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Agroforestry system biodiversity of Arabica coffee cultivation in North Toraja District, South Sulawesi, Indonesia

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[2] Faculty of Forestry, Universitas Mulawarman Jl. Ki Hajar Dewantoro PO. Box 1013, Gunung Kelua Samarinda Ulu, Samarinda 751116, East Kalimantan, Indonesia. Tel.: +62-541- 735089, Fax.: +62-541- 735379, ♥♥email: prof_abudir@yahoo.com; ♥♥♥ yruslim@gmail.com

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Abstract. *Lisnawati A, Lahjie AM, Simarangkir BDAS, Yusuf S, Ruslim Y. 2017. Agroforestry system biodiversity of Arabica coffee cultivation in North Toraja District, South Sulawesi, Indonesia. Biodiversitas 18: 741-751.* Sustainable coffee plantation emphasizes the concept that is able to provide services that can improve the quality of the environment and the ecosystem as a conservation efforts. Arabica coffee plants do not need full sunlight that they are planted according to agroforestry system which covers simple mix system to complex system such as forest. Shade tree has a very big role in sustainable coffee agro-ecosystem and become one of the conditions in the world's coffee certification. This study aimed to analyze the role of shade trees lamtoro types (*Leucaena glauca*), and calliandra (*Calliandra calothyrsus*) used by companies as an agroforestry systems on coffee cultivation in North Toraja located at an altitude between 1050-1250 m above sea level, this study was conducted from January to December 2016. Result of the study suggests that the shade trees lamtoro and calliandra influence the amount of sunlight intensity that reaches coffee plant. The shaded and unshaded coffee plants received different sunlight intensity of every minute with a coefficient of determination R^2 = 0.98 for unshaded and R^2 = 0.89 for under the shade of calliandra, with a diameter growth increased 7.8% $year^{-1}$, increase growth (riap) diameter decreased 2% $year^{-1}$. Cherry increased growth of 13.5% $year^{-1}$ with an average weight of 3.81 g $beans^{-1}$,while for the effect of lamtoro, the coefficient of determination is R^2 = 0.98 for unshaded and R^2 = 0.91 for under the shade. The percentage of light intensity outside and under the shade obtained from a 17 year coffee plant is on average of 58% for the types of tree of calliandra, while for lamtoro the average is of 72.5%, diameter growth of coffee tree in under shade lamtoro by 7.4% $year^{-1}$ and increase of growth (riap) diameter decreased by 2.5% $year^{-1}$, cherry growth increased by 13.3% $year^{-1}$ with an average weight of 3.92 g $beans^{-1}$. In addition to that, shading also affect the surrounding nutrient soil and maximum production of coffee is achieved at the age 17 years i.e. an average of 1.50 kg $tree^{-1}$ for a shaded tree calliandra species and 1.35 kg $tree^{-1}$ for lamtoro species.

Keywords: Agroforestry, Arabica coffee, lightintensity, shade tree

INTRODUCTION

South Sulawesi is a province rich with abundant natural resources that support the livelihood of farmers, such as through plantation crops produce. One of plantation crop commodities that play a pivotal role in the economic growth is coffee. Coffee, despite not being an indigenous plant of Indonesia, plays an important role in the nation-wide plantation industry. North Toraja District is the center of Arabica and Robusta coffee plantations cultivated by local people, domestic and overseas companies or by joint ventures between local people and company to form coffee plantation by clearing the forest or converting forest into a coffee plantation. These actions cause declining in forest area; land conversion from forest to coffee plantation or other agricultural systems will cause changes in environmental condition in the surrounding area, primarily hydrological function, soil fertility, carbon deposits, and biodiversity; causing deranged forest function. Therefore, wisdom values in utilizing natural resources are very important. It is particularly important, empirically because one of the most alarming crisis phenomena is a condition at which natural resources unwisely exploited. Thus, to achieve a sustainable forest management in society is not only requiring the awareness of local society but also considering the calculation of business cost and a more precise analysis, in order to maintain forest function (Muliadi et al. 2017).

Sustainability of coffee plantation business by people or firm is an important matter, and an effective and efficient strategy for agricultural ecology intensification (Dore et al. 2011), considering the importance of coffee as a plantation product or commodity in national economy, as shown by its role in providing job opportunity and foreign exchange through export. The desired coffee plantation is the one that provides an increasing crop produce and serves to remediate the environment. The use of shade trees with agroforestry system can function ecologically as a provider of nutrition (Lopes-Rodriguez et al. 2015) and firewood as an alternative additional income source (Shalene et al. 2014). Shade trees grown on coffee plantation can function as an incoming light attenuator for the coffee plants and a source of wood. Thus, the determination of composition is critical to maintaining the balance of ecological function and productivity of coffee agroecosystem (Kitai and Lahjie 2016). The sustainable coffee agroecosystem is the basis for the initiation of coffee certification. Shade trees are crucial for the development of a sustainable coffee agroecosystem and become the foundation upon which coffee certification initiative commencement. Coffee shade trees are the mean to conserve biodiversity in the tropical area, despite the extensification of coffee cultivation contributes to deforestation and loss of biodiversity (Ebisa 2014). Coffee cultivation using shade trees has been long utilized by the people or plantation company in North Toraja region. Agroforestry system applied on coffee plant with shade trees is a promising alternative to improve agricultural system (Cerdan et al. 2012) and as an effort to support the livelihood of local people in rural and remote area; it also functions to conserve biodiversity (in simple agroforestry system, understanding of characteristics, diversity and function of shade trees are necessary to improve the sustainability of coffee agroecosystem (Mamani-Pati et al. 2012). Measuring incoming light intensity is also an absolute requirement to understand the effect of shade trees on plant productivity underneath.

