 plots.

pH (H_2O)	Total N ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	CEC ($cmol\ kg^{-1}$)	Texture (%) Sand	Silt	Clay
4.59	1.8	22.2	9.7	34.4	19.5	46.1

soybeans (Njoroge and Kimemia, 1995 a), were reported to benefit from intercropping with young coffee plants. On steep sloped coffee farms, intercropping vegetables has not been thoroughly tested.

To test these hypotheses and to develop techniques for sustainable coffee production, a field experiment was conducted for four years. The primary objective of this paper is to analyze the effects of alley cropping and no-tillage on coffee bean production and on soil erosion control on steep slopes. Vegetable intercropping was also introduced before the coffee canopy was fully developed. Finally, an economic analysis of the coffee farms was conducted after the four years of the experiments to evaluate the effectiveness of the techniques that were introduced. Soil physics and coffee root growth will be reported elsewhere.

Materials and Methods

1. Experimental Site

In November 1995, an experimental field was established on a steep hillside in Sumberjaya, Lampung State, South Sumatra, Indonesia (105°01′E, 04°34′S, 780 m above sea level). The slope gradient was approximately 15 degrees. The average rainfall recorded from 1974 to 1998 was approximately 2500 mm/year, and the mean air temperature was approximately 22°C (Afandi et al., 2002). The temperature and rainfall during the experimental period are shown in Fig. 1. The 1997 dry season was quite severe, as occurs approximately once every 50-60 years. The soil at the experimental site was classified as *Vertic Dystrudepts* (Soil Survey Staff, 1998). The soil texture was heavy clay, but the internal drainage was very good (Afandi et al., 2002). The soil chemical properties are summarized in Table 1.

2. Field arrangement

Four treatments were set up by combining two cultivation techniques, alley cropping and no-tillage. Each treatment had three replications. Twelve plots were arranged according to a randomized complete block design along the contour line (Fig. 2). Each plot (approximately 108 m^2) comprised three square sections (6 m×6 m) along the slope. The lower side of each section was set up parallel to the contour line. In the alley plots, gamal (*Gliricidia sepium* (Jacq.) Walp.), a leguminous shrub, was densely planted at the lower side of each section as a hedgerow plant. Two gamal trees were also planted on the lower sides as shade plants for all plots. Each plot was enclosed with a zinc-coated metal plate to ensure that the eroded soil was collected. Twelve seedlings of one-year-old coffee (*Coffea arabica* L.) were planted on 17 Nov. 1995 at 2 m×1.5 m intervals in each square section. In the first three years, red pepper (*Capsicum frutescens* L.), mini tomato (*Lycopersicum esculentum* Mill.), and long bean (*Vigna sesquipedalis* L.) were successively cultivated between the coffee rows as intercrops along the contour line in all plots. The row spacing of all the vegetables was 2.0 m, and the intrarow spacing of red pepper, mini tomato, and long bean was 0.5 m, 0.5 m and 0.2 m, respectively. All the vegetables

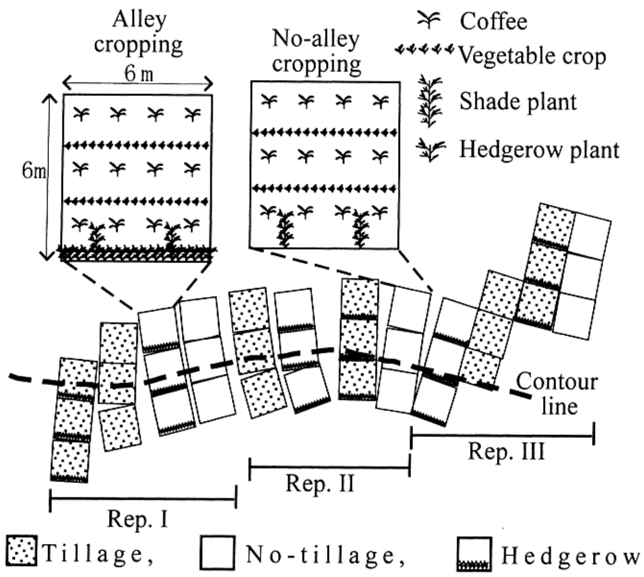

Fig. 2. Field map and arrangement of the experiment.

were planted at the beginning of the rainy season and harvested at the end of the rainy season.

