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 (0-10^0), (b) medium (10-30^0) 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

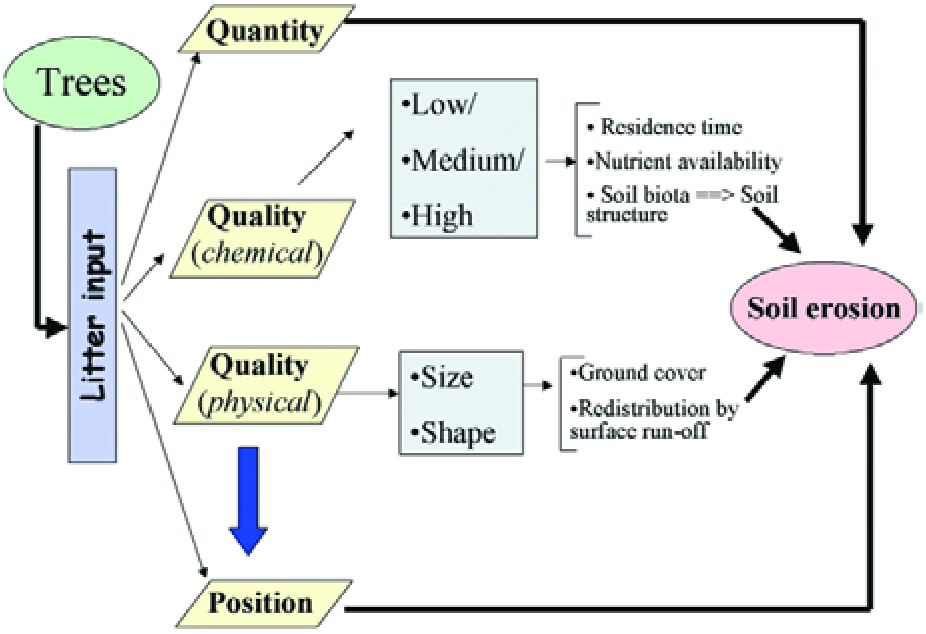

Figure 1. Schematic link between litter input and soil erosion

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.

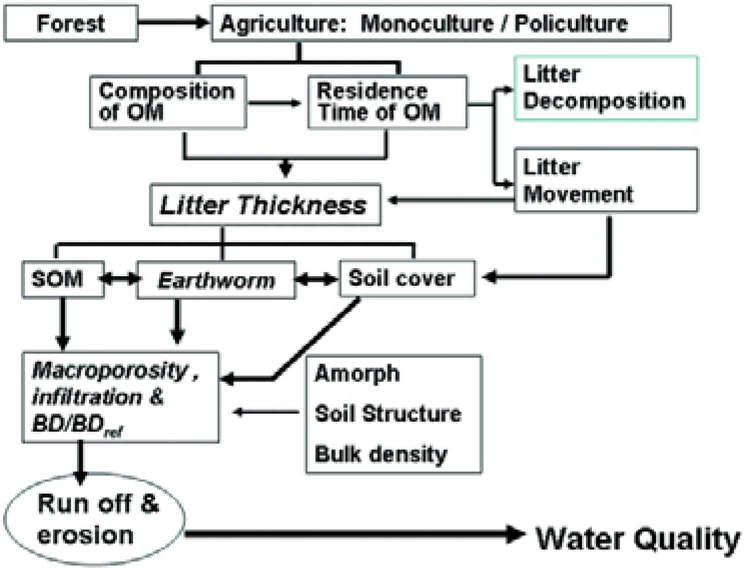

Figure 2. Schematic links between land use changes, thickness of litter layer and run off and erosion.

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.

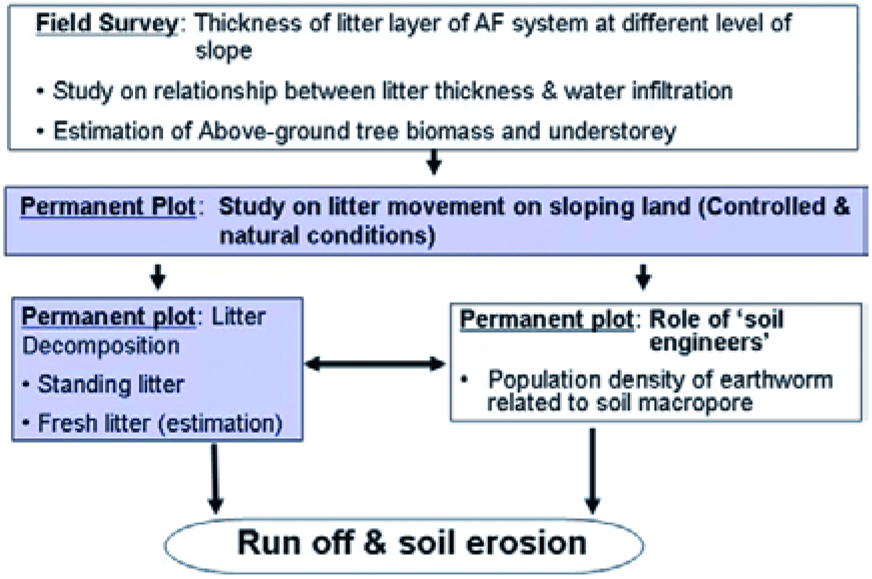

Figure 3. Flow chart of research approach and their main relationships.

