BIOMASS PRODUCTION OF SHADE-GROWN COFFEE AGROECOSYSTEMS

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Abstract

Biomass production has significance on sufficing human need, belowground C stock, nutrient cycling, soil organism activity, soil conservation, and weed diversity. To evaluate biomass production (litter fall, pruning residue, and weeding residue) a study was conducted at Conservation and Sustainable Management of Below-Ground Biodiversity (CSM-BGBD) site in Sumberjaya Sub-district, West Lampung, Indonesia, during 2007-2008 using two plots of *Coffea canephora*. Plot I was a long term experimental plot, established from shrub to young coffee agro-ecosystems with treatments of open-grown (sun) coffee and *Michelia champaca, Gliricidae sepium*, and *Erythrina indica* shaded-grown coffee. Plot II was mature coffee fields of 15 years old with the same types of shade trees.

The results were: (1) Based on total litter fall, pruning residue, and weed residue, shrub converting into sun coffee or technical shade-grown coffee agro-ecosystem would not significantly change biomass production but biomass structure was changed; (2) Weeding residue was still the major contributor of biomass production in young coffee agro-ecosystems and in mature open-grown (sun) coffee; (3) In mature agro-ecosystems, biomass harvested of coffee bean was only 4-8% of total biomass production; (4) Based on pruning residue, mature sun coffee yielded the lowest wood biomass production; (5) Mature sun coffee supplied the lowest C of litter fall while *Erythrina* and *Michelia* shaded coffee yielded the highest C.

Key words*: Coffee, biomass, c stock, litter fall, pruning residue, weeding, shade tree*

1. Introduction

The current area of Indonesian coffee plantation is about 1.3 million hectares that is grown by approximately two million households. It produced 682.9 thousand tons of coffee bean from which 442.3 thousand ton was exported (Deptan, 2009). Hence, coffee production is great importance for foreign exchange. Furthermore, coffee plantation generates income for farmers' family, supplies firewood and timber particularly if grown under shade tree systems.

No data was available about total areas of Indonesian shade-grown coffee plantation. However, in Sumberjaya Sub district, West Lampung, more than 50% of the plantations were shade grown. Moreover, in Trimulyo village, most of coffee plantation was multi-strata agro forestry (Evizal *et al*., 2004; Budidarsono dan Wijaya, 2004; Suyanto *et al*., 2005). It seems that as a smallholder plantation, shade-grown coffee is common in Indonesia. Therefore, any changes in Indonesia coffee plantation (such as land use change and land use management practices should have significance in global context especially in global warming and climate change.

Shade-grown coffee systems play an important role in biomass production (Dossa *et al*., 2008), including timber and firewood (Peeters *et al*., 2003), and C sequestration (Van Noordwijk *et al*., 2002). Even shade trees provide others ecological benefits such as soil conservation, biodiversity conservation, and providing nutrient through litter fall and nitrogen fixation if trees were legumes (Rice and Mclean, 1999; Philpott *et al*., 2008; Evizal *et al*., 2009).

There is limited information on dynamic of biomass and C production in coffee agro-ecosystems that established from abandon land (shrub and *Imperata* grassland). As forestland was no more available, abandoned lands remain for planting coffee (Evizal *et al*., 2004). Such information is important for policy making toward sustainable coffee production and sustainable development around protected forest or national park where most coffee trees were grown. Forest encroachment may be reduced if coffee plantation provides viable income and other demand including wood biomass such as timber and firewood.

2. Methods

2.1 Study Site

The study was conducted at Conservation and Sustainable Management of Below-Ground Biodiversity (CSM-BGBD) site in Sumberjaya Sub district, West Lampung, Indonesia, during 2007-2008. The site is located at coordinate of 5^{o}2'S and 104^{o}26'E, closed to the border of Rigis Hill protected forest, with a gentle slope and elevation of 800-900 m from sea level. The soils are dominated by Inceptisols, especially Vertic and Typic

Dystrudepts. Soil of plot I (where shrub was cleared and coffee seedlings were planted) and plot II (mature coffee) showed quite different properties both soil chemical and soil structure (Table 1).

