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Shade tree species diversity and coffee productivity in Sumberjaya, West Lampung, Indonesia

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Abstract. *Evizal R, Sugiatno, Prasmatiwi FE, Nurmayasari I. 2016. Shade tree species diversity and coffee productivity in Sumberjaya, West Lampung, Indonesia. Biodiversitas 17: 234-240.* Shade tree is an important variable that determines the productivity and sustainability of coffee plantation. In West Lampung, Indonesia coffee is grown on private land and on state land of Community Forest Program (CFP) using various types of shade trees. The research explored the diversity of shade trees and its influence on the productivity of coffee farms. The study area was one purposively sampled coffee farmer group in Sumberjaya District, West Lampung. We purposively chose one coffee farmer group. The group members' farms located in private land and in CFP land were sampled randomly, each consisted of 18 farms. From each farm, we observed a plot of 50 m x 50 m and interviewed the farmer who managed the farm. Data collected were on the species and the number of trees, farm age, coffee tree densities, and productivity of coffee in the last 3 years. Data analyses of important value, tree species diversity, correlation, and regression were performed. Shade trees found in coffee farms of Sumberjaya were 36 species, 10 species (28%) of them were legume trees. Technical shade trees that have high importance value were *Gliricidia sepium* and *Erythrina subumbrans.* Multi Purpose Trees Species (MPTS) widely planted were *Durio zibethinus* and *Parkia speciosa*. The wood trees with a high importance value in the CFP coffee farms were *Shorea javanica* and *Michelia champaca* while in private coffee farms were *Maesopsis eminii* and *Litsea* sp. Based on Shannon's index (H') and Simpson's dominance index (λ), a high diversity of shade tree species was found in CFP coffee farms at age ≥20 years. Shade trees with high dominance index had a positive effect on productivity of coffee and the percentage of MPTS had a negative effect. Whereas, the types of land tenure (private or CFP) and the abundance of shade trees did not affect the productivity of coffee.

Keywords: coffee, community forest, productivity, shade tree diversity

INTRODUCTION

Lampung Province is a center of the production of Indonesian Robusta coffee which is grown mainly in the mountainous region of Bukit Barisan (Philpott et al. 2008), including on private land and on the state land of Community Forest Program (CFP). As farmers participate in CFP must plant at least 400 trees per hectare, the CFP significantly increased planting of wood trees species and Multi Purpose Trees Species (MPTS) and also increased farmers' income (Pender et al. 2008).

Cultivating coffee under varieties of shade tree species is one of local wisdoms that have long been practiced in the District of Sumberjaya, West Lampung, Indonesia (Verbist et al. 2005). Understanding the diversity, characteristics and functions of shade trees as well as its strata is important in efforts to improve the sustainability of coffee agro-ecosystem (Mamani-Pati et al. 2012), and to improve biodiversity conservation (Lopez-Gomez et al. 2008) including to conserve native tree species (Tadesse et al. 2014).

Ecological functions of the shade trees in coffee agroforestry system are as environmental services, such as recycling nutrients (Lopez-Rodriguez et al. 2015), driving soil conservation (Lin and Richards 2007), improving growth, productivity, and quality of coffee (Bote and Struik 2011), and regulating biomass production (Evizal et al. 2009) including fire wood and timber as a source of alternative income (Shalene et al. 2014) and fodder for livestock production (Geta et al. 2014). Farmers realize those functions but decisions on shade trees management are more to keep the coffee production rather than reasons of environmental services (Cerdan et al. 2012). However, study on coffee agroforestry in Sumberjaya is important to support the conservation of water supply to the electric power plant of Way Besai (Pasha et al. 2012). Management of agroforestry systems in a sustainable manner requires conservation and proper management of MPTS strata (Tscharntke et al. 2011).

Shade trees in coffee plantations can be technical shade trees, wood trees, or MPTS. Determining the composition of shade trees is important to maintain the balance of the ecological functions and the coffee agro-ecosystem productivity (Tscharntke et al. 2011). Technical shade trees are legume trees planted on coffee plantations, not to harvest the yield but to provide shade for the coffee plants. In West Lampung, technical shade trees most widely grown are *Erythrina subumbrans* and *Gliricidia sepium* (Evizal et al. 2012).