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

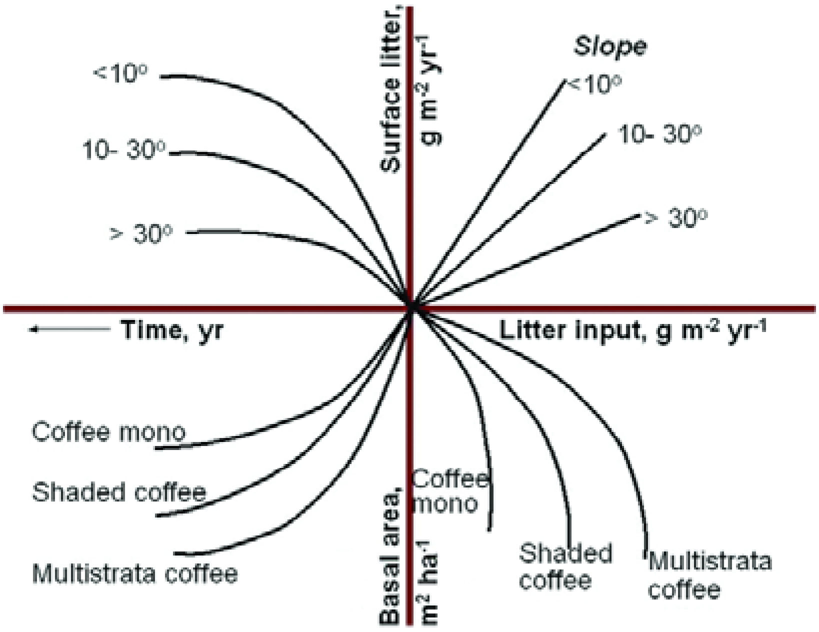

Figure 4. Hypothetical relationship of litter thickness and its distribution at different positions in a steep slope of coffee based systems.

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°25'46.50" - 104°26'51.40 E, 5°01'29.88" - 5°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

Trees diversity

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%**

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

where,

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

Tree biomass and canopy distribution

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.

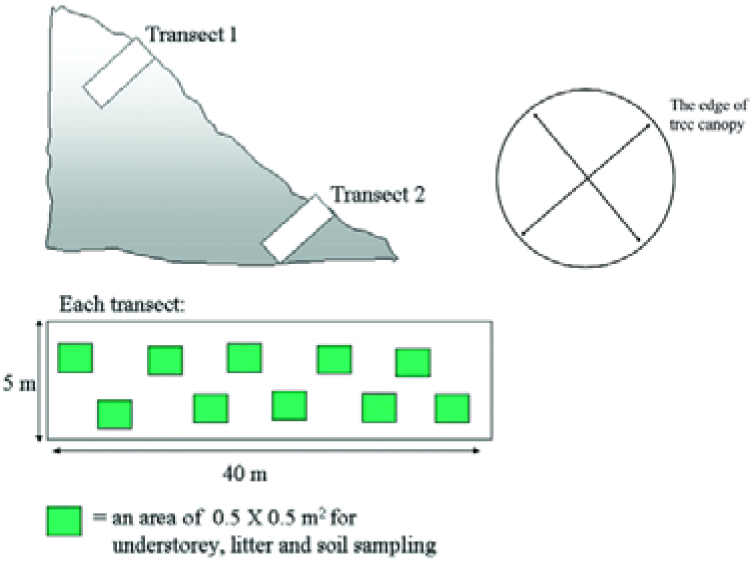

Figure 5. Position of sub plot (transect) in a slope (top) and schematic of litter, understorey and soil sampling (bottom).

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^{0}C 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^{0}C 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

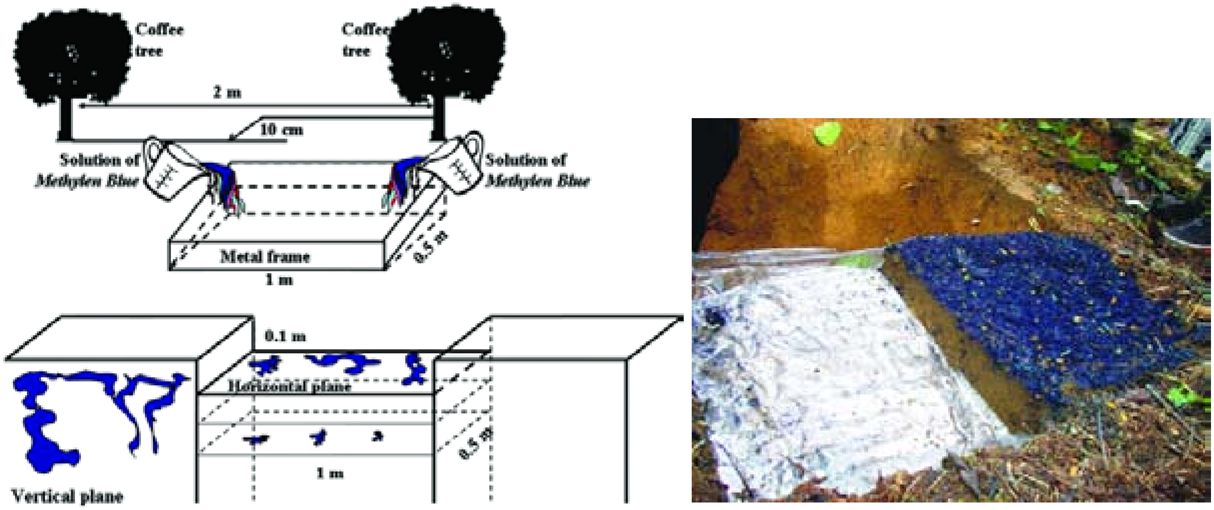

Figure 6. Schematic measurement of soil macroporosity distribution using methylen blue solution.