Table 1. Soil properties in study site

Soil properties	Shrub & young coffee		Mature coffee	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
pH (H_2O)	5.06	5.18	4.6	4.3
pH (KCl)	4.14	4.08	4.3	3.9
N (%)	0.21	0.25	0.15	0.08
C (%)	2.4	1.26	2.24	0.82
P2O5 (ppm)	2.96	0.02	8.3	2
Sand (%)	43.68	47.86	25	21
Silt (%)	27.73	25.36	30	25
Clay (%)	28.59	26.78	45	54

Analysis of the data from 1974-1998 showed that the average annual rainfall ranged from 2426 mm to 3366 mm, with average rainfall was 2500-2600 mm/year. Based on the classification of agroclimatic zone (Oldeman, 1975), this site belongs to agroclimatic zone B1, and according to the Köppen Climate Classification System, the benchmark belongs to tropical moist climate (Af) rainforest type (Afandi, 2004). However, data recorded during the study showed a longer (6 months) dry season (Figure 1).

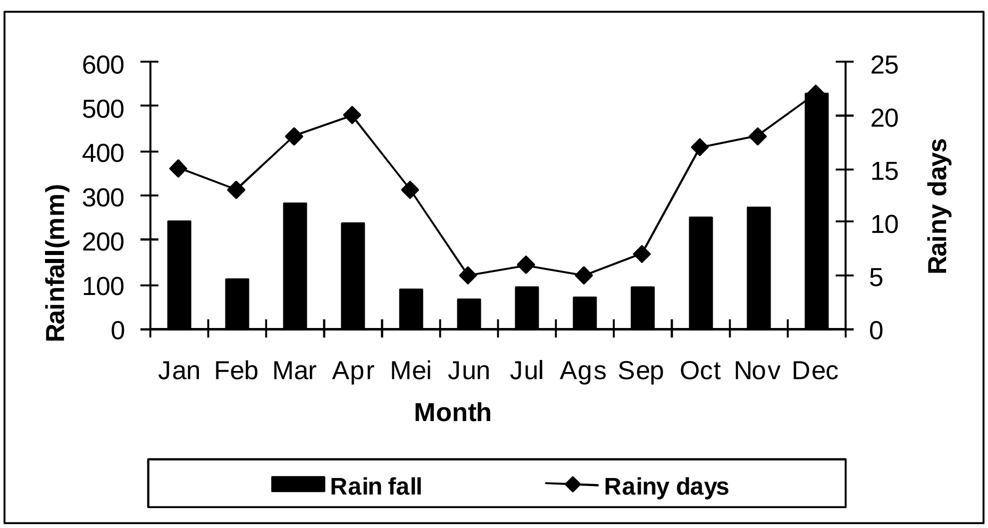

Figure 1. Rainfall and rainy days in study site

2.2 Plot management

In experimental plot I, after the shrub was cleared, Robusta coffee seedlings were planted using four shade treatments of sun coffee (without shade trees), *Michelia champaca Gliricidae sepium*, and *Erythrina indica* shade trees. The experiment used randomized complete lock design (RCBD) with three replications. Coffee trees spaced at 2 x 2 m while shade trees spaced at 4 x 4 m. Fertilizer dose of 75-25-50 NPK was applied.

Plot II was a mature Robusta coffee (*Coffea canephora*) fields of 15 years old with different types of shade trees namely sun coffee (without shade trees), coffee shaded by *Michelia champaca*, coffee shaded by *Gliricidae sepium*, and coffee shaded by *Erythrina indica*. Fertilizer of NPK (150-50-100) was applied. Others management practices were according to local standard.

2.3 Biomass sampling

The measurement of biomass production was based on litter fall, pruning residue, weeding residue, and coffee yield. To collect litter fall, three letter traps of 1 x 2 m width were installed in each plot. Litter fall of coffee trees (leaf and branch) were separated from litter fall of shade trees and oven-dried at 70^{o}C until constant weight. Composite sample for coffee trees, *Michelia champaca*, *Gliricidae sepium*, and *Erythrina indica* shade trees were analyzed for C content.

