Alternatives to Slash and Burn in Indonesia:

Facilitating the development of agroforestry systems

Phase 3 Synthesis and Summary Report

Editors:

Fahmuddin Agus and Meine van Noordwijk

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Cover photo:

A complex landscape of Sumberjaya, Lampung; Flowering coffee; Coffee with Arachis pintoi cover crop; Multistrata coffee system (Photographs by: F. Agus)

Design: Dwiati Novita Rini

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I. Summary
Alternative to Slash and Burn (ASB), phase 3: Facilitating the development of agroforestry systems

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Background and objectives

Conversion of tropical rain forest to other land uses is a major concern at global level. Loss of globally unique biodiversity, release of large amounts of stored carbon to the atmosphere, immediate health and visibility problems caused by the haze during forest conversion are only part of the story. The loss of forests as a regulator of water flows and as provider of local income are a concern at more local scales. The 'Alternatives to Slash and Burn' (ASB) program was started to test ways to reduce the loss of tropical forests, by enhancing the intensity of agricultural use in already converted lands, and/or to reduce the loss of 'forest functions' in land uses that qualify as 'modified' or 'domesticated' forests. The first approach came to be known as a 'segregate' approach (intensive agriculture + forest), the second as an 'integrate' pathway of development. The ASB program started activities in Indonesia in 1993 and first embarked on a diagnostic phase, to characterize land use and the type of problems that are perceived by various stakeholders. In the second phase a more detailed analysis was made of the trade-offs between local and global concerns. In between local stakeholders concerns (income, food security) and global concerns (biodiversity, carbon stocks), a 'missing middle' was identified: impacts on what is broadly called 'watershed functions'.

In phase 1 and 2 of the Alternatives to Slash and Burn program in Indonesia a number of farmer-developed land use practices were described and analyzed for benchmark areas in Lampung and Jambi that developed as alternative to annual-crop-based agriculture. These systems, broadly indicated as 'agroforests' provide income from domesticated forest and tree systems, with returns to labour exceeding those for upland annual crops, and with environmental values (carbon stocks, biodiversity) that are superior to short rotation crop/fallow systems. In the research, however, little attention was given to the broad category of 'watershed functions', while the main emphasis was on the lowland peneplain and lower foothills where erosion is not a major issue. To complement the Phase 1 and 2 results, a further effort was made to better understand the relationship between forests and derived land uses and these watershed functions - aiming again for a combination of a diagnostic phase ('what if any are the real problems?') and one aimed at practical solutions at farm level, in the context of existing policies for the forest-agriculture interface.

As part of the agenda for phase 3 a new benchmark area in the mountain zone of Sumatra was selected (in Sumberjaya, West Lampung Province, Indonesia) where conflicts between farmers and state forestry officials had led to large scale evictions. After the political change ('reformasi') farmers returned to the area. As the conflicts had been articulated on the basis of concerns over watershed functions of conversion to coffee-based production systems, the main issue was to analyze the relationship between land use and watershed functions. The research approach chosen for the area is based on a 'negotiation support' system (NSS), that combines *tools* for predicting the impacts of land use and landscape configuration on multistakeholder criteria and quantifiable indicators, with a *process* of negotiation between stakeholders of spatial land use plans and generic regulation and incentive systems.

The research reported here focuses on the options farmers have for improving their farms and recovering forest functions, by enhancing 'landscape filters' and increasing agrodiversity. Land use practices and technologies that generate income as well as manage the natural resources are needed. The Sumberjaya site has a complex settlement history, with phases of active government involvement in settling farmers (as a demobilization site for the army of Indonesias struggle for independence), phases of spontaneous migration and phases of eviction of 'squatters' from state forest lands. While some of this historical context is unique to the site, the ambivalent views of government on agricultural development in former forest areas are widespread - and reflect the problem of providing income opportunities for a large population, along with maintenance of essential environmental services such as water flows and the opportunities to use hydro-power. The situation in Sumberjaya reached an open conflict stage in the early 1990's, when the government started a forceful eviction program affecting farmers (a mix of spontaneous migrants from densely populated Java and official settlement programs) and uprooting their well-developed coffee trees to replace them with Calliandra shrubs for 'reforestation'. A substantial part of the land in Sumberjaya is classified as 'protection forest' zone, and the perception was that reforestation would secure water flows that the coffee gardens could not provide.

Coffee has been a primary agricultural product of Sumberjaya farmers for nearly a century. The success of coffee plantation in this area is indicated by the expansion of cultivated land for coffee. In 1970, about 60% of the area coverage was still natural forest. But by the early 1990's only some 15% of forest cover was left, at the start of the eviction period. Much of the later coffee expansion occurred on land registered as protection forest. The shift in utilization from forest to coffee-based farming systems has raised concern among many stakeholders that it may create serious impact to the deterioration of forest functions, declining of soil productivity, land degradation, and severe soil erosion. The government that holds the land title evicted people who farmed and lived in the protection forest to neighboring sub-districts (the infertile lowland peneplain of the northern Lampung ASB benchmark area or the swamp forest zone where land clearing fires cause intensive smoke/haze issues.

After the political transition from the New Order Government in 1997 to the 'Reformation' period, resettled farmers returned to Sumberjaya and reclaimed their right to use the land, replanting the areas with new coffee trees and/or grafted the still active stumps of the old coffee. In the new political reality and after a substantial devolution of government authority to the district level, an approach based on negotiation and accommodation of multiple perspectives was needed.

In the context of the new forestry law, a Ministerial Decree of the Ministrer of Forestry (No. 31, issued in February 2001) on Community Forest created the option of granting farmers semi permanent (could be as long as 25-30 years) land title to utilize forest land provided that they can propose and implement judicious land management systems for restoring the forest function. This decree provided an excellent basis for the negotiations in Sumberjaya to operate, although special permission was needed to apply this process on degraded 'protection forest' lands.

The Sumberjaya case this became an example of how the lack of negotiation among stakeholders in the tropics led to conflicts over land use in the past, and how new approaches could lead to a 'win-win' for environment and development, relative to that low baseline. ICRAF Southeast Asia, in collaboration with National Agricultural Research Services (NARS) and Non Government Organizations (NGOs), facilitated the negotiations in both the technical and institutional aspects, and the research reported here is part of that larger process of understanding the options and consequences of land use decisions.

This research was designed to address the following objectives:

(i) evaluation of promising management practices that meet farmers' preferences while lowering soil loss to tolerable level,

(ii) validation and refinement of the management practices considered in the first objective,

(iii) evaluation of the role of litter layers, as generated from different stages and systems of coffee farm, on soil structure, run-off and soil loss, and

(iv) delineation of areas in the Way Besai Watershed based on the levels of susceptibility to erosion.

This series of research was conducted in *Way Besai* watershed, with borders that almost coincide with that of Sumberjaya Sub district, West Lampung District, Lampung Province, Indonesia (4°45' to 5°15' S and 104°15' to 104°45' E). The elevation of Sumberjaya ranges from 700 to 1,700 m asl, but our research was conducted in the sites with 750 to 900 m asl elevation. Soils were predominated by Inceptisols (Humitropepts, Dystropepts, Dystrandepts, and Tropaquepts) and to a lessor extent, Ultisols (Hapludults) and Entisols (Troporthents). This research includes plot and micro catchment scale erosion measurement, evaluation of tree contribution to litter and soil fertility rejuvenation, and farmer-led test of soil conservation treatments in coffee-based farming systems.

Results

Results show that coffee trees can make a significant contribution to controlling erosion. Its effectiveness is maximized when the coffee is planted in combination with other trees in a multistrata system because of a complex canopy architecture that protects soil surface against heavy raindrops and the formation of tree litter on the floor of the garden or when additional conservation measures such as cover crops are used on young coffee farms.

Agroforestry/soil conservation options articles and booklets and the map of soil erosion susceptibility are among the key deliverables that this research can offer in the negotiation. Moreover, several research papers have been and will be contributing to agroforestry-related literatures.

Activity A (Table 1) has summarized background information of the case study site and provided a range of conservation options in coffee based agroforestry systems which are very central in the NSS. Farmers will know wider options than what they have been exposed to and practicing in their localities while the local forestry and agricultural services will also have reference of wider conservation options that can provide environmental services.

Plot and micro catchment scales measurements (activities B and C3) have produced convincing relationship of the effects of different stages of coffee growth and different soil conservation treatments on soil erosion and runoff. Soil loss in the Bodong site was the highest (about 85 t ha^{-1} yr^{-1}) under 1 year old coffee and sharply dropped as coffee canopy developed (coffee gets older). Under 5 year or older coffee, soil loss was basically within the tolerable level and multistrata coffee tended to be more protective against soil loss than monoculture coffee. Under 12 years old or multistrata coffee (which generally also coincides with 8 years or older coffee), soil loss was basically as low as that under forest. Thus additional soil conservation measures do not reduce soil loss any further.

Equally important, these activities have given information of how wide the variation of soil properties was and how important it was in influencing soil susceptibility to erosion. For instance, under 3 to 4 year coffee stand and about 500 mm of rainfall in 3 to 3,5 months period of measurement, soil loss was negligible (<2 t ha^{-1}) in Tepus and Laksana sites, but it was about 37 t ha^{-1} in Bodong site. This difference was attributed to distinct differences in soil structure. Drainage pore for 0 to 20 cm soil layer, for example, was between 6 to 12 % (v/v) in Bodong and about 23 to 32 % in Tepus and Laksana sites.

Because of the variation, we developed a map of soil susceptibility to erosion (Activity B.2.1.a, Table 1). This map can support the local government in prioritizing areas for implementing soil conservation.

Under Activity C3 we have learned the importance of tree litters produced by old and/or multistrata coffee in protecting soil surface against soil loss, reducing runoff, increasing soil organic carbon and increasing soil macropores. These qualities are close to that provided by the natural forest, suggesting that facilitating the local farmers to maintain tree based, multistrata land use system on the steep forest margin, is a judicious option and this will speed up the recovery of forest functions.

Implications and Benefits of Research

These findings implied that the intervention made by the government in mid 1990s by eviction of the farmers and replacement of coffee to *Calliandra callothirsus* was out of focus and only harmed the farmers, because, they in general, had almost no choice to earn a living in other sectors. Erosion and runoff reduction, the two forest functions most commonly voiced by the government have been clearly reduced as coffee (and other trees in the multistrata system) canopy and litter on the coffee floor develop. Additional conservation intervention is necessary only for selected sites with low infiltration capacity/low porosity. Multistrata coffee system is the closest to forest in its performance and in providing environmental services. Facilitation of the development of multistrata systems appears to be the wisest way the government should do forward.

This research also suggest that there are options of two-pronged soil conservation options that not only provide services to the public, but also promise private benefits important for farmers such as improvement or sustainability of soil fertility. These options include the use of cover crops, the use of shade legume trees and multistrata coffee systems. Both community and government efforts should prioritize in facilitation of these two-pronged interventions for smoother negotiation.

At the end of this three year implementation, this research has delivered not only scientific explanations for getting to grips with some of the deeprooted myths about forests and water, but also provided a range of wider options in soil conservation as well as delineation of the 'hot spots' in the watershed where extra efforts for soil conservation are actually needed.

Likely Direction of Future Research and Development

The most logical follow-up of the current research findings is integration these finding into existing development projects such as the GNRHL (Gerakan Nasional Rehabilitasi Hutan dan Lahan; the national level watershed management program, focused on reforestation and conservation) and HKm (Hutan Kemasyarakatan; Community Forest Program); both are under the Ministry of Forestry. This integration should be using the farmer-led approach, in which farmers and the rest of the community, with facilitation from researchers and local extension and NGO, will take initiatives in voicing the local natural resource problems, develop alternatives of problem solving, implement and evaluate the performance of natural resource management. The results of research presented in this report (erosion susceptibility map and technology options) could be used to assist farmers in their selection of technology and the facilitating agencies (government and non-government) in assisting the farmers. This approach, if successful, will revamp the current, mostly blanket recommendation implemented in the two programs.

Furthermore, valuation of environmental services from different management systems, and formulation of reward mechanisms for the service providers, will also be a very important aspect to study.

Collaborating Research Institutions

This research is implemented by NARS under the coordination of ASB-Indonesia (ICRAF SE Asia). The collaborating NARS and the research topics undertaken are listed in Table 1.

Table 1. Activities and implementing institutions.

Title	**Implementing Institution/evolution**
Identification and selection of profitable and environmentally-benign conservation measures.	ICRAF (2001). The results was published in a booklet, Agus, Gintings and van Noordwijk (eds.) (2002).
Validation and refinement of conservation/agroforestry practices	
Paired plot farmer participatory trials	SRI (Aug'01-Aug 04)
Validation of soil erosion prediction and refinement of conservation measures	
Plot scale soil erosion measurement under different conservation systems	SRI (Aug'01-Aug. '03)
Delineation of erosion prone areas in Sumberjaya	SRI (Aug'03-Aug '04)
Micro-catchment scale soil loss as affected by soil conservation practices	Unila (Aug'01-July 04)
Evaluation of resource use, sustainability, and profitability of tree crop production systems	
Village-level production of quality planting material	Tree domestication program, conducted by under ICRAF-Winrock collaboration
Interaction of tree crops with existing crops	Unila (Aug'01-July 02)
Tree diversity in the resilience of multi-strata agroforestry systems (litter function under different coffee systems)	Unibraw (Aug'01-Aug'04)

Remarks: SRI = Soil Research Institute, Bogor; Unibraw = University of Brawijaya, Malang, East Java ; Unila = Universitas Lampung, Bandar Lampung.

Publications Based on ASB3 Research in Indonesia:

Proceedings

Agus F, and van Noordwijk M (eds.). 2005. Alternatives to Slash and Burn in Indonesia: Facilitating the development of agroforestry systems, Phase 3 Synthesis and Summary Report. Proceedings of a Workshop held in Bogor, Indonesia 16 August 2004. World Agroforestry Centre, Southeast Asia. Bogor, Indonesia. (This volume).

Scientific Article

Ai Dariah. 2004. Erosi dan Aliran Permukaan pada Lahan Pertanian berbasis Kopi di Sumberjaya, Lampung Barat (Erosion and Runoff in Coffee Based System in Sumberjaya, West Lampung. PhD Dissertation. Bogor Agricultural University, Indonesia. (*In Indonesian with English Summary*).

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Hairiah K, Suprayogo, D, Widianto, Berlian, Suhara, Mardiastuning A, Widodo RH, Prayogo C, and Rahayu S. 2004. Alih guna lahan hutan menjadi lahan agroforestri berbasis kopi: ketebalan seresah, populasi cacing tanah dan makroporositas tanah (Land use conversion from forest to coffee based agroforestry: litter thickness, earth worm population, and soil macroporosity). Agrivita 26(1):68-80. (*In Indonesian*)

Hairiah K , Suprayogo D, Widianto, Widodo R H, Van Noordwijk M, 2004. 'Conversion of forest to coffee-based Agroforestry in Sumberjaya, West Lampung, Indonesia: Litter layer, population density of earthworm and soil macroporosity'. Paper presented in a workshop of the International Union of Forest Research Organizations (IUFRO). Forests and Water in Warm, Humid Asia. July 10-12, 2004, Kota Kinabalu, Sabah, Malaysia.

Hairiah K, Sulistyani H, Suprayogo D, Widianto, Purnomosidhi P, Widodo R H, and Van Noordwijk M, 2004. Litter layer residence time in forest and coffee agroforestry systems in Sumberjaya, West Lampung. Forest Ecology and Management (*Submitted to Forest Ecology and Management*).

Suprayogo D, Widianto, Purnomosidi P, Widodo RH, Rusiana F, Aini ZZ, Khasanah N, and Kusuma Z. 2004. Degradasi sifat fisik tanah sebagai akibat alih guna lahan hutan menjadi sistem kopi monokultur: kajian perubahan makroporositas tanah (*Degradation of soil physical properties as caused by land use conversion from forest to monoculture coffee farm: a macroporosity study*). Agrivita 26(1):60-68. (*In Indonesian*).

Widianto, Suprayogo D, Noveras D , Widodo R H, Purnomosidhi P dan Van Noordwijk M, 2004. Alih guna lahan hutan menjadi lahan pertanian : Apakah fungsi hidrologis hutan dapat digantikan sistem kopi monokultur? (*Land use coversion from forest to coffee farm: Can monoculture coffee restore the forest functions?*) Agrivita 26 (1) : 47-52. (*In Indonesian*)

Booklet

Agus F, Gintings ANg dan van Noordwijk M. 2002. Pilihan teknologi Agroforestri/ konservasi tanah untuk areal pertanian berbasis kopi di Sumberjaya, Lampung Barat (*Agroforestry/soil conservation technology options for coffee based farming area in Sumberjaya,Lampung*). International Centre for Research in Agroforestry, Southeast Asia Regional Research Programme, Bogor. (www.worldagroforestrycentre.org/sea). (*In Indonesian*).

Hairiah K, Widianto, Suprayogo D, Widodo, RH, Purnomosidhi P, Rahayu S, and van Noordwijk M. 2004. Ketebalan Seresah sebagai Indikator Daerah Aliran Sungai (DAS) Sehat (*Litter thickness as an indicator of healthy watershed*). 41 p. World Agroforestry Centre, South East Asia, Bogor. Indonesia. (www.worldagroforestrycentre.org/sea). (*In Indonesian*)

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II. Trees that produce mulch layers which reduce run-off and soil loss in coffee multistrata systems

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Abstract

The contribution that agricultural and accompanying tree species in multistrata agroforestry systems have on biological, physical, and chemical soil properties has been subject to debate. This research evaluated the contribution of trees in coffee based multistrata systems to soil surface protection, soil biota, soil physical properties, runoff and erosion. Part 1 of the study quantified litter thickness, earthworm populations and soil macroporosity in response to land use change, in the Sumberjaya Sub-district, (West Lampung, Indonesia) from in 2001 to 2004. Four Land use systems were compared: (a) remnant forest (control); (b) multistrata shaded coffee with fruit and timber trees as well as nitrogen-fixing shade trees (*Erythrina sububrams* and/or *Gliricidia sepium*); (c) shaded coffee (*Erythrina sububrams* and/or *Gliricidia sepium* nitrogen-fixing shade trees but less than 5 tree species per plot); and (d) sun coffee ('monoculture') with coffee forming more than 80% of total stem basal area. Plots were selected with an age of 7 - 10 years, in three slope classes: (a) flat ($0\text{-}10^0$), (b) medium ($10\text{-}30^0$) and (c) steep ($> 30^0$). The mean standing necromass was 6.1, 4.5, 3.8 and 3.0 Mg ha^{-1} for forest, shade coffee and sun coffee, respectively, without significant influences of slope. Part 2 of the study was a plot-scale erosion experiment, comparing various ages of monoculture coffee systems, various coffee-based systems and natural forest. Plots of 40 m^2 (10 m down slope and 4 m parallel with the contour line) were enclosed by metal sheeting and channeled into a splitter device called "Chin Ong meter". Results show that the mean standing litter stock was 6.1, 4.5, 3.8 and 3.0 Mg ha^{-1} for forest, shade coffee and sun coffee, respectively, without significant influences of slope. Soil organic carbon contents (C_{org}) was highest in the forest. The largest annual litter input of 14 Mg ha^{-1} $year^{-1}$ was found in the remnant forest, followed by multistrata, shaded and monoculture coffee systems i.e. 9.8, 6.6 and 4.0 Mg ha^{-1} $year^{-1}$, respectively. The population density of earthworms in the forest was 50 % lower than that in the multistrata coffee gardens (150 individuals per m^2), but its biomass (31g m^{-2}) was twice larger than that in the multistrata coffee gardens. The lowest population density of earthworm was found in the shade coffee system (150 individuals per m^2) with a biomass of 7 g m^{-2}. Well-developed coffee-based systems can control soil erosion to about as low as that of forest, but they can not restore surface runoff close to the original forest values. Forest conversion lead to 6 to 10 times increase of the overland flow and to accelerated soil loss particularly in the first two to four years after land clearing. The recovery of a surface litter layer in sun coffee systems can provide protection from erosion with time, but will not be sufficient to restore macroporosity at the level of forest soils, leading to hydrologic alterations that favor overland flow. This research confirmed the role coffee based multi strata systems can play in land rehabilitation.

Introduction

About 70 years ago Sumberjaya was almost completely covered by forest. Around 1990 the forest was converted into agricultural land by Semendo farmers (Verbist, 2001). They mostly practiced a shifting cultivation form of coffee production. Later this system developed into intensive and permanent coffee systems, mainly by migrants from Java causing a higher pressure on land (Budidarsono, 2000). Expansion of coffee systems into the steeper lands created a more serious soil erosion problem, especially where intensive coffee systems with intensive weeding were involved. Forest cover remained only on very steep slopes (steeper than 60%) and was by law declared as watershed protection forest by the state. Expulsion of coffee farmers from the protection forest zone was followed by attempts to reforestation with *Calliandra calothyrsus*, a fast growing leguminous tree species in mid 1990s. Growing need for agricultural land causes frequent re-opening of these *Calliandra* bush lands, especially after the 'reformasi' period in 1998, where the state institutions lost most of their control on land. But a situation of conflict between the State Forest Agency and farmers led to uncertainty among farmers in managing the land properly. Currently, a process of 'negotiation' and 'community forest management' look at multistrata coffee systems as a basis for compromise, allowing economically attractive opportunities for production, while maintaining the watershed protection functions of the protection zone.

According to the available data, conversion of mono-culture coffee into multistrata systems was a trend under conditions of secure land tenure. Economic analysis indicates long term benefits of these systems that exceeds the short term gains of monoculture coffee. Most multistrata coffee systems are using various legumes as shading trees such as *Gliricidia sepium*, *Erythrina orientalis*, or *Leucaena leucocephala*. These systems have also been practiced widely for decades in Java, the lowland peneplain of Lampung around Kotabumi, and other places in Indonesia. In many areas, this simple agroforestry systems evolved into a more complex system by planting more fruit tree species such as *Artocarpus heterophyllus* (jack fruit), *Nephelium lappaceum* (rambutan), *Gnetum gnemon* (Gnetum) and other multi-purpose tree species (MPTS). The positive effect of the complex agroforestry systems to the environment are mainly maintaining soil organic matter content, replenishing soil nutrients through tree contribution of litter and decayed roots, and reducing run-off and erosion through a better soil structure.

On sloping land, ground cover provided by plant litter ('mulch') improves water storage, regulates the microclimate, provides food for the soil organisms that improve soil structure and infiltration, and protects the soil surface against raindrop impact (splash) which causes the breakdown of aggregates to transportable sizes. This mulch-based strategy of erosion control may work when two required conditions are provided i.e. sufficient inputs of organic matter, and a sufficiently long residence time of litter on the soil surface, together ensuring that the soil is protected all the time, especially during high intensity rains. The degree of protection of the soil surface by litter depends on its residence time (inversely related to its decomposition rate and hence to its 'quality'), and its position on the slope (see schematic diagram in Figure 1).

Aspects of plant litter quality which play clear roles in governing the rates of decomposition, and particularly of N mineralization, are the concentration of N (or C/N ratio), lignin and polyphenols. Organic matter with a low C/N ratio (<25), and low concentration of lignin (<15%) and polyphenolics (<3%) (Palm and Sanchez, 1991) is considered as a high-quality i.e. the materials decompose and release nutrients rapidly. Leguminous trees such as *Gliricidia* and *Leucaena* mostly decompose rapidly (Handayanto

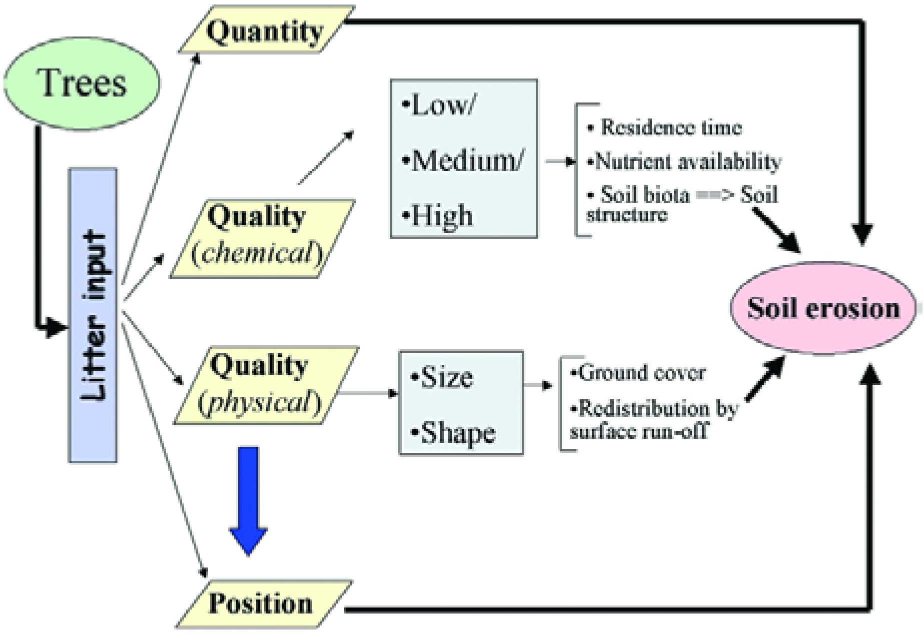

Figure 1. Schematic link between litter input and soil erosion

et al., 1994). *Peltophorum dassyrachis*, *Calliandra calothyrsus* and *Erythrina orientalis* decomposed more slowly over a period of 16 weeks (Handayanto *et al.*, 1992). For *Erythrina* the decomposition apparently slows down when about 20 % of the original amount is left, and for *Calliandra* when it was 45% and *Peltophorum* when it was 70 % left. Most of non legume trees either timber trees or fruit trees showed a lower quality than legume trees, mostly have a lignin concentration > 20 % (Hairiah *et al.*, 1996).

The tested general hypotheses are:

1. The multi strata coffee-based cropping system provides a better protection to the soil erosion than mono-culture coffee systems.
2. Trees that produce low 'quality' litter provide a better protection against erosion than trees with high quality litter, due to the longer residence time on the soil surface,
3. The size and shape of leaves influences the degree of contact cover during decomposition and trees with small or composite leaves are more effective than those with large and stiff leaves.

In combination, these hypotheses, if confirmed, may point to a maximum effectiveness of trees with small leaves of low quality, that provide a high degree of contact cover for a long time. That low quality alone is not always desirable is indicated by the observation of many farmers in Pakuan Ratu, N. Lampung who reported that teak (*Tectona grandis*) with its large leaves slowly decompose and easily burns during a dry season as it dries up and has little contact with the soil.

The quality of litter input may affect the abundance and diversity of "soil engineers" (soil organisms which modify soil structure). Most of soil biota are responding to litter quality, e.g. termites respond more to low quality material, ants respond to high quality, while the response of earthworms to litter quality is not yet clear, but they seem to prefer a higher litter quality as food. Earthworms play an important role in improving soil bulk density, soil porosity and water infiltration. Their role in reducing soil erosion varies, however, depending on cast type (Lavelle *et al.*, 1995). Figure 2 shows schematic links between land use changes, soil organic matter status, and soil biodiversity.

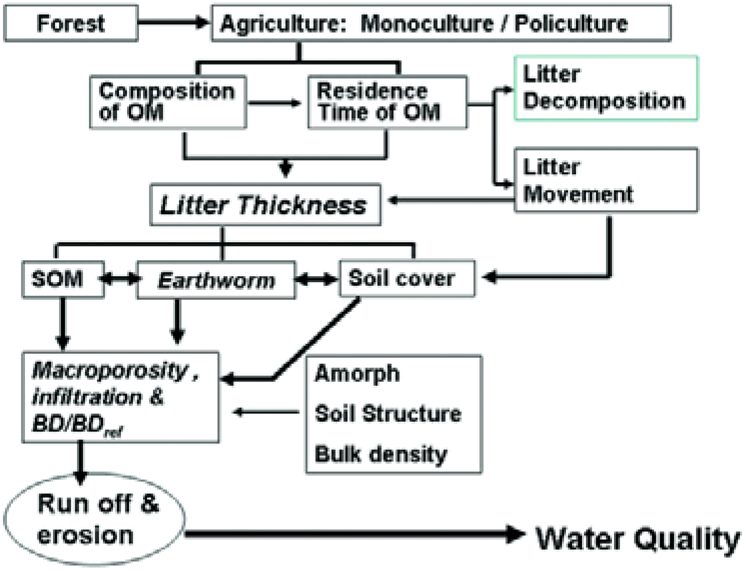

Figure 2. Schematic links between land use changes, thickness of litter layer and run off and erosion.

In the context of the Sumberjaya, our research focus was on the options available to achieve better erosion control under coffee multistrata systems through the choice of tree species and the density at which they are planted. This research was aimed to determine:

1. The percentage of surface cover required throughout the year to efficiently reduce runoff and soil loss,
2. The amount of organic material needed of various 'quality' levels to maintain this degree of surface cover, the tree density needed at plot level to provide this amount of litter.