Land conformity of a coffee plant is highly influential to plant growth, primarily microclimate condition around the coffee plant. Shading in coffee cultivation acts to control micro climate for an optimal coffee growth (Soedrajad 2013). In addition, a coffee plant does not require direct illumination (100%), thus coffee plant cultivated with agroforestry system is done by planting shade trees such as tiger's claw tree (dadap), white lead tree (lamtoro), albizia (sengon), calliandra, etc. Different shade trees will also give a different light intensity that affects plant physiological and morphological factors, as well as affecting plant production (Sholikha et al. 2015). Shade trees for coffee plant cultivated using agroforestry system will have ecological functions, i.e., to serve the environment by recycling nutrition (Lopez-Rodriguez et al. 2015). Shade tree functions in serving the environment for coffee agroecosystem as an agroforestry system (Jose 2009), such as the falling brown waste from shade trees constitute an important source of nutrient for coffee agroecosystem, producing and regulating biomass production (Evizal et al. 2009), improving the coffee bean yield and quality (Bote dan Struik 2011). Shade trees provide many benefits, i.e. (i) Increasing soil organic material and nutrient through brown waste or through nitrogen fixation if the shade is a legume, (ii) Reducing soil loss from erosion, (iii) building up carbon, (iv) improving biodiversity function as well as suppressing weed growth (Tscharntke et al. 2011).

Research about the effect of shade trees used for coffee cultivation on coffee plant growth and productivity has been widely conducted. Nevertheless, the result of those studies cannot be generalized for all region since each study location has different environmental characteristics. Therefore, this study aim to see and observe the used shade, received light intensity as well as their effect on nutrient and Arabica coffee production.

MATERIALS AND METHODS

Study area

North Toraja is one of district in the province of South Sulawesi, Indonesia which is famous for its Arabica coffee. The research was conducted at coordinate 03°01’04,7” - 03°01’13,2” N dan 119°58’25,3” - 119°59’44,9” S (Figure 1) from January until October 2016. The location altitude was between 1050-1250 m above sea level, relative humidity (RH) 75-90% and temperature 26-29°C. Annual average precipitation for the last 10 years (2005-2015) was 3466 mm. The precipitation data is visualized in Figure 2. Location selection was done by purposive sampling on 17-year-old coffee plants, direct variables measured in this study including light intensity, soil, and production of model coffee plants shaded by lamtoro (*Leucaena glauca)* and calliandra (*Calliandra calothyrsus*) trees, in 5-hectare areas. Meanwhile, plots of other plant ages were obtained as a secondary data from the company.

Procedure

Determining plot sample for calliandra and lamtoro: 10 total plots, with total plot area 10 ha, each plot has 1 ha area, and within each plot, there were 5 observation points. Each plot was divided into 5 points with diagonal pattern (Figure 3), and 40 m distance between each point. Light intensity measurement was conducted from 06: 00-18: 15. The light intensity measuring instrument was positioned above the coffee plant and beneath the shade trees (2-3 meters). The measurement was done every 15 minutes interval by using Lux meter KW06-291 Krisbow. Location coordinates were determined by using GPS instrument.

Data collection

Observations on biophysics condition of the Arabica coffee cultivation consist of shade type, shade biomass, soil macronutrients beneath the shade, and coffee bean yield as well as the type of conducted activity and coffee production data. Light intensity measurement was carried out beneath and outside the shade. For measurement beneath the shade, there were 5 points per hectare, at each point measurement was conducted every 15-minute interval from one point to another point. As for measurement outside the shade, there was only one measurement point at the top position located nearby the plot. Thereafter, calculation of light intensity percentage was done. To calculate the falling brown waste matter from the shade trees and coffee plants, 9 liter trap in the form of 5 x 5 m paranet was set. Soil sampling was done around the light intensity measurement point by using soil bore in the depth of 0-35 cm, soil samples taken from several plots were then composited and analyzed for their macronutrients at the laboratory of soil and water, Samarinda State Agricultural Polytechnic Institute.

The literature review was done by studying literature and reports from agencies associated with coffee plant cultivation in North Toraja District, as well as conducting in-depth interviews and group discussions with on-site company and workers of Arabica coffee cultivation in research location.