CFP of coffee plantations in protected areas requires planting trees or MPTS that will affect the shade tree diversity and productivity of coffee plants under the shade. The research objectives were to explore the diversity of shade trees and its influence on the productivity of coffee plantations on private land and CFP land in District of Sumberjaya, West Lampung.

MATERIALS AND METHODS

Field study

We purposively chose one coffee farmer group in Sumberjaya District, West Lampung, Indonesia (Figure 1). The group members' farms located in private land and in CFP land were sampled randomly, each consisted of 18 farms. From each farm, we observed a plot of 50 m x 50 m and interviewed the farmer who managed the farm. Data collected were on the species and the number of the trees, farm age, coffee tree densities, and productivity of coffee in the last 3 years.

Data analysis

Data analyses of importance value, tree species diversity, correlation, and regression were performed. Analyses of Importance Value (IV) and diversity index are based on report of Sumantra et al. (2012). We calculated IV as sum of Relative Density and Relative Frequency and expressed diversity index based on the proportion (n/N) of individuals (n) of one particular species found (i) divided by total number of individuals found (N). The formula of Shannon-Wiener index of species diversity (H') is:

$$H' = -\sum_{i=1}^{n}\left[\frac{ni}{N}\right]\ln\left[\frac{ni}{N}\right]$$

We calculate Simpson's dominance index (λ) using formula (Morris et al. 2014):