Research approach

To answer the above research questions some measurements based on survey on farmers plot and measurement on permanent plot were carried out in Sumberjaya. The flow chart of research approach is presented in Figure 3.

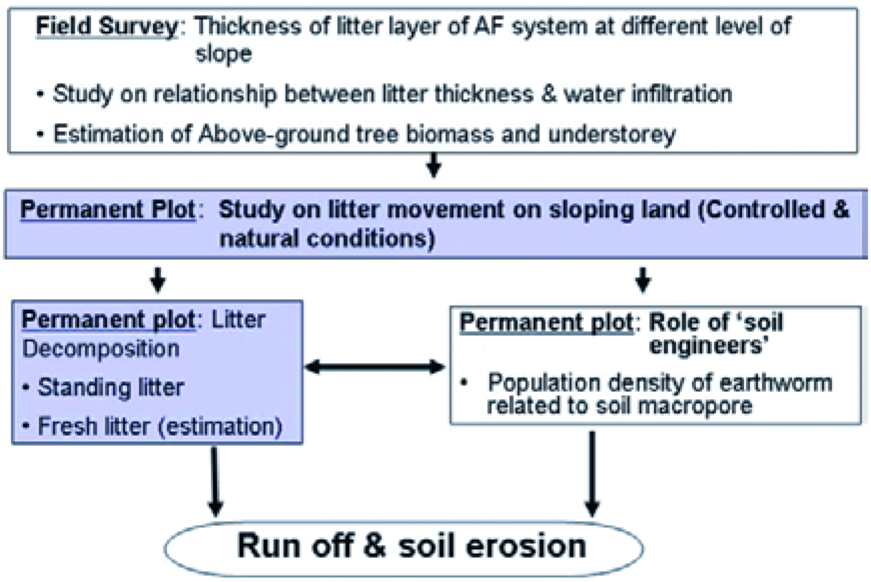

Figure 3. Flow chart of research approach and their main relationships.

Expected output

The expected output from this research was:

- Quantitative data on litter thickness and its distribution at different positions in a steep slope of coffee based systems (Figure 4)
- Quantitative data of earthworm population density related to soil organic matter content and its effect on soil macroporosity
- Data of the distribution of soil macro-porosity under different land use systems
- Information on litter movement on sloping land based on control and natural conditions
- Data of soil loss of different land use systems

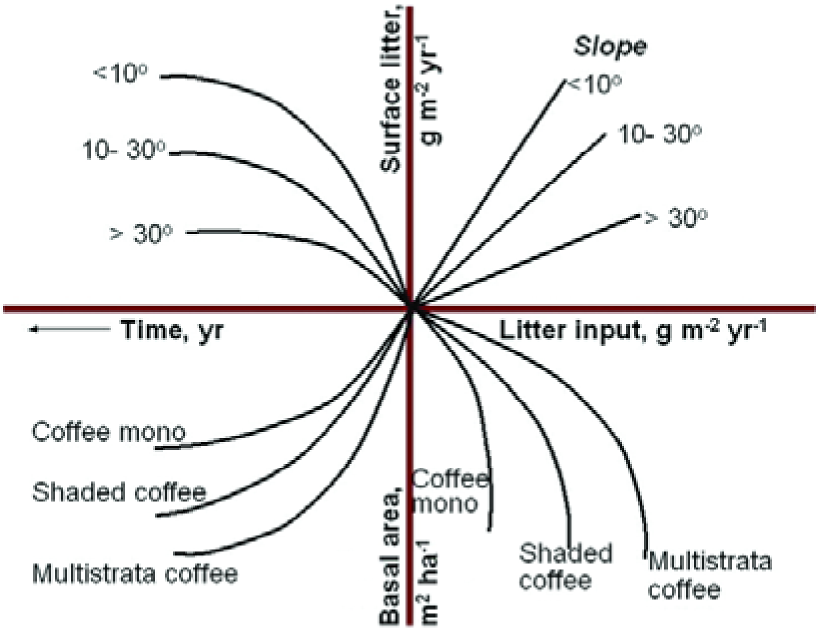

Figure 4. Hypothetical relationship of litter thickness and its distribution at different positions in a steep slope of coffee based systems.

Part 1.

Tree diversity and litter thickness relationship with earthworm population density and soil physical properties under different land use systems

Introduction

Forest conversion to coffee-based agroforestry initially leads to a decrease in the rate of litter fall and the standing litter layer covering the soil, reducing food for earthworms, decline in soil organic matter (SOM) and possible reduction of soil macroporosity. On sloping lands, a reduction of macroporosity and soil cover is likely to increase overland flow and erosion. We hypothesized a causal chain from litter input via earthworm populations to soil macroporosity and infiltration on one hand and an undecomposed litter influence on reducing erosion per unit overland flow on the other (Khasanah *et al.*, 2004). Litter movement on slopes will in this scheme reduce the effectiveness of litter in maintaining infiltration rates and thus lead to an increase overland flow and erosion.

The central hypotheses in this study are that (1) forest and multi-strata coffee based systems will produce the highest litter thickness due to diversity and density of their vegetation, (2) forest and multi-strata coffee based systems will stimulate higher population density of earthworm and, in consequent, higher macro porosity and soil infiltration than coffee monoculture. Therefore, the objectives of this study were to evaluate the relationship between soil surface cover by tree litter and tree canopy and population density of earthworm, macro pores, and soil infiltration under coffee based agroforestry systems.

Methods

The study was conducted in *Way Besai* watershed, West Lampung. The coffee based systems were selected from farmers plots in three villages i.e. South Bodong, North Bodong and Simpangsari, Tribudisukur (104^{0}25'46.50" - 104^{0}26'51.40 E, 5^{0}01'29.88" - 5^{0}02'34.20 S; with mean rainfall of 2500 mm year^{-1}). The soil properties of the study area are presented in Table 1.

Four land use systems were compared (a) forest as control, (b) multistrata coffee with fruit, timber trees and nitrogen-fixing shade trees (*Erythrina sububrams* and/or *Gliricidia sepium*), (c) shaded coffee with *Erythrina sububrams* and/or *Gliricidia sepium* as shade trees, (d) monoculture (sun) coffee.

The study was done in two steps:

(a) Measuring the litter thickness under forest and established coffee based systems (>7 years) and their effect on population density of earthworm, macroporosity and soil infiltration, in November 2001-June 2002

(b) Measuring the litter thickness under young coffee based systems (< 3 years and 3-7 years), in February-August 2003

Table 1. Soil properties of the studied area in Sumberjaya

Land use system	Soil depth cm	pH (H_2O)	pH (KCl)	Tot.C %	Tot.N %	C/N	Sand	Silt	Clay %
Forest		4.93	3.97	3.84	0.35	10.88	17.5	38.1	44.4
Multistrata		5.17	4.05	1.76	0.23	7.81	15.0	33.6	51.4
Shaded		5.20	4.08	1.49	0.21	7.42	14.4	34.3	51.4
Monoculture		5.01	3.96	1.46	0.24	6.93	13.5	31.7	54.8
s.e.d		0.17	0.20	0.22	0.03	0.63	2.05	2.57	3.96
Forest	0-5	4.87	3.98	4.99	0.44	11.45	16.8	41.2	42.1
	5-15	4.99	3.96	2.69	0.27	10.32	18.2	35.0	46.8
Multistrata	0-5	5.18	4.08	1.98	0.26	7.82	15.6	35.3	49.1
	5-15	5.16	4.02	1.54	0.20	7.81	14.4	31.9	53.7
Shaded	0-5	5.22	4.12	1.76	0.24	7.88	15.3	35.3	49.4
	5-15	5.17	4.04	1.22	0.19	6.96	13.5	33.2	53.3
Monoculture	0-5	4.98	3.94	1.65	0.27	7.02	14.1	34.1	51.8
	5-15	5.05	3.97	1.28	0.20	6.85	12.9	29.3	57.7
s.e.d		0.18	0.20	0.23	0.03	0.65	2.08	2.72	4.07

Note: The plot age was based on time after forest conversion, not on the age of coffee trees as the formers is more directly related to the litter thickness within the plot.

Measurements

<u>*Trees diversity*</u>

The survey was conducted in established agroforestry coffee based systems. To distinguish between the two coffee based systems, criteria have been developed based on trees diversity per area and its basal area. The multistrata coffee based system should have **trees species > 5** and **basal area 80%**

$$(\text{Basal area } (\%) = (D_{coffee}^{2}) / (D_{coffee}^{2} + D_{non\text{-}coffee}^{2}) \times 100)$$

where,

D = tree diameter at breast height (dbh, 1.3 m above soil surface)

<u>*Tree biomass and canopy distribution*</u>

Methods for quantifying tree biomass were used as specified in the ASB protocol (Palm *et al.*, 1996). Sampling of vegetation was done within a 40 x 5 m^2 transect on uphill (top) and downhill (bottom), see Figure 5. The uphill transect was made at certain distance from the top of hill (about 10% of slope length); all transects were made along the contour.

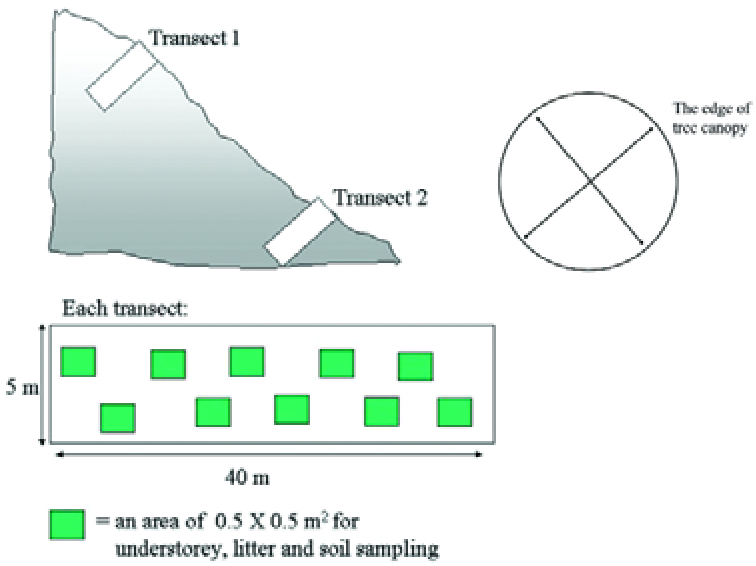

Figure 5. Position of sub plot (transect) in a slope (top) and schematic of litter, understorey and soil sampling (bottom).

Tree position and canopy distribution within plot were copied on a fine-grid paper. Data on canopy width (m) were collected by measuring the edge of canopy from two sides.

All tree diameters at breast height (>5 cm) were measured, and data were converted into aboveground biomass with an allometric equations as presented in Table 2.

Table 2. Allometric equation used for estimating tree biomass in Agroforestry system (Y= tree biomass (kg $tree^{-1}$); ρ = wood density, g cm^{-3}; D = tree diameter, cm)

Tree type	Equations	Reference
Coffee	$Y = 0.2811\ D^{2.0635}$	Arifin (2000)
Banana	$Y = 0.030\ D^{2.13}$	Arifin (2000)
Other trees in Agroforestry system	$Y = 0.11\ \rho\ D^{2.62}$ (ρ=0.62, g cm^{-3})	Ketterings *et al*. (2000)
Paraserianthes falcataria	$Y = 0.0272\ \rho\ D^{2.831}$	Sugiarto (2002)

0.62 is mid medium value of wood density in secondary forest Sumberjaya (Van Noordwijk *et al*, 2002)

Biomass of understorey, litter and soil sampling

Understorey branches and twigs was sampled from ten 0.25 m^2 sampling rectangles within the 40 * 5 m^2 transect. Samples were oven dried at 80^0C for 48 hours and weighed. At the same point, litter was collected from the same sampling rectangles at the soil surface. Soil particles and clods was removed by light washing before drying the samples in an oven at 80^0C for 48 hours. The litter was separated into 2 classes i.e. coarse (>5 mm) and fine litter (<0.5 mm).

A composite soil samples were collected underneath the litter from each sampling point at 0-5 and 5-15 cm depths, analyzed for its organic C (C_{org}), clay and silt contents, and soil pH. C_{org} were compared to the reference value (C_{ref}) for soils of the similar texture, pH and elevation, based on a large Sumatran data set (Van Noordwijk *et al.*, 1997).

Earthworm population

The earthworm population density was determined from soil monolith at five points of measurements in each transect, at three soil depths (0-10 cm, 10-20 cm, and 20-30 cm) (Susilo, 2000). Earthworm sample was collected by hand sorting and classified based on its ecological function i.e. ecosystem engineer (anesic + endogeic) and the decomposer (epigeic), and weighed for its biomass measurement.

Soil Physical condition

Soil physical properties were measured from each land use on a steep and flat slopes. Soil porosity was measured using a methylen-blue (0.05 g/l) solution, by pouring the solution within a metal frame of 1 * 0.5 m^2 and leaving it to infiltrate overnight. The distribution of methylen blue in the soil profile was copied to transparent plastic sheets (Figure 6).

The rate of water infiltration (cm day^{-1}) was measured on a plot with a high litter layer (lower slope position) and low litter layer (upper slope position) using a 625 cm^2 Rainfall Simulator. Rainfall simulator was placed randomly between trees. To quantify the effect of litter on water infiltration, the measurement was performed on the soil with and without litter. The rate of water infiltration was calculated as follows:

$$\mathbf{I = P - R}$$

Where : I = infiltration per 30 second, mm
P = Constant rainfall per 30 second, mm
R = Volume of rainfall collected in rainfall simulator, mm

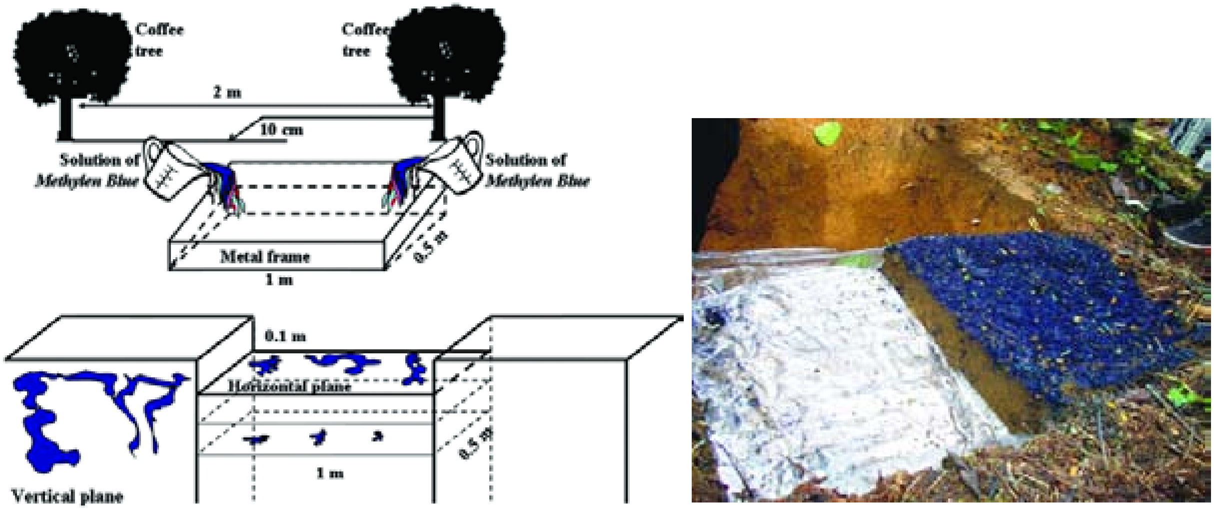

Figure 6. Schematic measurement of soil macroporosity distribution using methylen blue solution.

Calculation of constant infiltration rate of each land use type was conducted by using Philip's equation (Hank dan Ashcorft, 1980):

$$I = ic + 1/2\ st^{-1/2}$$

ic = Rate of water movement under saturated condition (rate of constant infiltration)
s = soil sorptivity
t = time, minute

A linier regression was used to analyzed the Philip equation (Suprayogo, 2000):

$$Y = a + b\ x$$

where, a = ic; b = S; x = ½ t ½

Result and Discussion

Tree diversity and litter

Tree diversity

In established plot of shaded and multistrata coffee systems, tree diversity enhanced the soil surface cover through increasing shade given by tree canopy and litter layer, although for short-term it may be reducing profitability. The two coffee based systems have the same coffee density per area of about **0.84** (coffee population density relative to total population per area), but they are different in the number of tree species per area. In the shaded coffee system the average number of tree species was about **5** (coffee, *Gliricidia* or *Erythrina*, banana and other fruit trees), while in multi-strata coffee system it was about **8** species (coffee; shade leguminous trees such as *Gliricidia*, *Erythrina*, *Leucaena*; slow growing timber trees such as mahogany, teak, shorea; fruit trees such as durian, rambutan, jack fruit, banana; and cash crops such as glove and cinnamon). As the slope was steeper the relative density of coffee in multi-strata system decreased from 0.88 to 0.78, reflecting farmers' preference to plant more fruit or timber trees than coffee in the steeper slopes (Figure 7).

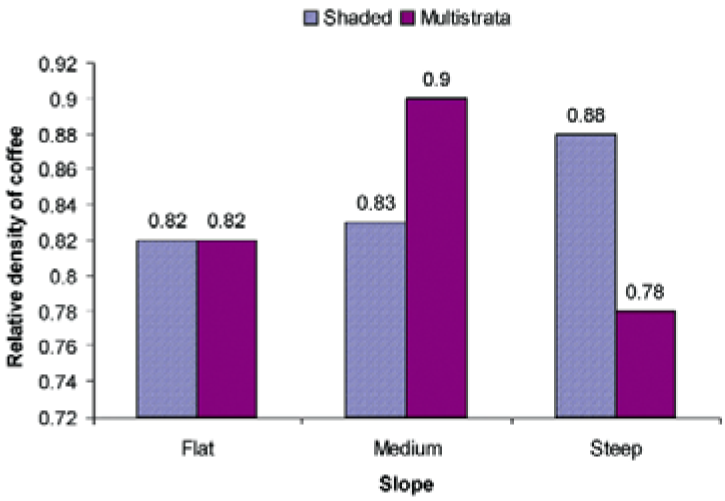

Figure 7. Relative density of coffee trees at different steepness of slope

Tree biomass

Conversion of forest to agricultural land dramatically reduced tree biomass, but the biomass gradually increased over time as the coffee and other tree canopy develop (Figure 8). After more than seven years, tree biomass in monoculture coffee system increased about 38 % already, although it remains very low; while under agroforestry system the increment is higher due to the existence of non-coffee shade trees. If the condition is right, within 40 - 340 years agroforestry coffee based system may have similar amount of tree biomass as in

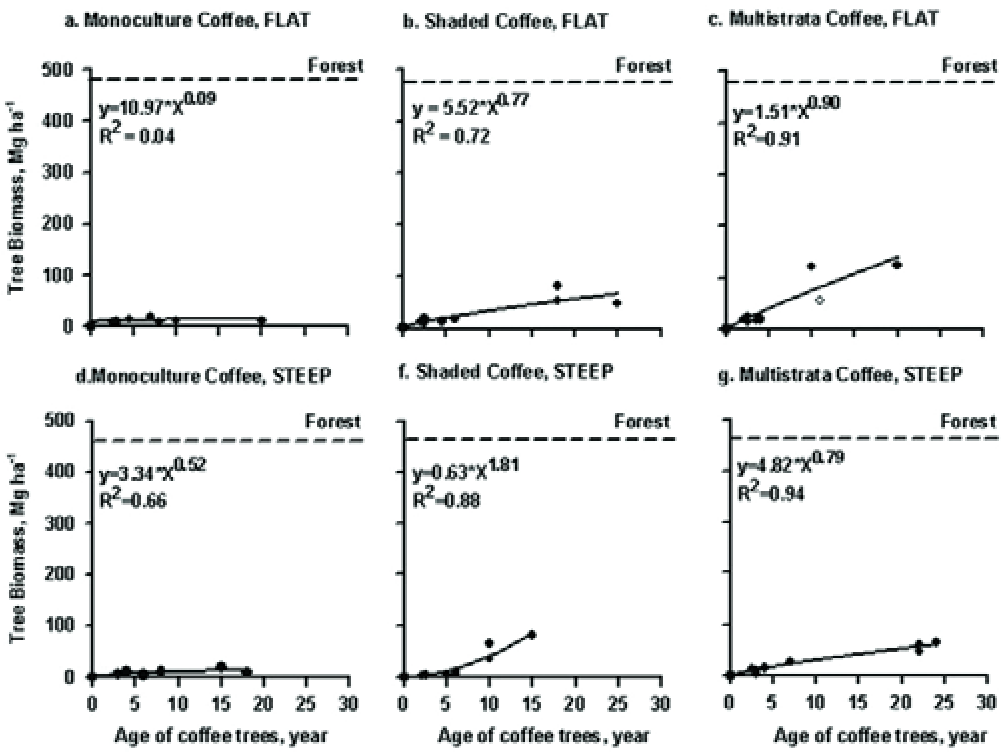

Figure 8. Tree biomass of monoculture and agroforestry coffee based system at different age of coffee trees on flat and steep slope land with tree biomass under forest system as a reference.

forest (470 Mg ha^{-1}), although in reality for Sumberjaya condition it is unlikely to happen. Normally farmers will replant coffee trees after 30-40 years and non coffee trees after a maximum of 100 year period.

In the period more than seven years, no significant effect of slope to tree biomass was found (Figure 9). Tree biomass under coffee based system of about 50 - 75 Mg ha^{-1} was significantly ($p<0.05$) lower than in the forest of 434 Mg ha^{-1}, Biomass under monoculture coffee was much lower (as high as 16 Mg ha^{-1}).

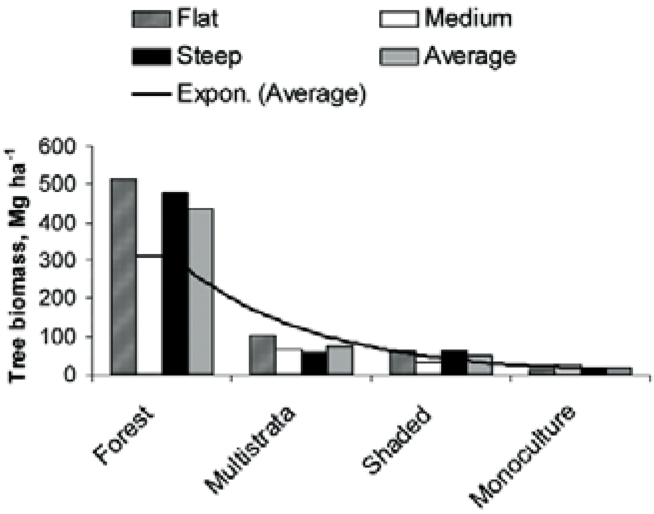

Figure 9. Tree biomass in the forest and in the mature (> 7 years) coffee based systems

Soil surface cover

Surface litter layer, vegetation (trees and understorey) have a direct protective role in reducing 'splash' effects of raindrops that could otherwise lead to a dispersal of soil aggregates. Depending on soil texture, splash impacts can lead to a sealing of the soil surface and, in turn, blocking of water entry into the soil, as well as to the entrainment of soil particles into overland flow. The protective function of surface litter is positively related to its resistance to decomposition.

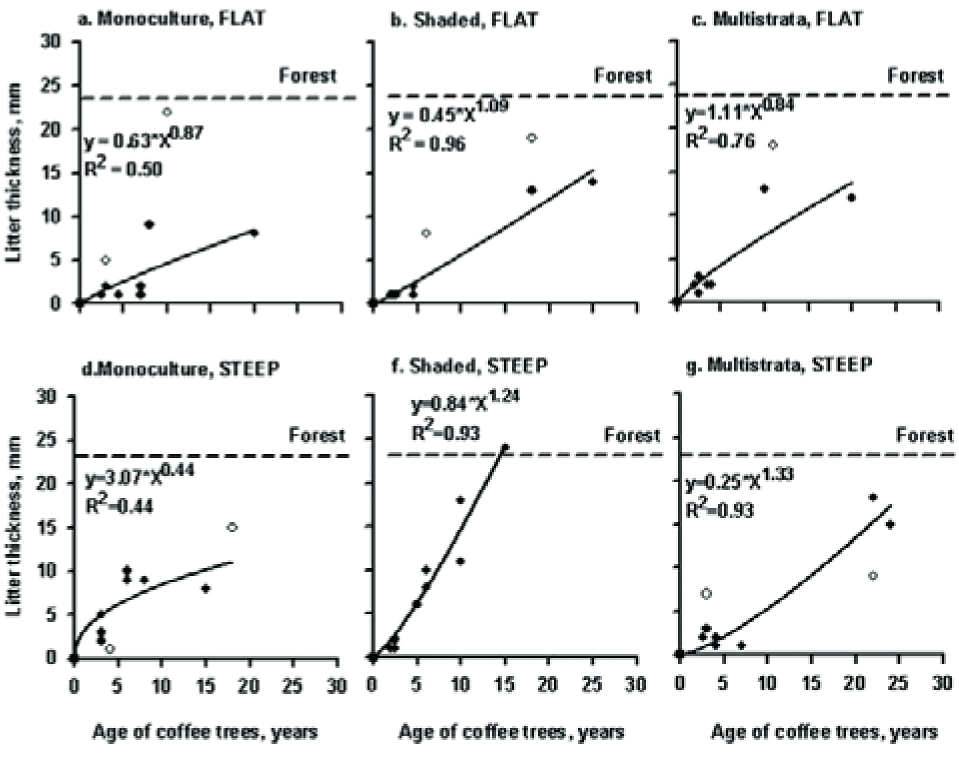

Figure 10. Thickness of litter layer under coffee based systems on flat and steep slopes at various age of coffee trees.

Thickness of litter layer

Conversion of forest to coffee based system reduced thickness of litter layer significantly ($p<0.05$), with time it increased gradually (Figure 10). The litter thickness varied between slope and land use types. Under mature (> 7 years) coffee multistrata system the thickness of litter layer was 30 % lower than in the forest of 22.8 mm. To gain similar litter layer thickness as in the forest, shaded coffee system and multistrata system may need 15-37 years which is a shorter time than needed by monoculture system of 60 years.

1. Composition of surface litter after forest conversion

At initial stage (1 to 3 years) after forest was converted to coffee based system, litter was dominated by coarse fraction (> 5 mm) and little branches (twigs), but later (after > 7 years) it was more dominated by branches than leaves (Figure 11). The change in litter composition lead to the change in litter quality which is important in regulating soil biota activity and root growth (Wardle and Lavelle, 1997) and other effects of biotic interactions on soil ecological processes.

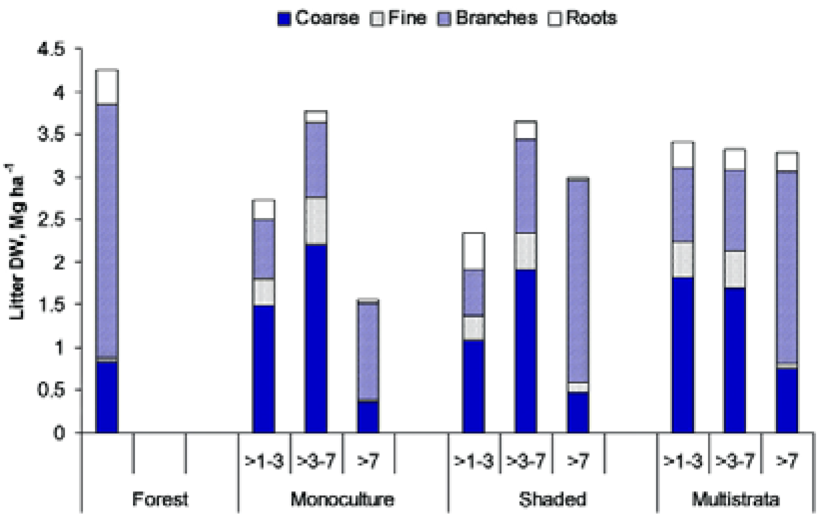

Figure 11. Composition of standing litter and roots found in litter layer of forest and mature coffee based systems (> 7 years).

2. Thickness of litter layer under established Agroforestry coffee based system (>7 years)

The mean litter dry weight was 2.1, 1.8, 1.2 and 1.2 Mg ha^{-1} for forest, multistrata coffee, shade coffee and monoculture coffee, respectively (Figure 12). No significant influence of slope to litter dry weight was found. However, under forest and coffee multistrata systems the dry weight of fine litter reduced significantly ($p<0.05$) with increasing slope; but there was no such evidence found under shaded coffee and coffee monoculture systems.