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).

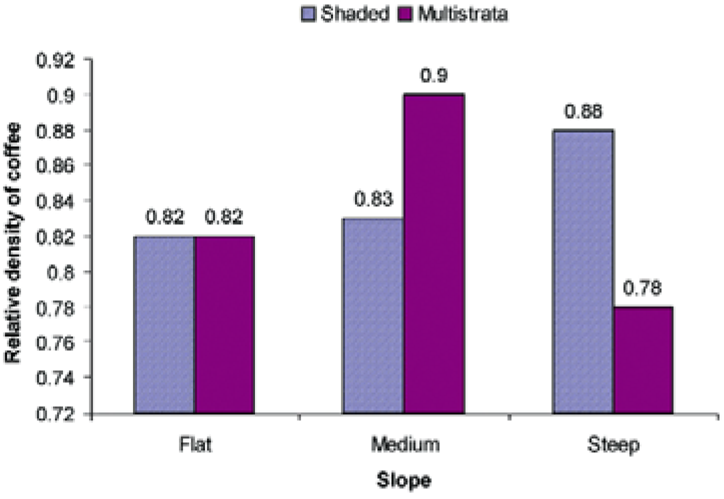

Figure 7. Relative density of coffee trees at different steepness of slope

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

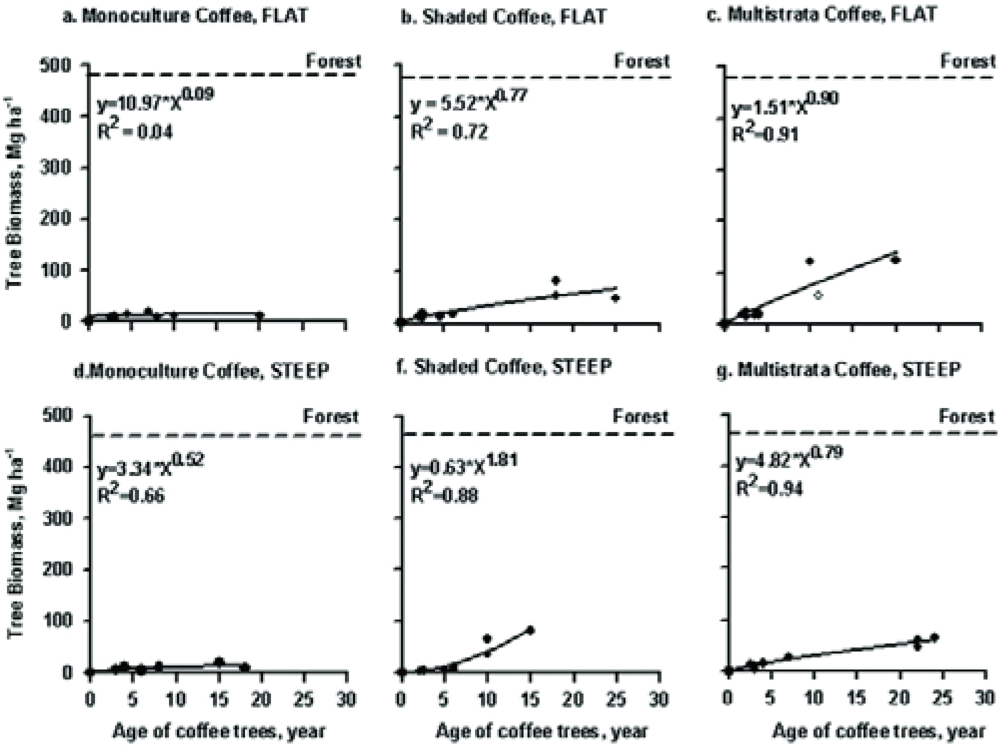

Figure 8. Tree biomass of monoculture and agroforestry coffee based system at different age of coffee trees on flat and steep slope land with tree biomass under forest system as a reference.

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}).

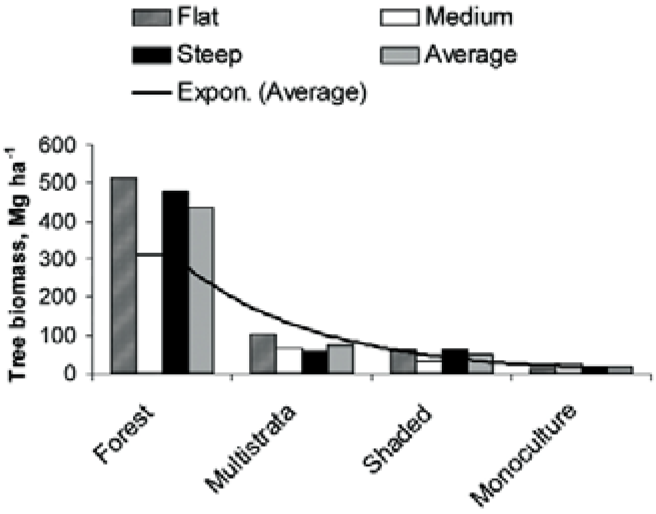

Figure 9. Tree biomass in the forest and in the mature (> 7 years) coffee based systems

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.