$$\lambda = \sum_{i=1}^{n}\left[\frac{ni}{N}\right]^2$$

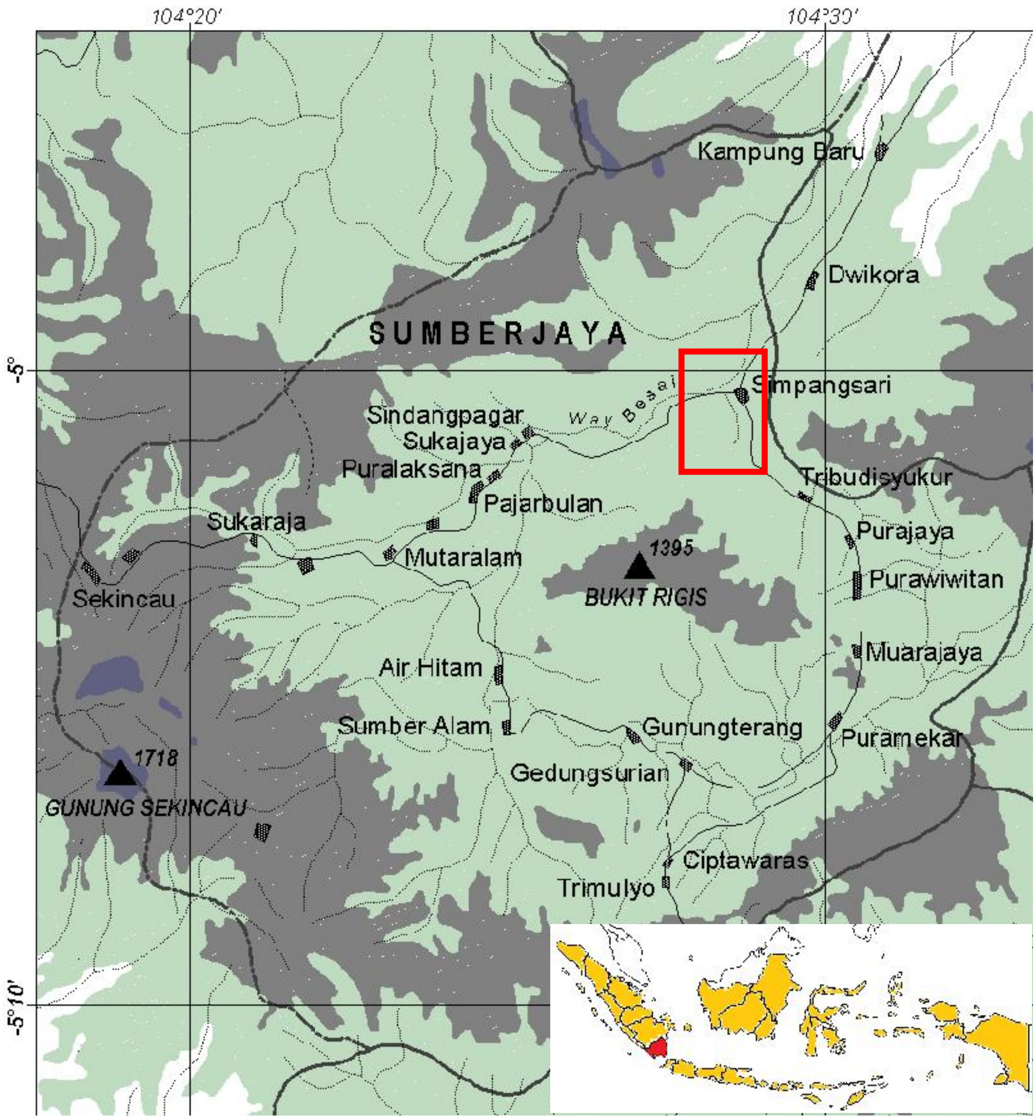

Figure 1. Study site in Sumberjaya, West Lampung, Indonesia (in red mark) (ICRAF in Pender et al. 2008)

RESULTS AND DISCUSSION

Importance value

Shade trees found in coffee farms of Sumberjaya were 36 species, 10 species (28%) of which were legume trees, namely *G. sepium* (gliricidia), *E. subumbrans* (coral trees), *Leucaena leucocephala* (lamtoro), *Dalbergia latifolia* (black rosewood), *Paraserianthes falcataria* (sengon), *Parkia speciosa* (petai), *Swietenia mahagoni* (mahogany), *Acacia* sp., *Archidendron pauciflorum*, and *Archidendron microcarpum*. CFP coffee farms had higher richness of shade trees with 31 species, whereas private coffee farms had 24 species. Comparing between coffee farms at age of <20 year and at age of ≥20 year, the density of shade trees increased from 97 to 160 trees in private coffee farms and from 276 to 350 trees in CFP coffee farms (Table 1). Technical shade trees species found in coffee farms were *G. sepium*, *E. subumbrans*, *L. leucocephala*, *D. latifolia*, and *P. falcataria*, but only *G. sepium* and *E. subumbrans* had high Importance Value. MPTS widely planted in coffee farms were *P. speciosa*, *Durio zibethinus* (durian), *Artocarpus heterophyllus* (jackfruit) and *Musa paradisiaca* (bananas). The wood trees with a high importance value in the CFP coffee farms were *Shorea javanica* and *Michelia champaca* while in private coffee farms were *Maesopsis eminii* and *Litsea* sp.

These results indicated that the shade trees commonly found in coffee farms in Sumberjaya were exotic species. Native tree species that had significant importance value in the CFP coffee farms were *D. zibethinus*, *Alstonia scholaris*, *Shorea* sp. and *S. javanica*. Trees of native species and exotic species were planted because it has economic value as an incentive (Ambinakudige and Sathish 2008), so that shaded coffee farms could serve as refugia for native tree species (Tadesse et al. 2014). In Sumberjaya, shade trees also functions as source of fodder from leaves of *G. sepium*, *E. subumbrans*, *P. falcataria*, *M. eminii*, *Litsea* sp., *M. champaca*, *A. heterophyllus*, *Artocarpus champeden* and *Persea americana*.

Tabel 1. Abundance and importance value (IV) of shade trees in private and CFP coffee farms