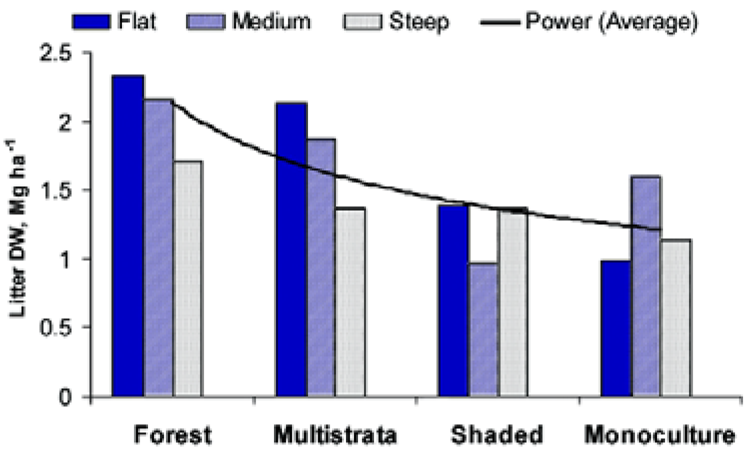

Figure 12. Dry weight of surface litter under forest and coffee based system at different slopes.

Soil surface cover

1. Tree canopy

Forest soil surface become more open after cut and clearing of vegetation leading to more vulnerability to run off and erosion. Soil cover by tree canopy increased with time (Figure 13), but lower relative to that of forest.

2. Basal area

The amount of land occupied by tree trunk (basal area) which is reliable for biomass indicator, is shown in Figure 14. The basal area slowly increased over time and agroforestry coffee based system has a higher basal area than monoculture coffee system. The highest basal area was found under coffee multistrata system (with 20 year old coffee) on flat land, but it still 60-70 % lower than in the forest.

3. Understorey

Distribution of tree canopy may affect the density of understorey plants under forest system or weed under agriculture system. One strategy to control weed under agricultural system in the tropics is by reducing light incidence on soil surface. In general weed reduced crops production, but it plays an important role on soil surface protection from rain drop leading to reduction of soil erosion.

Understorey dry weight of monoculture coffee system is higher than under agroforestry coffee based system (Figure 15) due to less cover provided by coffee tree canopy (Figure 13). Understorey dry weight in agroforestry coffee based system on flat land was relatively constant with time, but on steep slope it tended to reduce with time. Reduction on understorey population may improve crop yield, however, it may increase run off and erosion.

Earthworm density of different land use systems

The disturbance such as conversion of natural forest to agricultural systems will alter population density of earthworm due to changes on (a) microclimate, (b) amount of litter input, (c) litter quality (Tian *et al.*, 1997).

1. Earthworm population density

The population density of earthworm is presented in Table 3, with the highest population density in multistrata coffee system (149 individuals or head m^{-2}) followed by coffee monoculture (88 ind m^{-2}), shaded coffee (83 ind m^{-2}) and forest (75 ind m^{-2}). However, the size of earthworm under multistrata coffee system is smaller than under forest. The average earthworm biomass under multistrata coffee system was about 0.12 g per individual compared to 0.41 g per individual under forest.

In the classification of earthworms based on main ecological groups, we found that more ecosystem engineers (anesic + endogeic) than decomposer (epigeic) were found under natural forest, which may lead to a higher formation of soil macropores, increase water infiltration and reduced surface run-off. Similar results were found under multistrata coffee based system, while in monoculture coffee system more decomposer earthworm was found.

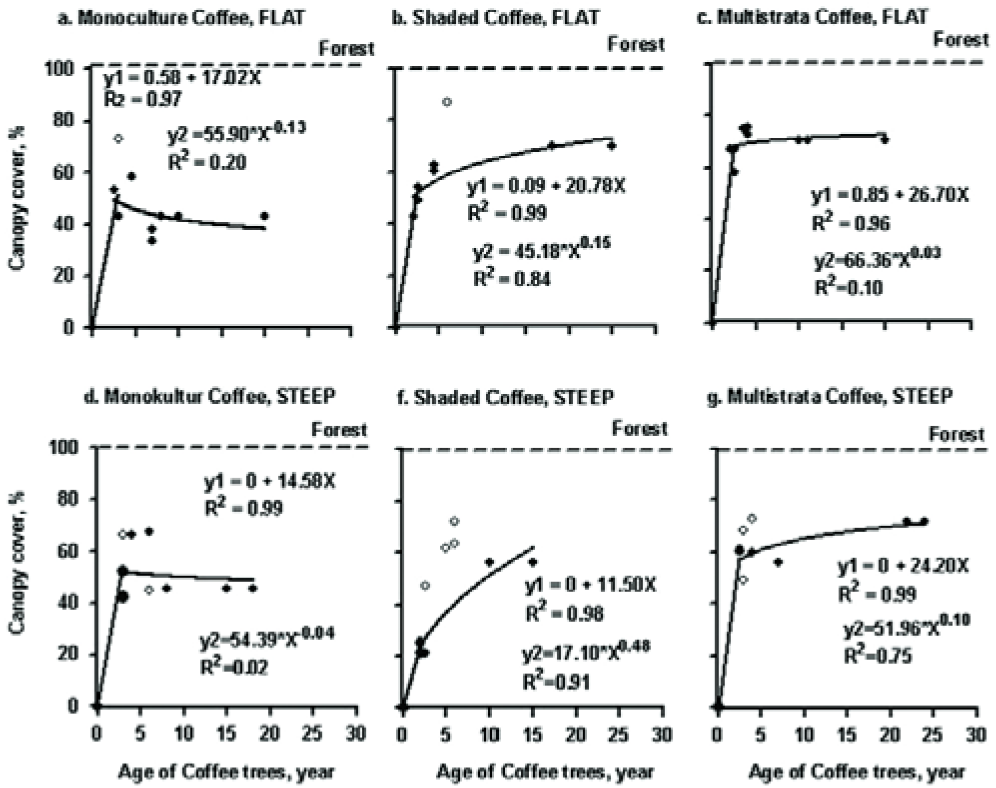

Figure 13. Area covered by tree canopy of Agroforestry systems and monoculture coffee based system relative to canopy cover under forest 100 %.

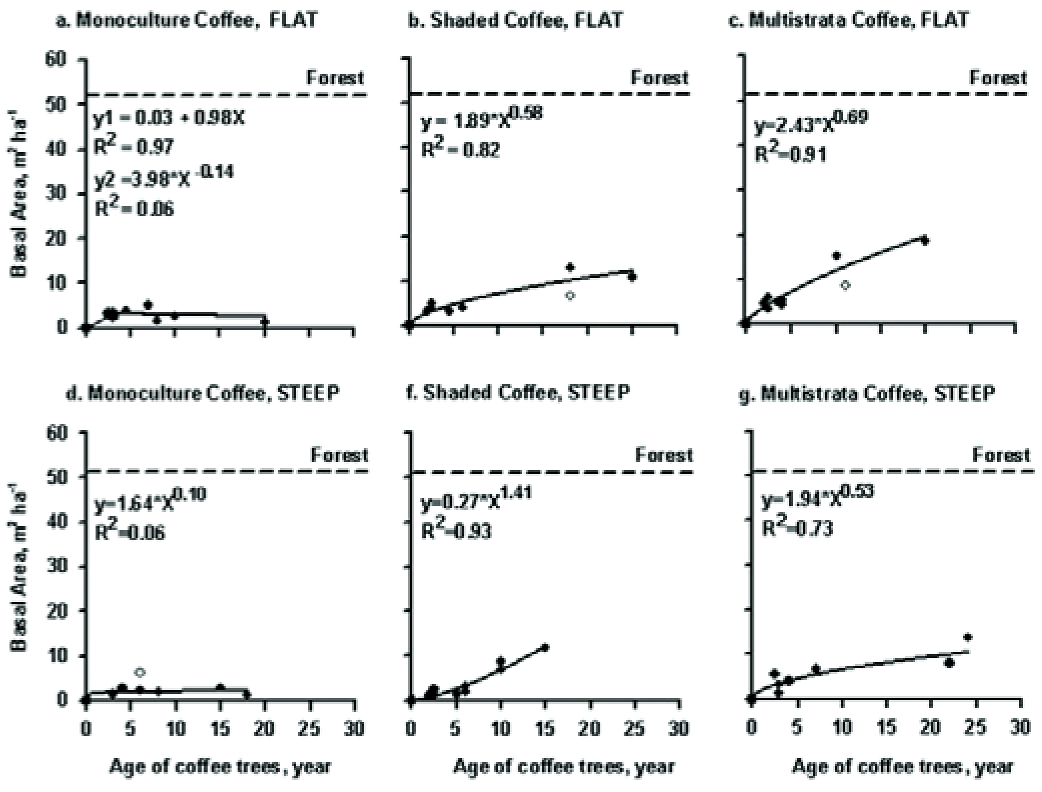

Figure 14. Tree basal area of Agroforestry systems and monoculture coffee based system compared to remnant forest

2.Cast production

A higher soil organic matter content in the natural forest increased the earthworm activity as shown by a high cast production of about 339 g m^{-2} or 3.4 Mg ha^{-1}, while the lowest was found under shaded coffee system it was about 55 g m^{-2} or 0.55 Mg ha^{-1}.

Table 3. Earthworm population density and its classification based on ecological type where the ecosystem engineer = (Anesic + Endogeic) / Total population.

Land Use	Population density (P), Indiv. m^{-2}	Biomass, (B) g m-2	B/P g per indiv.	Ecological Type			
				Epigeic (EP), Indiv. m^{-2}	Anecic (A), Indiv. m^{-2}	Endogeic (En), Indiv. m^{-2}	(A+En)/P , %
Remnant Forest	75 a1)	31 c	0.41	5 a	36 a	34 a	93
Multistrata Coffee	149 b	18 b	0.12	14 a	77 b	59 b	91
Shaded coffee	83 a	7 a	0.08	7 a	38 a	38 ab	92
Monoculture coffee	88 a	12 ab	0.14	11 a	51 ab	25 a	87

1) Different letters after number in the same column indicate significant differences as tested by the LSD at p<0.05)

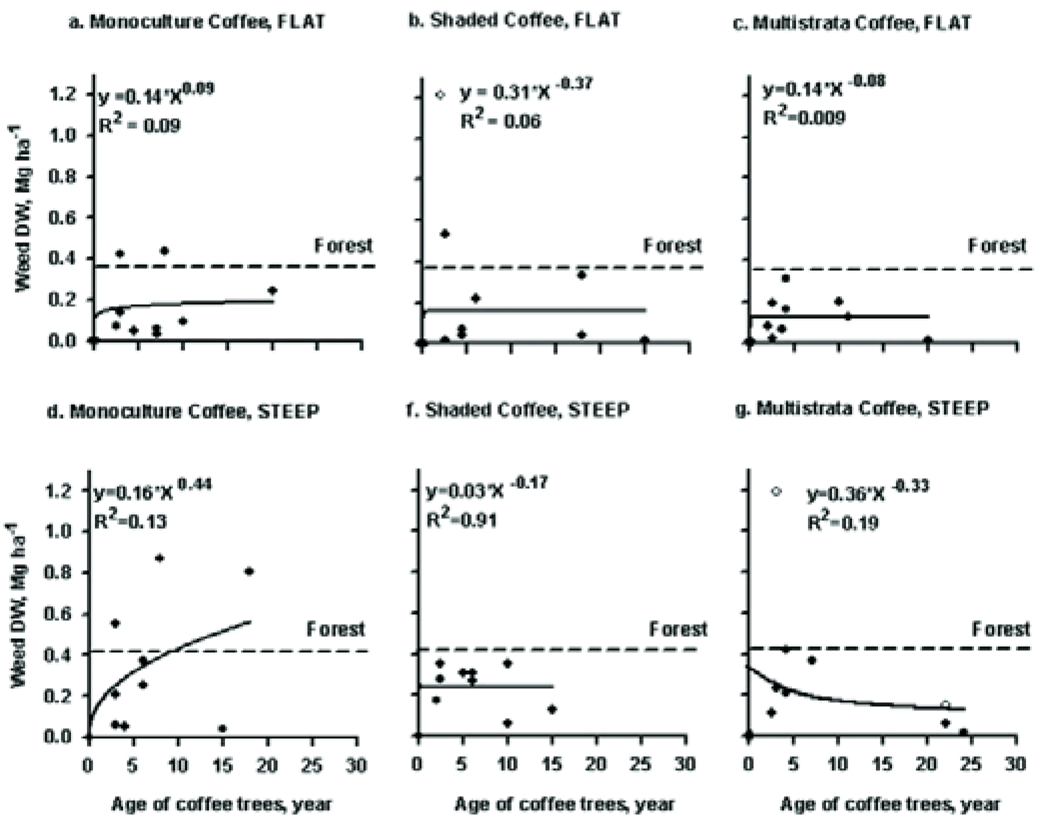

Figure 15. Understorey (weed) dry weight under forest and coffee based system

Soil Physical measurements

1. Macropore Distribution

The distribution of Methylen blue in the soil profile indicated the distribution of soil macropores, the larger the colored area indicates higher macro pores formed either by root or biota activities or decomposition of soil organic matter. The highest macropore distribution was found under forest condition, followed by shaded, multistrata and monoculture coffee systems (Figure 16). Quantitative measurement on soil macropore on the vertical plane showed that coffee based agroforestry system was 70 % in the total macroposes compared to that found in the forest soil (Figure 17).

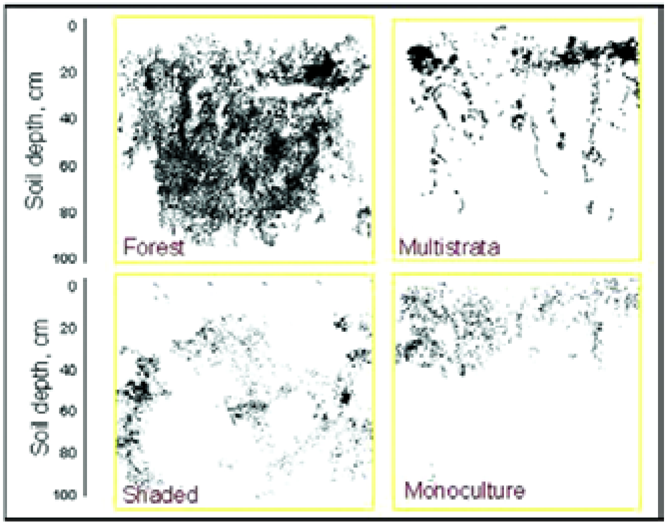

Figure 16. The distribution of the flow of Methylen Blue through soil profile as indication of the distribution of soil macro-pore in different land use systems (Forest= Natural Forest, Multi-strata = multi-strata coffee system, Shaded = shaded coffee system and Monoculture = monoculture coffee system).

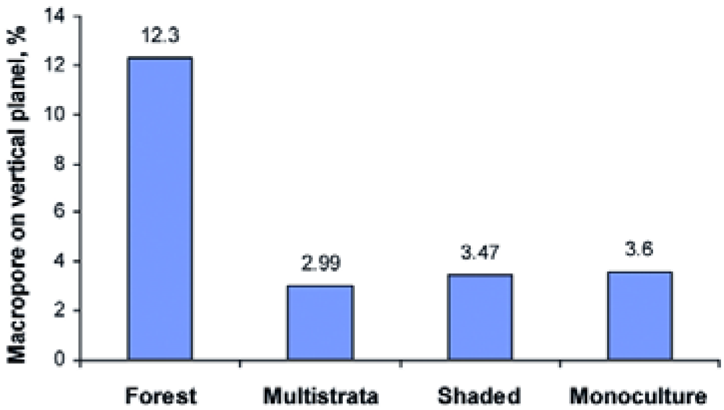

Figure 17. The average number of soil macropore on vertical plane under forest and coffee based systems

The measurement on the horizontal plane showed that conversion of forest to coffee based systems on the flat slope reduced about 70 % of the soil macropores especially at the top layer of 0-5 cm, however, no reduction was found on the steep slope (Figure 18).

2. Water infiltration rate

The results of our measurements showed that soil infiltration pattern for all systems are the same, except for forest which was high and more constant overtime. Overall water infiltration on flat land is higher than on steep sloping land, with the average value of about 2.74 and 2.59 mm min^{-1}.

Litter on soil surface play an important role on maintaining soil macropore and water infiltration. On flat slope, addition of litter did not significantly affect water infiltration. The average water infiltration rate of forest soil was about 4.9 mm min^{-1}, while of multistrata, shaded and monoculture coffee systems was about 2.2, 1.8 and 2.1 mm min^{-1}, respectively

(Figure 19A and B). Apparently, in our condition, surface litter is important in maintaining soil infiltration on steep slope land only.

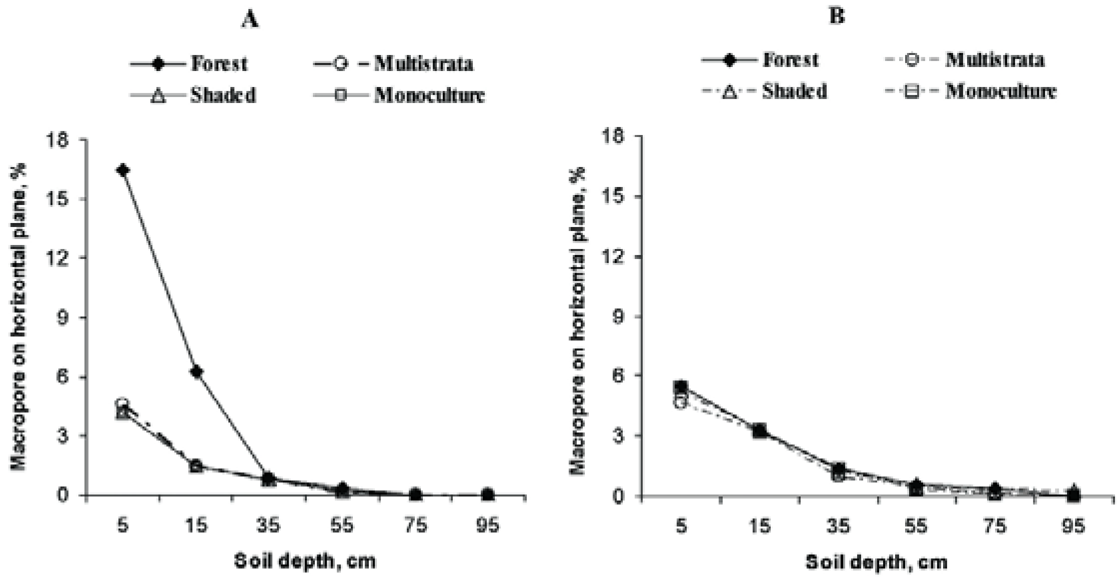

Figure 18. Distribution of soil macropore on horizontal plane of soil profile on (A) steep slope and (B) gentle slope (of forest and coffee based systems

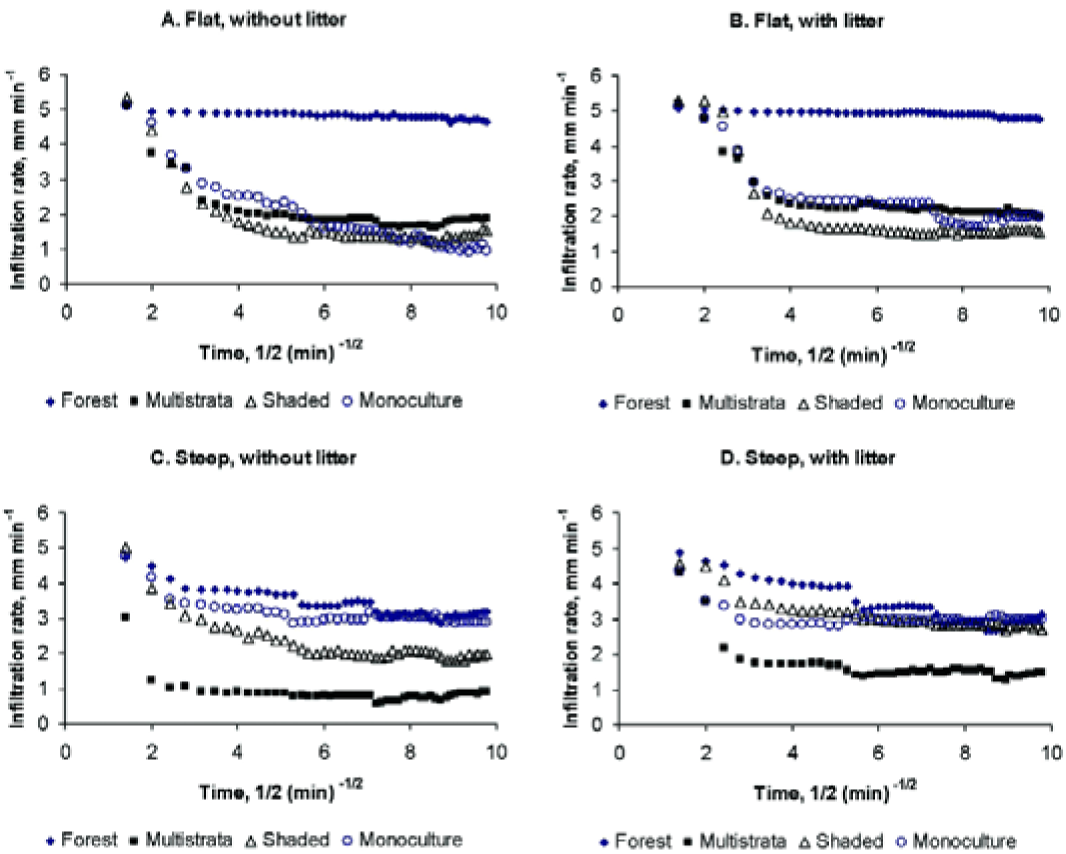

Figure 19. Water infiltration (mm minute-1) of different land use types on flat land without and with litter (A and B) and on steep slope land (C and D).

On a steep slope, infiltration rate of forest soil reduced with time but it was still higher than coffee based systems (Figure 19C and D). Surprisingly the average of water infiltration rate of forest soil was similar to monoculture coffee system of about 3.0 mm min^{-1}, while of multistrata and shaded coffee systems they were about 1.3, and 2.65 mm min^{-1}.

A high water infiltration rate under monoculture system as found in this study might be explained by a high intensity of weeding and surface roughness created by farmer e.g. making a small sediment pit known as '*rorak*' to reduce surface run-off (Agus *et al.*, 2002) and also for making compost *in situ* with green materials from pruning and weed. Further detail study, however, is still needed to explain this phenomenon.

Part 2.

Overland flow and soil loss under different land use systems

Introductions

Forest conversion leads to increase the overland flow as well as soil erosion. Tremendous increase of runoff and soil erosion was recorded at the experimental sites in Sumberjaya at the early years after forest cutting (Widianto *et al.*, 2004). Coffee-based systems seem to be able to reduce runoff and soil erosion only after several years (more than 5 years) after conversion.

Direct exposure of soil due to the absence of canopy cover at the early stage of conversion accelerate the degradation of physical and hydrological properties of particularly top soils and simultaneously increase the water run off.

Planting trees will gradually provide soil cover by both their canopy and litter. In long term it will improve soil properties and at the same time it is able to intercept more portion of the rain. These will increase infiltration capacity of the soil and hence reduce runoff as well as soil erosion.

The important factors to be considered in the selection of trees are (a) growth rate in terms of producing biomass (for canopy cover and litter production), and (b) quality of litter (affects the improvement of soil quality).

Purpose of this study was to evaluate the effects of canopy cover (as a function of the age of trees) and litter quality (as represented by various trees species) on overland flow and erosion as well as soil properties and water balance at plot level.

Methods

Two series of erosion experiments were carried out since 2000 in Sumberjaya, West Lampung. Surface runoff and soil loss was measured from erosion plots of various land cover on a daily basis. The first experiment was started in 2000/2001 on various ages of monoculture coffee systems, while the second was started one year later on various coffee based systems. Both series were compared to erosion plot under natural forest.

The first series consisted five treatments of monoculture coffee plots of 1, 3, 7 and 10 years after coffee planting (in 2000/2001), as well as under natural forest. The second series consisted of five land uses i.e. monoculture coffee, single-species shaded coffee, multistrata shaded coffee systems, and natural forest. The shade-tree species selected in the shaded coffee systems are *Gliricidia* sp and *Erythrina* sp The coffee species was 15 years old (in 2001/2002).

An area of 40 m^2 is enclosed by a strip of metal sheeting, called as an erosion plot, with guttering installed on the lower boundary of the plot to channel runoff into a splitter device called as "Chin Ong-meter". The volume of water collected after each runoff event as well as its sediment concentration were measured. One liter of water sample from the runoff collector was filtered to determine the sediment load. This report covers the period of three years (2000/2001 to 2002/2003).

Results

a. Effects of time after forest conversion into monoculture coffee system on the overland flow (surface run-off) and soil loss (erosion)
The results of measurement as a function of time after forest conversion are given in Figure 20 and 21.

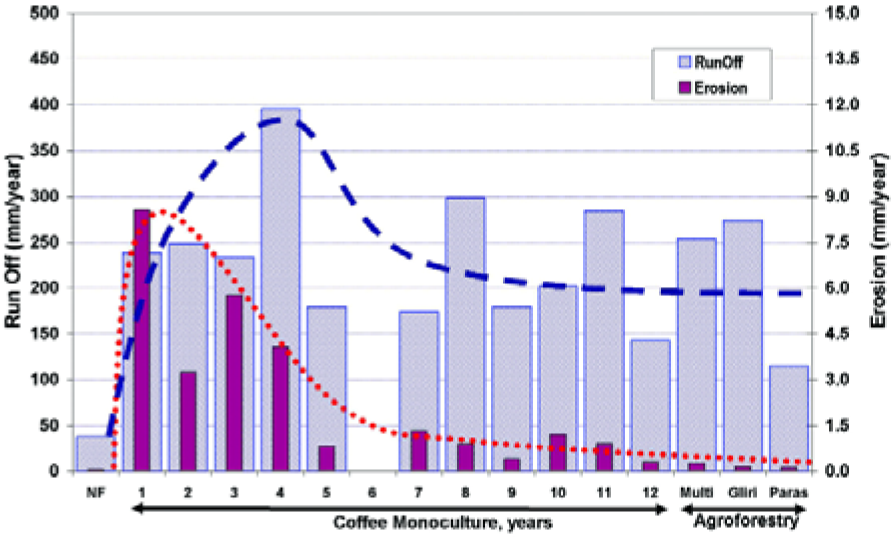

Figure 20. Surface runoff, erosion at various ages of monoculture coffee systems after forest conversion

The surface runoff and erosion from natural forest land is very small as many people believed so far. When the forest is cleared for conversion to agricultural uses, the overland flow and erosion increased tremendously. Soil loss is stimulated by the exposure of the soil surface because of removal of canopy cover as indicated by the highest sediment concentration in the surface runoff or the erosion and runoff ratio in the 1st year after coffee planting. With time, runoff and erosion tended to decrease. It seems erodibility decreased with the growth of coffee as it provides more shade and litter.

Soil loss from natural forest was less than 1 Mg ha^{-1} yr^{-1} and it increased to nearly 70 Mg ha^{-1} yr^{-1} when the forest was cleared. At the same time, surface runoff also increased but only about 6 times bigger than under natural forest. The soil loss declined on the following years and after 5 years under coffee, soil loss was way below 15 Mg ha^{-1}. Under 12 years or older coffee, or under multistrata coffee, soil loss was way below 5 Mg ha^{-1}.

b. Effects of coffee based agroforestry systems after forest conversion on the runoff and erosion

The measurement of surface runoff and soil loss from erosion plots under various coffee based agroforestry systems at 10 to 12 years old showed that those systems are able to reduce runoff and soil loss although it they were still above those of natural forest (Table 4 and Figure 21). The lowest surface runoff was measured under the *Paraserianthes* shaded coffee plot, while the *Gliricidia* shaded coffee gave the highest overland flow. On the other hand, the highest soil loss was collected from monoculture coffee plot. Multistrata and shaded coffee systems were able to protect soil surface and improve better than the monoculture coffee system, through their canopy and litter production.

Erosion to runoff ratio of multistrata and shaded coffee systems were very small as compare to the monoculture coffee. This indicates the important roles of tree species for the soil surface improvements, particularly the contribution to litter production and protection of soil surface by canopy.