Fresh biomass of prune residues was weighted from three sample trees of coffee and shade. Composite sample was oven-dried to measure dry weight. Before hand weeding (every 3 months), weed sample with frame of 1 x 1 m was cut and oven dried. Composite sample was done to analyze C content. A part of plot I, after land clearing, was abandoned for a year to let the shrub re-grow. Then shrub sample of 1 x 1 m frame was cut and dray weighted. Fresh coffee berries of 400 m^2 sample area was harvested and weighted. Coffee berries from three sample trees were processed to get coffee bean of 14% water content.

3. Results and Discussion

When shrub was converted into sun coffee or shade-grown coffee agro-ecosystem, there was no significant change on biomass production based on total litter fall, pruning residue, and weed residue. The dynamic productivity was about 10-13 ton ha^{-1} year^{-1} (Figure 2). Following land clearing, soil was more fertile (Table 1) to support young coffee to grow faster. Then in mature sun coffee agro-ecosystem, biomass productivity tended to be lower, proving that shade trees was important to sustain biomass productivity.

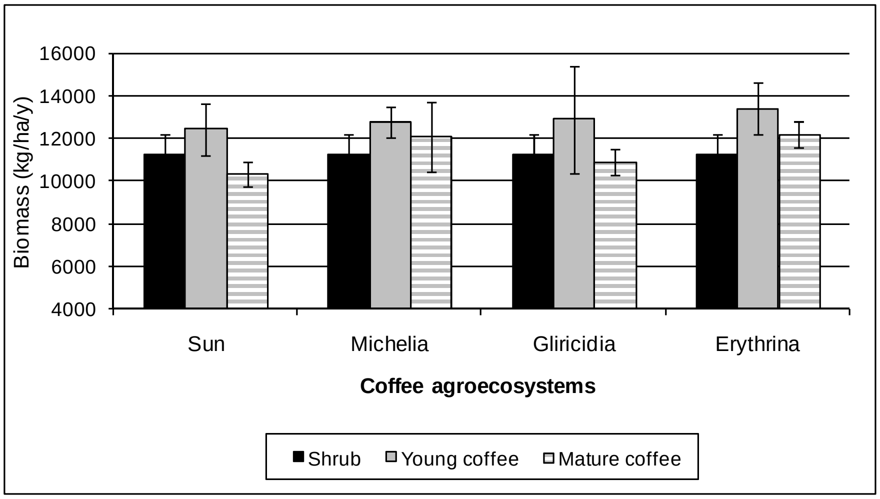

Figure 2. Biomass production of shrub, young and mature coffee

However, young and mature coffee agro-ecosystem was different in biomass structure. Weeding residues dominated biomass production of young coffee agro-ecosystems (Figure 3). As weeding residues contributed 66-77% of biomass production, it was a potential source of soil organic matter. Weed was important for sustaining biomass production of young coffee agro-ecosystems, more or less being like shrub agro-ecosystem. No doubt, that weed management was critical for sustaining growth and yield of new planting coffee, while young shade trees (2 years old) provided little cover and not much litter fall to suppress weed growth. Intensive clear weeding would have effect on higher soil erosion and lower biomass production that resulted in yield drop and soil degradation that commonly found in young "pioneer" coffee (Gillison *et al.*, 2004). Litter fall and pruning residues gave less contribution on biomass production of young coffee.