Tree species	Private (n=18)				CFP (n=18)			
	< 20 y		≥20 y		< 20 y		≥20 y	
	Tree ha^{-1}	IV	Tree ha^{-1}	IV	Tree ha^{-1}	IV	Tree ha^{-1}	IV
Gliricidia sepium	12.50	19.85	73.73	64.05	67.78	32.86	43.75	17.34
Erythrina subumbrans	6.67	13.80	14.54	21.09	7	8.78	9.75	7.62
Leucaena leucocephala	1.67	5.17	0	0	0	0	0.75	1.83
Dalbergia latifolia	0	0	0.27	2.17	0	0	7.75	7.05
Paraserianthes falcataria	0	0	0.91	2.57	0	0	0	0
Maesopsis eminii	12.5	23.30	6.64	10.15	0.22	2.164	1.25	1.97
Litsea sp.	14.5	21.92	3.45	6.16	3.33	3.29	0	0
Alstonia scholaris	0	0	8	6.99	0.67	2.32	25.62	12.16
Swietenia mahagoni	7.33	14.50	0	0	13	10.95	0	0
Michelia champaca	4	7.59	0	0	54.11	32.08	45.12	20.96
Tectona grandis	0	0	0	0	0	0	3.5	2.61
Shorea sp.	0	0	0	0	0	0	3.125	2.51
Cananga sp.	0	0	0	0	0	0	0.75	1.83
Toona sinensis	8.333	12.08	0	0	0	0	0	0
Acacia sp.	0	0	2.27	3.42	0	0	0	0
Shorea javanica	0	0	0	0	57.78	27.16	65	23.42
Parkia speciosa	3.333	6.90	7.73	12.83	18.44	19.17	21	14.07
Durio zibethinus	4.17	11.21	23.82	28.88	28.89	20.87	36.87	21.83
Artocarpus heterophyllus	2.33	12.76	6.09	13.8	4	7.70	7.12	10.10
Musa paradisiaca	11	21.74	6.27	11.92	2.22	2.89	6.25	5.01
Persea americana	0.33	7.24	0.73	4.45	2.78	5.17	5.75	8.09
Cinnamomum burmannii	0.50	3.97	0	0	0	0	5	3.04
Archidendron pauciflorum	0	0	4.54	4.84	8.22	13.39	1.87	3.76
Carica papaya	0.67	4.14	0	0	0	0	0	0
Areca catechu	4.667	8.28	0	0	0.89	2.40	5.12	4.69
Anacardium occidentale	2	5.52	0	0	0	0	0	0
Artocarpus communis	0	0	0	0	2.22	2.89	5	4.65
Aleurites moluccana	0	0	0	0	3.11	5.29	2.5	2.33
Mangifera indica	0	0	0.82	4.51	0	0	0.37	1.72
Artocarpus champeden	0	0	0.27	2.17	0	0	0.63	1.79
Hevea brasiliensis	0	0	0	0	0	0	42.5	13.76
Ceiba pentandra	0	0	0	0	0	0	0.75	1.83
Syzygium aromaticum	0	0	0	0	0	0	2.5	2.33
Gnetum gnemon	0	0	0	0	0	0	0.25	1.68
Archidendron microcarpum	0	0	0	0	1.11	0.40	0	0
Syzygium aqueum	0	0	0	0	0.56	0.20	0	0
Total	96.5	200	160.1	200	276.3	200	349.9	200

Tree composition

Types of shade trees consist of technical shade trees (legumes), wood trees, and MPTS. When comparing the composition of shade tree types, in the private coffee farms at age <20 years, the dominant shade trees are MPTS, especially bananas, whereas at age ≥20 years, the dominant trees are technical shade trees, especially *G. sepium*. This showed that in the initial opening of the coffee farms, farmers planted banana as a source of income and planted *E. subumbrans* as shade, then planted *G. sepium* trees while *E. subumbrans* grew old and died.

In the CFP coffee farms, the dominant shade trees are MPTS (Table 2). Cultivating coffee and MPTS in a protected area is legal under license of CFP. Farmers are allowed to harvest non-wood yield such as fruits, beverages, spices, resin, or latex to generate income. There is no incentive for farmers to plant wood trees in CFP land because farmers are not allowed to cut and harvest timber. Meanwhile, cultivating coffee and MPTS in state-owned forest of national park is illegal so that, as Phillpot et al. (2008) reported, there are more abundant MPTS in private coffee farm land than in illegal coffee farms of national park. In general, shaded coffee plantations have high number of tree species (Capitan et al. 2014) even more than in forest areas (Lopez-Gomez et al. 2008) that may have been disturbed.

The number of shade trees increases with the increasing of coffee tree age, which was shown by the ratio of shade trees to coffee tree (Table 2). Thus the carbon stocks of shaded coffee farms increases with the age of coffee and shade trees particularly in the farms at the age of 20 years and more. When the coffee trees grow larger and shade tree species increase in number and diversity, it will form a complex coffee agroforestry that shaded coffee plantations have a role in carbon sequestration (Goodall et al. 2014) and climate change mitigation (Mbow et al. 2014).

The private coffee farms of ≥20 years, with 51.8% of the shade trees are technical of legume shade trees, gave the highest productivity compared to the other types of coffee farms (Table 2). This indicated that the high coffee productivity was obtained when technical shade trees, especially legume tress, were established. Legume trees that serve moderate shade level, shed the leaves in the dry season which created conditions to encourage coffee flowering, and produced much litter biomass (Evizal et al. 2009).