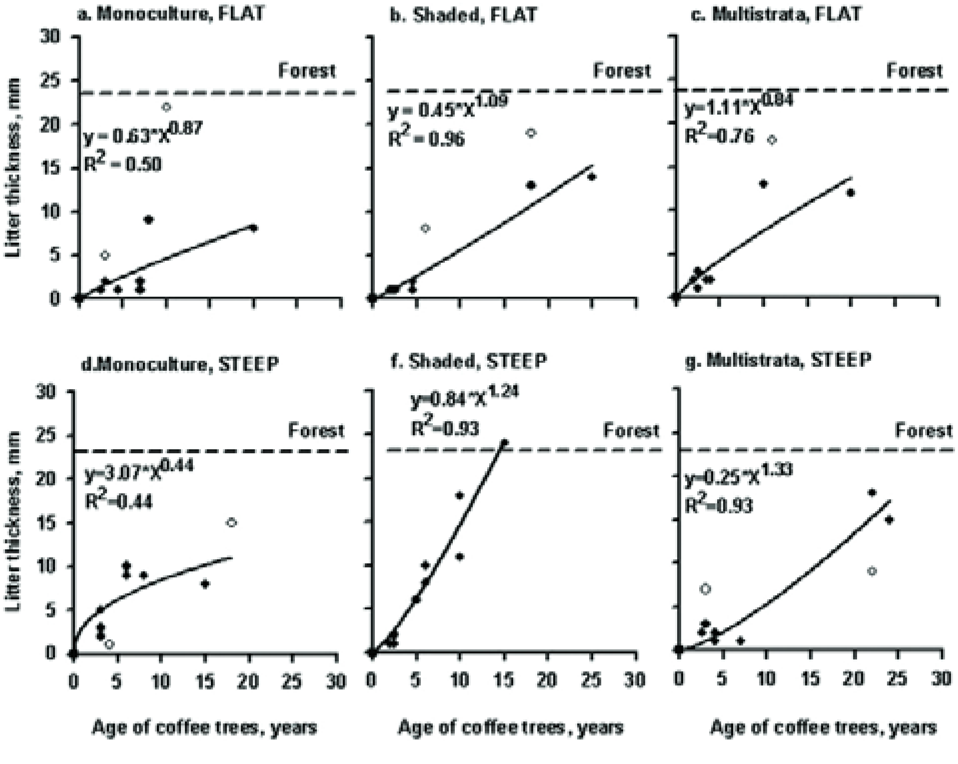

Figure 10. Thickness of litter layer under coffee based systems on flat and steep slopes at various age of coffee trees.

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.

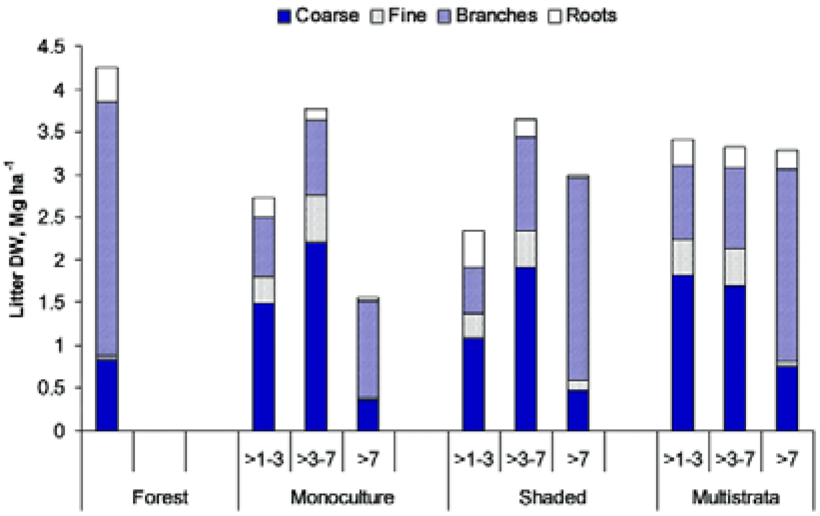

Figure 11. Composition of standing litter and roots found in litter layer of forest and mature coffee based systems (> 7 years).

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.

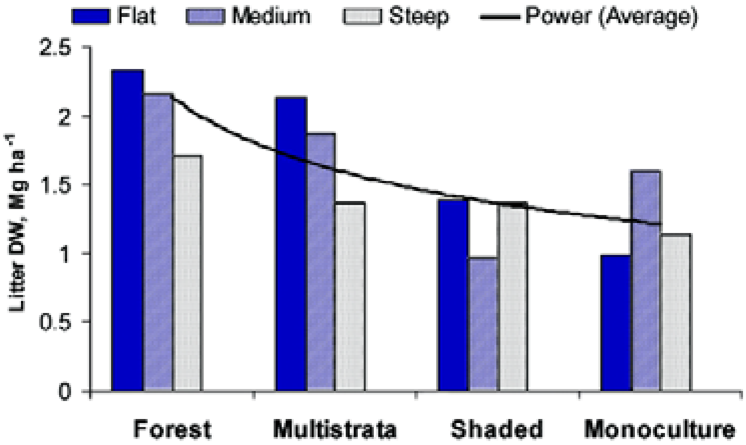

Figure 12. Dry weight of surface litter under forest and coffee based system at different slopes.