3. Field management

In no-tillage treatment, the field was not tilled for four years except for the planting hole of vegetable intercropping. In tillage treatment, the field was cultivated two to three times a year for weeding and intertillage purpose. The recommended amount of fertilizer was applied to each crop. N, P_2O_5, and K_2O applications (kg ha^{-1}) for coffee plants at the year 98/99 was 225, 105, and 260, respectively. In the previous years, reduced amounts were applied following government recommendation. N, P_2O_5, K_2O applications (Kg ha^{-1}) for red pepper and tomato was 24, 18, 56, and that for long bean was 45, 30, and 40, respectively. Fertilization was conducted twice a year for the coffee plants, except for the last (98/99) season. For the intercropped vegetables, the entire amount was applied as a basal dressing. All the fertilization was a surface-layer application. Watering was done only at the transplanting time and during the severe drought of 1997. In the no-tillage treatment, roundup was sprayed for weed control, whereas, in the tillage treatment, weeding was done with a hoe. Fastac 15 EC (α-cypermethrin 15 g L^{-1}) was used for pest control (ants and fly ants), and Dithane M45 was used for prevention of fungal disease of coffee plants.

4. Plant performance, soil erosion, and economic evaluation

Coffee bean harvesting started in the second year. The canopy size and shoot fresh weight of the coffee plants were measured on 9 July 1999, approximately 44 months after planting. Eight plants from each treatment were harvested. The fresh yields of the intercropped vegetables were also measured at harvesting. The yields of vegetables were estimated based on the whole field including the area occupied by coffee. The eroded soil was sampled sequentially with soil collectors made of metal plates and plastic sheets placed at the lower edge of each plot. Samples were collected every one to two months during the rainy season, and just one or two times per dry season depending on the amounts of soils accumulated in the erosion collectors. The soil was sun-dried and weighed at each sampling time. A soil subsample was oven-dried to estimate the water content. The farm economy was evaluated continuously for four years after the coffee plants were planted. The net income was calculated with the costs of agricultural inputs and income from the harvested crops. Labor costs were not included in the economic evaluation.

Table 2. Effects of no-tillage and alley cropping on the yield (kg ha^{-1}) of intercropped vegetables. Captions in parentheses show the growth periods. Ns, not significant.

Treatment	Red pepper ('96 Jan - May)	Tomato ('96 Nov- '97 Feb)	Long bean ('97 Nov- '98 Mar)
No-tillage	109	824	1552
Tillage	97	827	1633
	ns	ns	ns
Alley	110	833	1597
No-alley	96	819	1588
	ns	ns	ns

5. Statistical analysis

Two-way analysis of variance (2-way ANOVA) was performed on all the data to verify the effects of the treatment. Furthermore, on the amount of erosion, one-way analysis of variance (1-way ANOVA) and Duncan's multiple range test were also conducted to compare means among the four treatments.

Results

The yield of intercropped vegetables planted between coffee rows did not significantly differ between the tillage treatments and alley treatments (Table 2). The size of the coffee canopy at 44 months after transplanting was also not significantly different among the treatments (Table 3). At this stage, the canopy width, over 2 m, was almost the same as the coffee row spacing; thus, the vegetable intercropping was not effective after this stage of coffee growth. Coffee shoot fresh weight in no-tillage was 14% higher than that in tillage. Alley cropping also tended to increase the shoot fresh weight, even though the difference was insignificant. Coffee dry-seed yields at three continuous cropping seasons were not significantly different among the four treatments (Table 4). Similarly to the shoot fresh weight, the yield in no-tillage was slightly better than that in tillage, although they were not significantly different. Soil erosion was signifi-

Table 3. Effects of no-tillage and alley cropping on the growth of coffee plants 44 months after transplanting. Ns, not significant; !, significantly different at the P< 0.1 level.

Treatment	Canopy height (m)	Canopy diameter (m)	Shoot fresh weight (kg plant^{-1})
No-tillage	2.03	2.07	4.84
Tillage	1.96	2.05	4.15
	ns	ns	!
Alley	1.99	2.08	4.75
No-alley	1.99	2.04	4.23
	ns	ns	ns

Table 4. Effects of no-tillage and alley cropping on the dry-seed yield (kg ha^{-1}) of coffee for three seasons. Figures in parentheses indicate months after transplanting. Ns, not significant.

Treatment	Season		
	96/97 (22)	97/98 (32)	98/99 (44)
No-tillage	377	739	1067
Tillage	327	629	1023
	ns	ns	ns
Alley	330	646	1064
No-alley	374	722	1025
	ns	ns	ns

Table 5. Effects of no-tillage and alley cropping on soil erosion (t ha^{-1} year^{-1}).