Meanwhile according to farmers, some species of shade trees could harm the growth and productivity of coffee trees, especially those of MPTS including *Aleurites moluccana, Cinnamomum burmannii, Hevea brasiliensis, D. zibethinus* and those of wood trees including *M. eminii, Shorea* spp.*, M. champaca,* and *Litsea* sp. Some studies reported that the dominant shade tree species affect the growth and productivity of coffee (Kufa and Burkhardt 2011; Ebisa 2014). Farmers classify the effect of shade trees on the coffee plants as hot, medium, and cool. To choose shade tree species, they consider the shape of the canopy, litter production, rooting properties (Cerdan et al. 2012), nitrogen fixation, and the harvest of fruit or wood. Preferred tree species will dominate the composition of coffee shade trees (Valencia et al. 2015).

At the private land, higher Shannon diversity index of shade tree species was found in coffee farms at age of <20 years, while at the CFP land, higher Shannon diversity index was found in coffee farms at age of ≥20 years (Table 3). However, the diversity indexes were still classified as a medium diversity. The diversity index of shade trees found in private coffee farms at age of ≥20 years was <1 and categorized as low diversity (Maridi et al. 2014). Related to Simpson's dominance index (λ) and species richness, in the private coffee farms, the older the coffee farms the lower the diversity index of shade trees. On the contrary, in CFP land, the older the coffee farms the higher the diversity index of shade trees. These results indicated that the composition of shade tree was dynamic according to the knowledge and local wisdom of farmers to sustain productivity of coffee farm (Soto-Pinto et al. 2007). Sustainable coffee plantations are not only determined by the high diversity of flora and fauna as ecological indicators (Moonen and Barberi 2008), but also by the coffee productivity as an economic indicator. As further analysis, the relationship between the diversity index of shade trees and coffee productivity was approximated by correlation and regression analysis as shown at Tables 4 and 5.

Coffee productivity

There was a negative correlation (r = -0.57) between the shade tree diversity (Shannon's index) and the coffee production in CFP land. This meant that a high diversity of shade tree species could lead to lower coffee productivity. The same meaning was indicated by positive correlation of dominance index (r = 0,58), that a high dominance of shade trees species could induce higher coffee productivity. Meanwhile the productivity of coffee in the private farms and the diversity of shade trees showed a weak correlation.

There was a fairly strong positive correlation between the productivity of coffee and some variables including the percentage of technical shade tree (r = 0.60) and the percentage of legume shade trees (r = 0.48) in CFP land, and the age of coffee farms (r = 0.52) in private land. However, the productivity of coffee was negatively correlated (r = - 0.53) with the percentage of timber shade tree in CFP land.

It is clear that age of coffee trees affects its productivity (Potvin et al. 2005) and the increasing age of the coffee will decrease the density of shade trees (Goodall et al. 2014) if not being replanted. Regarding to shade tree diversity, it has been reported that in Guatemala, by using four species of shade trees, the coffee production reached 925 kg ha-1, while in Peru that uses 17 species of shade trees, the coffee production was 386 kg ha-1 (Rice 2008). As the dominant shade tree, the genus *Inga* has been widely reported as legumes that enriches the soil due to the accumulation of biomass (Siles et al. 2010) and symbiosis with legume nodule bacteria. Therefore, the legume trees were widely used in the farm of organic coffee (Grossman et al. 2006).

Table 2. Shade tree composition and coffee productivity

Land tenure	Coffee age	Technical shade tree (% ha^{-1})	Wood trees (% ha^{-1})	MPTS (% ha^{-1})	Ratio shade/coffee (% ha^{-1})	Coffee productivity (00 kg ha^{-1})
Private	< 20 year	25.285	24.579	50.135	4.290	6.93
	≥20 year	51.867	18.575	29.556	7.424	11.06
CFP	< 20 year	27.201	23.934	48.864	14.193	7.47
	≥20 year	14.919	29.717	55.363	16.358	7.37
Average		32.73	23.50	43.76	10.86	8.52