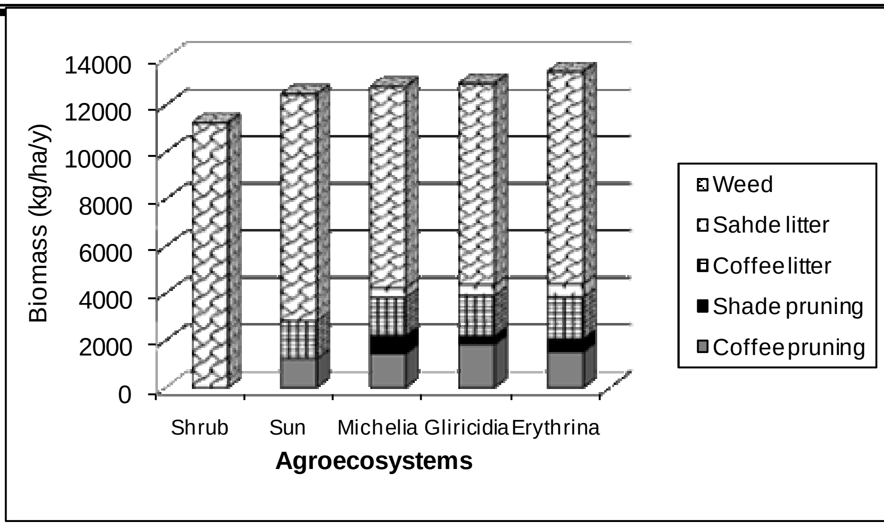

Figure 3. Biomass structure of young coffee agro-ecosystems

Figure 4 showed a remarkable difference of biomass structure between young and mature coffee agro-ecosystem. Even though weeding residues was still the major contributor of biomass production, it only contributed 31-35% biomass of shade-grown coffee. In open-grown (sun) mature coffee, weeding residues contributed 67% of biomass production similar as those of young coffee. Shading of coffee and shade trees could decrease weed biomass as reported by Evizal *et al*. (2009). Litter fall created dense mulch on the soil that could lower weed biodiversity (Berendse, 1999).

Another important biomass source was pruning residues which consisted mainly by wood component. In shade-grown coffee agro-ecosystems, it contributed 17-25% of biomass production or about 2-3 ton ha^{-1} year^{-1} of dried wood. It could meet annual household demand of firewood (Figure 4). In fact, shade-grown coffee was the main source of firewood for farmer household. Wood production (firewood and timber) may be increased by integrating more trees including timber tree (such as *Michelia*) in the systems to create coffee multi-strata systems (Peeters *et al*., 2003). Based on pruning residue, sun coffee yielded the lowest wood biomass production. While pruning residue of *Michelia* and *Gliricidia* shaded coffee were the highest (Figure 5).