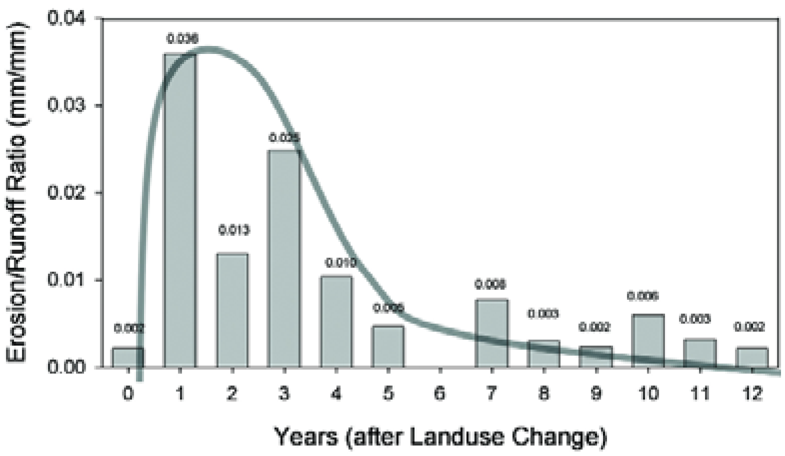

Figure 21. Erosion/runoff ratio at various ages of monoculture coffee systems after forest conversion

Table 4. Surface runoff, erosion at various coffee-based systems at 10 to 12 years after forest conversion

No	Landuse system	Runoff mm	Erosion Mm	E/R ratio mm/mm
1	Forest	37.6	0.08	0.0021
2	Multistrata	253.9	0.28	0.0011
3	Shaded by *Gliricidia*	273.4	0.15	0.0005
4	Shaded by *Paraserianthes*	114.6	0.12	0.0011
5	Monoculture	209.5	0.81	0.0038
Total rainfall 1,589 mm and bulk density of soils is (ρ^{β}) 1,200 kg m^{-3}				

Conclusions

Following forest clearing, perennial tree crop like coffee, can reduce erosion and runoff significantly in the steep slope area with mostly Inceptisols soils order in the humid tropic of Lampung, Sumatra, Indonesia. Inclusion of trees into coffee-based systems can reduced soil loss but not surface runoff as compared to monoculture coffee system. Coffee-based agroforestry systems provide better protection to soil surface since their tree canopy can cover more than 60 % and also produce more litter per unit of area of soil surface while the monoculture coffee system covers less than 50 % of the surface.

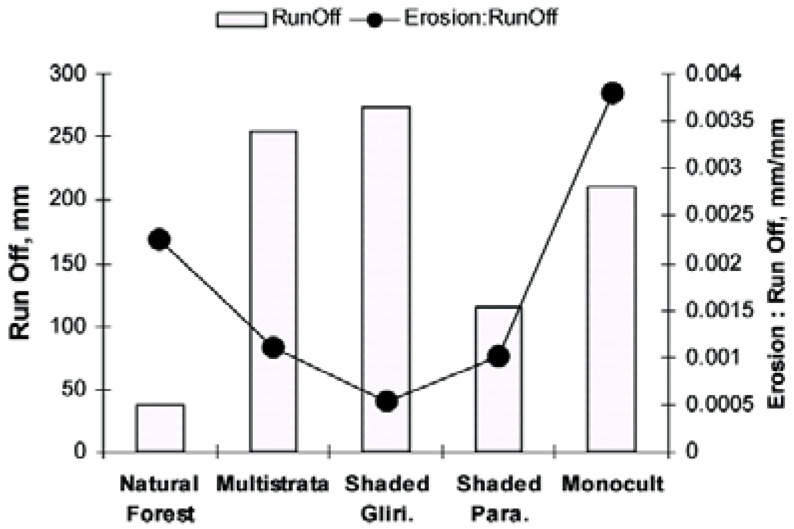

Figure 22. Surface runoff and Erosion to surface runoff ratio from various coffee-based agroforestry systems

Well-developed coffee-based systems can control soil erosion as low as forest, but it is not able to restore surface runoff close to the original forest condition.

Forest conversion will lead to increase of the overland flow to about 6 to 10 times higher, and accelerate soil loss particularly in the first two to four years after land clearing.

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III. Conservation Measures and Variation in Soil Susceptibility to Erosion

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Abstract

Agricultural land uses, such as coffee based farming, have been perceived by policy makers as having a high erosion and being a major source of sedimentation. This research was aimed at testing the level of soil loss on 3 year old coffee farm treated with different soil conservation treatments. The research was conducted on land with slopes ranging from 50 to 60% at Laksana and Tepus sites of Sumberjaya Sub-district, West Lampung province from November 2001 to July 2003. Erosion measurement was conducted at plot scale (15 m long and 8 m wide), for testing treatments: (1) Sun coffee (monoculture coffee), (2) Coffee+Gliricidia as shade tree, (3) coffee+ Gliricidia as shade tree +dead end trench (rorak), (4) Coffee+Gliricidia as shade tree + hedgerows of natural vegetation, and (5) Coffee+Gliricidia as shade tree + ridging. All treatments were replicated four times and arranged in a completely randomized block design. Data from this study were compared with those of similar study in the area, and analysis of key soil physical properties were used to explain variation in soil loss. Results show that soil bulk density, drainage pore, total pore space and saturated hydraulic conductivity were dominant factors in determining the level of soil loss in the study sites. Erosion on the 3 year old coffee farm with porous soil structure was very low (< 2 Mg ha^{-1} yr^{-1}) and thus soil conservation treatments had no significant effects on soil loss, run-off, and soil organic matter and nutrient losses. Similar study in Bodong village with similar landscape and farming system, but much less porous soil, indicated an erosion level of 37 t ha^{-1} within three month period under 830 mm of rainfall. These results call for the importance of delineation of soil susceptibility to erosion as a guide to prioritization of conservation intervention.

Key words: erosion, run-off, soil quality, coffee, soil resistance

Introduction

Conversion of forest to agricultural land in the tropics and intensive and non conservative use of agricultural lands lead to natural resource degradation. Previous studies showed that conversion of forest to agricultural land resulted in an increase in the amount of run-off and soil loss (Lal, 1985), significant changes in soil organic matter (Juo, et al, 1995), reduction of the concentration of exchangeable Ca^{2+}, Mg^{2+} , K^{+}, (Obara *et al.*, 1995) and an increase in temperature due to the increase of solar radiation reaching the ground surface (Udarbe, 1994).

Despite these environmental threats following forest conversion, the pressure of population living in the outskirts of forest is equally an important aspect to be taken into consideration. When the pressure to intensify the utilization of forestland is unavoidable, approaches to convert human activities from a threat to actively taking the lead in judicious conservation of the land must be made.

Smallholder coffee plantation is the dominant form of farming system in the protection forest areas of Sumberjaya Sub-district, Lampung Province. The soil is perceived by local stakeholders as prone to erosion owing to the exposure of soil surface to rain drops especially on newly cleared forest, undulating to hilly physiography, high intensity and high amount of rainfall areas.

Farmers have farmed both on the public and private lands for decades for coffee, but in mid 1990s the government evicted those farmers utilizing the public lands because of perception that the rate of soil loss would be multiplied. Coffee were replaced with *Calliandra calothyrsus* and it rapidly covered the land, but the evicted farmers lose their main (only) source of income. The people returned to the land in 1997 after the fall of the New Order Government. They cleared the *Calliandra* bush and grafted the remaining coffee stumps and replanted sparsely populated areas with new coffee trees.

With still insecure tenure, there is anxiety among farmers that they could be evicted again and as such they can not taking active participation in soil conservation efforts. A new 'community forest' scheme, fortunately, was introduced by the following government in which the farmers can obtain long term land use right as long as they implement or willing to implement conservation as shown by the community land management proposal.

The objectives of this research was to evaluate the effects of alternative agroforestry technology in coffee-based farming system on soil loss and soil fertility changes. This results were expected to be among the input in the community forest proposal.

Materials and methods

This research was conducted from August 2001 to August 2002 on 3 year old farmers' coffee farm having 50 to 65% land slopes in Tepus and Laksana Sub Villages of Simpangsari Village, and in Bodong village, Sumberjaya Sub-district, Lampung Province, Indonesia ($4^0$45'-$5^0$15' S and $104^0$15'-$104^0$45'E). The soil was classified as Oxic Dystrudept in Tepus and Laksana and Typic Paleudults in Bodong village.

Treatments tested included:

T.1 Open field **sun** coffee, typical treatment on young (<4 years) coffee farm

T.2 **Shade** coffee using *Gliricidia sepium* as shade tree. The distance between Gliricidia tree was 1.50-1.75 cm.

T.3 T2 + dead-end trench or "**rorak**" of 0.4 m wide, 0.3 m depth and 1 m long perpendicular to the slope direction and spaced at about 3 m downslope and 3 m parallel to slope in a 'zigzag' order.

T.4 T2 + **partial weeding** i.e. leaving natural vegetative strip of 0.25 m wide, perpendicular to the slope direction, at 3 m longitudinal distance.

T.5 T2 + **contour ridging** of about 20 cm tall, with 3 m longitudinal distance.

Plot size is 15 m long down slope and 8 m wide along the contour line. The upper and side borders of the plots were installed with 30 cm wide GI-sheet; 15-cm of the sheet was buried vertically into the ground and the remaining 15 cm protrude on the soil surface to protect run-on and runoff into and out of the plots. The lower parts of each plot were equipped with gutter for collecting bed load. Runoff water from the gutter was channeled to "Chin Ong" meter or subsequently called Chin Ong meter" (Khan 1998; see also Hairiah *at al.*, this volume).

Surface soils (0-10cm) and sub soils (10-20cm) were sampled from upper, midle and lower plots in November 2002 to determine its property. Six manual rain gauges were installed besides the plots i.e., three each in Tepus and Laksana sites to measure daily rainfall. The amount of rainfall reaching the plot was corrected by multiplying with the cosine degree of slope. The plots were manually weeded using sickle every two months. Fertilizers Urea, SP-36 and KCl at the rates of 75, 50, and 50 g per plant, respectively were broadcast within the diameter of 50 cm around each coffee tree twice a year, in Nov 2001 and June 2002.

As this research developed, we found a great variation in soil loss between Bodong (Hairiah *et al.*, this volume) and Tepus and Laksana sites. Therefore we developed additional activity aiming to study dominant soil characteristics that determine the level of erosion on coffee farm. The descriptive observations were carried out by evaluation of soil morphology. Quantitative observations were conducted by analyzing physical properties including bulk density, soil porosity, soil permeability, and soil aggregate stability and soil organic matter content. The soil samples were collected from three soil depths namely 0-10, 10-20 and 20-40 cm.

Results and discussion

Soil loss and runoff under different soil conservation measures

Soil loss on 3 years coffee farming area in Laksana dan Tepus was very low. With or without conservation technique, the average soil loss was 1.1 - 1.5 Mg ha^{-1} yr^{-1} and run-off coefficient was 2.1 - 2.5%. As such, the conservation treatments did not give significant effects on runoff and soil loss (Table 1). The conservation measures also had no significant difference on total organic C and nutrient loss (Table 2), as well as nutrient enrichment ratio (Table 3). Nutrient enrichment ratio is the ratio of nutrient in the deposited sediment and the nutrient content of original 0-10 cm surface soil layer.

Table 1. Effect of conservation techniques on run off and soil loss as observed from November 2001 to October 2002.

Treament	Run off (mm)	Run off Coeff. (%)	Soil loss (Mg ha^{-1})
T1 = Sun coffee	53,25 [a†]	2,3 [a]	1,50 [a]
T2 = Kopi + Gliricidia as shade tree	46,36 [a]	2,0 [a]	1,29 [a]
T3 = T2 + rorak	49,27 [a]	2,1 [a]	1,24 [a]
T4 = T2 + partial weeding	60,71 [a]	2,5 [a]	1,28 [a]
T5 = T2 + ridging	55,58 [a]	2,4 [a]	1,14 [a]

† Mean in the same column followed by common letter are not significantly different as tested using the LSD at 5% level.

Table 2. Nutrient content in run off and sediment

Treatment	Sediment				Runoff		
	C-org	Total N	P2O5	K2O	N	P	K
				kg ha^{-1}			
T1 = Sun coffee	47 [a†]	3.5 [a]	0.3 [a]	0.2 [a]	1.7 [a]	0.001 [a]	5.7 [a]
T2 = coffee+ Gliricidia as shade tree	35 [a]	2.9 [a]	0.2 [a]	0.2 [a]	2.5 [a]	0.006 [a]	3.7 [a]
T3 = T2 + rorak	30 [a]	2.6 [a]	0.2 [a]	0.2 [a]	1.3 [a]	0.001 [a]	2.2 [a]
T4 = T2 + partial weeding	36 [a]	2,9 [a]	0.2 [a]	0.2 [a]	3.3 [a]	0.001 [a]	3.2 [a]
T5 = T2 + ridging	29 [a]	2.6 [a]	0.1 [a]	0.2 [a]	2.0 [a]	0.001 [a]	4.0 [a]

†Mean in the same column followed by common letter are not significantly different as tested by the LSD at 5% level.
In runoff water, measured N in the NH_4^+ and NO_3^- forms, P in $PO4^{-3}$, and K in K^+ forms.

Table 3. The enrichment ratio for each treatment

Treatment	C-Org	N	P	K
T1 = Sun coffee	1,09 [a†]	1,46 [a]	0,72 [a]	1,90 [a]
T2 = Coffee+ Gliricidia as shade tree	1,11 [a]	1,34 [a]	0,55 [a]	1,67 [a]
T3 = T2 + rorak				
T4 = T2 + partial weeding	0,93 [a]	1,30 [a]	0,66 [a]	1,74 [a]
T5 = T2 + ridging	1,03 [a]	1,33 [a]	0,54 [a]	1,97 [a]
	1,02 [a]	1,27 [a]	0,45 [a]	2,22 [a]

†Mean in the same column followed by common letter are not significantly different as tested by the LSD at 5% level.

Relationship between Soil Characteristics and Soil Loss on Coffee Based Farming System in Sumberjaya

Data showed that soil loss in Bodong was significantly high while in Tepus and Laksana it was negligible (Table 4). The erosion plots in the three sub-villages were established similar slope, rainfall and coffee age.

Soil Morphology

Soil morphology at each research site is given in Table 5. Properties of each soil layer determine the rate of water infiltration into soil that finally will affect the amount of runoff. On the average, the soil solum depth at the three locations is > 100 cm. However, there is significant difference in soil layer properties. The existence of clay illuviated horizon (Bt) at Bodong indicates a low water infiltration. Laksana site has a more permeable soil layer that characterized by friable to very friable soil condition up to 160 cm depth (Table 5).

The distinct contrasts in soil characteristics between sites seemed to be dominant factor that determined erosion level at the 3 locations.

Table 4. Slope, rainfall and soil loss at three sites in Sumberjaya under 3 year old sun coffee system.

Sites	Slope (%)	Rainfall (mm)	Soil loss (ton ha-1)
Bodong	60-70	458	37.21**
Tepus	57-66	434	0.42
Laksana	56-68	571	0.02

* Observation periods: Bodong (May - July 2001), Tepus and Laksana (May-July 2002).
** Source: Widianto *et al*. (2002).

Table 5. Soil morphology at the 3 research sites.

Location Altitude	Horizon	Depth (cm)	Color	Aggregate	Consistency	Texture
Bodong	AP	0-22	Brown	AB†	Firm	Clay
830m	Bt1	22-65	Light brown	AB	Slightly firm	Clay
	Bt2	65-89	Light brown	AB	Friable	Clay
	Bt3	89-153	Light brown	AB	Friable	Clay
Laksana	Ap	0-23/40	Dark brown	SAB	Friable	Clay
820m	Bw1	23/40-63	Yellowish red	SAB	Friable	Clay
	Bw2	63-99	Red	SAB	Very Friable	Clay
	Bw3 Bw4	99-138	Red	SAB	Very Friable	Clay
			red	AB	Very Friable	Clay
Tepus	Ap	0-22	Dark brown	SAB	Slightly firm	Clay
820m	Bw1	22-63	Strong brown	AB	Friable	Clay
	Bw2	63-105	Strong brown	AB	Friable	Clay
	BC	104-144	Reddish yellow	AB	Very firm	Clay
	C	>144	Reddish yellow	-	-	

†AB= angular blocky, SAB=sub-angular blocky

Physical properties and soil organic matter

The result of descriptive observation as shown in Table 9 is supported by the results of soil physical and organic matter analyses. Laksana dan Tepus had a higher total porosity and lower soil bulk density, higher permeability and drainage pore in the 3 soil depths compared to Bodong (Figure 1 and 2).

Organic C content affects several soil physical properties, such as water holding capacity and aggregate formation and stability. Organic-C content in Laksana was higher than that of Tepus and that of Tepus was higher than that of Bodong (Figure 25).

Figure 1. Total porosity and bulk density of 3 different soil depths of soils at Tepus, Laksana, and Bodong sites.

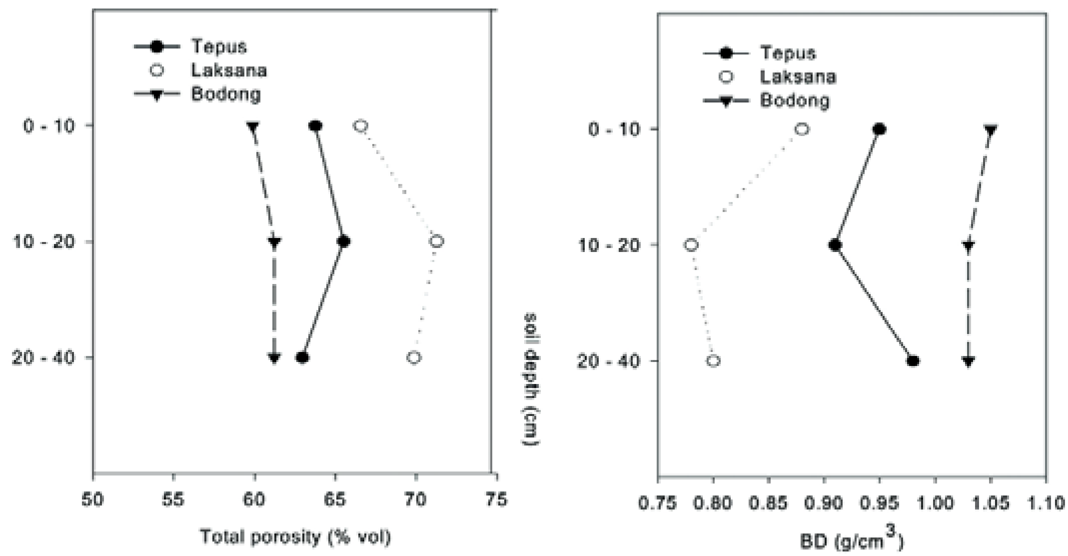


Figure 2. Soil permeability and drainage pore at 3 different soil depths at three research sites (Tepus, Laksana, Bodong)

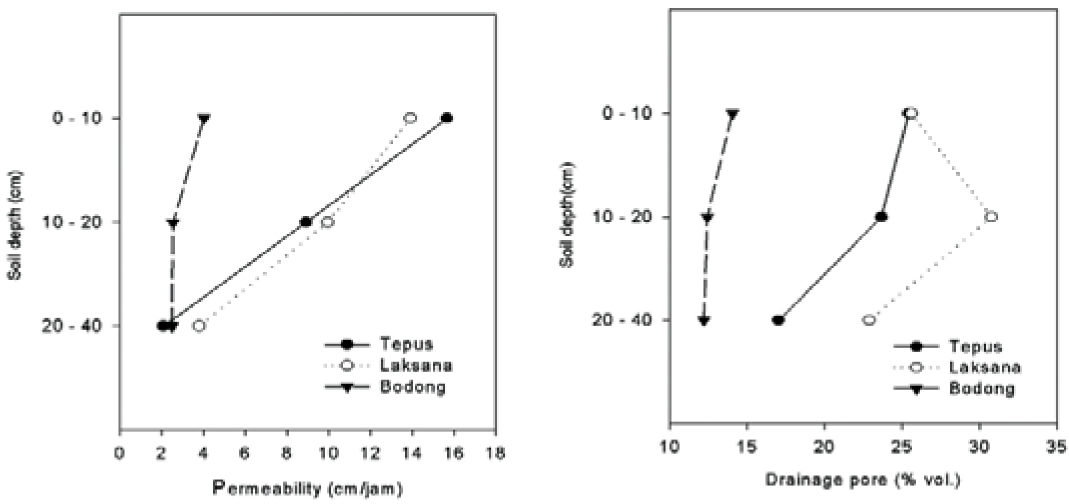
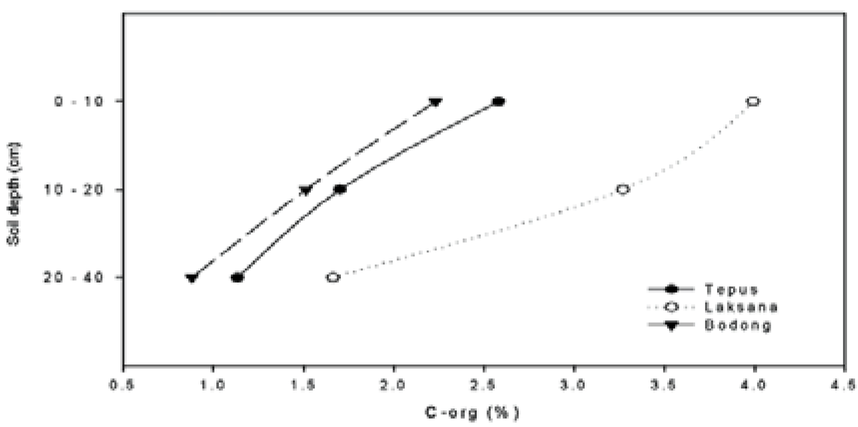
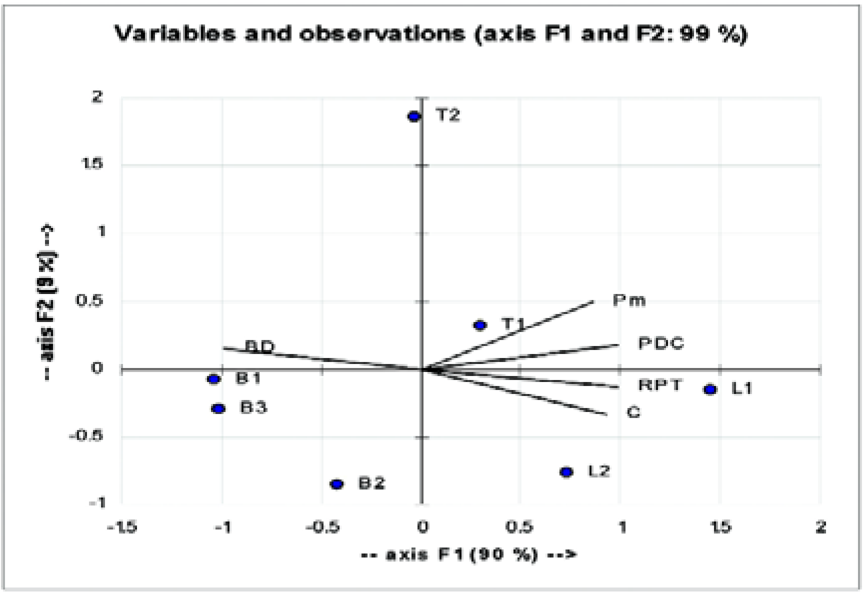


Figure 3. Organic C content at 3 different soil depths at Tepus, Laksana, and Bodong research sites



Using the principal component analysis (Mattjik *et al.* 2002), including variables of bulk density, total pore space, percent of drainage pore, permeability (hydraulic conductivity in saturated condition) and organic C, resulted in two principal components, subsequently referred to as F1 (the first principal component) and F2 (the second principal component). The two components serves as new variables that can explain 99% of data variance (90% with F1 and 9% with F2). Variables contributed to F1 were bulk density (21.5%), total pore space (21.6%), percent of drainage pore (21.3%), permeability (16.5%) and C organic (19.1%). Variable that contributed to F2 are permeability (57.2%), C-organic (26.6%), while bulk density, total pore space, and drainage pore, each contributed < 7%.

The Biplot analysis was used in grouping of research location on the basis of the two principal components (Figure 4).



Legend: B1,B2,B3 = Bodong, T1,T2=Tepus, L1,L2 = Laksana, BD=bulk density, RPT = total pore space, PDC= drainage pores, Pm = permeability (saturated hydraulic conductivity, C = organic C.

Figure 4. Biplot of 7 sampling sites on the basis of two principal component value

The Biplot analysis showed that the location that have the lowest soil loss (Laksana /L1 and L2) were the locations that have the highest F1 value (having soil physical properties unsusceptible to erosion and high in soil organic matter).

Conclusions

Erosion level on coffee based farming system in Sumberjaya Sub-district varied greatly. Soil physical properties especially drainage pores, total pore space, permeability (K-sat) and bulk density were dominant factors that determine the deference in soil loss in the three study sites (Bodong, Tepus, Laksana). Implementation of soil conservation measures on soils with low erosion level, in this study case, Oxic Dystrudept, did not give significant effects on soil loss, runoff and nutrient enrichment in the lower slope position. Therefore coffee by itself, is sufficient to control erosion. On erosion susceptible soils, however, additional soil conservation measures than coffee may be necessary during the first few years since the coffee is planted.

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IV. Participatory Trials for the Refinement of Conservation Practices

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Abstract

Farmer-led research is believed to be effective in testing and, at the same time, disseminating research results. We facilitated farmers in cross visits to inspect practices of conservation for tree-based farming and in conducting research on small plots on their farm. Fifty farmers, representing several farmer groups participated in the study in Sumberjaya Sub-district, West Lampung District, Lampung Province, Indonesia. The objectives were to test the effectiveness of *Arachis pintoi* cover crop in controlling erosion and improving soil fertility under their young (3-5 year old) coffee in 2001-2004. Results showed that farmers, in general, were curious in testing the techniques they newly came across. *A. pintoi* adapted quite well under relatively good soil conditions and it tolerated shading. Weeding in the first few months was important for this legume establishment. *A. pintoi* increased C and N concentrations in the soil. Soil loss was very low in the study site and the use of the cover crop decreased soil loss several folds. After one or more years of testing in small plot of 10 m by 10 m, a few farmers expanded the planting of *A. pintoi* on larger areas of their land. Other farmers, however, expressed that the cover crop caused difficulty in coffee harvest as the dropped cherries become unseen in *A. pintoi* mat. Farmers recognized several indicators such as slope degree, soil texture, infiltration, water holding capacity, color, organic matter and compaction, using their terminology, to describe soil fertility and erodibility. Despite some difficulty in harvest, the use of cover crop promises benefits for coffee and other tree crops and weeding techniques, such as ring weeding at 1.5 m diameter around coffee trees, may untangle the harvesting problem.

Introduction

Because of exposure of most of soil surface to rain drops in the first few years after coffee planting, there is a possibility of high soil loss. Therefore, it is necessary among farmers as well as policy makers to recognize such problem and find possible rectifying measures.

Several conservation techniques, such as sediment pit and contour bund, have been implemented by some farmers and the use of shade trees, especially *Gliricidia sepium*, has been adopted by the majority of farmers (Agus *et al.*, 2002).

In the pepper (*Pepper nigrum*) plantation, some farmers use *Arachis pintoi* as cover crop. To avoid competition between the cover crop and pepper ring weeding (weeding in 1.5 m diameter area around the pepper hill) has been practiced. The technique was worth trying for coffee area with mostly steep slope.

In many cases, especially for conservation technique, voluntary adoption of the tested technologies is rather difficult. This is partly due to lack of ownership among farmers because of lack of their involvement during technology generation and adaptation. Therefore, the technique of farmer-led research is suggested (Agus and Widianto, 2004).

The objectives of this research were to (i) evaluate the effects of alternative conservation technology (in this case the use of *Arachis pintoi* leguminous cover crop) in coffee-based farming system on soil loss, soil fertility changes, coffee production and profits generated from the coffee farms and (ii) appraise farmer's method of evaluating soil quality and susceptibility to erosion.

Material and Methods

This research was conducted in Sumberjaya Sub-district, West Lampung District, Indonesia from July 2001 to June 2004. We facilitated several farmer's group included Sumbersari, Tritunggal, Laksana Jaya and Mekarsari groups to test the treatments of their choice.

We initiated this research by exposure to farmers several conservation techniques during a cross visit. The farmers then were given opportunity to test the technique of their interest. Fifty farmers, representing the four groups expressed their willingness to test *Arachis pintoi* as a cover crop of coffee farm.

The plots were scattered on several farmers field. Each farmer was comparing the use of the cover crop with the conventional practice, i.e. no cover crop on plots 10 m x 10 m in area. Pairs of treatments from different farmers were tested using the pair t-test for coffee yield, profits (from labor allocation, investment for supplies, farm gate revenue), soil loss and soil properties.

Monitoring included soil fertility, financial analysis, coffee yield and, for selected plots, soil loss. Undisturbed core samples of surface soil were taken by copper rings with a diameter of 76 mm and height of 40 mm to analyze physical properties such as saturated hydraulic conductivity, bulk density and soil moisture characteristics. Composite soil samples were taken to analyze soil carbon, nitrogen, potassium, calcium, magnesium, sodium, cation exchange capacity and pH. In addition, farmers' practices of applying fertilizers, pests and diseases control, etc. were recorded. Changes of soil properties were monitored every year.