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.

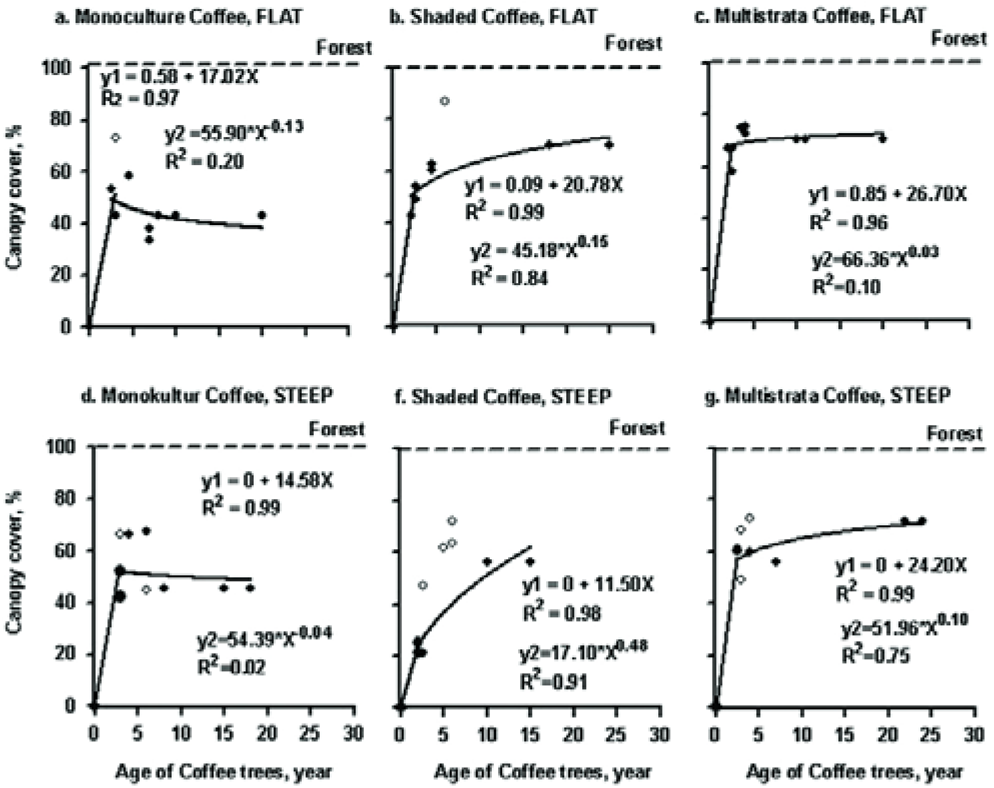

Figure 13. Area covered by tree canopy of Agroforestry systems and monoculture coffee based system relative to canopy cover under forest 100 %.

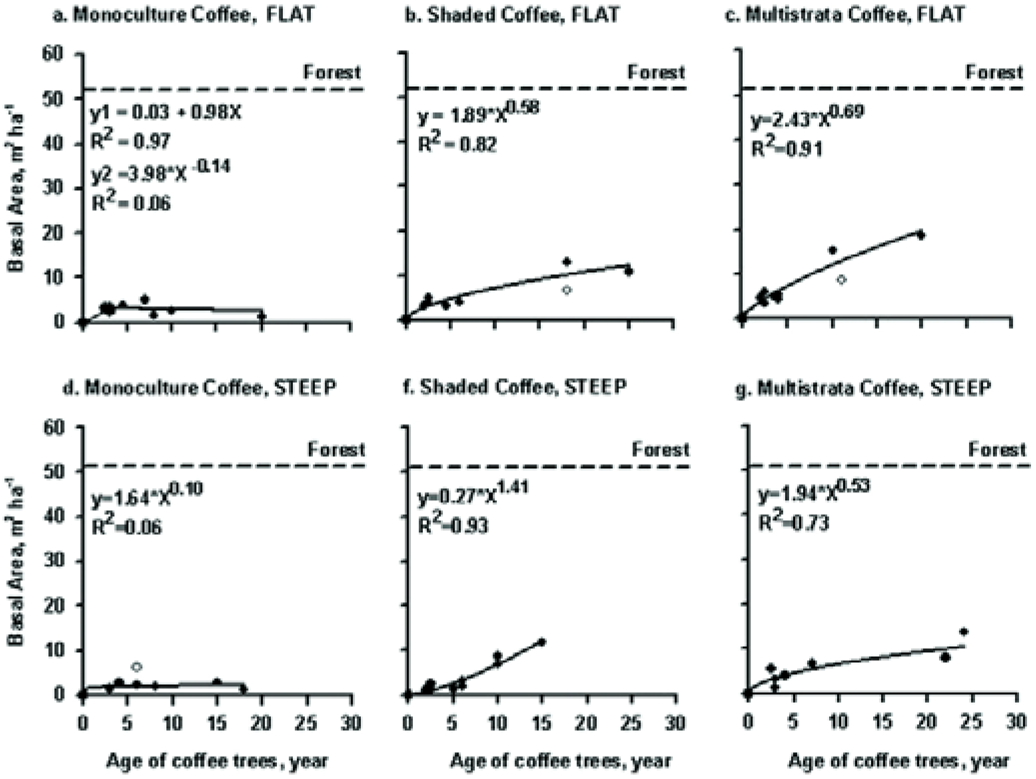

Figure 14. Tree basal area of Agroforestry systems and monoculture coffee based system compared to remnant forest