	Treatment	Erosion	
Two way	No-tillage	3.8	**
	Tillage	6.1	
	Alley	2.6	***
	No-alley	7.3	
One way	Alley & No-tillage	2.0	a
	Alley & Tillage	3.3	a
	No-alley & No-tillage	5.7	b
	No-alley & Tillage	8.9	c

** and *** mean P<0.01 and 0.001 level of significance, respectively. Two-factor interaction was not significant. The same letters indicate no significant difference at the P<0.05 level according to Duncan's multiple range test.

cantly reduced by both no-tillage and alley cropping (Table 5). Soil erosion was reduced by 37% with no-tillage and by 64% with alley cropping. Local farmers' practice which till and do not use alley cropping have four times more soil erosion than that recorded in experi-

Table 6. Effect of no-tillage and alley cropping on sales, cost and net income for four years of cultivation. Values are shown by 106 Rp ha^{-1}. Percentages are used to indicate the ratio of No-tillage and Alley to Tillage and No-alley, respectively. No significant effect was found between the treatments.

Treatment	Sales	Cost	Net income
No-tillage	10.7	4.3	6.4
Tillage	10.0	3.7	6.3
	106.6%	115.4%	101.3%
Alley	10.3	4.0	6.3
No-alley	10.5	4.0	6.4
	98.3%		97.2%

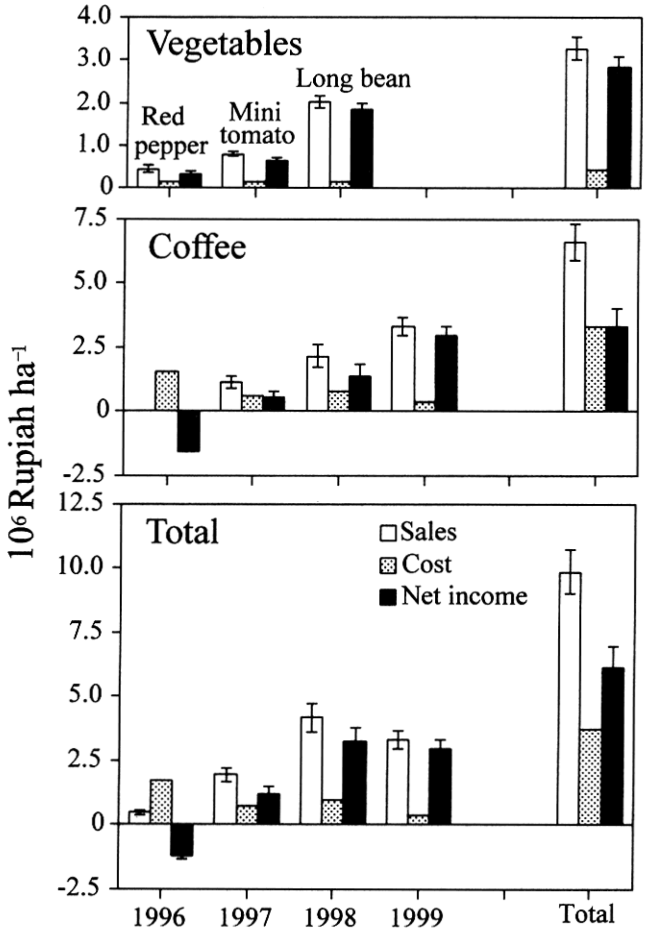

Fig. 3. Sales, cost, and net income of intercropped vegetables and coffee plants in the experiments with tillage and without alley cropping. An error bar shows the standard error of the replication (n=3).

ments without tillage and with alley cropping.

The farm economy of four continuous years after transplanting coffee was evaluated by the gross income and agricultural inputs without including labor costs. The prices fluctuated significantly within the four seasons of the experimental period. In a comparison of the farm economy with two types of cultivation, a 7%

Table 7. Comparisons of yield, net income, soil erosion, extra labor requirements, and economic benefits in the different cultivation techniques. The difference is from the conventional practice used by the farmers.

	No- tillage	Alley cropping
Yield	No significant difference (10.3 % higher on average)	No significant difference (3.8 % lower on average)
Net income	No significant difference (1.3 % higher on average)	No significant difference (2.8 % lower on average)
Soil erosion	Lower (37 % lower soil loss)	Lower (63 % lower soil loss)
Extra labour and/or cost requirement	More weeding and/or chemical weed control	The hedgerow has to be made in the contour line at the time of field establishment before coffee planting.
Economical and/or labour benefit	Reduce the cost of tillage. No- tillage between coffee rows may not disturb the growth of surface roots, which actively absorb fertilized nutrients.	The alley system will result in terrain changes from a steep slope to terraced fields in the near future. After that, field management will be much easier.

increase in production was achieved in no-tillage at a 15% increase in cost, resulting in a similar net income (Table 6). In the case of alley cropping, the farm economy was not affected when the cost of labor for alley cropping was not considered. The net income obtained with tillage and without alley cropping, both of which are typical of the local farmers, is shown in Fig. 3. The net income for the first year was -1.3 million Rupiah which was attributed to the fact that no coffee beans were harvested and that the income from the red peppers was small. For the second year, the coffee beans were harvested, and the net income was + 1.2 million Rupiah. In the third year, the long bean production was quite beneficial for the farm economy, which was equivalent to the fourth year of the net income from the fully developed coffee. After the fourth year, coffee production was expected to stabilize for a while. In conclusion, vegetable intercropping was beneficial for the farm economy when the coffee bean production was limited in the first two to three years following the transplanting of the coffee seedlings.