Amount of investment in terms of labor, material, fertilizer, seedlings etc. and coffee yield and farm price were recorded and converted to the monetary value for estimating profits of each technique. Farmer's evaluation to alternative agroforestry systems were assessed throughout the course of this study. Farm record keeping method was used as much as possible.

For selected plots (7 pairs of plots), sides and upper plot borders were bordered with earthen bund and sediment collectors were installed at the lower border. Participating farmers were trained how to weigh, collect and store sediment samples every fortnightly for further water content and chemical analysis.

Farmers suggested that the research topic be expanded to soil fertility aspects as related to combination of practices that would increase coffee yield, reduce erosion and improve soil fertility. Therefore, for the 2nd year study, the farmers tested three treatments: 1) coffee with current farmer practices, 2) coffee with *Arachis pintoi* and 3) coffee + *Arachis pintoi* +

phosphorus fertilizer. For the 3rd year studies the farmers continued with the evaluation of these treatments. The nutrients analyzed included nitrogen (N), phosphorus (P) and potassium (K).

Five group of local community (each group consisted of 5 persons) conducted focus group discussions about their perception on soil condition (properties and erodibility) and management practices of different land use systems i.e: forest, old coffee (more than 10 years old), young coffee (less than 4 year old), coffee multistrata cropping and imperata grass (*Imperata cylindrica*). At the same time, undisturbed and composite surface soil samples (0-10 cm depth) were collected to analyze physical and chemical properties from each land use. Information on slope, soil color, canopy cover, and drainage were determined.

Results and Discussion

Until the third year of the research, a total of 50 farmers in Sumberjaya had been participating to experiment *Arachis pintoi* on their coffee farms. This study revealed the effects of *A. pintoi* on soil properties under coffee farming systems. This is important because the sustainable improvement of existing coffee farming systems relies on the use of leguminous crops to enhance soil fertility because of low or no fertilizer use during this time of low coffee price.

a. Adaptation and adoption of Arachis pintoi as legume cover crop

The growth and adoption of *Arachis pintoi* as legume cover crop were observed. Classification of growth performance of *A. pintoi* was determined arbitrarily. Percentages of land cover were grouped as >75%, 50 - 74% and <50% cover and/or biomass production per meter square every cutting time (every 3 months) were grouped as >1000g, 500-999g and <500 g to classify *A. pintoi* growth into good, fair and poor, respectively. However, if no *A. pintoi* growth on the plot, it unlikely have meant that the farmers had already rejected it and they returned to their initial practice of clean weeding. Data of growth performance of *A. pintoi* after two and half years of introduction are shown in Table 1.

Table 1. Growth performance of *Arachis pintoi* as a cover crop on coffee based farming system after two and half years of introduction.

Growth Performance	Farmers	
	(Number)	(%)
Good	22	44
Fair	3	6
Poor	17	34
No adoption	8	16
Total	50	100

Good, Fair and Poor growths are indicated by >75%, 50-74% and <50% land cover and/or >1000g, 500-999g and <500 g m-2 biomass production every cutting time (every 3 months) of *A. pintoi*.

In general, *Arachis pintoi* growth was related with soil fertility and land ownership status. For example, in Tanjungsari with relatively poor soil fertility, *Arachis pintoi* growth was also poor and out-competed by weed. Majority of farmers did not cultivate their farms (coffe and *A. pintoi*). In Lewi Monyet and Wonosari with good soil fertilility, as indicated by darger soil color and friable soil structure, *Arachis pintoi* growth was also good. Of the 50, 8 farmers did not adopt *A. pintoi* at their experimental plots because of various reasons; 1 farmer due to change of land use to non agriculture, 3 farmers due to the change in land holders, and 4 farmers explained that they had difficulties in weeding and coffee harvesting thus returned to the practice of clean weeding.

A couple of farmers expanded their *A. pintoi* to larger plots and they donated the cutting to other farmers who were interested in planting the legume. There were farmers in Wonosari site planting *A. pintoi* around their home after they saw good performance of *Arachis pintoi* on farmers' plot experiment. In this case they planted *A. pintoi* for ornament and ruminant fodder.

There were several in *A. pintoi* introduction: 1) in general, at the early growth of *A. pintoi* was competed by weeds and it required hand weeding for best performance which was time consuming. If the weed included imperata grass, the weeding problem was more serious, 2) it requires fairly good soil fertility to start and it seems the application of P fertilizer improved the growth, 3) a number of farmers expressed difficulties of coffee harvest, because the dropped berries within *A. pintoi* covered area were difficult to find.

b. Biomass and nutrient contribution

The contribution of *A. pintoi* to produce biomass and nutrients on coffee-based farming systems are shown in Table 2. The fertilizer contribution (recycling) equivalent is given in Table 3. Annual fresh biomass production ranged from 14 to 59 Mg ha^{-1} or equivalent with 3 to 13 Mg ha^{-1} dry biomass. It contained 54 - 234 kg, 4 - 17 kg, and 18 - 79 kg per hectare per year N, P and K, respectively if its biomass recycled as mulch or incorporated in surface soil layer. These amount equivalent with 30 - 127 kg, 6 - 27 kg and 15 - 63 kg urea, SP36 and KCl fertilizers respectively. The results indicated that the legume *A. pintoi* had a good prospect to improve soil fertility under coffee based farming system. *A. pintoi* seemed to fix significant amount of nitrogen, enough to supply coffee need for N.

Table 2. Biomass production and nutrient contents of *Arachis pintoi* cuttings in coffee based farming system in Sumberjaya.

Parameters	Production		
	Minimum (poor growth)	Maximum (good growth)	Mean (Fair growth)
Fresh Biomass (t ha^{-1} yr^{-1})	14	59	32
Dry Biomass (kg ha^{-1} yr^{-1})	3	13	7
C (kg ha^{-1} yr^{-1})	1.4	6.0	3.3
N (kg ha^{-1} yr^{-1})	54	234	126
P (kg ha^{-1} yr^{-1})	4	17	9
K (kg ha^{-1} yr^{-1})	18	79	43
Ca (kg ha^{-1} yr^{-1})	15	66	36
Mg (kg ha^{-1} yr^{-1})	10	44	24

A. pintoi have been used as animal fodder, particularly for cattle and goats, in Sumberjaya. *A. pintoi* potentially produces 38 to 162 kg ha^{-1} day^{-1} fresh biomass. This amount can be contributing to 8 - 36 heads of cattle for fodder mix, based on assumption that *A. pintoi* can compose 15% (4.5 kg) of daily fodder need of approximately 30 kg per head of cattle. This reflected direct benefit that *A. pintoi* can promise. The use of the cutting for fodder, however, will need higher nutrient replacement (especially of P, K, Ca, and Mg) in the form of manure and/or fertilizers as cut and carry practices means transporting of these nutrients out of the coffee farms.

Based on field observation, this legume often appears more vigorous under shading tree (coffee multistrata system) and good soil fertility than in open area (monoculture coffee). Under open area (full sunlight), which often coincides with poorer soil fertility, its growth was suppressed and it had yellow leaves.

Table 3. Average N, P, and K fertilizer equivalent produced/recycled in *A. pintoi* cutting.

Growth Condition	Fertilizer equivalent (kg ha^{-1} yr^{-1})			Monetary Value (Rp)
	Urea	SP36	KCl	
Min (poor)	30	6	15	71,700
Max (good)	127	27	63	305,400
Mean	69	15	34	165,900

Low coffee production, expensive fertilizer price and low coffee price were among the main farmer's problems in Sumberjaya causing farmers unable to maintain (fertilization and weeding) their farms. Therefore *A. pintoi* have a good potential to overcome the soil fertility problems.

c. The effects of A. pintoi on soil properties

Soil under *A. pintoi* tended to have a higher C and consistently higher N contents than the control plots (Figure 1). The accumulations of nitrogen via N_2 fixation is important to alleviate N fertilization.

d. The effects of A. pintoi on soil loss

Coffee farming system on moderate to steep slopes can lead to high rates of soil loss. Introduced *Arachis pintoi* as a cover crop is a possible practical means to decrease erosion and increase coffee yields because it's stems and roots form a dense mat that protect the soil from high-intensity rainfall. Comparison in soil loss between *Arachis pintoi* and control plots from November 2003 to June 2004 measurement is shown in Figure 2.

e. Participatory analysis of soil properties

Farmes' identification of several parameters of soil properties are shown in Table 4. Farmers used a variety of criteria to classify soil fertility such as: slope, texture, infiltration, water holding capacity, color, organic matter and hardness/compaction. Of the five type of land uses (forest, old coffee, young coffee and, multistrata coffee), forest area is considered by farmers to have the highest fertility followed by multistrata system, old coffee, young coffee and Imperata grass. Farmer were also used the same indicators (as soil fertility) to classify soil erodibility. The farmers' ranking of soil erodibility from highest to lowest of the five-types of land use were young coffee followed by imperata grass, old coffee, mix coffee and forest.

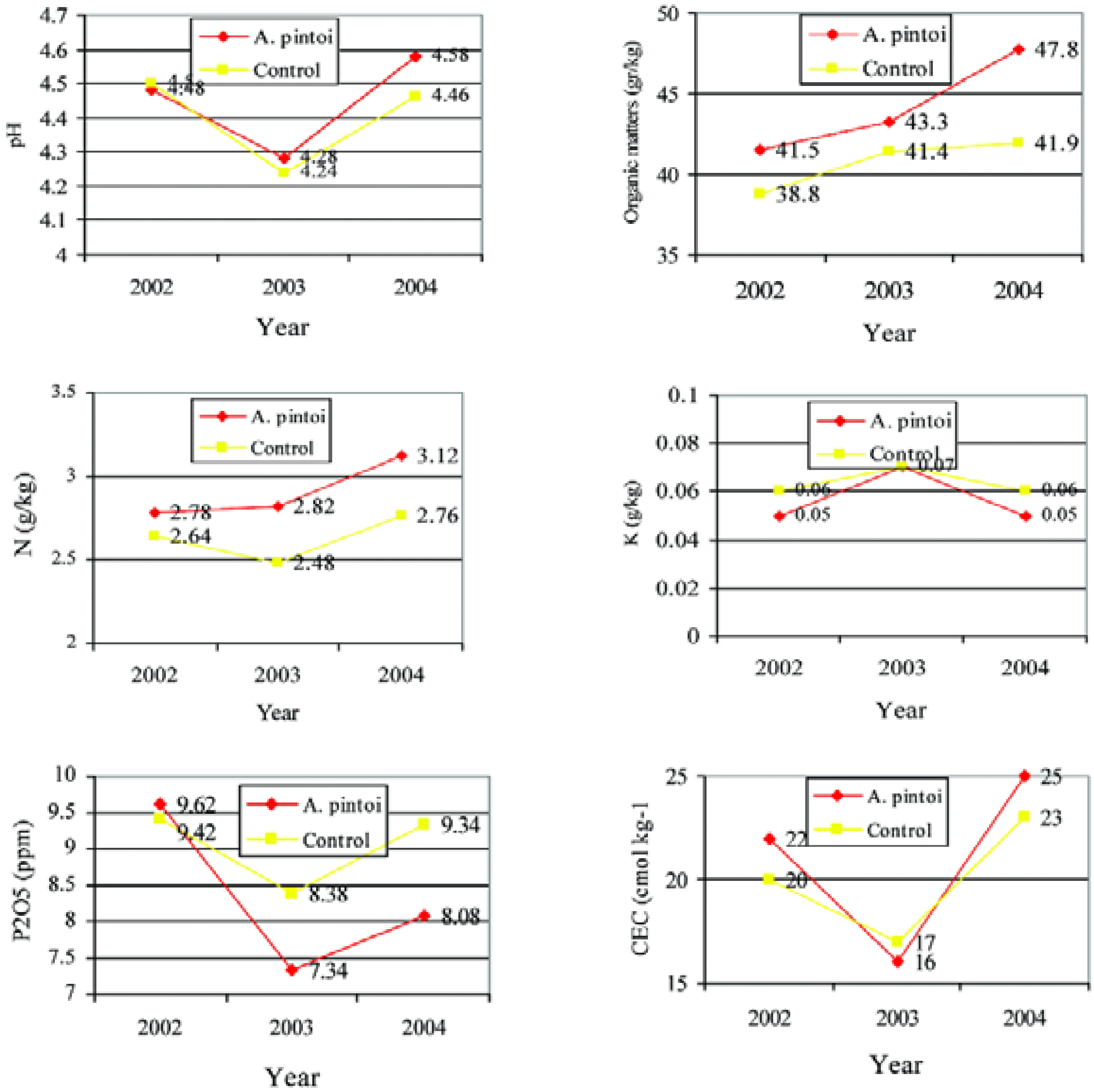

Figure 1. The changes in soil properties of top soil (0 - 10cm) of *Arachis pintoi* and control plot from year 2002 to 2004.

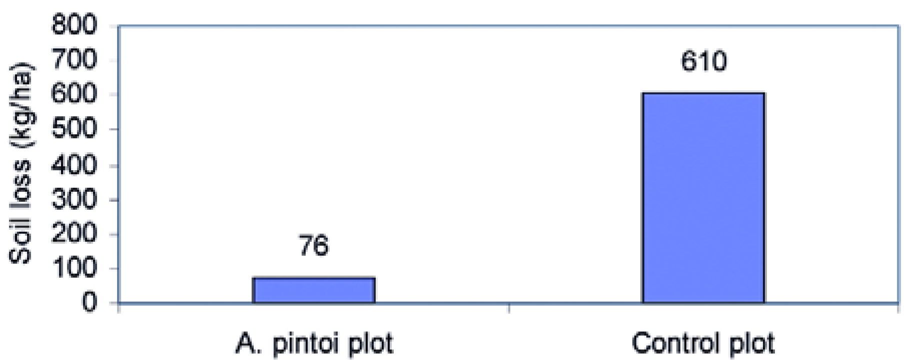

Figure 2. Comparison in soil loss between *A. pintoi* and control plots two years after introducing A. pintoi on coffee farm, based on Nov. 2003 to June 2004 measurement.

Figure 2 shown that the difference in soil loss between the *Arachis pintoi* and control plots was very significant. But as has shown by Dariah *et al*., (2005, this volume) soil loss in this research site was very low.

Tabel 4. Farmers' evaluation of soil fertility and erodibility.

Parameters	Indicators	Fertility	Erodibility
1. Slope			
• Steep	> 70%	Poor	Higher
• Gentle	<70%	Fertile	Lower
2. Texture			
• Coarse	Soils with more sand	Poor	Higher
• Fine	Soils containing high loam and silt, little sand	Fertile	Lower
3. Infiltration			
• Fast	Soils with aggregates and many pipes	Fertile	Lower
• Slow	Fine and compact soils	Poor	Higher
4. Water holding capacity			
• Greater	More organic matter	Fertile	Lower
• Lower	Little organic matter	Poor	Higher
5. Color			
• Black	High organic matter and litter, friable, porous and easy to cultivate.	Fertile	Lower
• Brown	Similar with black color, but organic matters (humus) already integrated with the soil	Fertile	Lower
• Yellow	Dry, granular/loose particles because of low cementing agents	Poor	Higher
• Red	Dry, low water holding capacity, sticky wet, compacted in dry season..	Poor	Higher
• White/Pale	Low water holding capacity and easily cause landslide.	Poor	Higher
6. Organic matter			
• Higher	Black soil, more earthworm, good tilth, and greater water holding capacity.	Fertile	Lower
• Lower	Soil color red or yellow, low water holding capacity and easily compacted	Poor	Higher
7. Hardness			
• Compact	Sticky soils, low water infiltration, soil color red or yellow, in dry season soils become broken	Poor	Higher
• Loose	Soil color black, greater infiltration rate	Fertile	Lower

Conclusions

- The present study showed that the use of *Arachis pintoi* as a cover crop for (young) coffee was able to improve soil C and N contents and reduce erosion. Despite a need to somewhat intensive weeding in the early stage of its growth, and perhaps a need to improve soil P status for less fertile soils, it can be easily integrated into coffee farms; once it is established it is adapted quite well under the high (800 m asl) elevation area like Sumberjaya, and it tolerates shading and cutting.

- Farmers were interested to test *Arachis pintoi* for improving their coffee farms because of multifunctions it promises such as: erosion control, soil fertility, fodder and/or organic matter source. It has a great potential as a cover crop and for some tree crops like coffee, it requires adaptation in weeding/cutting technique; for instance by practicing ring cutting technique prior to coffee harvest.

- Several soil indicators, such as slope degree, texture, infiltration, water holding capacity, color, organic matter and compaction could be used by local farmers to describe their soil fertility and erodibility.

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V. Delineation of Erosion Prone Areas in Sumberjaya, Lampung, Indonesia

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Abstract

In developing soil conservation measures under several conservation projects, criteria for targeting the erosion prone areas have been based on slope gradient and the nature of crop cover. Research in Sumberjaya, Lampung, Indonesia, under coffee based farming systems has revealed that soil physical properties are also of prime importance in determining soil susceptibility to erosion. Although in many of the popular erosion prediction models this has been understood, but this factor has not been fully exercised. As such, recommendation has lead to unnecessary overly interventions on some parts of landscape and negligence on other parts where interventions are really necessary. This research was aimed at providing information of 'hot spots' where attention for soil conservation interventions is necessary in the form of 'erosion prone' map under coffee-based farming systems in Sumberjaya, West Lampung, Indonesia. Previous study showed that some physical soil properties such as drainage pores and saturated hydraulic conductivity (K-sat) strongly affected soil erodibility. This provides insights to simplify assessment approach of soil susceptibility to erosion. This delineation activity included observation of mini pits and characterization of soil physical properties within land units that have been defined using topographic map, land form map, and soil map. Using existing slope and land use maps, as well as observation on soil depth, erosion prone map was developed. This map will be used for targeting priority areas for conservation; a product necessary in the on-going negotiation support system in the research area under the Community Forest (*Hutan Kemasyarakatan, HKm*) scheme.

Introduction

Many methods have been used for predicting plot scale soil loss. These include the empirical, famous and popular model of Universal Soil Loss Equation/USLE (Wischmeier and Smith, 1978) and the physical process-based model such as *Griffith University Erosion System Template*/GUEST (Rose *et al.*, 1997). Several models have also been developed to predict soil loss under catchment scale such as *Areal Non-point Sources Watershed Environment Response Simulation*/ANSWERS and *Agricultural Non-Point Source Pollution Model*/ AGNPS. However, it is often that those methods are not practicable due to many parameters involved that can not be fulfilled in most development projects. This is one of the most challenging tasks when the budget is limited or due to lack of sufficient number of trained personal in (Srinivasan, 2003). Many others studies have recently been conducted by some authors concerning erosion prediction model for ungauged watershed (for example, Sharma and Sharma, 2003; Aksoy, 2003; Santos *et al.*, 2003).

A simple method to delineate erosion hazard has been developed, which is based on the relationship between pedogenetic processes and erosion. Slope length and gradient, crop cover and management level, rainfall erosivity, and soil erodibility have long been understood by many authors as important factors in soil erosion, but recommendation at field level mostly considered slope gradient and, to a lesser extent, tree cover (Agus, 2001) because it is readily observable and the data are relatively easily available.

Soil property spatial data that enable one to calculate soil erodibility and subsequently soil erosion hazard are rare, and without this data, targeting of area for soil conservation will be inappropriate in a way that there are areas that receive too much attention while other areas that may actually need intervention are neglected.

In area of Sumberjaya, many studies have been conducted involving methods to predict erosion in both plot and catchment scales under the coffee based cropping system. Previous research results as cited by Agus *et al*. (2002) and Agus (2002) showed that coffee trees after three years old, by themselves, serve as effective soil conservation measures especially if they were planted in association with other trees in a multi-strata architecture. Furthermore, other research showed that the level of soil loss under coffee based cropping system is very site specific. Under 3 year cropping soil loss ranged from around 1 t ha^{-1} yr^{-1} to 37 t ha^{-1} yr^{-1} (Dariah *et al*., this volume; Khairiah *et al*., this volume). This comparison, based on experiment conducted under similar coffee system and slope gradient, explained that these two factors were not the most important determinant of soil erosion. Thus, soil physical properties at the research sites were evaluated and the data convincingly suggested that these properties have strong correlation with soil loss (Dariah *et al*., this volume).

The objectives of this research were to:

a. develop acceptable approach to estimate erosion hazard through characterizing properties of the soil

b. correlate selected soil properties with potential soil loss

c. provide soil erosion prone map for Sumberjaya Sub-district as a guide for soil conservation measures and to assist the local farmers and forestry services in negotiating where and what technology intervention to be implemented.

Materials and Methods

a. The Watershed Setting

This research was located in Way Besai Watershed which shares almost coincident borders with the Sub-district of Sumberjaya, West Lampung District, Lampung Province, Indonesia ($4^0$45' - $5^0$15' S and $104^0$15' - $104^0$45' E). The area map is given in Figure 1. The altitude of this area ranges from 700 to 1,700 m asl. The study area, the Way Besay Watershed, of 47,800 ha is surrounded by the mountains of Subhanallah (1,623 m asl) in the north, Sekincau (1,718 m asl) in the west, Tangkit Tebak (2,115 m asl) in the east and Tangkit Begelung (1,213 m asl) in the south.

Landscape of the study area is formed during the eruption of part of the mountainous area of Bukit Barisan. As reported by Van Bemmelen (1949), this area was situated in the ignimbrite eruption area which was called the Tuff of Lampung. The eruption occurred in relatively short period forming a variable landscape over the entire area consisted of plateau, cliff, and the hilly remnant at the center of the area.

The hilly remnant is composed of basalt and granite. The second very big eruption occurred after a decade at the Ranau lake (Van Bemmelen, 1949). Ranau lake is situated about 60 km north of the study area. Acid materials such as Dasite and Liparite from the bottom of Ranau lake erupted to the surface and covered some parts of the study area. The eruption of Sekincau mountain occurred in the quarter era to which the erupted materials flowed into western part of the study area.

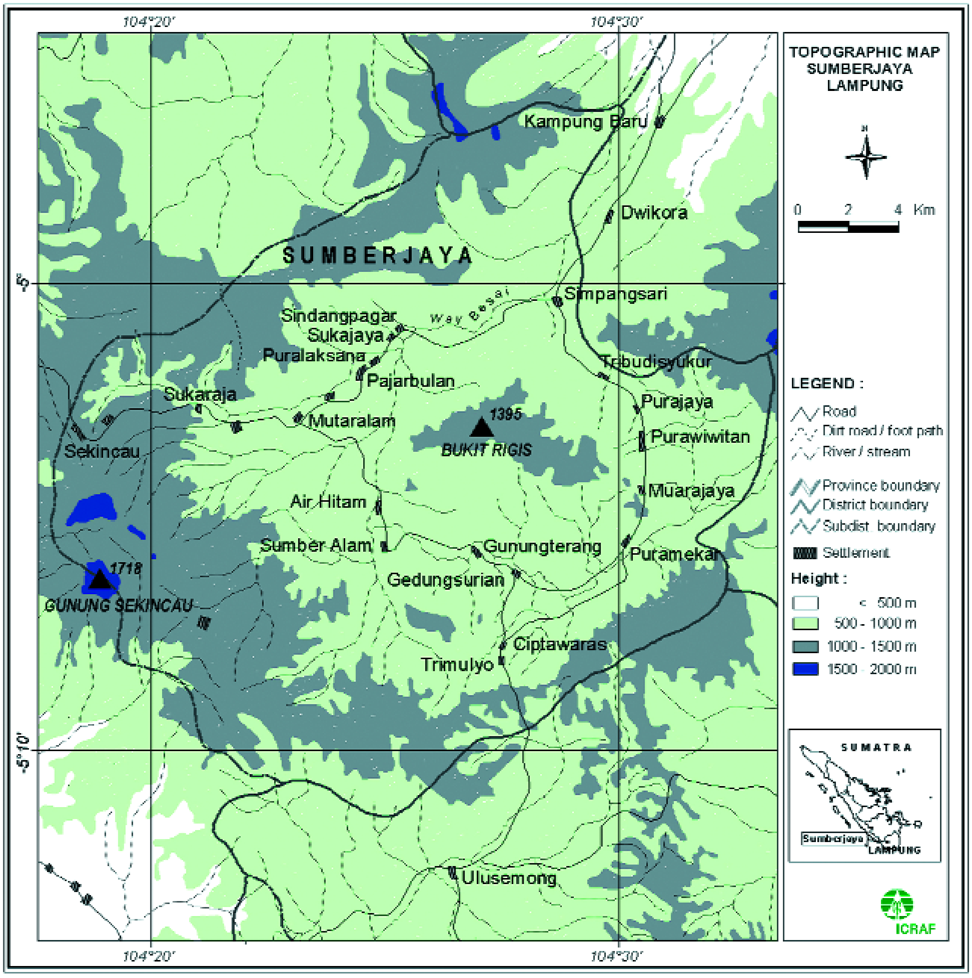


Figure 1. The area of Sumberjaya, Lampung

The Way Besai Watershed has a bowl-like or 'horse shoe'-like shape. The caldera floor is relatively flat, which is bordered by very steep wall of caldera. Part of the hilly top has not been erupted forming a hilly remnant, which then called as the Rigis Hill. Other hills were of basaltic and granite materials.

According to Koppen, Sumberjaya belongs to the climate type Af or type A as classified by Schmidt-Ferguson (1951), with no dry months. According to Oldeman *et al.* (1979), this area belongs to B1 zone with 7 wet months (rainfall > 200 mm) and only 1 dry month (rainfall < 100 mm). The mean annual rainfall is 2,614 mm yr^{-1} and mean daily temperature is 21.2^{0}C.

b. Survey and Mapping Techniques

Field survey and laboratory measurements were done to characterize soil physical properties and relating those to susceptibility to erosion. Four thematic maps i.e. topographic map, landform map, soil map and land cover map at uniform scale of 1 : 50,000 were used to produce a land unit map of Sumberjaya area. A land unit map was produced *based on an* overlay of the slope map and landform map as the basis for land units, and the land units were further subdivided into smaller land units on the basis of differences in land cover. The topographic maps at scale of 1: 50,000 was used to determine the slope length. Slopes were classified into 5 different classes (Table 1).

Table 1. Slope Classes of Sumberjaya Sub-district.

Slope class	Class interval (%)	Description	Distance between contour lines (mm)*
I	0 - 8	Flat to gentle sloping	> 6.2
II	8 - 15	Moderately sloping	3.3 - 6.2
III	15 - 25	Strongly sloping	2 - 3.3
IV	25 - 40	Moderately steep to steep	1.2 - 2
V	> 40	Very steep	< 1.2

* Map scale 1:50,000 and contour interval 25 m

Landform classes were described by characteristic assemblages of slope, relief, drainage patterns and rock types. These were obtained from soil and geological maps, and/or field knowledge.

The land units were used as the basis for all further assessment concerning land resource factors. At each different land unit, soil samples were taken at 10, 20 and 30 cm depths, including core and bulk samples. The collection of soil samples was carried out using systematic sampling technique.

Soil pits *were* dug *at* representative *points* at each land unit to characterize morphogenesis of soil, observe soil depth, and to take soil samples. Soil physical properties including particle size distribution, structure, and saturated hydraulic conductivity (K-sat) were analyzed in the laboratory using the core and bulk samples. Other analyzed soil physical properties such us bulk density, total soil pores, pore size distribution and aggregate stability index were required to produce delineation of erosion prone areas of Sumberjaya more comprehensively.

To choose the most determinant parameter to potential soil loss, a principal component analysis (PCA) was done. The variables which passed from the screening of PCA were considered in the delineation of erosion prone areas. To relate the soil variables with the potential soil loss, data of soil loss from previous study were used.

To delineate the erosion prone, most determinant soil properties and slope were overlaid. Three classes of erosion prone were introduced by considering those three parameters including low, medium and high levels. The overall framework to produce erosion prone map is presented in Figure 2.

Results and discussion

Landform

Using aerial photo interpretation and combined with ground check, the study area can be classified into 2 major landform groups including (a) Alluvial and (b) Volcanoes. Alluvial landform was generated through the fluvial process of materials from the river. This is the major landform of the river sides, which is well known as the floodplain and the stream channels. The alluvial plain covered an area of 1,127 ha (2.52%). This landform generated subgroups of meandered river plain (A 1.1.2) and the stream channel (A 1.5).

The volcanoes were formed through volcanic activity, from which the materials were generated. This landform included the young, which has typical cone like shape (for instance Mount Sekincau), as well as the old volcanoes. This area was very commonly composed of basalt and granite.

The volcanic landform dominated the study area covering an area of 43,637 ha (97.48%). Nine sub groups have been generated from this landform including upper slope volcano (V.1.1.2), middle slope volcano (V.1.1.3.), lower slope volcano (V.1.1.4), old volcano plain, old hilly volcano (V.3.2), old mountainous volcano (V 3.3), volcanic intrusion (V.4), caldera walls (V.11.2.1) and caldera floor (V.11.2.2) as presented in Table 2.