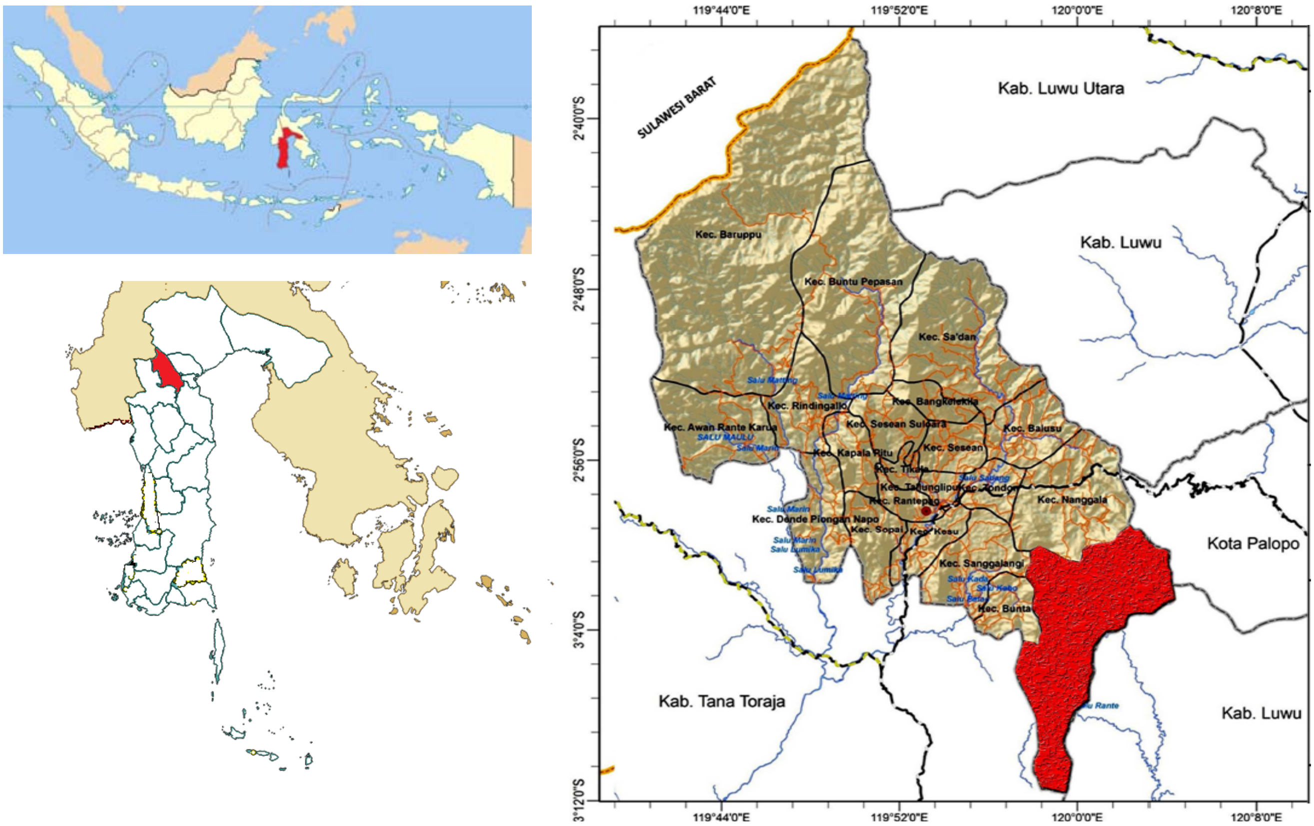


Figure 1. Research location at Pedamaran Village, Rantebua Subdistrict, North Toraja District, South Sulawesi Province, Indonesia

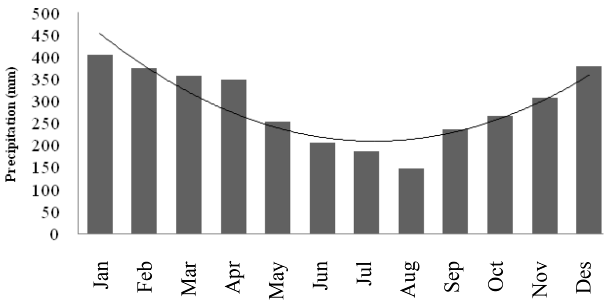


Figure 2. Annual average precipitation for the last 10 years (2005-2015) in Pedamaran, Rantebua, North Toraja, South Sulawesi, Indonesia

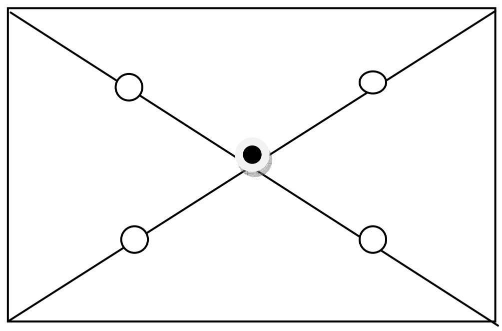


Figure 3. The pattern of light intensity measurement points by using lux meter instrument

Data analysis

Data analyses including:

Light intensity percentage value (%) of each plot was calculated by using formula:

$$\text{Light intensity} = \frac{A}{B} \times 100\%$$

A = ight intensity above the coffee plant canopy (beneath the shade)

B = full light intensity (outside the shade)

Analysis of maximum coffee bean yield was done based on measurement time interval (cycle) by calculating average annual production *average product* (AP) and *marginal product* (MP) van Gardiningen et al. (2003).

$$AP = \frac{Pt}{t}$$

AP = average annual production (average product)
Pt = total production at age t
t = age

$$MP = \frac{P_t - P_{t-1}}{T_t - T_{t-1}}$$

MP = Annual on-going production (marginal product)
P_t = total production at age t
P_{t-1} = total production at age t-1
T = measurement age at year 1

RESULTS AND DISCUSSION

The coffee plant is a C_3 plant whose cultivation does not require full sunlight illumination, there by necessitating shade trees. Shade trees for a coffee plant can be varied and consisted of higher tree species (Capitan et al. 2014), but in this study shade trees used were Calliandra (*Calliandra calothyrsus*) dan lamtoro (*Leucaena glauca*). Farmer chose a leaf-and-twig-dense tree, by taking into consideration the shape of canopy production, brown waste, root property, nitrogen fixing property, as well as fruit and wood yield (Cerdan et al. 2012). Shade trees generally used for the coffee plant is legume tree such as dadap (*Erythrina sububrams*), gamal (*Gliricidia sepium*) dan lamtoro (*Leucaena glauca*). Many of organic coffee plantation using legume as shading trees were found in Indonesia. In Sumberjaya Lampung, Indonesia, 10 species out of 36 tree shade tree species belong to the legume family, such as *Gliricida sepium, Dalbergia latifolia, Paraserianthes falcataria, Parkia speciosa, Acacia* sp., *Archidendron pauciflorum* and *Archidendron microcarpum* (Evizal et al. 2016).

Shade trees used in Arabica coffee plant cultivation differ from one site to the others because each region has different climate and environment characteristics. Planting shade trees is one of the ways to achieve desirable environmental for growing the coffee plant. This method has been used in some countries including Ethiopia which cultivating its coffee plant under shading condition (DaMatta et al. 2007). Utilization of shade tree in Arabica coffee plantation will reduce light intensity received by the plant, thus causing changes in temperature and humidity around the plant area.

A shade tree is highly influential for coffee seed growth, in addition to climate, soil condition, seed superiority and immunity against disease. Shade trees are really necessary for the coffee plant to alleviate the detrimental effects of high-intensity sunlight irradiation and to lengthen economical age of a plant. A shade tree will attenuate sunlight intensity received by the plant (Marino et al. 2016). Each plant will require a certain range of light intensity from the sun to be able to conduct a maximum photosynthesis. Thus, shading aims to provide a desirable light intensity for such photosynthesis process. In addition, the nutrient also plays a pivotal role for coffee plant growth and productivity. Since coffee plant does not require a direct sun illumination, thus it is highly suitable to apply a coffee plantation scheme based on agroforestry system. Shade tree pruning is done once every 3.5 years, there after pruning is done every year. When the plant is still young, a relatively high shading intensity is provided. Shading intensity is then gradually reduced as the coffee plant grow older, or depend on the various growing factor. The older the coffee plant age, the higher the light intensity given (for a 4-8-year-old plant, the received light intensity is around 30-40%), at the age of 4-13 years, the light intensity is about 46-55% and 56-89% for plant above 13 years. Shading level required by coffee plant differ according to phase and growth requirement of the plant. At seeding phase or young age, the required shading level is higher than that of adult phase or generative growth phase (Arif et al. 2011). Sunlight intensity dynamics of calliandra and lamtoro shade trees can be seen in Figure 7 dan Figure 8.