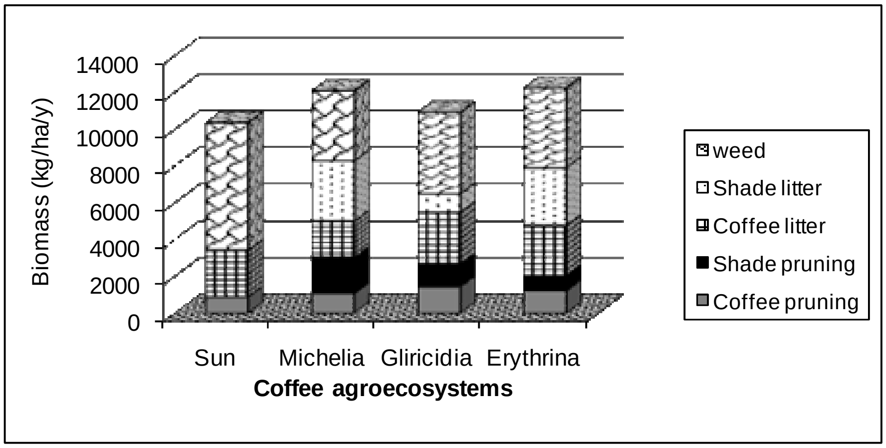

Figure 4. Biomass structure of mature coffee agro-ecosystems

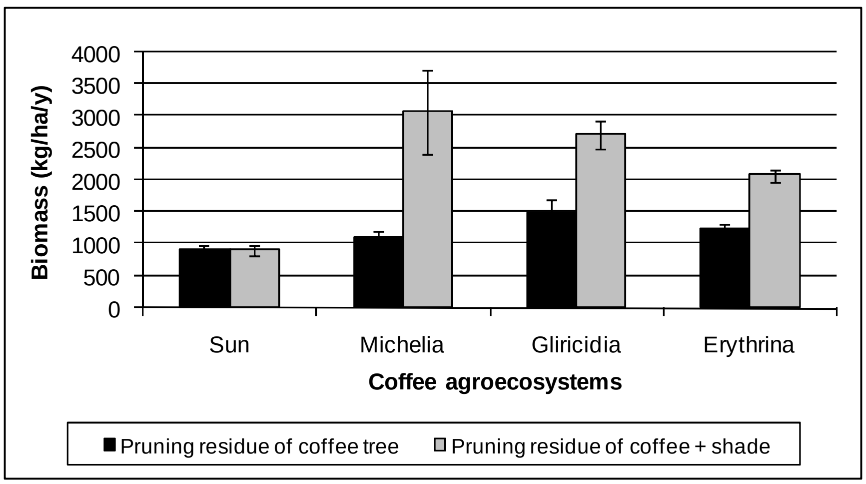

Figure 5. Biomass of pruning residues of mature coffee agro-ecosystems

Table 2 showed no significance of shade tree on biomass production. The production rate was about 10.4-12.2 ton/ha/year as reported by Beer (1998). Sun coffee produced high weed residue, while addition biomass from litter fall and pruning residue of shade trees followed by decreasing of weed residue. *Michelia champaca* provided higher biomass of litter fall and pruning residue than *Gliricidia* and *Erythrina*. In mature agro-ecosystems, harvested biomass of coffee bean was only 4-8% of total biomass production. Litter fall from shade trees were even bigger than that biomass export.

Table 2. Significance of shade tree and weed on biomass production

Biomass production (kg/ha/year)	Sun coffee	Shaded coffee		
		Michelia	*Gliricidia*	*Erythrina*
1. Litter fall of shade tree	0 c	3280.1 a	1019.3 bc	3144.6 ab
2. Pruning residue of shade tree	0 c	1965.6 a	1250.9 ab	831.8 b
3. Litter fall of coffee tree	2529.6 a	1959.6 a	2775.3 a	2704.9 a
4. Pruning residue of coffee tree	913.6 b	1104.8 ab	1468.6 a	1242.4 ab
5. Weed residue	6932.7 a	3975.1 b	4408.3 b	4326.0 b
6. Biomass production total (1+2+3+4+5)	10375.9a	12105.1a	10922.3a	12249.6a
7. Coffee bean yield	683,5 b	534,5 b	805,6 ab	987,5 a
8. Biomass export (7:6) (%)	6.59	4.41	7.37	8.06

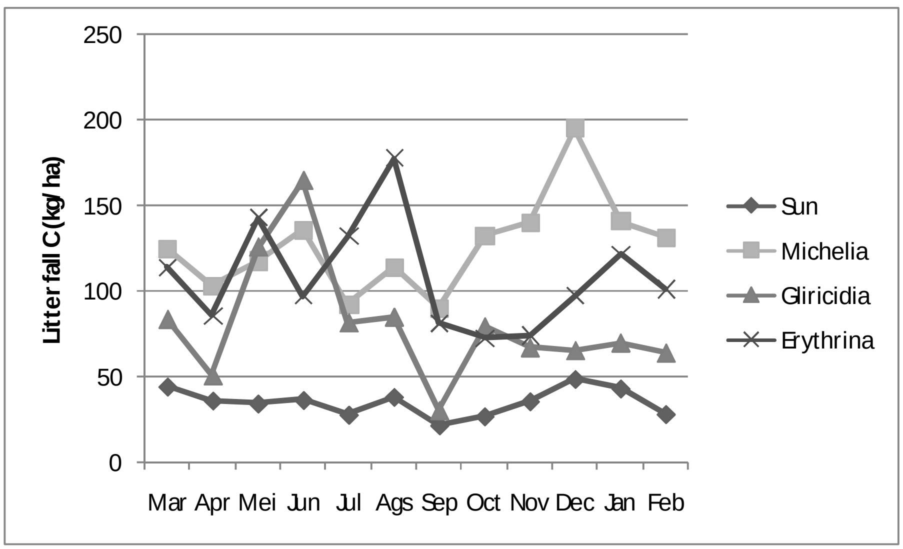

Figure 6. Monthly dynamic of C from litter fall

Litter fall was among the important source of carbon for soil living organism and C stock in the soil. Figure 6 showed the dynamic of litter fall C in monthly. As contributed only by coffee tree litter fall, sun coffee supplied the lowest C. While *Michelia* shaded coffee supplied the biggest C of litter fall except in the beginning of dry period when legume trees (*Erythrina* and *Gliricidia*) commonly shed all their leaves. Nevertheless, the total in a year, *Erythrina* and *Michelia* shaded coffee yielded the highest C of litter fall, while *Gliricidia* shaded coffee was in between (Figure 7).