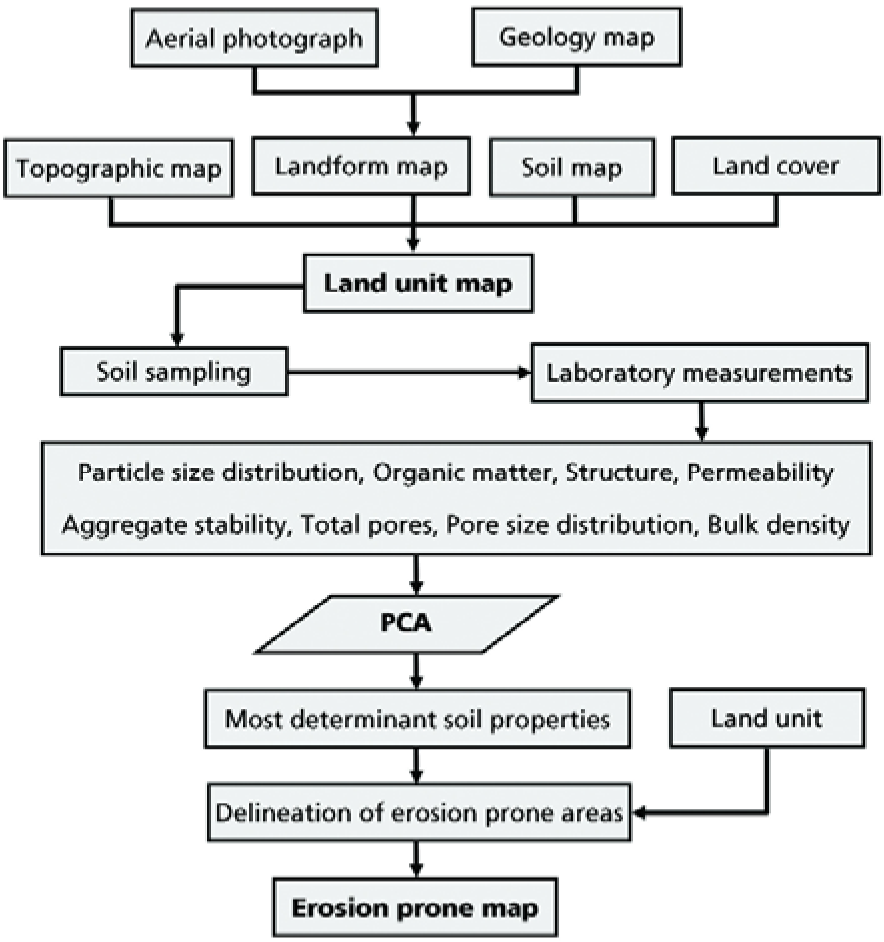


Figure 2. Framework to produce erosion prone map

Meandered floodplain, the stream channel, the caldera floor had relatively flat to gentle slopes (< 15%), while upper slope volcano, old mountainous volcano, and caldera wall are had the steep to extremely steep slopes (> 40%). Middle slope volcano, old hilly volcano and volcanic intrusion have moderately steep to steep slopes (15-40%). The lower slope volcano and old volcanic plain have gentle to undulating slopes (3-15%).

As it has been indicated from the interpretation of aerial photo and Landsat TM 7 image and field observation, the area of Sumberjaya was formed by the volcanic activities. The processes involved in the formation were eruption, intrusion, and secondary geomorphic process, which has generated a specific landform.

As the center of eruption of Lampung tuff, the area possessed the original materials and specific landform such as depression, cliff, hilly remnants (the Rigis Hill) and the recent formation through the subsequent eruption process. On the top of the cliff was the hilly and mountainous formation of Bukit Barisan and the recent formation of volcano activity such as mount of Sekincau.

Table 2. Landform composition in the study area

Symbols	Description	Area	
		Ha	%
A.1.1.2	Meandered river plain	691	1.54
A.1.5	Stream channel	436	0.97
V.1.1.3	Upper slope volcano	1,596	3.57
V.1.1.4	Middle slope volcano	3,285	7.34
V.1.1.5	Lower slope volcano	3,044	6.80
V.3.1	Old volcano plain	5,425	12.12
V.3.2	Old hilly volcano	5,468	12.21
V.3.3	Old mountainous volcano	10,081	22.52
V.4	Volcanic intrusion	1,033	2.31
V.11.2.1	Caldera walls	5,786	12.92
V.11.2.2	Caldera floor	7,921	17.70
Total		44,764	100.00

Table 3. Slope steepness of the Sumberjaya area

Symbols	Description	Slope (%)	Area	
			Ha	%
f	Flat	< 1	1,105	2.47
n	Nearly flat	1-3	1,808	4.04
gs	Gently slope	3-8	6,561	14.66
s	Sloping	8-15	5,046	11.27
ms	Moderately steep	15-25	4,690	10.48
st	Steep	25-40	10,258	22.92
vst	Very steep	40-75	7,911	17.67
a	Extremely steep, abrupt	> 75	7,385	16.50
Total			44,764	100.00

Landform having a single slope is dominated by the unconsolidated materials such volcanic ash. The light material was easily transported and deposited over the land surface. Soils developed from volcanic ash materials formed specific characteristics such as Typic Hapludands. This soil distributed over the area of caldera floor, upper slope volcano,

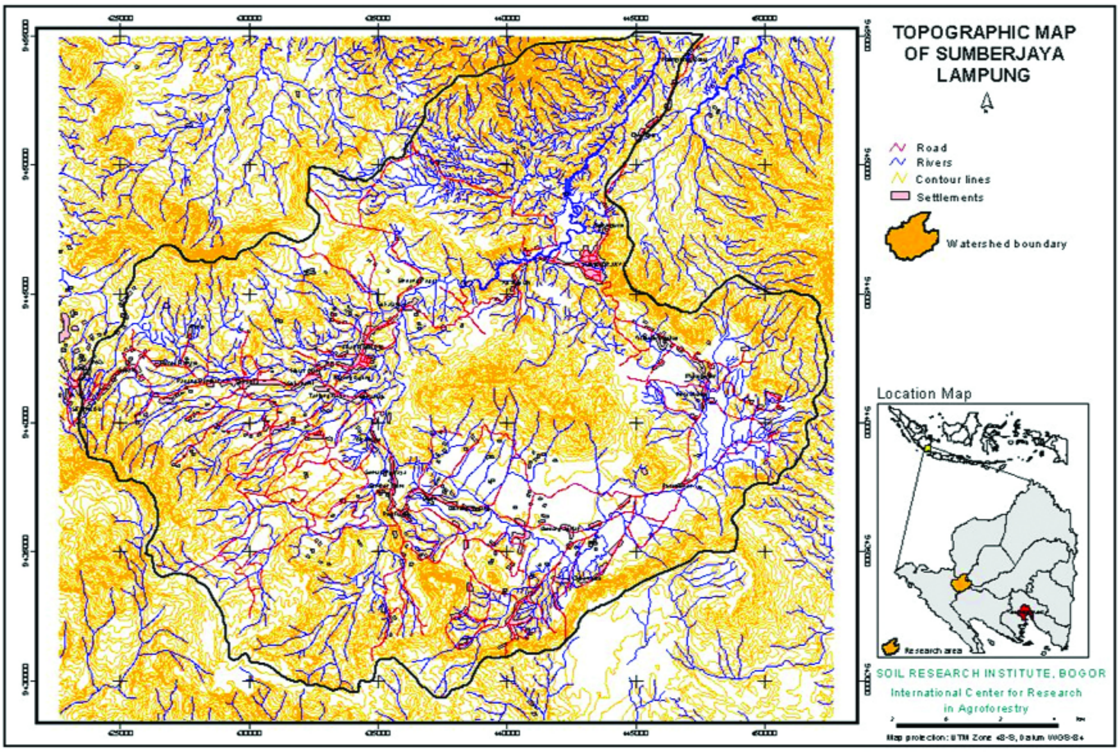


Figure 3. Topographic map of the Sumberjaya area, Lampung

middle slope volcano and lower slope volcano including M. Sekincau and M. Subhanallah. Caldera walls with a single slope is generally dominated by consolidated materials such as tuff and lava, which are locally covered by unconsolidated materials including Typic Dystrudepts, Andic Dystrudepts, and Typic Hapludands.

Landform with complex slopes is dominated by consolidated materials such as tuff and lava. Landform of the Ranau tuff has a specific physical characteristic, where the soil has relatively high clay content with an obvious argillic horizon. This characteristics have formed Typic Hapludults and Typic Paleudults. Landform generated from tuff and lava materials covered by thick volcanic ash and formed Andic Dystrudepts, while that covered by thin volcanic ash formed Typic/Humic Dystrudepts and Ultic Hapludands.

Parent materials and Soil Classification

Parent material is the major factor affecting soil formation in the area of Sumberjaya. Usually, the soil characteristics can be detected from the type of parent materials from which the soils are formed. There were nine parent materials identified to form the soils of this area (Table 4). The tuff and volcanic materials had the largest distribution among the other materials, which comprise an area of 8,688 ha (19.41%). The spatial distribution of parent materials is presented in Figure 4.

Soil physical characteristics are very much determined by the parent materials and the time of soil formation, which were indicated in the soil classification. The field survey of soil morphology and the laboratory analyses shown that there were three soil orders including Inceptisols, Andisols and Ultisols, which generated 11 soil sub groups in this area (Table 4).

a. Inceptisols

The presence of cambic horizon and the feature of soil structure are the keys to classifying soils into Inceptisols as it has been found as well in the area of Sumberjaya. This soil order distributed over various landforms of flat, hilly, volcanic intrusion and caldera walls with dominant materials of tuff and granite. The aquic regime soils are the soils of the suborder Aquepts, which distributed along the river plain with dominant paddy fields. This soil included Typic Epiaquepts. In dry land area, most of the soils belong to the suborder Udepts, where the coffee plantation has been dominated. This suborder generated three subgroups of soils including Andic Dystrudepts, Humic Dystrudepts, and Typic Dystrudepts.

Table 4. Parent materials of the major soils in Sumberjaya area

Symbols	Description	Area	
		Ha	%
Al	Alluvium	1,127	2.52
kv	Colluvium ash and volcanic tuff	7,921	17.70
av(s)	Volcanic ash (M. Sekincau)	5,387	12.03
av(b)	Volcanic ash (M. Subhanallah)	2,476	5.53
tr	Ranau tuff	2,691	6.01
tv/av	Volcanic tuff covered by volcanic ash	3,577	7.99
tlv(g)	Tuff and old volcanic lava (Rigis hill)	3,765	8.41
tl(g)/av	Tuff and old volcanic lava (Rigis hill) covered by volcanic ash	648	1.45
	Tuff and old volcanic lava covered by volcanic ash		
tlv/av	Tuff and old volcanic	7,451	16.64
tlv	Basalt	8,688	19.41
bs	Granite	436	0.97
gr		597	1.33
Total		44,764	100.00

1. Typic Epiaquepts

This soil was developed from old tuff and volcanic materials and Ranau tuff, which has distributed over the area of caldera walls, old volcanic plain and old volcanic hilly. It has cambic horizon and having oxidation and reduction processes at the deeper horizon (> 100 cm) with poor drainage condition. The soil color was grayish dark brown, silty clay loam texture, soft consistency, granular structure, and pH of 5.5-6.0. .

2. Andic Dystrudepts

This soil developed from tuff and old volcanic materials which was covered by volcanic ash (for instance Rigis). It has cambic horizon with relatively low base saturation (<25%), bulk density of < 1.0 $g.cm^{-3}$ at one third atm, and Al + 1/2 Fe (by Ammonium oxalate) range from 1 to 2 %, deep soil (>100 cm), and good drainage condition. The soil color is dark brown, silty clay loam texture, soft consistency, granular structure, and pH of 4.0-4.2.

3. Humic Dystrudepts

This soil developed from the parent materials of volcanic tuff. It was covered by volcanic ash, which distributed in the area of old volcanic plain. Molic epipedon and cambic sub horizon has been used to characterize the soil to be Humic Dystrudepts and it has also been found in the area of Sumberjaya. The soil has low base saturation (< 25%), deep soil (> 100

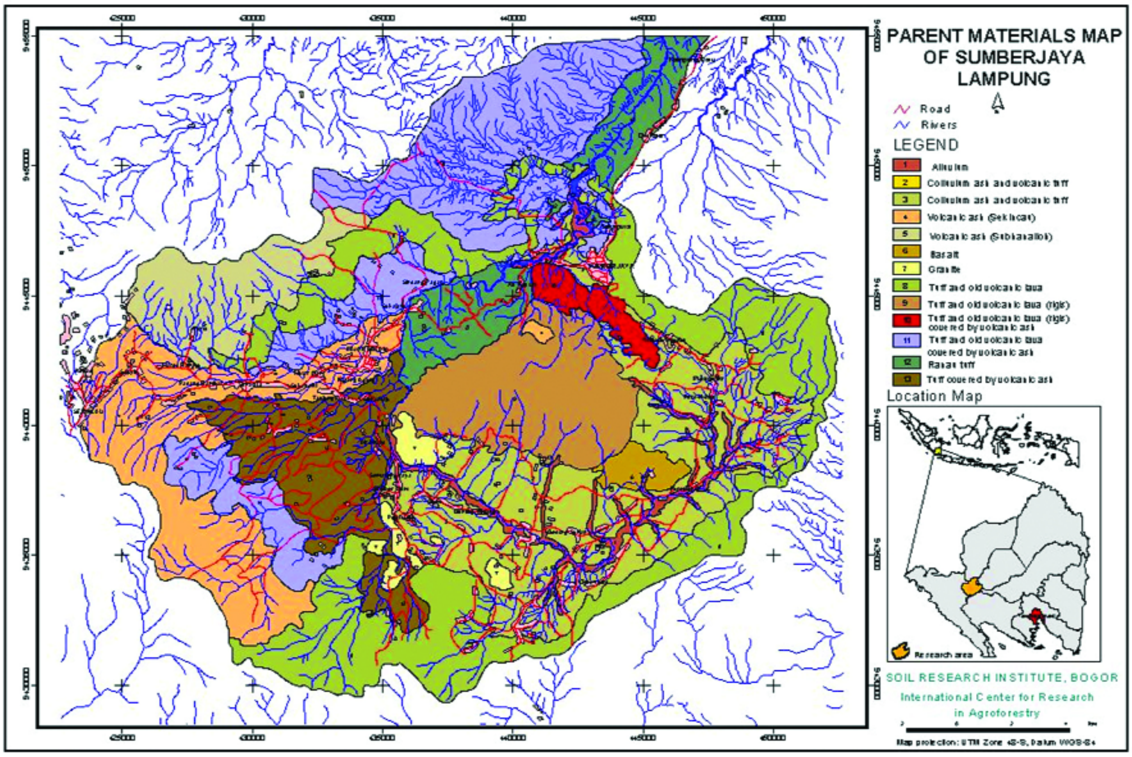


Figure 4. Parent materials map of the Sumberjaya area, Lampung

cm) and good drainage condition. The upper soil horizon (0-30 cm depth) has reddish dark brown color, soft consistency, granular structure, and pH of 4.0-4.2, while the sub soil horizon (30-60 cm depth) has yellowish red color, clay loam texture, slightly hard consistency, sub angular blocky structure, and pH of 4.2-4.5.

4. Typic Dystrudepts

This soil developed from the parent materials of old volcanic tuff and lava and granite. In the Sumberjaya area, this soil distributed in the area of old volcanic hill, caldera walls and volcanic intrusion. It has cambic horizon with relatively low base saturation (<25%), deep soil (> 100 cm) and good drainage condition. The upper soil horizon (0-30 cm depth) is brown, soft consistency, granular structure, and pH 4.0-4.2, while the sub soil horizon (30-60 cm depth) has yellowish red to red color, clay loam, slightly hard consistency, sub angular blocky structure, and pH 4.2-4.5.

b. Andisols

Andisols were developed from the parent materials rich in volcanic ash or volcanic tuff and lava, which has been characterized by andic properties of > 36 cm thickness of the 0-60 cm soil profile. In the field, this property can be indicated by using pH NaF, volcanic glass, fine texture, and the smeary property. The upper soil horizon has dark color and the soil is thick, while the subsoil horizon has yellowish brown, very deep, silty loam, smeary, light weight, and very soft. The andic properties of soils in Sumberjaya has been characterized as having > 85% phosphate retention, > 2 % of Al + 1/2Fe content (using ammonium oxalate), and bulk density of < 0.9 g.cm-3. The typical profile of this soil is given in Annex 1.

Andisols developed under the aquic regime has generated aquands suborder, which distributed in the area of paddy field. This suborder generated soil subgroups of Typic Epiaquands and Typic Endoaquands. In dry land this soil has been found as Udands.

1. Typic Epiaquands

In the area of Sumberjaya, this soil developed from the parent materials of alluvium and colluvium of volcanic ash, which distributed in the stream channel area, caldera floor, middle and lower slope volcano. The oxidation and reduction processes occurred, the soil was deep (> 100 cm) and have a poor drainage condition. The upper soil horizon (0-30 cm depth) was grayish dark brown, silty clay texture, soft consistency, granular structure, and pH of 4.0-4.2, while the sub soil horizon (30-60 cm depth) is grayish dark brown, clay loam, slightly hard consistency, sub angular blocky structure, and pH of 5.5-6.0.

2. Ultic Hapludands

This soil developed from the parent materials of old volcanic tuff and lava covered by volcanic ash, which distributed in the old mountainous volcano area. It has argilic horizon, deep soil (> 100 cm) and slightly good to good drainage condition. The upper soil horizon (0-30 cm depth) was brown, silty clay loam, soft consistency, granular structure, and pH 4.0-4.2, while the sub soil horizon (30-60 cm depth) has yellowish red color, clay texture, hard consistency, sub angular blocky structure, and pH 4.2-4.5.

3. Typic Hapludands

Typic hapludands in the Sumberjaya area developed from the materials of volcanic ash. This soil distributed in upper slope of volcano, middle slope volcano, lower slope volcano, and caldera floor. It is a deep soil (> 100 cm) with good drainage condition. The upper soil horizon (0-30 cm depth) was black to dark brown, silty clay loam, soft consistency, granular structure, and pH 4.0-4.2, while the sub soil horizon (30-60 cm depth) was dark brown to brown color, clay loam, slightly hard consistency, sub angular blocky structure, and pH 4.2-4.5.

c. Ultisols

The soil developed with typical characteristics of the presence of clay skin as resulted by illuviation in the B horizon (argilic horizon). This soil distributed in old plain volcano, old hilly volcano, and old mountainous volcano. In the field, the argilic feature can be indicated by clay skin and hard soil consistency.

Ultisols in dry land of Sumberjaya area included Humults and Udults suborder. The subgroup soils, generated from humults order, wasTypic Haplohumults, while Udults generated Typic Paleudults and Typic Hapludults.

1. Typic Haplohumults

The soil was formed from the parent materials of old volcanic tuff and lava covered by volcanic ash and basalt. The soil distributed in old plain volcano, old hilly volcano, old mountainous volcano and volcanic intrusion areas. The upper soil layer (0-15 cm) has 0.9% organic C and the soil was characterized by the presence of argilic horizon. It is deep (> 100 cm) with slightly good to good drainage condition. The upper soil horizon (0-30 cm depth) is dark brown, silty clay loam, soft consistency, granular structure, and pH 4.0-4.2, while the sub soil horizon (30-60 cm depth) has yellowish red to red color, clay, hard consistency, sub angular blocky structure, and pH 4.2-4.5.

2. Typic Paleudults

This soil developed from the materials of the Ranau tuff, which has distributed in old hilly volcano. Argilic horizon has been characteristic of this soil profile and it has deep profile (> 150 cm) with slightly good to good drainage condition. The upper soil horizon (0-30 cm depth) has brown color, silty clay loam, soft consistency, granular structure, and pH 4.0-4.2, while the sub soil horizon (30-60 cm depth) is reddish brown, clay, hard consistency, sub angular blocky structure, and pH 4.2-4.5.

3. Typic Hapludults

Typic Hapludults of the area of Sumberjaya were developed from the parent materials of the Ranau tuff and old volcano tuff and lava. As other sub group, this soil has argillic horizon and deep soil (> 100 cm) with slightly good to good drainage condition. This soil were distributed in old hilly volcano and old mountainous volcano. The upper soil horizon (0-30 cm depth) has dark brown color, silty clay loam, soft consistency, granular structure, and pH of 4.0-4.2, while the sub soil horizon (30-60 cm depth) is reddish brown, clay, hard consistency, sub angular blocky structure, and pH of 4.2-4.5.

Soil properties

Soil properties varied with parent materials in which the soils originated from the volcanic ash materials coincided with low erosion hazard, while the soils derived from the tuff materials mostly susceptible to erosion.

Soils derived from volcanic ash have highest C-organic (6.06%) with low bulk density (0.72 g cm^{-3}) and high aggregate stability index of 105. Soils generated from basalts and granite had lower aggregate stability index (86) (Table 5).

From the PCA (Figure 5) it was identified that the saturated hydraulic conductivity (permeability) was the most important soil physical variable that affected erosion proneness in the study area. Other important soil characteristic in this respect was organic matter content.

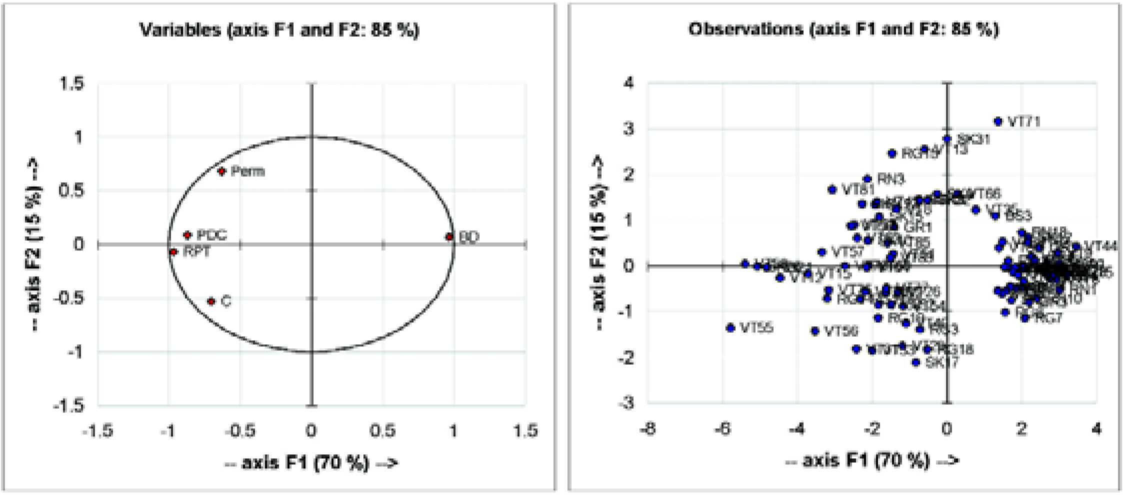
Land cover

Coffee plantation is the major land use in the study area. Other land uses were also identified including forest and sawahs (lowland rice fields). The distribution of land covers over the entire area is presented in Figure 6. Land cover by crop canopy varied very widely depanding on the level of coffee growth and the farming systems (Table 6). Land cover of 25-50 % was the largest. The area having > 75 % land cover was still large reflecting good soil protection, in general.

As far as the erosion is concerned, land cover plays an important role to intercept rainfall and protect the surface soil aggregates from detachment of high energy rain drops. This is the reason why the land cover is integrated into the procedure to delineate erosion prone over the study area.

Table 5. Bulk density, aggregate stability index, Permeability and C-organic of soils with different materials

Parent materials	Bulk density (g cm^{-3})	Aggregate stability index	Permeability (cm hr^{-1})	C-organic (%)
Volcanic ash	0.72	105	12.4	6.1
Tuff and lava	0.93	101	7.4	3.3
Basalts	1.04	102	8.1	2.2
Granite	0.95	86	6.2	2.6



Legend:
Perm = permeability (saturated hydraulic conductivity); PDC = Quick drainage pores; RPT = Total pore space; BD = Bulk density; C = Organic carbon.
VTi = indicate pints of observation

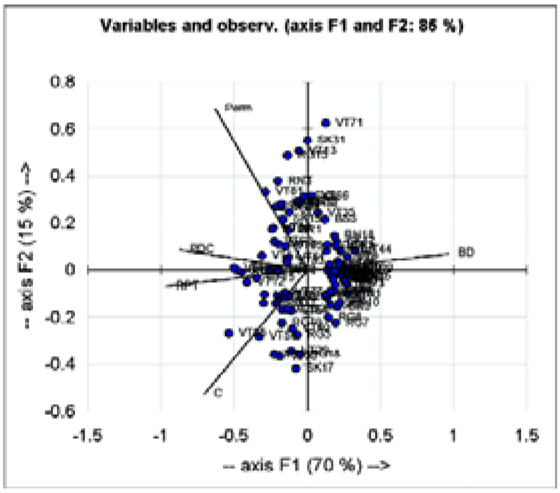


Figure 5. Results of principal component analysis of several soil properties in relation to erosion

Erosion susceptibility map

The erosion susceptibility/erosion prone map was based on delineation of the potential erosion into 4 classes i.e. negligible, low (< 2 Mg ha^{-1} yr^{-1}), medium (2-10 Mg ha^{-1} yr^{-1}) and high (> 10 Mg ha^{-1} yr^{-1}). The classes (low, medium and high) were derived from the PCA analysis and the analysis and interpretation of the landform (for the 'negligible' class). The distribution of the erosion prone area is presented in Table 7 and depicted in Figure 7. About 37% of the area is susceptible to erosion, 29% with medium erosion rate and 30% with low erosion rate. Only about 4% is the area with negligible erosion level.

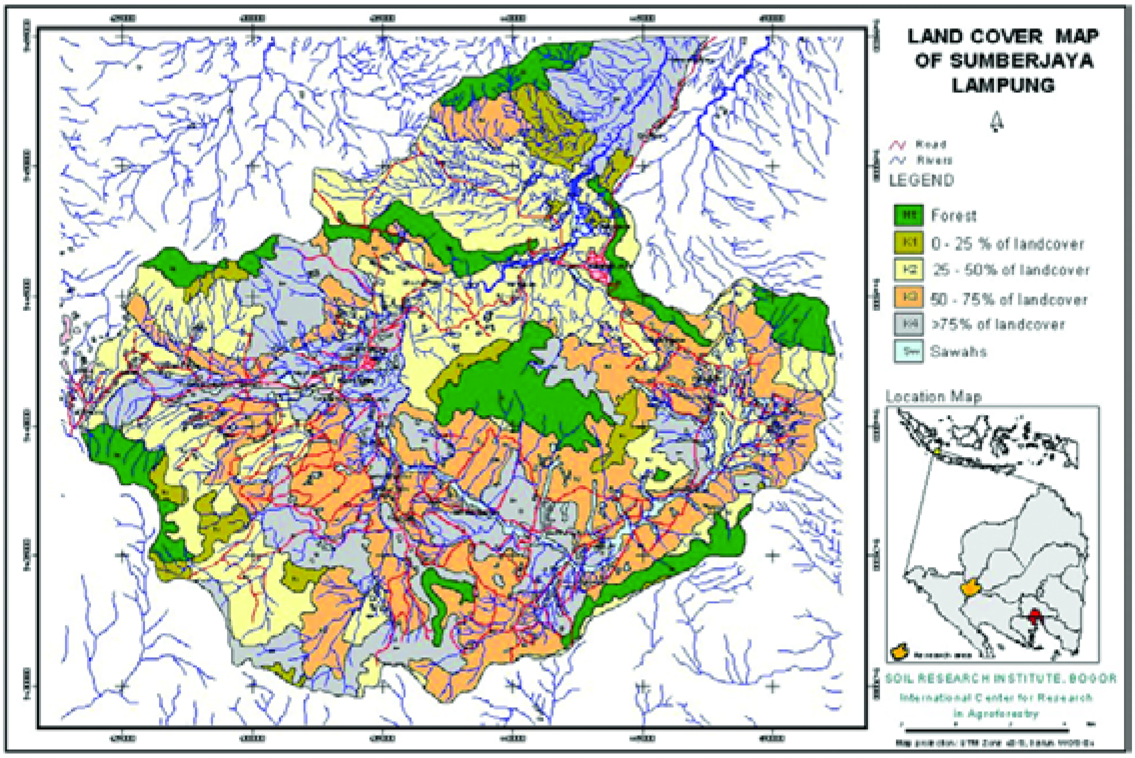


Figure 6. Land cover map of the Sumberjaya area, Lampung

Table 6. Distribution of land covers in the Sumberjaya, lampung.