Observation results of light intensity measurement done for 4 months starting from April, July, October, and January on coffee plants beneath 17-years-old calliandra or lamtoro shade showed a different perception in light intensity. According to the measurement under calliandra shade, the light intensity received by shaded and non-shaded coffee plants differed in every minute and the data showed represented observation conducted on each shade at the same time. The coefficient of determination of the light intensity in non-shaded Arabica coffee plant was R^2 = 0.98, while that of the shaded plant was R^2 = 0.89 (Figure 7). Similarly, in the lamtoro-shaded group, the coefficient of determination of the light intensity in the non-shaded coffee plant was R^2 = 0.98, meanwhile, that of the shaded plant was R^2 = 0.91. These result meant that the determination was positive with a very strong correlation,

Figure 4. Arabica coffee plants and their shade trees

Figure 5. Calliandra *(Calliandra calothyrsus)* shade tree (tree, leaves and flower form)

Figure 6. Lamtoro (*Leucaena glauca*) shade tree (tree, leaves and flower form)

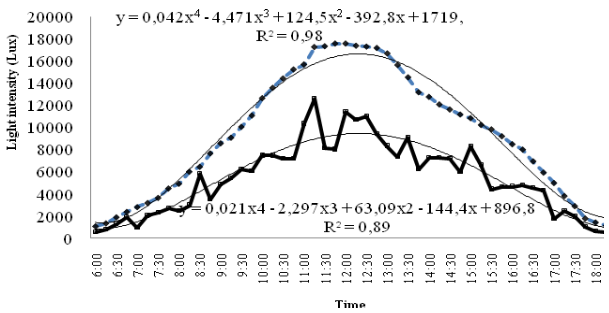


Figure 7. Light intensity on calliandra (*Calliandra calothyrsus*) shading

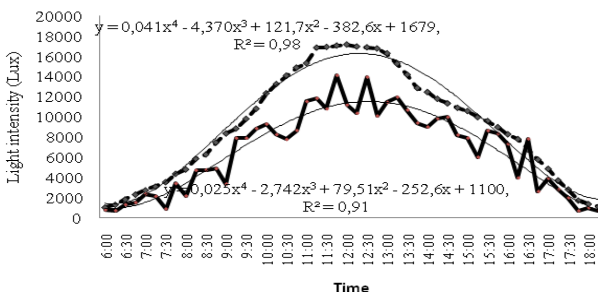


Figure 8. Light intensity on lamtoro (*Leucaena glauca*) shading

in other words, there is a correlation between light intensity (Y) with time, as the time progressing the light intensity become increasingly higher, and vice versa. However, there were other factors that can affect the perceived light intensity, such as, canopy area, wind blow, etc. Calliandra and lamtoro shade differ in size and leaf as well as canopy size, causing different light intensity passed down to the Arabica coffee plants. Long et al. (2015) suggested that change occurred in light perceived by coffee plant shaded by durian (*Durio zhibethinus*), jati cina (*Alexandria senna*), and lamtoro in which light intensity in lamtoro shading was bigger than those in durian and jati cina trees.

A few conducted studies showed that the utilization of shade trees on coffee plant cultivation will give certain effects on biotic and abiotic factors, such as temperature, humidity, and the wind (Jaramilo et al. 2013; Marino et al. 2016). While, the measurement of average light intensity comparison received by Arabica coffee plant under and outside calliandra shade was 58% (5419 lux), on lamtoro measurement, the light intensity was 72.5% (6590 lux) (Figure 9), the light intensity under the shade had a different light intensity movement for each minute. Shading level is closely related to the light intensity, whilst light intensity is closely related to plant photosynthesis and stomatal activity. The received light intensity described above is estimated to be sufficient for the coffee plant to carry our photosynthesis, a process of organic compound formation from inorganic material in a plant which occurs with the energy from light. As previously described by Sobari (2012) that desirable light intensity is ranged between 40% to 70%. The light that passes down under the calliandra and lamtoro shade can be utilized as optimum as possible for flowering and fertilization of coffee plant. Higher sunlight intensity and temperature received by the plant in coffee plantation area will affect net carbon assimilation, and in turn, will decrease photosystem II efficiency and stomatal conductivity. In coffee plant photosynthesis, light quality and quantity hold a very important role (Parwoto 2007;Charbonnier 2013).

Coffee plant exposed to high light intensity will cause a bigger energy loss compared with energy used for photosynthesis activity. The difference in light intensity will affect photosynthesis yield. Temperature increase around a coffee plant will affect CO_2 and O_2 levels around leaf surfaces. According to Mayoli and Gitau (2012), higher temperature and excessive light intensity also cause the breaking of O_2 from H_2O, making more O_2 molecules more abundant on leaf surfaces than CO_2. This in turn, will cause photorespiration, leading plant to lose the energy for its growth. Photorespiration does not produce energy beneficial for the plant. Thus, one of the efforts to repress photorespiration rate and to increase productivity is to utilize shade trees. High light intensity cause temperature increase around the plant, especially on the surface of the coffee plant. Excessive sunlight intensity and its uneven distribution will interfere with growth and developmental processes into flowering and fertilization. Geromel et al. (2008) suggested that sucrose and sucrose-phosphate synthesis activities are apparently higher on the shaded coffee plant compared with that of without shading (full sunlight irradiation). Reduction in photosynthesis yield will also inhibit coffee plant growth and development, including fruit formation.

A difference in shading type usage for a coffee plant can cause different physiological responses on the plant. Shade trees or awning can control the incoming sunlight intensity needed by the coffee plant for flowering and fertilization. Coffee plant growth and development is also affected by shading condition (Muliasari 2016). Shade trees also play an important role in the sustainable agroecosystem of coffee plantation by performing soil conservation endeavor through shade trees and brown waste management (Vaast et al. 2008; Evizal et al. 2010). Shade trees also remediate environment by providing nutrients (Lopez-Rodriguez et al. 2015). Biomass and nutrient analyses on Arabica coffee cultivation using agroforestry system with calliandra and lamtoro shadings can be seen in the Figure 10.