Young coffee agro-ecosystem supplied significant higher C of weed residue then mature coffee (Figure 8). Among mature coffee, open-grown coffee agro-ecosystem contributed high C of weed residue similar to young coffee. Weed residue of young coffee and mature open-grown coffee supplied C even higher than litter fall.

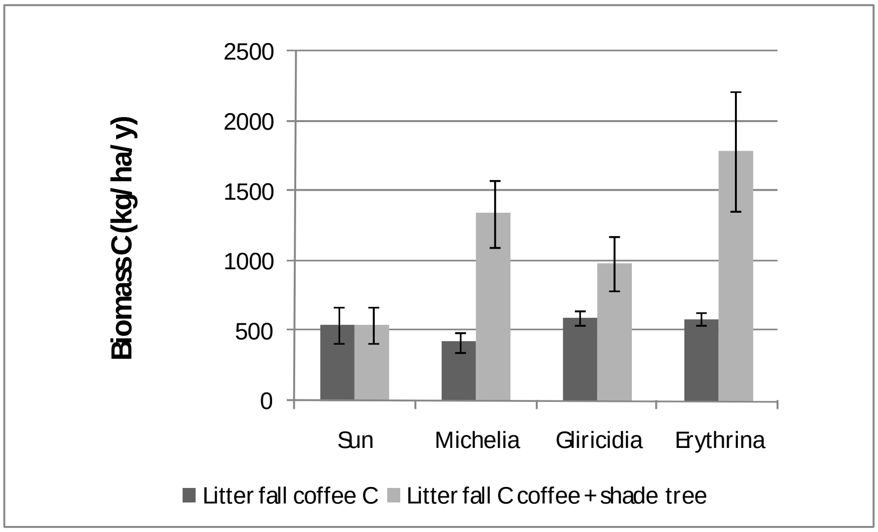

Figure 7. Total C of litter fall in mature coffee

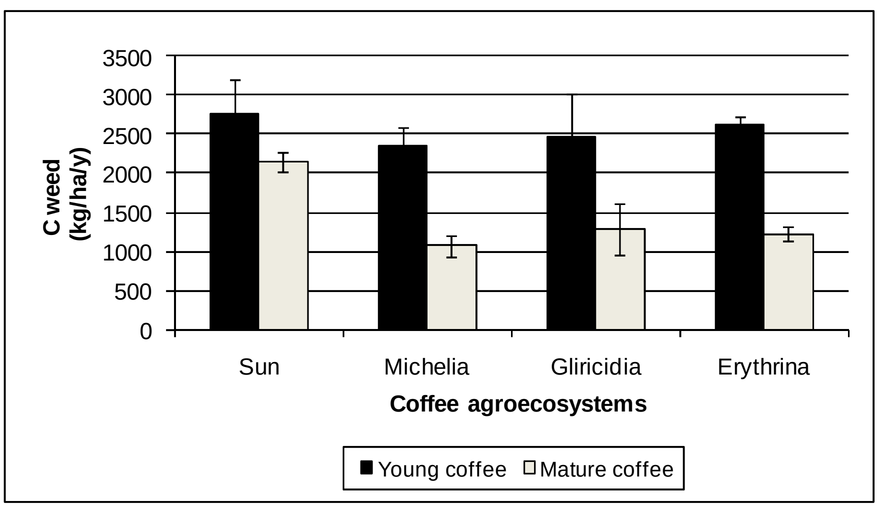

Figure 8. Total C of weeding residue young and mature coffee

4. Conclusion

(1) Based on total litter fall, pruning residue, and weed residue, shrub converting into sun coffee or technical shade-grown coffee agro-ecosystem would not significantly change biomass production but the biomass structure was changed.

(2) Weeding residue was still the major contributor of biomass production in young coffee agro-ecosystems and in mature open-grown (sun) coffee.

(3) In mature agro-ecosystems, harvested biomass of coffee bean was only 4-8% of total biomass production.

(4) Based on pruning residue, mature sun coffee yielded the lowest wood biomass production.

(5) Mature sun coffee supplied the lowest C of litter fall while *Erythrina* and *Michelia* shaded coffee yielded the highest C.

5. Acknowledgement

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