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)

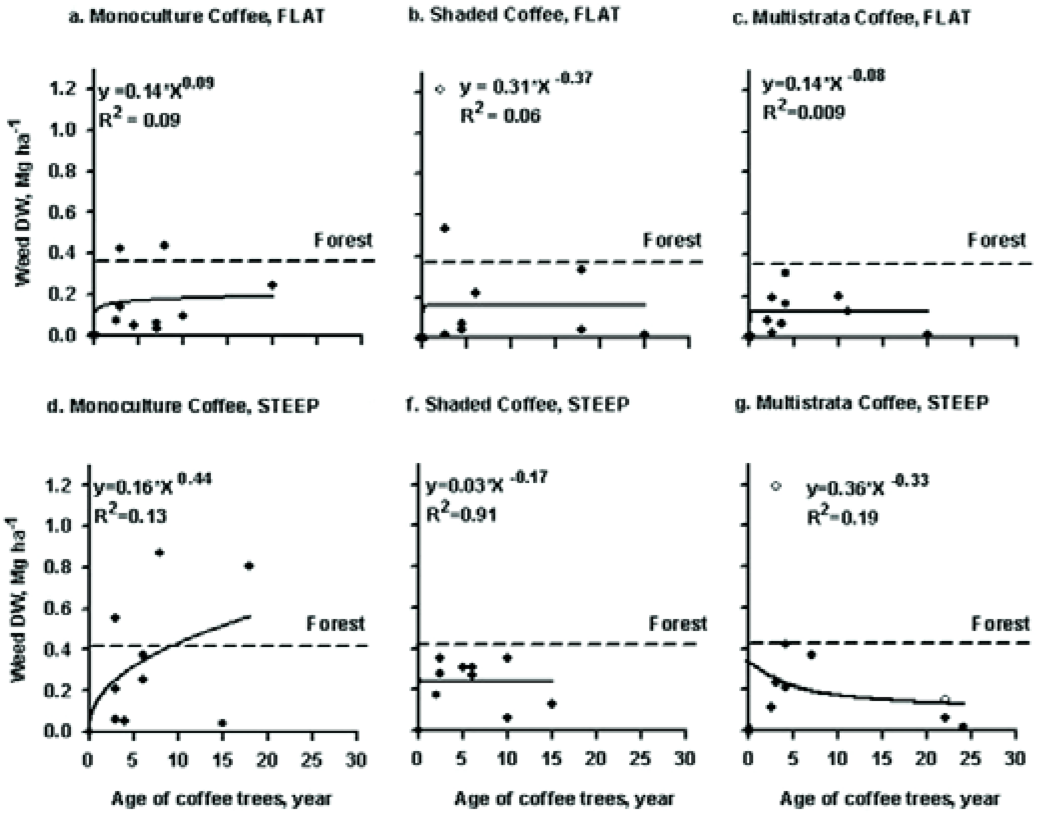

Figure 15. Understorey (weed) dry weight under forest and coffee based system

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).

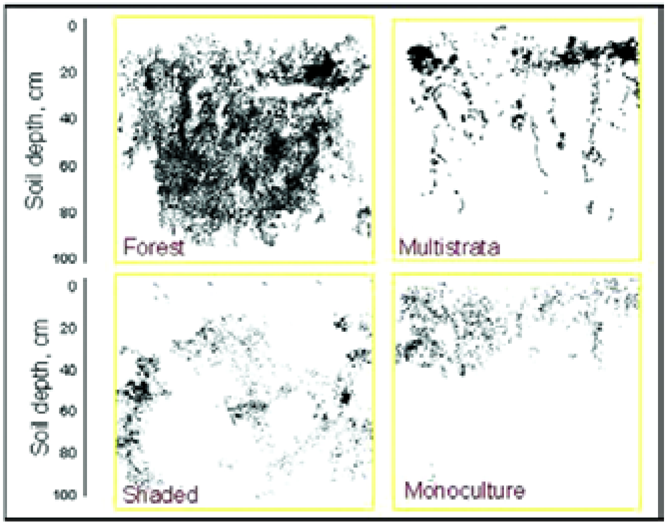

Figure 16. The distribution of the flow of Methylen Blue through soil profile as indication of the distribution of soil macropore in different land use systems (Forest= Natural Forest, Multi-strata = multi-strata coffee system, Shaded = shaded coffee system and Monoculture = monoculture coffee system).