Symbols	Description	Area	
		Ha	%
Ht	Forest	5,057	11.3
K1	0-25% of land cover	1,999	4.5
K2	25-50% of land cover	13,251	29.6
K3	50-75% of land cover	12,050	26.9
K4	> 75% of land cover	10,313	23.6
Sw	Sawahs	1,840	4.1
Total		44,764	100

Table 7. The distribution of erosion prone classes of Sumberjaya Sub-district, Lampung

Erosion rate (Mg ha^{-1} yr^{-1})	Description	Area	
		Ha	%
0	Negligible	1,840	4.11
< 2	Low	13,508	30.18
2-10	Medium	12,838	28.68
> 10	High	16,578	37.03
Total		44,764	100.00

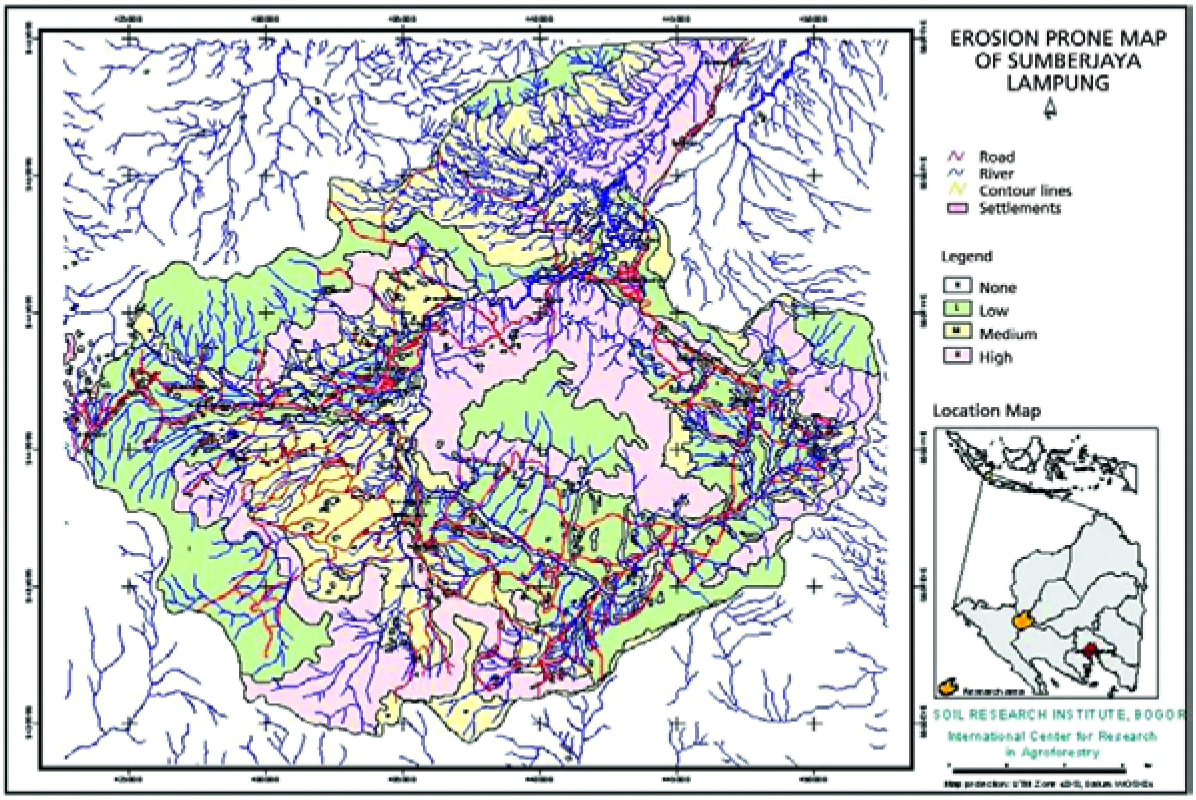


Figure 7. Erosion susceptibility map of the Sumberjaya area, Lampung

Conclusions

- For the Sumberjaya case, it appears that the erodibility "K" could not sufficiently explain the soil susceptibility to erosion and thus, a few key soil physical properties were selected to meet this purpose.
- Soil physical properties are highly influenced by pedogenetic features and this knowledge guided us for a simpler procedure to delineate erosion prone areas compared to conventional technique.
- About 37% of the Sumberjaya area has a high (> 10 Mg ha^{-1} yr^{-1}), 29% medium (2-10 Mg ha^{-1} yr^{-1}), 30% low (< 2 Mg ha^{-1} yr^{-1}) erosion rate and 4% with negligible erosion rates. This delineation could be used as a guide to set the priority areas for soil conservation intervention.

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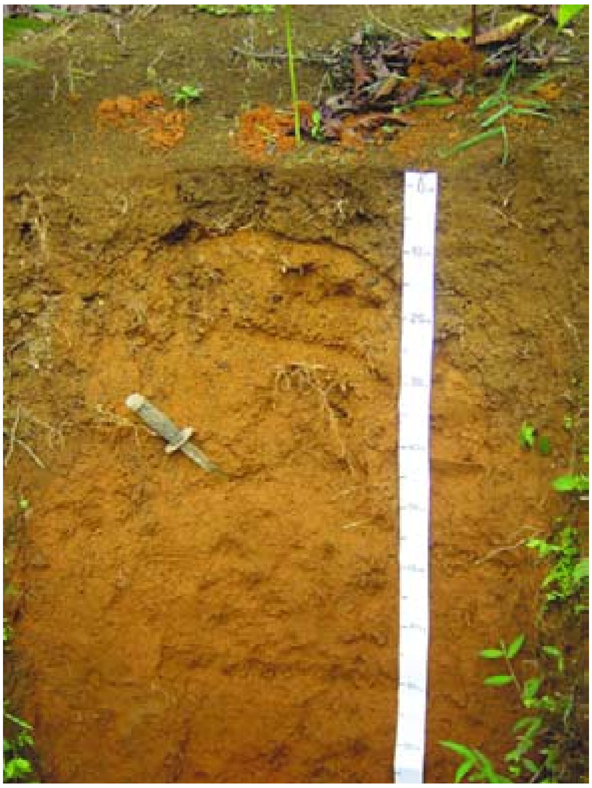
Annex 1. Soil profile of Sekincau (volcanic ash, left) and Laksana (tuff and volcanic lava, right)



No obs. TB 2 (Sekincau)

Soil Classification
USDA (1999): Typic Hapludand
Parent material: Volcanic ash of Sekincau
Physiographi/Landform: Volcanic plain
Slope: Moderately sloping (single slope)
Drainage: Good
Land Use: Coffee tree > 75% coverage
Village: Dusun Tambak Jaya

No obs. TB 5 (Laksana)

Soil Classification
USDA (1999): Andic Dystrudepts
Parent material: Tuff and old volcanic lava (Rigis hill) covered by volcanic ash
Physiographi/Landform: Volkanic hill
Slope: Flat to gently sloping (single slope)
Drainage: Good
Land Use: Coffee tree 25-50% coverage
Village: Dusun Simpangsari

VI. Runoff and Sediment Yield from Coffee Micro-Catchment Under Humid Tropical Climate of Lampung, Indonesia

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Abstract

Anthropogenic activities such as path and road constructions, may affect the measured soil loss and sediment yield. Runoff and sediment yield from a micro-catchment dominated by coffee (*Coffea robusta*) was investigated from 2001-2004. The micro- catchment is named "Saino" catchment, having an area of 1.86 ha and located in the Sumberjaya Sub-district, West Lampung District, Sumatra, Indonesia. Sediment yield increased sharply from 10 Mg ha^{-1} to 59 Mg ha^{-1} in the second year, and 140 Mg ha^{-1} in the third year. Monthly sediment yield data showed coincidence of sediment yield increase with farm footpath 'improvement' involving cutting of the original slope and accumulation of the loose soil clods downslope of the road. This path cut process exposed the unprotected and loose soil clods to the raindrops and runoff water and thus induced accelerated transport to the stream. The ratio between maximum and minimum discharge was very high (>1000) due to the small size of the catchment, very steep slope, catchment's shape and the short distance of the traveling runoff water in the catchment. The runoff ratio which was calculated based on quick flow/effective rainfall was about 13% on average, with the maximum value of 84%. The water budget calcaultion showed that the average storage capacity, i.e. percolating water that was not captured at the measuring flume, was 1.05 mm day^{-1}.

Keywords: catchment, coffee, sediment yield, runoff

Introduction

The mean yearly rainfall which is around 2500 mm, soil susceptibility to erosion, as well as the clean-weeding management in the coffee areas are considered as the main erosion factors in the humid tropical coffee areas of West Lampung, Sumatra, Indonesia. The rapid change of land use from forest to agriculture and from non intensive to very intensive agriculture may accelerate soil erosion. Other activities such as road construction, especially if it is done near the stream, may escalate the measured sediment in the stream.

In 1970 forest occupied 57% of Way Besai, a 54,000 ha watershed in which the Saino micro-catchment exists. Forest area decreased to 21% in 1990 and to about 13% in 2000. On the other hand, small holder coffee (*Coffea robusta*) plantations increased from 0% in 1970 to 42% in 1990 and to about 70% in 2002 (Syam *et al.*, 1997; Dinata, 2002). This process was continued, except for a small scale intercrop horticultural crop planting, due to very low price of coffee bean since 2001.

Although the effect of forest conversion to stormflow is still a controversial issue (Bonell, 1993), the change of land use and management practices may effect the outflow of sediment yield from the catchments. Erskine *et al.* (2002) showed that the sediment yields from forest/woodland increased by 1.07 times under pasture and 2.29 times under cultivation. Nelson and Booth (2002) showed that human activity in the watershed, particularly urban development, has caused an increase of nearly 50% in the annual sediment yield.

The availability of hydrological data including rainfall, streamflow and sediment concentration from coffee areas is rare for the humid tropics. Afandi *et al.* (2002) reported that the average soil loss from clean-weeded coffee areas, based on erosion plot measurement, was low, about 12 Mg ha^{-1} yr^{-1}. However, it is difficult to extrapolate the result of plot scale measurement to catchment scale owing to the very complex process of sediment transfer in the latter. The existence of vegetative filter as "temporary sediment sink" makes the relationship between runoff and sediment yield and the simple descriptor of catchment uncertain. Vegetative filter strips has been proved to effectively entrap sediment, while the "hot spot " such as bare road, footpath, land slide, serve as erosion sources. The transport of sediment is also determined by the existence of "temporary sediment sink", such as paddy field areas which usually located at the valley bottom. Paddy fields entrap the sediment from the adjacent areas temporary and may release it if there is enough energy to carry it.

Ceballos and Schnabel (1998) showed that valley bottom has great influence on hydrological response of the catchment, and made difficulty in estimating the importance of rainfall factors, while the experiment of Braud et al. (2001) in Andes region showed difficulty in relating runoff volume and sediment yield to simple descriptors of the catchments such as the average slope and/or the average vegetation cover.

This research emphasizes the measurement of runoff and sediment yield in micro-catchment dominated by coffee trees with paddy field at the valley bottom in Lampung, Sumatra, Indonesia.

Material and Methods

Description of the study area

The study was conducted from October 2001 until June 2004 in Bodong Jaya sub village, Sukajaya village, Sumber Jaya Sub-district, West Lampung District (Figure 1). The location is about 187 km northwest from the capital of Lampung Province, Bandar Lampung. The geographic position is approximately $105^0 26'$ E and $05^0 02'$ S.

Runoff and sediment yield data were collected from Saino micro-catchment having an area of 1.86 ha. The catchment is dominated by steep slope, with average of about 55%. The highest altitude in the catchment was 920 m and the lowest altitude was 864 m asl.

The length of the stream at Saino catchment was 88 m. Although the catchment is very small, the streamflow never dries during normal dry season. Coffee was planted about 8 years prior to the initiation of this study. Paddy field was developed in January 2002 at the valley bottom and the creek was stretching in the middle of paddy field areas. Before the paddy field was created, the areas were fully covered by grass with no distinct channel. The land use was dominated by coffee tree with various type of management depended on the land ownership. Each farmer managed their land according to their experience. The main land use type is shown in Table 1 and Fig 2.

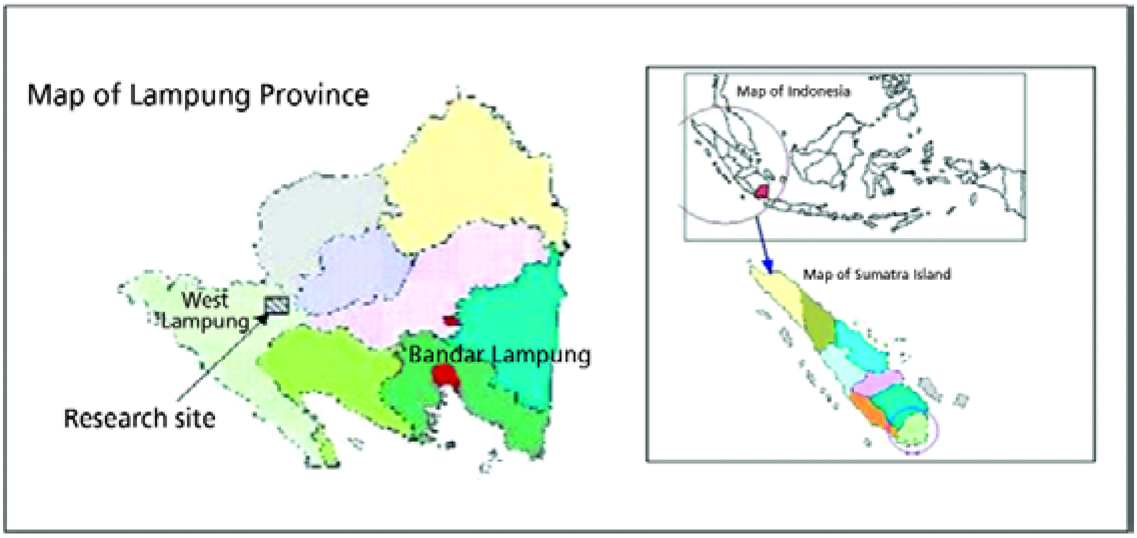

Figure 1. Situation map of the research site

Table 1. Land use type in Saino Catchment

No	Land use type	area		dominant vegetation	Second dominant vegetation	Other vegetation
		ha	%			
1	Mixed garden	0.26	13.93	*Ceiba pentandra* (randu), *coffea robusta*	*Mengifera indica*	*Musa* spp, *Sacharum officinarum*,*Cocos nucifera*, *Nephelium longan*, Coffea sp (liberica)
2	Coffee with *Glyricidea sepium*	0.39	20.80	*Coffea robusta*	*Gliricidia sepium*	*Artocorpus heterophylus* (nangka), *Citrus nobilis*, *Erythrina subumbrans*, *Tectona glandis* (jati), *Mengifera indica*, *Durio zibethinus*, *Musa* spp, *Ananas comusus*
3	Rice field	0.02	1.2	*Oryza sativa*	-	Grass
4	Coffee with horticulture crop	0.19	10.22	*Coffea robusta*	tomato	Long bean
5	Shrub	0.118	6.56	*Imperata cylindrica*, *Chromolaena odorota*	*Musa* spp.	*Coffea* sp (*robusta*)
6	Coffee in monoculture System	0.73	39.31	*Coffea robusta*		*Eugenia aromatica*, *Ceiba petandra*, *Cinnamomum burmanii*, *Musa* spp., *Artocarpus heterophyillus*, *Syzyglum* sp., *Thea sinensis*
	Total	1.86	100			

The monoculture coffee at Saino catchment, which occupied about 39% of the total area, was dominated by old (>8 years) coffee tree with thick litter covers on the soil surface, and the weeding was done not so intensively because the thick litter prevented the growing of the weeds. A small landslide occurred downslope of the mixed-garden was deposited at bottom of the valley, and this areas were planted by young coffee. The clean-weeded management was done for the young coffee to prevent the competition between weeds and the crops, because several horticultural crops were planted among the coffee trees.

The research site was situated at Recent Volcanic Formation in the Holocene age. The materials of the formation consist of andesitic to basaltic breccia, lava, and tuff (Amin *et al.*, 1994). According to the Soil Taxonomy Classification (Soil Survey Staff, 1998), the soil was dominated by *Vertic Dystrudepts*. This soil is dominated by clay fraction in all depths, high exchangeable Al, medium organic carbon, acid to very acid, high (>55%) total porosity, and low (<1.0) bulk density.

Rainfall and Streamflow

The amount of rainfall was observed using manual and automatic "pulse counter type" rain gauges. The effective rainfall was considered as the amount of rainfall that occurred after the beginning of direct runoff.

Parshall-flumes (Figure 3) were set up at the outlet of micro catchment to monitor the streamflow leaving the cacthment. The throat width of Parshal flume was 36 cm, and the length was 120 cm. The Parshall flume was calibrated using the floating method during rainfall event and the volumetric method for low streamflow. The relationship between water depth and streamflow (discharge rating curve) was calculated using the power regression, and the result was used as the basic of streamflow calculation. The water depth in Parshall flume was monitored using an automatic water level recorder (AWLR, Figure 3), which was installed near the Parshall flume; the chart of the AWLR was changed daily. Based on the rating curve derived, the stream flow was calculated.

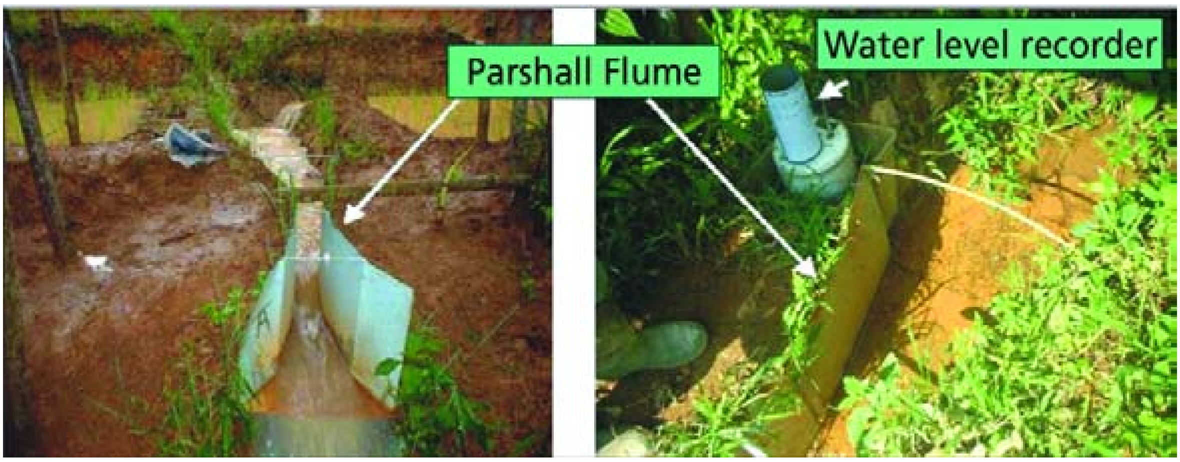

Figure 3. Parshall flume and automatic water level recorder

Sediment Yield

Water sample, about 500 ml, was taken at outlet of the Parshall flume site with the sampling time as follows:

(1) Two times a day, around 7:00 and 17:00, if there was no rain.

(2) Several times during the rainfall or runoff event from the beginning of direct runoff until the streamflow receded.

The water sample was filtered using "newspaper paper" and oven dried. Calculations of sediment yield were done by separating the water samples into samples during rainfall event and samples during no rainfall event. In case of no rainfall event, the total sediment yield was calculated by averaging the sediment yield taken in the morning and in the afternoon using the following equation:

$$Sy = (Sd_m + Sd_a)/2 \times Qd \times 24 \times 3600$$

S_y : daily sediment yield (g day^{-1})

Sd_m and Sd_a : sediment concentration (g l^{-1}) taken in the morning (Sd_m) and in the afternoon (Sd_a)

Q_d : average daily streamflow (l s^{-1})

24×3600 : time (second)

In case of rainfall event, the sediment calculation in one day was separated into three groups: before rainfall events, during direct runoff event, and after direct runoff was over. The following formula was used to estimate the sediment yield:

$$Sy = (Sd_m \times Q_m \times t_m) + \sum_{n=1}^{n} Sd_n/n \times Q_r \times t_r + \{(Sd_o + Sd_n)/2\} \times Q_o \times t_o$$

S_y : daily sediment yield (g day^{-1})

Sd_b, Sd_n , Sd_o, Sd_n : sediment concentration which taken before runoff event (Sd_b), during runoff (Sd_n), after runoff was over (Sd_o), and in the next morning (Sd_n) (g l^{-1})

Q_m,Q_r,Q_o : average discharge when the sediment was taken(l s^{-1})

n : number of sediment sampling during runoff event

t m,t,r,t,o : time (second)

Results and Discussion

Rainfall

The monthly rainfall recorded in 2001-2004 is shown in Figure 4. The highest monthly rainfall occurred on March 2002, which was 453 mm, and the lowest rainfall occurred on October 2002, which was 26 mm.

The amount of rainfall during this experiment time was normal for this area. Based on 24 years data (1974-1998), Afandi *et al.* (1999) reported that the average rainfall from the adjacent raingauge station (Pajar Bulan climate station) was around 2426 mm yr^{-1}, and the maximum rainfall occurred in 1978 was 3540 mm yr^{-1}.

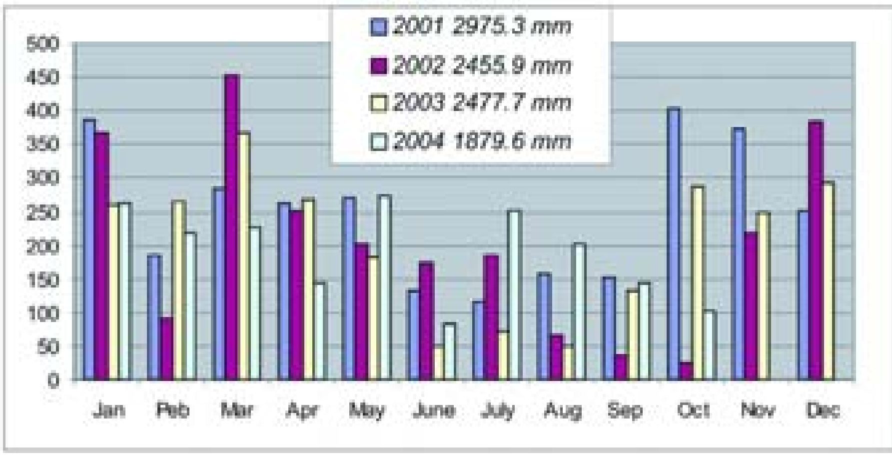

Figure 4. Monthly rainfall in Bodong Jaya, from January 2001- October 2004

Sediment Yield

The pattern of monthly runoff (streamflow), rainfall and sediment yield during rainy season at Saino catchment is shown in Figure 5.

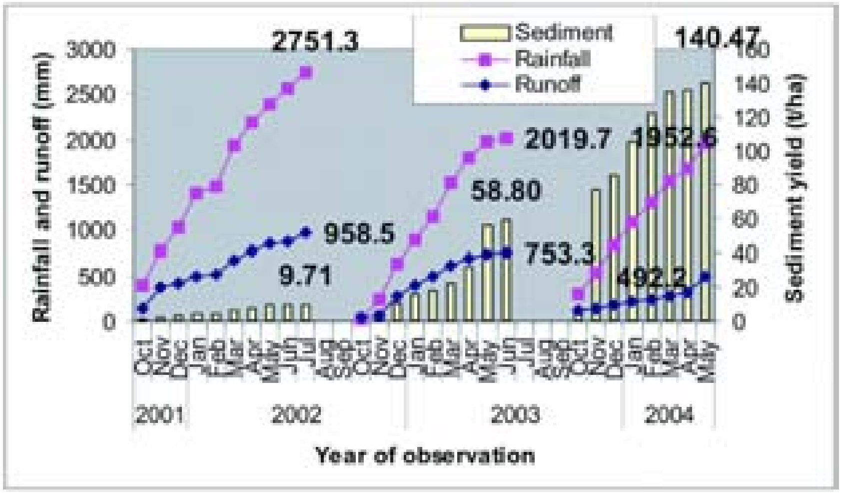

Figure 5. Cumulative of rainfall, runoff and sediment yield during the rainy season in 3 years experiment

Figure 5 shows that correlation between rainfall and sediment yield is low. Although in the first year of the experiment the total rainfall is higher than the second and the third year, the sediment yield was the lowest. The sediment yield increased from 10 Mg ha^{-1} in the first year to 59 Mg ha^{-1} in the second year, and 140 Mg ha^{-1} in the third year. Comparing these results with total soil loss data from plot scale experiment in other studies in Indonesia, the second and third year sediment yield data as shown in Figure 5 were very high. On vegetables steep terrace, Sinukaban *et al.* (194; 1998) reported soil loss of 42-75 Mg ha^{-1} yr^{-1}, while on agricultural bench terrace with mixed rainfed crops, van Dijk (2002) reported soil loss of 40 Mg ha^{-1} yr^{-1}.

The increase of sediment yield in 2003 was attributed to soil clods mass transport (small landslides) which occurred near the catchment outlet, because a foot-path was developed in February 2003. The sediment yield increased sharply in April, May, and November 2003 (Figure5) due to this event.

The maximum runoff was 100 l sec^{-1} while the minimum was 0.08 l sec^{-1}. The high ratio between maximum and minimum discharge is very high (>1000), but considered normal because of the small size catchment (thus short distance of traveling runoff water) and the very steep slope of about 55%. Other factor was probably because of the high drainage density of about 47.3 m ha^{-1}.

Hydrograph Component

Analysis of hydrograph components showed the runoff ratio which was calculated based on quick flow/effective rainfall of about 13% in average, with maximum value was 84%.

Table 2. Summary analysis of hydrograph component

	Total flow	Base flow	Direct flow	Total Rainfall	Eff Rainfall	% Eff Rainfall	Runoff ratio
Average	2.04	0.49	1.56	22.41	11.12	52.35	12.83
Max	9.97	1.76	8.84	47.50	32.50	97.78	84.09
Min	0.07	0.04	0.01	4.00	0.95	8.16	0.52

Several micro-catchments studies in similar hydroclimatic conditions in Indonesia showed that runoff coefficient varied, and usually the value was low. The value of runoff coefficient as much as 17% was reported y Sinukaban *et al.* (1994; 1998) at vegetables steep terrace, while Rijsdijk (in van Dijk, 2002) found 12%. In steep slope bench terraced agriculture with mixed-rainfed cropping system, van Dijk (2002) found 5-9% of runoff coefficient for average 6 yr observation. The value of 2-6% was found by Rijsdijk (in van Dijk, 2002) for mixed plantation forest.

Water budget

In a catchment scale, a simple equation of water budget could be written as follows:

$$R = Q + ET + S$$

where, R: rainfall, Q:streamflow; ET: evapotranspiration and S: storage in soil, infiltrate into deep layer, and transported as lateral flow but not passing the measuring gauge.

The values of R and Q could be found in this experiment. Using Penman method, Ban (2000) measured potential evapotranspiration (PET) from coffee areas at Sumber Jaya from January until August 1999, and found that the average PET was 3.8 mm day^{-1}. This value is not different with the measure values of pan evaporation at Sumber Jaya, which ranged from 3.5 to 4.9 mm day^{-1} (Afandi *et al.*, 1999). If we can use these values, the water budget of these two catchments could be calculated and the results were shown at Table 3.

Table 3. Estimation of water budget in Saino catchment during 3 years experiment

Total rainfall	Total streamflow	Potential Evaporation	Storage
	Mm		
7081	2366	3695	1020

Table 3 showed that the storage (S) of the catchments was very high, 1.05 mm/day. Probably most of storage water will infiltrate into the deeper soil and flow out to downstream areas, enhance the high leaching. This high leaching was shown by the fact that although the soil was located at recent volcanic areas, the soil has already been weathered intensively, and landslide is frequently occurred during rainy season.

Conclusions

During a three years experiment from 2001-2004 in a coffee microcatchment in Lampung, Indonesia, the sediment yield recorded increased sharply year by year, from 10 Mg ha^{-1} in the first year, to 59 Mg ha^{-1} in the second year, and 140 Mg ha^{-1} in the third year. This sharp increase was attributed to mass soil transport from footpath construction near the outlet of the catchment. The ratio between maximum and minimum discharge is very high (>1000) due to the very steep slope, catchment's shape and the small size catchment. The runoff ratio which was calculated based on quick flow/effective rainfall was about 13% on average, with a maximum value of 84%.

This research reemphasized that construction, near the stream, of road or foot paths, as well as any other activities that causes the loosening and exposure of soil to raindrops should be avoided because of its severe effect on sedimentation in the stream.