The biomass and brown waste matter production increased as the tree grow older. Meanwhile, tree productivity was depended on shade tree type. Calliandra and lamtoro are legumes which regularly shed their leaves in the dry season that occur on May-September and there is still a low-intensity rain occurred (6-7 days per month). Annual productivity of brown waste matter from shade tree and its monthly dynamics pattern depended on the shade tree type (Evizal et al. 2009). Lamtoro tree is a type of

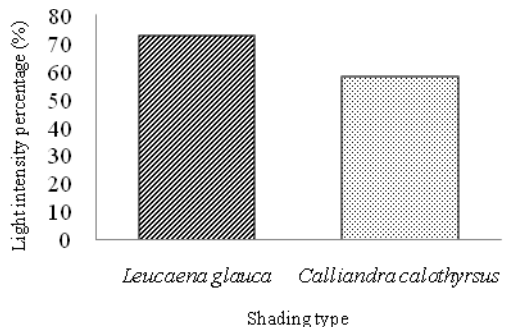


Figure 9. Light intensity percentage on calliandra (*Calliandra calothyrsus*) and lamtoro (*Leucaena glauca*) shading types

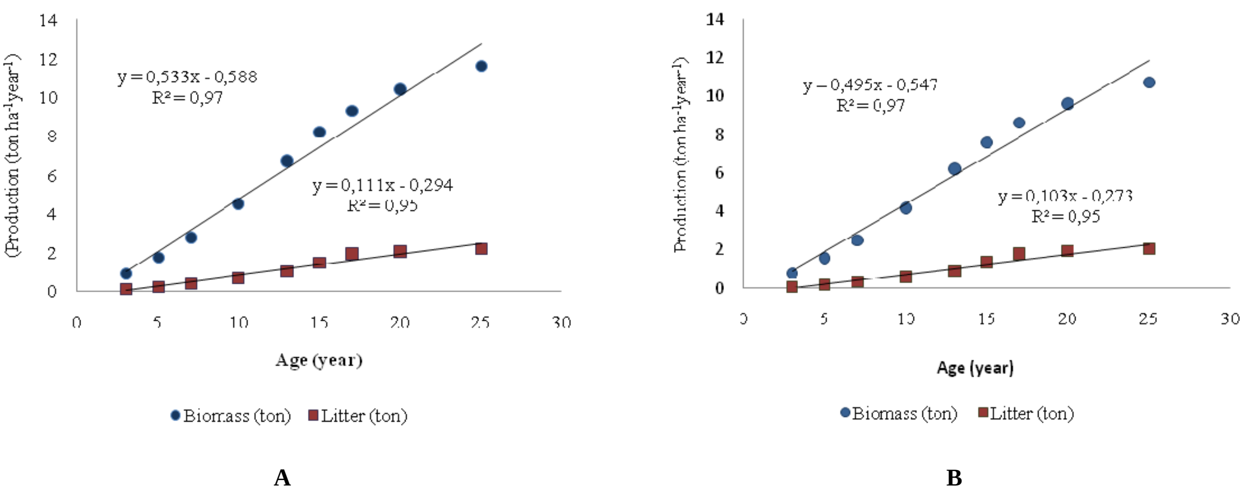


Figure 10. Biomass and brown-waste matter on: A. Lamtoro (*Leucaena glauca*), B. Calliandra (*Calliandra calothyrsus*) shadings

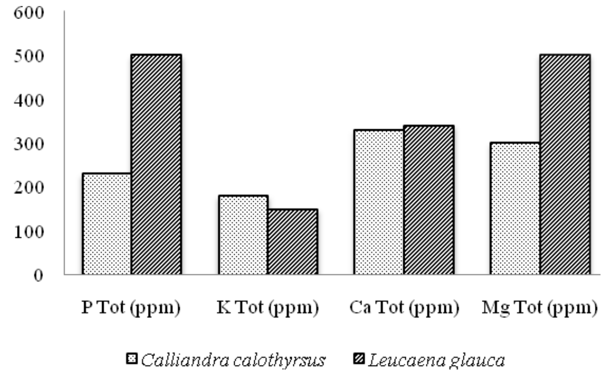


Figure12. Macronutrients on calliandra (*Calliandra calothyrsus*) and lamtoro (*Leucaena glauca*) shadings

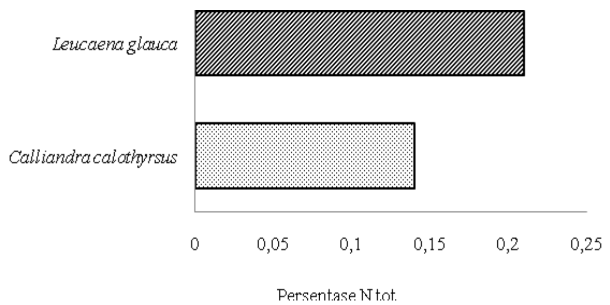


Figure 13. Total N content on calliandra (*Calliandra calothyrsus*) and lamtoro (*Leucaena glauca*) shadings

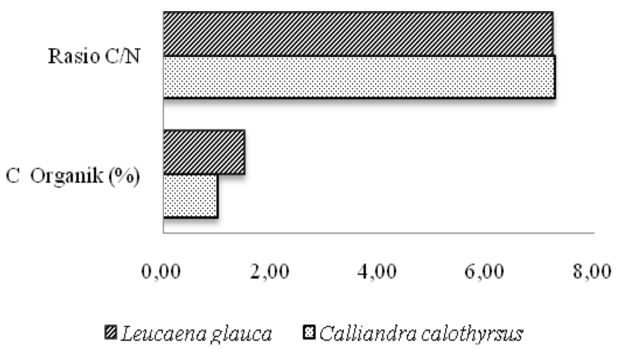


Figure 14. Macronutrients content on calliandra (*Calliandra calothyrsus*) and lamtoro (*Leucaena glauca*) shadings

legume that shed almost all of its leaves in dry season. The fallen brown waste matter of the tree is important in contributing nutrients, especially nitrogen to replace nutrient loss during coffee bean harvest. Thus, coffee agroecosystem with shade trees generally requires lower fertilizer input than that without shade tree.