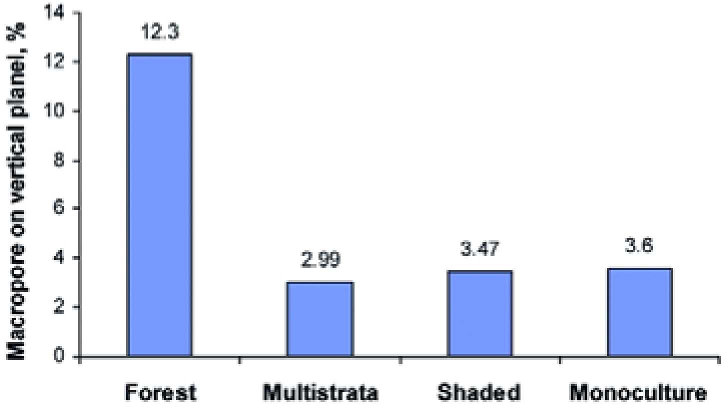

Figure 17. The average number of soil macropore on vertical plane under forest and coffee based systems

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.

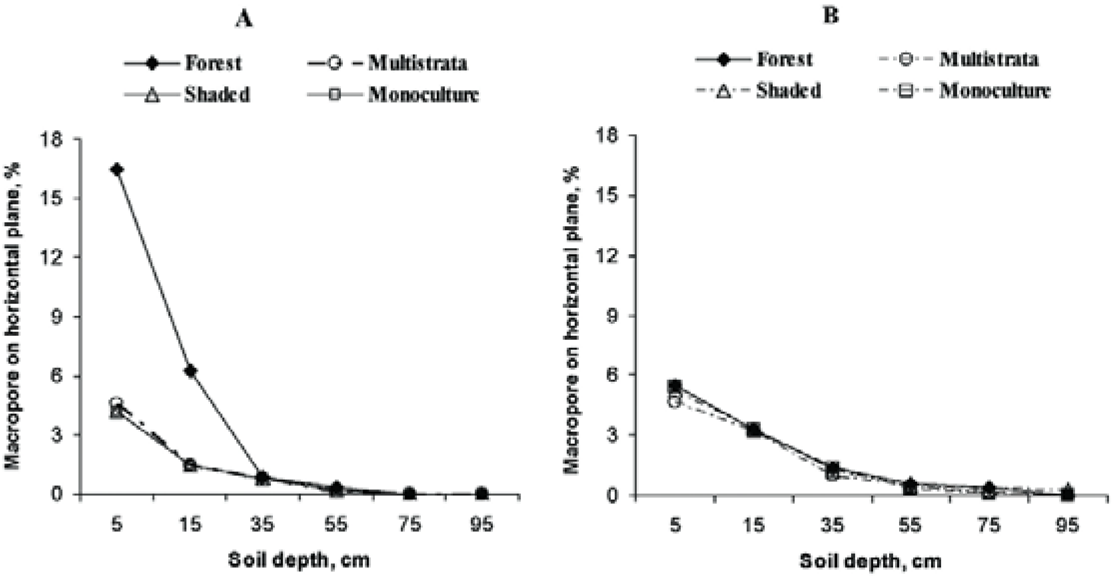

Figure 18. Distribution of soil macropore on horizontal plane of soil profile on (A) steep slope and (B) gentle slope (of forest and coffee based systems

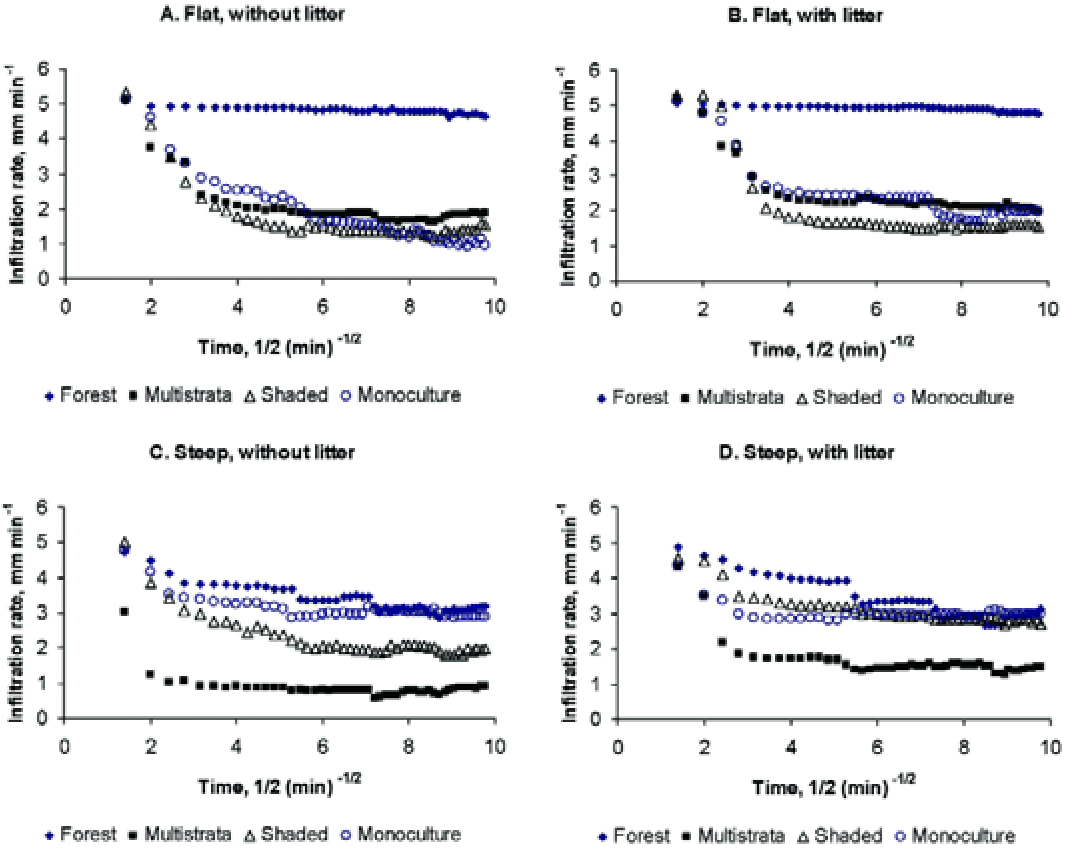

Figure 19. Water infiltration (mm minute-1) of different land use types on flat land without and with litter (A and B) and on steep slope land (C and D).