Acknowledgment

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VII. Multistrata Coffee System as an Alternative to Sustain Sumberjaya Ecological System

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Abstract

Multistrata tree-based systems is considered as one of the most ideal form of farming in the protection forest margin as they promise not only environmental protection, but also support the people livelihood that depends on the land. The management and canopy arrangement of the systems, however, may affect it the microclimate and coffee growth and yield. This research compared sun (monoculture) young coffee of about three years old, young multistrata coffee of 4 years old and old multistrata coffee with 12 years old coffee, each measured from plots of 2000 m^2 area. The young monoculture and multistrata coffee had less canopy cover and implicitly allowed more light entrance into the canopy. The old multistrata system may have been overshaded and thus yielded less coffee berries than the young multistrata. The pattern of evaporation was unclear may be due to insufficient replication and instrumentation. Pruning of some of the shading trees or rejuvenation of coffee may be necessary if farmers consider coffee as the main component in the system.

Introduction

Vegetation cover influences micro-climatic and hydrological processes because of interception of precipitation and thus modification of the amount of precipitation delivery to the ground surface and change in the partitioning of water between infiltration and overland flow. Different kinds of canopy modify the spatial and temporal distribution of rainfall before it reaches the ground. Tree canopies can also influence the radiation regime, temperature, humidity, and wind speed of the understorey environment. The objective of this research were to evaluate the effects of multistrata (agro-forestry) of coffee-based systems on (i) water balance (net rainfall, potential evaporation, and soil evaporation), (ii) light interception in monoculture coffee system and some existing multistrata systems, (iii) coffee growth and production, and (iv) economic benefits of coffee in monoculture system and multistrata coffee systems.

Materials and Method

This research was conducted on coffee-based farmers field in Sumberjaya, West Lampung, Sumatra, Indonesia in 2002. The selected research plots were:

a. Plot 1 : Open, clean-weeded mono culture (sun) coffee (with about 3 year old coffee)
b. Plot 2 : Young existing multistara coffee system (with coffee of 4 years old)

c. Plot 3 : Old existing multistrata coffee system (with coffee of 12 years old)

Some field preparations that had been done before the measurements included:

1. Selection of farmers field that met the research purpose
2. Setting plot borders of approximately 2000 m^2 ($40x50m^2$) dimension.
3. Plot-level survey to identify trees positions and characteristics, and to sketch tree spatial arrangement
4. Based on trees position and types, microclimate measuring device: manual rain gauges, micro-lysimeters and pan evaporimeters, were set inside the borders.

Measurements were made for tree species and distribution, tree growth and growth components, as well as microclimate condition and the water balance.

Result and Discussion

Canopy coverage and tree strata

Figure 1 shows the comparison of open and shaded area of the three plots. Plot 1 had 1600 m2 (or 83%) of open area from the total of 2000 m^2 plot size, while plot 2 had 54 % and plot 3 had about 44 %.

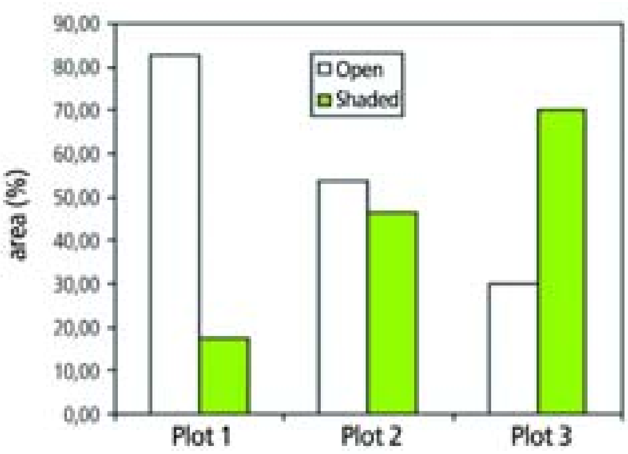

Figure 1. Percentage of open and shaded areas of the three research plots (Plot 1: Open, clean-weeded monoculture sun coffee, Plot 2: Young multistara coffee system and Plot 3: Old multistrata coffee system.

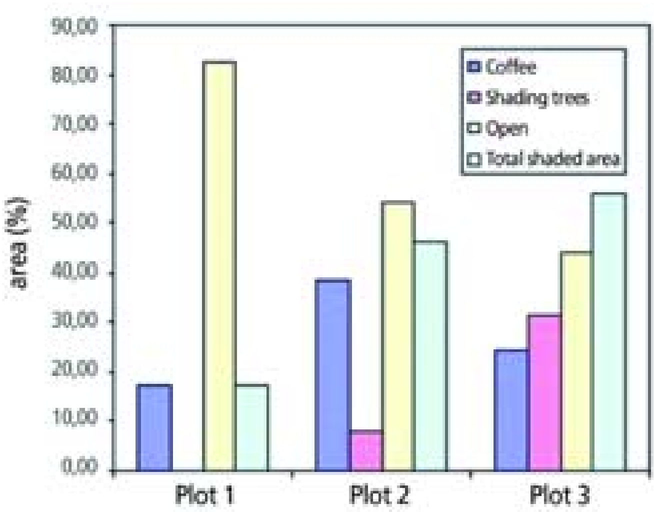

Figure 2. Comparison of coffee canopy cover to other shading trees.

Figure 2 shows that the coverage for plot 1 (17%) completely came from coffee canopy since this plot is a monoculture coffee plot, plot 2 was still dominated by coffee canopy (38%) compared to other shading trees (8%), and plot 3 (with 56% coverage) and shading tree canopy was higher than coffee (31% to 25%).

Figures 3 showed the spatial distribution of canopy projection area (coverage) for the multistrata plots. Plot 2 was generally covered by trees (beside coffee) with canopy area about 1.64 m^2. Some parts of the plot were covered by trees that has larger canopy areas (3.3 to 6.6 m^2). Most parts of plot 3 were covered by trees with canopy between 6.5 to 8 m^2.

There were 4 strata for both Plots 2 and 3. For Plot 2, clove and pepper were at the first (lowest) stratum; coffee, sour soup and mango at the second stratum; banana in the third stratum and Gliricidia, sweet bark, and avocado at the fourth (highest) stratum. Coffee grew together in almost the same height with other trees (mango and soursop) and in some extent were covered by other trees (Gliricidia, sweet bark, banana and avocado), but coffee canopy was dominated the coverage (8 to 38%). This condition allowed the coffee to received enough sunlight. However, competition for water might occur in this plot.

For Plot 3, cacao and coffee were in the lowest stratum, pepper at the second stratum; Gliricidia, jack fruit, guava, dammar, and stink bean (*Parkia speciosa*) at the third stratum, and then erythrina at the fourth stratum. Coffee in this plot were all covered far under other shading trees and the shading trees canopy had higher coverage than the coffee (25 to 31). This condition might reflect the amount of sun light that enter the plot which could influence the growth and production of the coffee.

In general, coffee tolerates shading and root competition especially with trees in different root depth. Erythrina (*Erythrina poeppigiana*), Gliricidia (*Gliricida sepium*), dammar, cacao (*Theobroma cacao*), mango (*Mangifera indica*), soursop (*Annona muricata*), cinnamon (*Cinnamomum burmanii*), banana (*Musa* spp.), guava (*Psidium guajava*), clove (*Eugenia aromatica*), jack fruit (*Artocarpus heterophylus*) and avocado (*Persea americana*) are trees that grow together with coffee in research plots. Erythrina and Gliricidia were the most commonly found shading trees because of their ability to nitrogen in association with Rhyzobium root-nodulating bacteria, being fast growing trees and easy adaptation to local soil condition. Since they need full light they should be planted before the coffee.

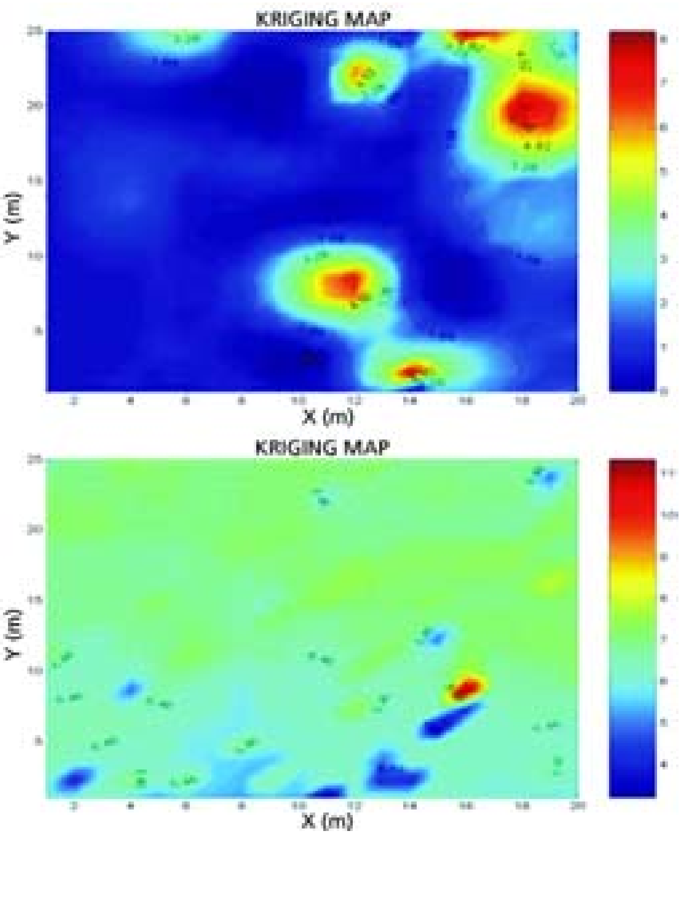

Figure 3. Kriging map of canopy coverage area (m^2) of young multistrata coffee (top) and old multistrata coffee (bottom).

Loke coffee, cacao tolerates shading, but needs deeper soil. Mango and avocado have deep roots and need full light, and so could function as shading trees. They probably will not compete with coffee because of different depth of root distribution; most coffee roots are distributed in surface soil layer. Soursop, cinnamon, guava and banana need about the same light intensity as coffee but soursop and cinnamon have higher trunk than coffee and thus could probably compete for light. Banana has about the same canopy height as coffee and has deeper roots, and thus compatible with coffee. Clove grows better in lower altitude than coffee so it is not recommended to be planted in the Sumberjaya area with elevation of about 800 m asl. Jackfruit and guava have deeper root than coffee, and hence water competition would likely not occur.

Net rainfall

Canopy cover influences the amount of rainfall that reaches the soil surface. Figure 4 shows the net rainfall on each plot. Plot 1 (monoculture coffee) received average net rainfall of 12 mm (about 63% of rainfall of this particular event), while Plot 2 (a young multistrata) received 12 to 13.9 mm with most of the plot area received 12.5 mm, and Plot 3 (old multistrata) received 7.3 to 9.6 mm (most of plot area received 8 mm) rainfall. It could be said that soil surface under more dense (68%) canopy received about 37% less rainfall while difference canopy cover between 17% to 34% didn't make much difference in net rainfall. The rain on open area from the temporary climate station recorded during the research was about 12 mm, that means canopy on Plot 1 and 2 did not retain any rain in the canopy.

This result is higher than that was found by Wallace *et al.* (1999) in a research in Kenya that canopy cover difference of about 50 % reduced net rainfall about 11 to 15 %. Oke (1978) found that the canopy of a deciduous forest can intercept 10 - 25 % while for coniferous forest can intercept 15 - 40% of the total annual precipitation. The high canopy interception in this research (about 37%) was because of low intensity rainfall compared to the result from the area of Wallace

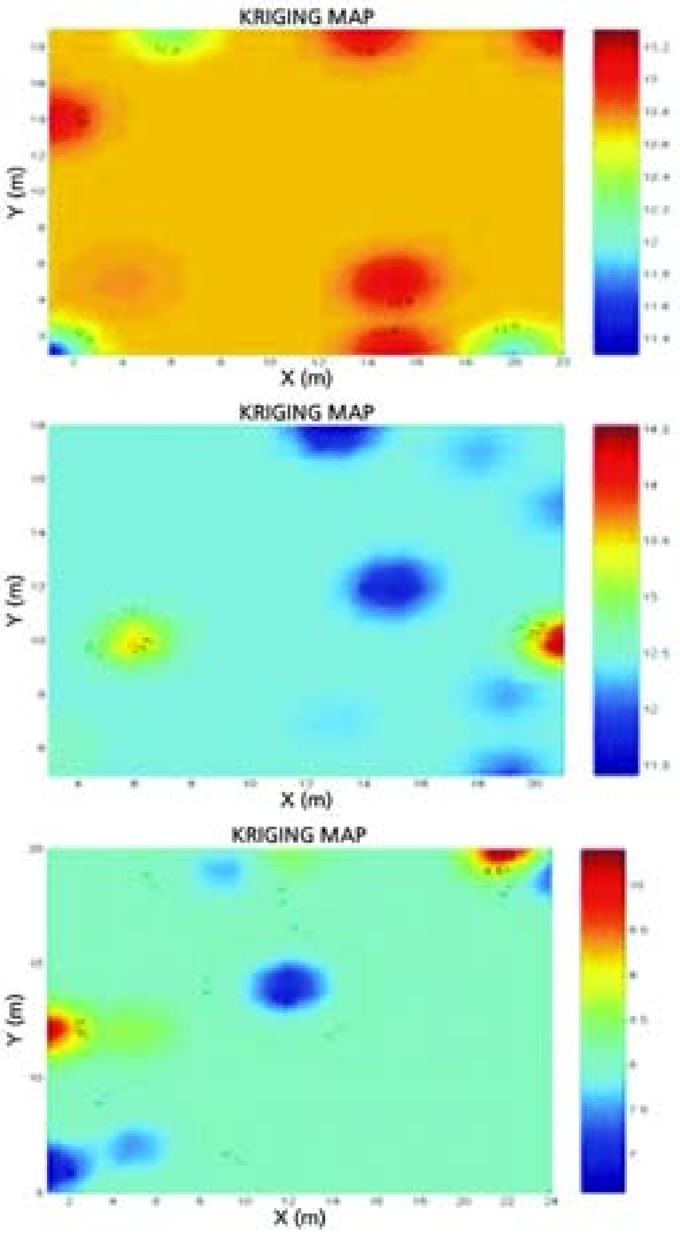

Figure 4. Kriging map of net rainfall (mm for a 12 mm rainfall event for mono culture plot (top), young multistrata coffee (middle), and old multistrata coffee (bottom).

et al. (1999) study. Canopy interception depends upon the nature of the rainstorm than upon the tree species (Oke, 1978).

Potential Evaporation

Potential evaporation reflects atmospheric demand of water from soil and leaves surface. This value is influenced by radiation interception, air temperature and humidity. Figure 5 shows that Plot 1 evaporated from free water surface 5.5 to 6.4 mm day^{-1} with most of the plot evaporated 5.8 mm day^{-1}, while Plot 2 evaporated 4.4 to 5.2 mm day^{-1} with most of the plot evaporated about 5 mm day^{-1} and Plot 3 evaporated 2.6 to 4.4 mm day^{-1} and most of the plot evaporated about 4 mm day^{-1}. Little potential evaporation difference between Plots 1 and 2 shows that different canopy cover between these plots didn't make much difference in air temperature and humidity, they both had similar temperature and humidity. Air temperature and humidity were not measured regularly in this research. Plot 3 with more dense canopy cover showed lower potential evaporation. Air temperature was lower and/or air humidity was higher below the canopy with coverage more than 50 %.

Canopy cover has a function to block air fluctuation. Therefore, atmosphere or weather factors under dense cover will be more stable compare to the open one. Potential evaporation of Plots 1 and 2 were similar, meaning that shading trees on Plot 2 still allowed radiation to enter the plots in about the same distribution with that of Plot 1. Plot 3 had higher variation of potential evaporation and lower evaporation rate (4 mm day^{-1}) than Plots 1 and 2.

Actual Evaporation

While potential evaporation is totally affected by the atmosphere, actual evaporation is also affected by soil and vegetation factors. In this research, vegetation factor i.e. transpiration rate was not measured because of difficulties of setting up lysimeter under tree farm environment. In this research, actual evaporation was mainly due to soil surface evaporation. Loss of water from the soil surface through evaporation is often a major component in the soil water balance especially in the area where full ground cover is not achieved (Jackson and Wallace, 1999).

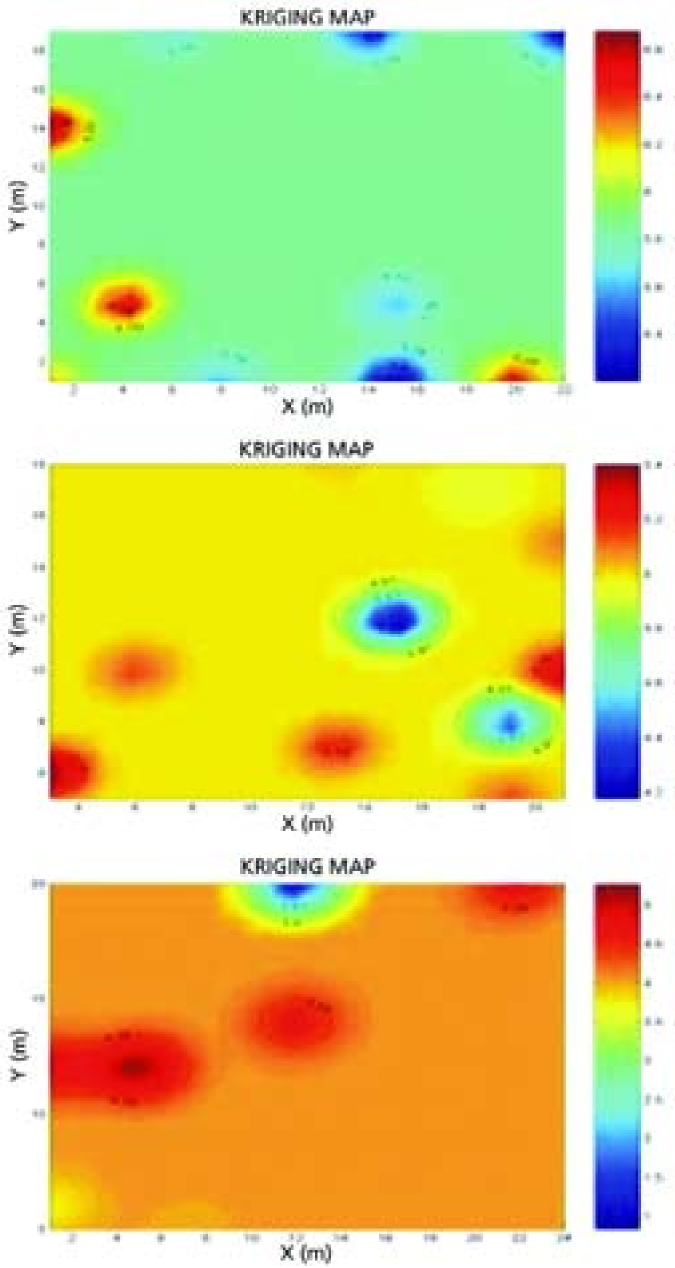

Figure 5. Potential evaporation (mm day^{-1}) for monoculture (top), young multistrata (middle) and old multistrata coffee (bottom).

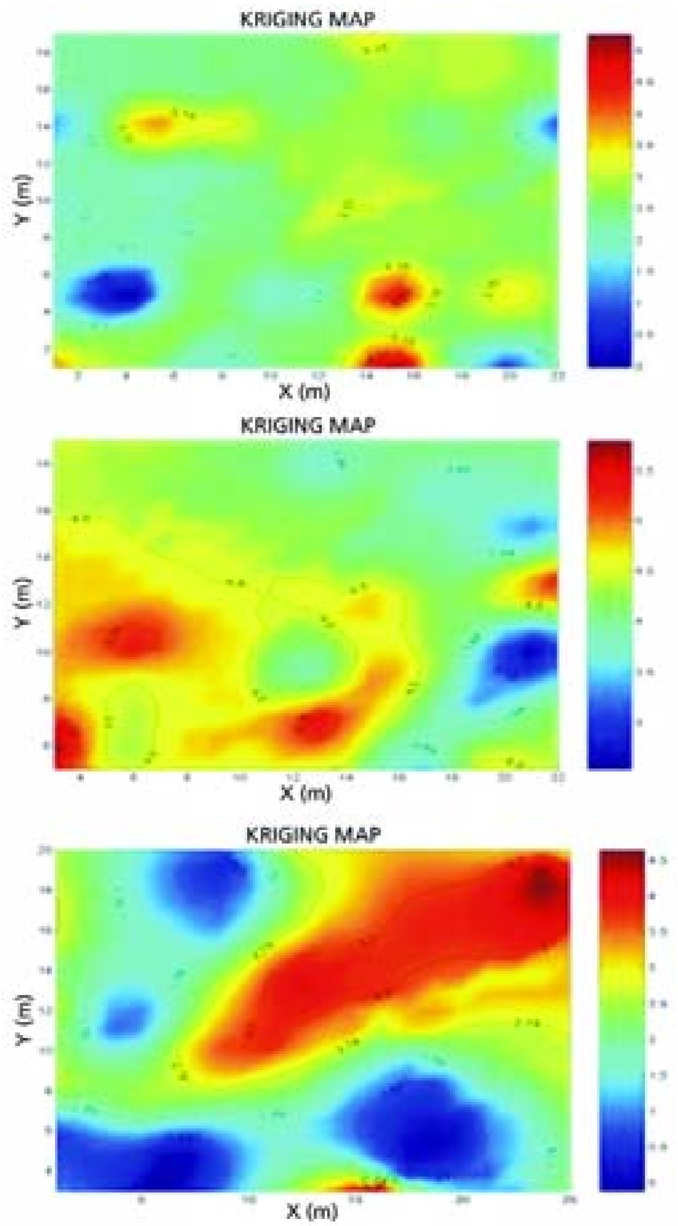

Figure 6 shows that soil surface of Plot 1 evaporated 1 to 4.2 mm water per day, Plot 2 3.8 to 4.5 mm day^{-1}) and Plot 3 (0.8 to 3.7 mm day^{-1}) but no average value could be drawn since the spatial distribution is "patchy". Canopy coverage had certain influence on actual evaporation by reducing radiation and input of rain due to canopy interception. Therefore more coverage often means less evaporation, and soil condition created variability on the actual evaporation. This can be seen in Plot 2. Although it is has more shading and also some litter under the trees but it had higher evaporation than Plot 1.

Comparison of Plot 1 and Plot 3 showed that canopy of Plot 3 reduced evaporation by 12 - 24 %. Wallace *et al.* (1999) found that on an annual basis it has been shown that on average tree canopy can reduce soil evaporation 35 % compared to completely bare soil and about 21 to 25 % for not fully shaded (around 50%) cover.

Figure 6. Actual evapotranspiration of mono culture (top), young multistrata (middle) and old multistrata coffee (bottom).

Plot 3 which was old field has more stable and compact soil surface than the other two plots which were new fields. Evaporation variation over this plot was greater because of canopy cover distribution. With clean weeded management on a hill slope and almost no litter under the trees, soil surface at Plot 1 are easier to dry and erode. Plot 2 was also managed as clean weeded but this plot had more canopy cover and started to have some litter under the trees which caused the evaporation more stable (less varied) over the plot.

Surface coverage related to soil moisture could also be evaluated from the ratio between actual evaporation and potential evaporation. If the ratio is high, it means that there is enough water kept on the soil surface and this also showed that the surface has good coverage as to cause smaller actual evaporation than potential evaporation (Black and Ong, 2000). The actual/potential evaporation ratio were 0.2 to 0.7 for Plot 1; 0.8 to 0.9 for Plot 2 and 0.2 to 0.9 for Plot 3. The numbers reflect that surface of Plot 2 was the most uniform and had a more stable moisture and that means that the canopy over this plot covers the surface more evenly. For the other plots some parts of the area was dry or open, and other part was moist or shaded.

In short, the above data reflect the water balance of the plot. For Plot 1 with input (net rainfall) of 12.6 mm and the output (actual evaporation) of 1 to 4.2 mm, the soil surface received 8.4 to11.6 mm water. For plot 2 the input was 12.5 mm and the output was between 3.8 and 4.5 mm and the surface retained 8 - 8.7 mm. For Plot 3 the input was 8 mm and the output was 0.8 - 3.7 mm and the surface retained 4.3 - 7.2 mm. Plot 1 and 2 retained almost the same amount of water; more than plot 3 since plot 3 received much less rain because of the dense canopy. There is a possibility that water competition occurred in plot 3.

This fact is consistent with the result by Wallace *et al.* (1999) who found that in humid climate, where either annual rainfall is high and/or rainfall intensities are high, losses due to interception may be greater than savings due to reduced soil evaporation.

Approaching actual evaporation using lysimeter in this research had some weaknesses. Being a closed system, the lysimeter did not allow water to infiltrate into the soil and as the result in rain days the lysimeter surface could be filled with water. Even though the water was removed before measurement took place, the wetness of soil in the lysimeter din't reflect the real soil surface condition. There is a need to improve the design of the lysimeters to get a better and more accurate result for this tree-based systems.

Coffee growth and production

Table 1 shows the comparison of coffee growth and production. Coffee on Plot 3 were the tallest (162 cm) and has biggest stem circumference (17.6 cm). Plots 2 and 3 had coffee with almost the same height, but coffee on Plot 2 had better trunk, because perhaps of too much shading in the former.

Coffee in plot 3 were not productive as reflected by the low number of productive twigs (9.0 compare to 33.6 on Plot 1 and 38.8 on Plot 2) and the non productive twigs were the highest (13.4) for this plot. Average twigs length was highest on Plot 3 (104 cm) in compare to Plot 2 of 93 cm and Plot 1 of 62 cm. This was closely related to the number of nodes/twig. From the average number of nodes/branch and number of productive twigs, Plot 2 had the highest yield potential (with 585 nodes), Plot 1 had 264 nodes, while plot 3 hads the lowest (135) nodes.

The average yield (berries dry weight) per plot were 192 kg in Plot 1, 349 kg in Plot 2, and 124 kg in Plot 3 (Table 1).

From this data it can be suggested that some treatments should be done for Plot 1 and 3 to increase the yield. The summary of plots characteristics and all measurements on the three plots is shown in Table 2.

In general, all farmers did not supply their field with fertilizers and pesticides, and hence most of the expenses were assumed coming from labors. The young multistrata coffee system (Plot 2) gained highest income, and followed by the monoculture system (Plot 1), and then by the old multistrata system (Plot 3).

Table 1. Comparison of average coffee growth and production between the three plots.

Variable		Plot 1	Plot 2	Plot 3
Plant height (cm)		92	134	162
Number of productive twigs/plant		33.6	38.8	9.1
Stem circumference (cm)		10.6	15.2	17.6
Canopy diameter (cm)		104	156	167
Number of unproductive twigs per tree		3.5	3.1	13.4
Twig length (cm)	Top	8	73	89
	Middle	85	96	107
	Bottom	92	111	116
	Average	62	93	104
Number of nodes/twigs per tree	Top	2.5	9.2	14.2
	Middle	9.7	16.2	15.8
	Bottom	11.9	19.6	17.0
	Average	8.0	15.0	15.7
Yields (kg per plot of 2000 m^2)	1^{st} harvest	19.3	69.8	18.7
	2^{nd} harvest	57.8	85.6	31.2
	3^{rd} harvest	75.1	158.9	51.1
	4^{th} harvest	40.5	34.9	23.7
	Total/plot	192.6	349.2	124.6
	Yield ha^{-1} yr^{-1}	963	1746	623

Table 2. Summary of measurement results over the research plots

No	Type	Total canopy coverage (%)	Coffee Coverage (%)	Shading trees coverage (%)	Shading trees Canopy area (m2)	Average tree height (m)
Plot 1	Monoculture coffee	17	17	0	0.69	1.1
Plot 2	Young multistrata	45.9	38	7.9	1.64	0.5 - 4
Plot 3	Old multistrata	56.45	25	31.45	6.46 - 8	1.62 - 12.7

No	Type	Net rainfall (mm)	Potential Evaporation (mm)	Actual evaporation (mm)	Coffee height (cm)	Berries dry weight (g/plant)
Plot 1	Monoculture coffee	12.5 - 12.9	5.5 – 6.38	1.04 - 4.21	93	385
Plot 2	Young multistrata	12 - 13.9	4.2 – 5.16	3.84 - 4.5	134	873
Plot 3	Old multistrata	7.34 - 9.64	2.61 – 4.39	0.8 - 3.7	162	249

Conclusions

From this research it can be concluded that canopy cover affects the water balance if it shades more than 50 % of the farm area. The young multistrata plot allowed coffee to get enough light. Most of the shading trees under this study were unlikely compete with coffee for water and light. Maintenance (pruning) of canopy may be needed for the multistrata system to allow enough light interception so is to stimutae fruiting.

The old multistrata plot canopy was too dense and needs some pruning to allow more light to reach the canopy to enhance fruiting. Dense canopy did not always mean that the soil surface below the canopy would retain more water because higher canopy interception decrease the net rain.

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