Calliandra and lamtoro shading produce a lot of macro- and micro-nutrients needed by coffee plant and one factor that determine the successful coffee plant cultivation as well as the sustainability coffee cultivation in improving the environment for coffee agroecosystem using agroforestry system (Jose 2009). Agroforestry is an alternative form of land utilization consisting of hard plants mix (trees or shrubs) with or without perennial plants. Thus, agroforestry is a proposed means to conserve biodiversity, food production, and provide other ecosystem services such as climate change and carbon deposit (Beenhouwer et al. 2016; Wiryono et al. 2016). Agroforestry can be considered as land sharing strategy to conserve biodiversity and increase agricultural production (Fischer et al. 2014) and as an endeavor to reduce the CO¬2¬ level in the atmosphere, in the light of carbon provision in the atmosphere in agricultural land (Hergoualc’h et al. 2012).

Shade trees as brown waste producer and source of organic material in coffee plantation which are obtained from fallen and pruned leaves. Lamtoro (*Leucaena glauca*) shading contributes the total P and Mg more than those of calliandra shading. Evizal et al. (2009) reported that shade trees affect the structure of brown waste structure produced by a mature coffee agroecosystem. Shade trees as brown waste source plays an important role in sustainable coffee plantation system, since they are associated with provision of nutrient cycle and suppression of soil erosion (Sepulveda and Carillo 2015) apart from their function as a regulator to create microclimate condition able to adapt to climate change suitable for coffee plant growth and development because climate change affect the produced coffee bean (Craparo et al. 2015). Shade plants also function to maintain ecological balance and soil nutrition and to provide macro nutrition to the coffee plant cultivation with agroforestry system (Soedrajad 2013).

A shade tree is one of a crucial subsystem to recover nutrient cycle in a coffee plantation and gives a positive impact toward soil fertility by increasing the input of organic materials and increasing soil N availability. N element is critical for the vegetative growth of a coffee plant, including fruit branch formation, thus potential to be more fruitful (Evizal et al. 2009). A shade tree is able to reduce organic material and nutrient loss from the soil through its role in reducing erosion as well as retaining water (Sepuvelda and Carillo 2015). Evisal et al. (2009) suggested that brown waste falling from shade trees and coffee plants is highly affected by dry season and the brown waste matter productivity is determined by the presence of shade trees.The presence of this shade trees will serve the environment by producing brown-waste matter, reducing coffee tree leaf shedding in during the dry season, as well as repressing weed growth. Branch and twig pruning of shade trees and coffee plants will provide additional organic matter input. Furthermore, the organic matter on the soil surface and pre-existed in the soil will undergo decomposition and mineralization releasing nutrients into the soil. Brown-waste matter from shade trees is an important nutrient source, in particular, nitrogen for coffee plantation. N element is the key factor to productivity and sustainability coffee agroecosystem (Van der Vossen 2009). The high N input of soil beneath the shade will affect the increase in coffee and forest production associated with the resulting absorption N biomass, thus the cultivated coffee under shadings highly recommended to be improved as an ecosystem sustainable effort (Lopez-Rodriguez et al. 2015).

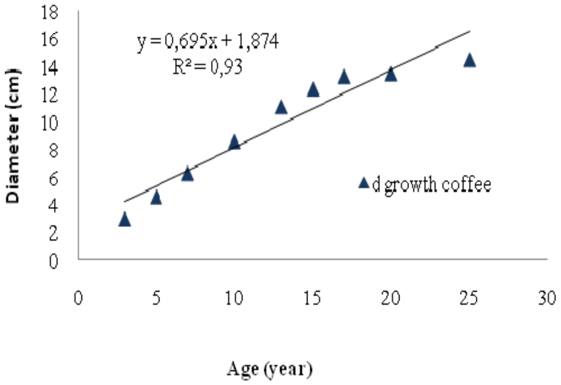
The contribution of N and P nutrients is higher on lamtoro (*Leucaena glauca*) shading than that of calliandra shading on 17-years-old coffee agroecosystem. Agroecosystem type contributes to P of the brown waste. According to Evizal et al. (2012) on coffee agroecosystem without shade trees, weed's brown-waste primarily contributes for P, reaching up to 89%. Meanwhile on coffee agroecosystem with shading, weed's brown-waste primarily contributes 46-60% P. Despite the fact that the difference in brown waste P indicating a positive value on all type of mature coffee agroecosystem, weed is a strong competitor for coffee plant because it consumes a lot of P. Therefore, coffee plantation weed need to be controlled wisely. Uncontrolled weed growth will cause fertilization failure.

In addition to affecting the produced nutrients, calliandra and lamtoro shade trees affect diameter growth and coffee cherry which will determine the Arabica coffee production, as shown in the result Figure 15, 16, 17, 18.

Calliandra and lamtoro shade trees provide a different light intensity on the Arabica coffee plants. This difference will cause a different effect on growth and physiological character of the cultivated Arabica coffee plants. The difference in the perceived light intensity will affect plant photosynthesis (Pompelli et al. 2010; Dwiyono 2011; Sholikha et al. 2015). The difference in light intensity perceived by coffee plants is caused by the difference of the shade trees. Calliandra and lamtoro possess little differences in the shape and size of their leaf and canopy; this will lead to different light intensity passed down to Arabica coffee plant. Figure 15 showed that coffee plant diameter growth under lamtoro tree shade has a highly linear correlation, with a growth of 7.4% year^{-1}. As the age increased, the diameter increase. Meanwhile, the diameter growth increment decrease by 2.5% year^{-1}. Under calliandra shading, coffee plant diameter growth increase as much as 7.8% year^{-1}, while its diameter growth increment decrease by 2% year^{-1}. Shade intensity provided will affect the seed growth, including height, leaf number, diameter, etc. (Muliasari 2016).