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.

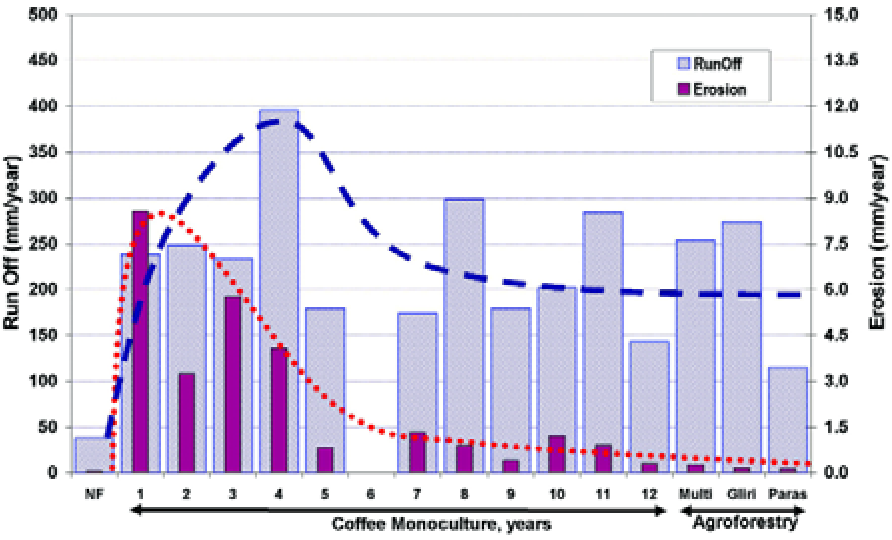

Figure 20. Surface runoff, erosion at various ages of monoculture coffee systems after forest conversion

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.

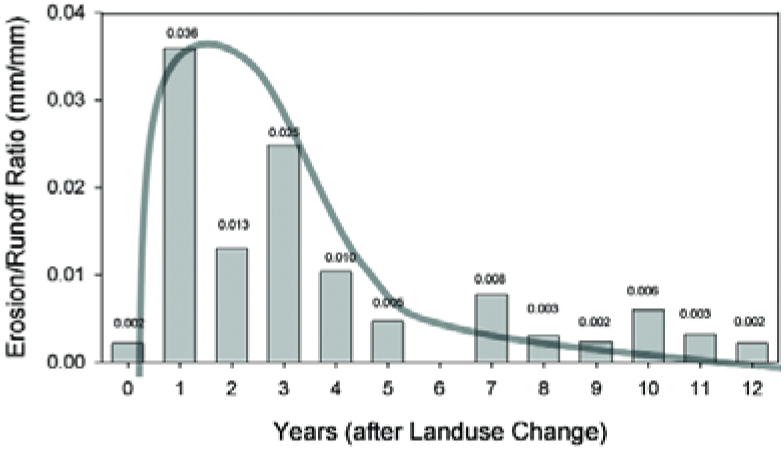

Figure 21. Erosion/runoff ratio at various ages of monoculture coffee systems after forest conversion

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

No	Landuse system	Runoff	Erosion	E/R ratio
		mm	**Mm**	**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.

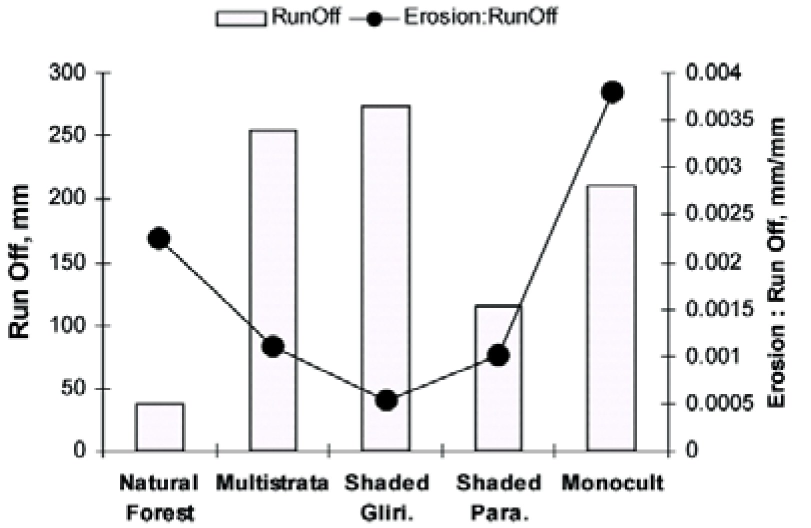

Figure 22. Surface runoff and Erosion to surface runoff ratio from various coffee-based agroforestry systems

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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