Table 3. Diversity index of coffee shade tree species

Land tenure	Coffee age (year)	Shannon-Weiver Index (H')	Simpson's dominance Index (λ)	Species richness
Private	< 20 years	1.3052	0.3184	4.6666
	≥20 years	0.8229	0.4162	4.5454
CFP	< 20 years	1.1547	0.4242	5.5555
	≥20 years	1.4454	0.3510	7.7500

Table 4. Correlation among variables on coffee productivity in private and CFP farms

Variables		Coffee productivity	
		Private	CFP
Shade tree	Shannon's index (H')	-0.0177	-0.5688
	Dominance index (λ)	0.0721	0.5779
	Species richness	0.0455	-0.3870
	Abundance	0.0873	0.2646
	Technical shade tree (%)	0.1661	0.5955
	Wood tree (%)	0.1628	-0.5348
	MPTS (%)	-0.3960	-0.1479
	Legume tree abundance (%)	0.1306	0.4778
Coffee tree	Density (tree ha-1)	0.3483	0.2791
	Age (year)	0.5234	-0.0898

Table 5 presented the regression analysis of variables dominance index, the percentage of MPTS, type of land tenure, and the number of shade trees on the productivity of the coffee farms. Table 3-4 earlier showed that based on Shannon Index (H') and species richness, the highest diversity of shade trees was found in the CFP coffee farms aged ≥20 years. Moreover, in the CFP coffee farms, dominance index (λ) and the percentage of technical shade trees positively correlated to the coffee productivity. Likewise, Table 5 showed that the dominance index had a positive effect on productivity of coffee and the percentage MPTS had a negative effect. The type of land tenure (private or CFP) and the abundance of shade trees did not affect the productivity of coffee. In general, this indicates that the dominance of shade trees or technical shade trees such as *G. sepium, E. subumbrans*, *L. leucocephala*, *D. latifolia*, and *P. falcataria* had positive effect on the productivity of coffee. On the contrary, the higher the percentage of MPTS resulted in the lower the coffee productivity.

In private coffee farms the average density of shade trees was 135 trees ha^{-1}, and in the CFP coffee farms was 310 trees ha^{-1}. That could be included as medium density of shade trees based on farmers' norm on new planting of coffee in farms in Sumberjaya Sub-district (density < 100 trees = low, 100-400 = medium, >400 = high). Rice (2008) reported that dominant shade of legume tree had a positive influence on coffee productivity. However, Ebisa (2014) reported that both legume and non-legume species of shade trees had less significant effect on the productivity of coffee. Shade trees could decrease or raise the productivity of coffee or could have no effect (Shalene et al. 2014)

Table 5. Regression analysis of some variables on coffee productivity

Variable	Coefficient	Std. Error	t calc.	Significance
Constantan	0.8584	0.2331	3.68254	0.00094
Dominance index (λ)	0.8104	0.4711	1.72037	0.09602*
% MPTS	-0.6018	0.3267	-1.84184	0.07575*
Land tenure (private vs CFP)	-0.2258	0.2027	-1.11397	0.27444
Shade trees abundance	0.0003	0.0007	0.34125	0.73538
R^2	0.263			
F calc.	2.581			
Significance of F calc.	0.058			

Note: * Significant at level α 10%

depending on the species of shade trees (Long et al. 2015), the density and diversity of shade trees (Schmitt et al. 2009), shade tree structures (Hernandez-Martinez et al. 2009), fertilization, variety and age of coffee (Potvin et al. 2005). The characteristics of trees that serve optimal shade, fertilize the soil, and provide additional products would affect the farmers in selecting the species of shade trees to plant in coffee farms (Kalanzi and Nansereko 2014).

In conclusion, shade trees found in coffee farms of Sumberjaya were 36 species, 10 species (28%) of which were legume trees. Technical shade trees that have high importance value were *G. sepium* and *E. subumbrans.* MPTS widely planted were *D. zibethinus* and *P. speciosa*. The wood trees with a high importance value in the CFP coffee farms were *S. javanica* and *M. champaca* while in private coffee farms were *M. eminii* and *Litsea* sp. Based on Shannon's index (H') and Simpson's dominance index (λ), a high diversity of shade trees species was found in CFP coffee farms at age ≥20 years. Shade trees with high dominance index had a positive effect on productivity of coffee, and the percentage of MPTS had a negative effect. Whereas, the type of land tenure (private or CFP) and the abundance of shade trees did not affect the productivity of coffee.

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