The harvested coffee fruit is a fully mature red fruit or cherry. The cherry coffee production increased. Figure 16 shows analysis result of cherry fruit under lamtoro and calliandra shades. The graph showed that the cherry production is also determined by coffee plant diameter and showed a strong correlation with the coefficient of determination R^2 = 0.97. This result means that as the age increased, the diameter becomes bigger. The production of cherry increased with growth reach as much as 13.3% year^{-1} from 3- until 25 years-old, with an average fresh weight 3.92 g bean^{-1}. Under calliandra shading, the resulting cherry was bigger than that under lamtoro shading. The cherry size also increased as the plant age and diameter increased, with a growth of 13.5% year^{-1} and average been weight 3.81g bean^{-1}. To be a dry coffee bean, cherry undergoes a series of processing to reduce the water content. Dry coffee bean total production in this study showed an annual increase as the plant age increased. Similarly, the average annual production (AP) increased and at age 17 years-old showed the maximum yield for both shading types. This is indicated by the intersection point between AP 105.9 kg tree^{-1}ha^{-1} and average on-going annual production or marginal product (MP) 95 kg ha^{-1}year^{-1} or 1.35 kg tree^{-1} ha^{-1}for lamtoro. Meanwhile, under calliandra shading, AP 105.9 kg tree^{-1}ha^{-1} and MP 105 kg ha^{-1}year^{-1} or 1.50 kg tree^{-1}ha^{-1} (Figure 17).

Figure 18 showed that the total dry bean yield (kg^{-1}ha^{-1}) increased by 0.12% of total bean dry weight under lamtoro (*Leucaena glauca*) shading, with a coefficient of determination R^2 = 0.83. Meanwhile, under calliandra shading, the total dry bean yield (kg^{-1}ha^{-1}) increased by 0.17% of total bean dry weight showing a strong correlation with a coefficient of determination R^2 = 0.94.



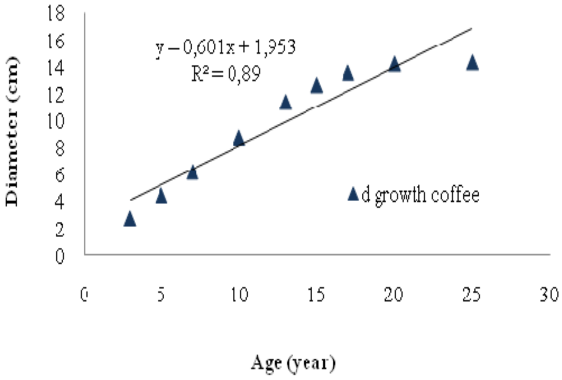
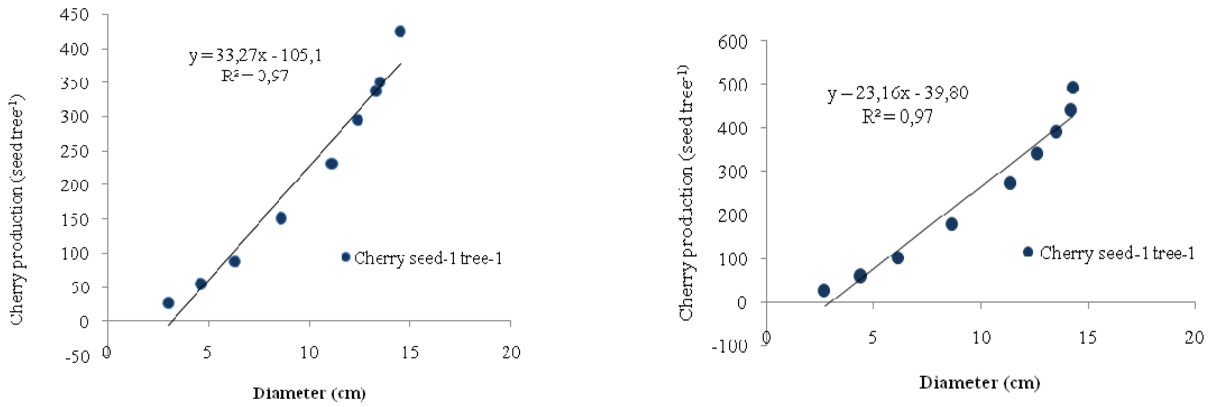
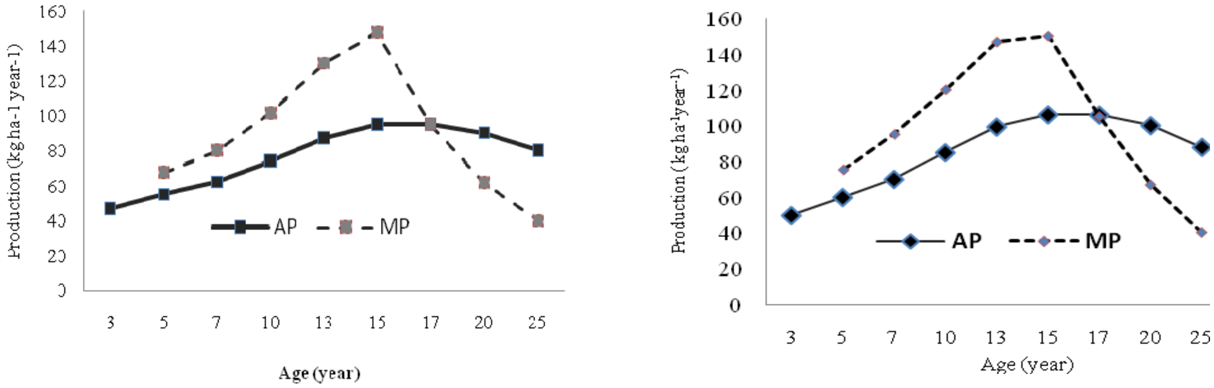


Figure 15. Diameter (d) growth of coffee plant under: A. Lamtoro (*Leucaena glauca*), B. Calliandra (*Calliandra calothyrsus*) shading