Discussion

In this experiment, no-tillage and alley cropping on steep sloped coffee fields were evaluated in Lampung State, South Sumatra, Indonesia. The efficiency criteria of the two practices, in terms of appropriate cultivation techniques for farmers, are as follows : 1. Significant reduction of soil erosion; 2. Absence of effect on growth and yield of coffee plants; and 3. Limited labor and expense for implementation. The labor cost, however, was not included in the farm economy analysis. The benefits and problems associated with the introduction of the cultivation techniques are summarized in Table 7. Reduction of soil erosion, growth of coffee, and vegetable intercropping were discussed as follows.

Firstly, both alley cropping and no-tillage significantly reduced soil erosion (Table 5). Monsalud et al. (1995) reported that the erosion of steep sloped maize and groundnuts field was effectively controlled by introducing the hedgerow of *Gliricidia* with napier grass at the Tanay site, Philippines. The annual erosion in the hedgerow plot was only 3 t ha^{-1} $year^{-1}$, which is quite similar to our result of alley & tillage treatment, as compared with that of 36 t ha^{-1} $year^{-1}$ in the control plot. Paningbatan et al. (1995) reported that leguminous shrub hedgerows reduced the annual erosion of maize and mung bean field from 100 to 200 t ha^{-1} $year^{-1}$ to a rate of less than 5 t ha^{-1} $year^{-1}$. Although the soil erosion of coffee field in this study was not so severe when compared with those of annual food crop cultivation cited above, an effective erosion control by the alley cropping, which was more evident than that by no-tillage, was also demonstrated. With the alley cropping the hedgerow has to be made on a contour line. This, of course, requires more labor at the time the field is established before the coffee plants are planted. It is likely, however, that alley cropping will result in terrain changes from a steep slope to terraced fields, which are advantageous. With the terraces, soil erosion should be significantly reduced, and field management will improve. Furthermore, alley cropping using leguminous trees or herbs as hedgerow plants would be more effective not only for the erosion control but also for the maintenance of soil properties.

Secondary, neither alley cropping nor no-tillage affected the growth or yield of coffee (Table 4) and intercropped vegetables (Table 2); the yield in no-tillage was even slightly better than that in tillage, although they were not significantly different, especially at the first and second year harvest (Table 4). Tillage between coffee rows may have disturbed the growth of surface roots, which actively absorb fertilized nutrients. Without tillage, weeding must be done much more carefully than with the conventional system. This requires considerably more labor and/or chemical herbicide. Although extra herbicide was applied when tilling was not performed, it did not alter the net income due to the slightly higher coffee bean production.

Thirdly, vegetable cultivation was also introduced as an intercrop between coffee rows. Three vegetables were tested during a three-year period. During the early stages of coffee establishment, the harvest of coffee beans was low which resulted in a little or no income for the farmers (Table 4 and Fig. 3). At this stage, vegetable intercropping can be a significant benefit to the economy of the farm. Studies of farm economy in Kenya have reported that some vegetables were beneficial for intercropping with young coffee, but others were not (Njoroge and Kimemia, 1995 a and b). For example, intercropping with maize or sweet potatoes was not feasible because of their adverse effects on coffee growth in the early stages of coffee establishment. In the present study, vegetable intercropping was not experimentally compared with the control treatment. Therefore, the effect of specific vegetables on the coffee plants was not investigated. Economically, long beans were quite successful for this field condition in the third year. The test field was acidic field with pH 4.59, which is restrictive for some vegetable growth, and the steep slopes limit cultivation management, such as proper watering during plant establishment. Further study will be necessary to identify economically beneficial annual crops to intercrop with coffee and for crops that provide good erosion control.

In conclusion, the no-tillage and alley cropping are beneficial for sustainable coffee production on steep slope fields in Lampung State, and vegetable hedgerow cultivation before the full maturity of coffee plants is financially beneficial to coffee farmers. Without tillage, higher coffee shoot biomass production was observed along with a tendency for higher coffee bean production. The disturbance of the coffee surface-root growth during tillage might account for these phenomena. In a second paper from this experiment, the soil physical conditions and coffee root development on steep slopes will be examined in greater detail.

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