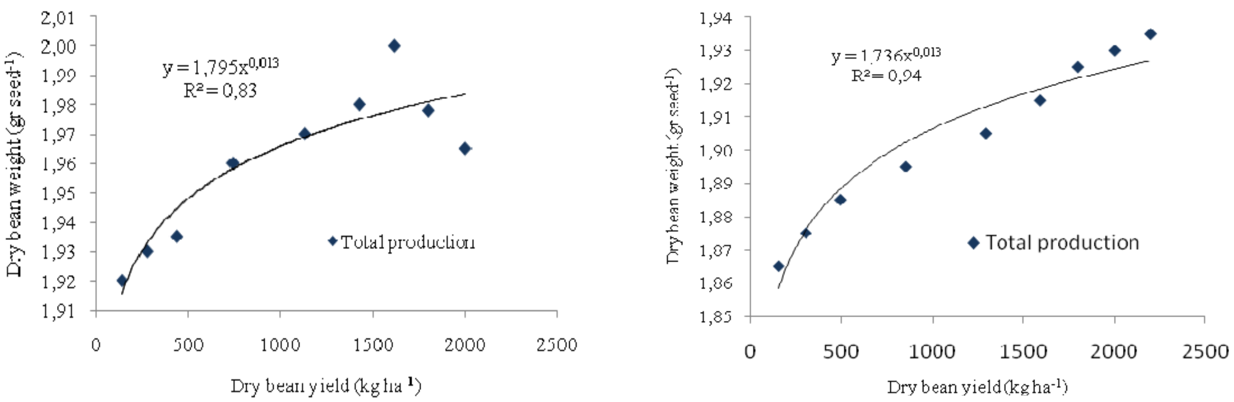
A B

Figure 16. Coffee cherry production under: A. Lamtoro (*Leucaena glauca*), B. Calliandra (*Calliandra calothyrsus*) shading



A B

Figure 17. Correlation between average annual production (AP) and average on-going annual production or marginal product (MP) of Arabica coffee under lamtoro (*Leucaena glauca*) (left) and calliandra (*Calliandra calothyrsus*) (right) shading



A B

Figure 18. Arabica coffee bean total production and bean dry weight produced under lamtoro (*Leucaena glauca*) (left) and calliandra (*Calliandra calothyrsus*) (right) shading

Total dry bean yield produced under both lamtoro and calliandra shadings increased every year with an average of 1062 $kg^{-1}ha^{-1}$ and 1186 $kg^{-1}ha^{-1}$, respectively. Dry coffee bean yield produced under calliandra shading was 11.7% higher than that under lamtoro shading because the perceived light under lamtoro shading was less intense than that under calliandra shading. Shade type and shading percentage coverage onto a plant will affect photosynthesis. Since shading level is strongly correlated with the perceived light intensity, coffee plant will perform photosynthesis better if the received sunlight illumination is no more than 60% (Prawoto 2007). Too high or low light intensity will cause sub-optimal photosynthesis.

A difference in the perceived light intensity will affect plant photosynthesis (Pompelli et al. 2010; Dwiyono 2011; Sholikha et al. 2015). The difference in the perceived light by the Arabica coffee was caused by the difference in shading type applied. Calliandra and lamtoro shadings have little dissimilarity in shape and size of leaf and canopy, thus the transmitted light intensity received by the coffee plant will differ as well. Too high or low light intensity will cause sub-optimal photosynthesis. According to Schroth et al. (2009), an increase in temperature will reduce coffee bean yield. The difference in the perceived light intensity by the coffee plant was caused by the presence of shade trees which affected the plant yield. Shading applied on the coffee plant will affect the amount of light intensity received. Light intensity reduction using agroforestry system can increase the quality of produced coffee bean, reduce water stress, increase light utilization efficiency (Charbonnier 2013).

The presence of shade trees will affect the amount of light intensity received by the plant. Shade trees planted in an adequate number will ecologically and economically impact coffee plant cultivation. The effect of shade trees to control production depends on soil and environmental conditions, tree species, and plantation management. A number of previous studies suggested that shade trees affect coffee growth and productivity (Soto-Pinto et al. 2000; Kufa and Burkhardt 2011; Ebisa 2014). Evizal et al. (2016) suggested that there was a positive correlation between shade trees with coffee productivity. Percentage-wise, legume shade trees can either increase or decrease yield, and if they are not managed properly, for example by controlling weed growth which a strong competitor that need to be controlled wisely, the uncontrolled weed growth will cause coffee fertilization failure (Lemes et al. 2010).

In an effort to create desirable environmental conditions suitable for coffee plant growth, thus shade plants that play a crucial role in a sustainable coffee production system are used (Evizal et al 2009). Coffee plant growth and productivity with and without shading showed different results. Coffee plant under shading condition yield much bigger and heavier produce (Bote and Struik 2011). Tree characteristic that can optimally function as a shade such as contributing to soil fertility as well as providing additional products will influence farmers in selecting shade trees to be used in the coffee plantation (Kalanzi dan Nansereko 2014).

As the conclusion, shade trees act as an important pillar for a sustainable coffee plant agroecosystem. Calliandra shade tree transmitted lower light intensity on Arabica coffee plant, with a coefficient of determination $R^2 = 0.89$. The average percentage ratio of light under and outside the shade was 58%; diameter growth increased by 7.8% $year^{-1}$; while diameter growth increment decrease by 2% $year^{-1}$. The coffee cherry produced increased by 13.5% $year^{-1}$with average weight 3.81g $cherry^{-1}$ and higher yield of 1.50 kg $tree^{-1}ha^{-1}$. For lamtoro tree shading, the transmitted light intensity was higher, with a percentage ratio of light under to outside the shade 72.5% and a coefficient of determination $R^2 = 0.91$. The coffee plant diameter growth under the lamtoro shading was 7.4% $year^{-1}$ and the diameter growth increment decreased by 2.5% $year^{-1}$. Meanwhile, the cherry growth increased by 13.3% $year^{-1}$ with an average weight of 3.92 g $bean^{-1}$ and plant yield was 1.35 kg $tree^{-1}ha^{-1}$. The maximum coffee production was achieved at age 17-years-old. Different light intensity causes a different coffee plant productivity. In addition, shade trees is able to produce biomass and brown waste matter beneficial for nutrient cycle, as well as to function as regulator for microclimate condition conducive for coffee plant growth and development.

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