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The improvement of microclimate and soil characteristics in cocoa-tree agroforestry patterns

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Abstract

Shade trees are used in agroforestry patterns for production and service aspects. Cocoa-tree agroforestry pattern is expected to improve the atmospheric and rhizosphere zone in cacao plantations. However, the information related to this is still quite limited. This study was conducted using a nested design, with types of shade trees as nests. Shade trees used were *Falcataria moluccana*, *Cocos nucifera*, and *Cassia spectabilis*, and without shade was used as control. Variables observed were light, air temperature, humidity, soil temperature, soil texture, bulk density, permeability, and moisture content. Soil chemical properties were also observed, including organic C, pH, total N, P, K, Ca, Mg, B and content of available P, K, Ca, Mg, and B. The results showed that cacao agroforestry pattern using *F. moluccana* and *C. spectabilis* was able to improve the microclimate characteristics and soil fertility. However, *F. moluccana* showed lower soil fertility than *C. spectabilis*. *F. moluccana* and *C. spectabilis* shade trees were able to optimize light plants from 33 % to 34 %, and from 38 % to 39 %, respectively. *F. moluccana* could provide optimal air and soil temperature of 30 ^{o}C to 32 ^{o}C and 27 ^{o}C, respectively. Meanwhile, *C. spectabilis* could provide optimal air and soil temperature of 29 ^{o}C to 31^{o}C and 26 ^{o}C to 27 ^{o}C, consecutively. Cocoa-tree agroforestry pattern using *C. Spectabilis* shade trees could optimize soil moisture content, pH, total N, and P, and availabilities of K, Ca, Mg, and B in soil.

INTRODUCTION

Habitat of cocoa is wet tropical forests, and they grow under forest. With good cultivation practices, some of properties of their natural habitat are still maintained, providing adequate shade. The continuous use of shade trees in cocoa cultivation is due to the relatively low level of light saturation for photosynthesis process. Photosynthesis takes place optimally at 60 % light intensity of direct irradiation. Light is the most important factor for growth in young cacao stands, and less attention is paid to older cacao stands (Tscharntke et al., 2011). Several studies indicate that the highest cocoa productivity is achieved in an environment partially protected from full sun. The cheapest way to achieve this condition is to use shade plants through an agroforestry pattern. An agro orestry pattern is a form of resource management that combines forest management activities or timber trees with certain commodities or short-term crops. Agroforestry pattern in cocoa plantations usually utilizes woody trees as shade plants. The use of shade trees is due to two reasons, namely for productions and services. Agroforestry improves atmospheric and rhizosphere zone of cocoa plantation. Other benefit of agroforestry is timber production from shade trees.

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The atmospheric zone is a microclimate around cocoa plantations, such as temperature, humidity, and light intensity. Microclimate characters are main factor that control growth and development of cocoa. Cocoa is C3 crops that is sensitive to high light intensity, which is able to inhibit metabolic activities rate due to high temperature. High temperature inhibits photosynthetic rate of cocoa due to the increase in photorespiration. Photorespiration decreases photosynthetic rate up to 20 % to 50 %. Under high temperature, photorespiration and photosynthesis occur simultaneously. Based on this situation, carbohydrate production capacities of cocoa tends to decrease. If this situation happens for long time, productivity of cocoa decreases significantly.

The rhizosphere zone is a zone that affects water and minerals uptake of plants. Water and minerals are elements that are very important for growth and development. Agroforestry pattern by utilizing shade trees can produce organic matter in the form of leaf litter, twigs, and others. Organic matter is one of building blocks of soil, although, in a small percentage, this organic matter has a complex role. Organic matter could improve physical and chemical properties of soil. The improvement of soil fertility due to organic matter is affecting growth and development of cocoa. Cocoa agroforestry has potential to improve mineralization of organic C, total N, organic P, microbial biomass pf N and C, and N content (Zaia et al., 2012).

Cocoa agroforestry in Indonesia using *Gliricidium spium* as shade increases water absorption capacity of cocoa (Kohler et al., 2009). Cocoa agroforestry using *Inga* spp and *Erythrina* spp as main shade trees increases biodiversity and farmer's livelihoods compared to monoculture systems (Armengot et al., 2016). Cocoa agroforestry provides supporting services, namely optimal light intensity for cocoa growth, air, nutrition, pest and disease control, and microclimate regulation (Mortimer et al., 2018). Shade trees are important to cocoa so that the selection for optimal type of trees is absolutely necessary. The information regarding the most suitable types of shade trees for cocoa is still less available, making this research quite important to conduct.

MATERIALS AND METHODS

The field experiment was conducted in a cocoa plantation owned by PT. Pagilaran in North Segayung Production Unit, Tulis District, Batang Regency, Central Java Province. Crop tissue analysis was carried out at Crop Production Laboratory, Faculty of Agriculture, Universitas Gadjah Mada, and soil analysis was performed at Soil Laboratory, BPTP Yogyakarta. The research was conducted from September to December 2020. Crop materials used in this research were cocoa stands, KKM 22 clone. The field experiment was arranged in a nested design, with type of shade tree used as nest. The treatments consisted of three shade trees, including *F. moluccana*, *C. nucifera*, and *C. spectabilis*, and cocoa without shade tree used as control. There were five replications in each treatment. The total number of samples were 20 cocoa stands. Variables observed were microclimate and soil fertility characteristics. Micro-climate characteristics were light absorption, air temperature, humidity, and soil temperature. Soil physical properties were soil texture, volume weight, permeability, and moisture content. Meanwhile, soil chemical properties observed include organic C, pH, toal N, P, K, Ca, Mg, and B, and available P, K, Ca, Mg, and B.

The experimental plots were determined by selecting blocks that represent whether or not the shade plants are good, based on the findings of field observations. The shade plants used consisted of three types of plants, namely *sengon* (*F. moluccana*), *ramayana* (*C. spectabilis*), and coconut (*C. nucifera*). Meanwhile, without shading was used as a control for comparison. The three shade plants were located in different blocks, which were far from one another with the same soil type and slope level. The 7 year-old sengon trees, with a total population of 59 trees per ha (14 m × 14 m equilateral triangle), were located in block I. The 5 year-old ramayana trees, with a total population of 115 trees per ha (10 m × 10 m equilateral triangle), were located in blok II. Meanwhile, the 39 year-old coconut trees, with a total population of 59 trees per ha (14 m × 14 m equal triangle), were used in blok III. The treatment without shade trees was in blok VIIIB.

Microclimate observations were carried out once a week from September to December. In micro-climate observations, measurements were made on light absorption, air temperature (Co), air humidity (RH), and soil temperature (Co). Measurement of light intensity was carried out at 11.00, while the measurement of air temperature, humidity, and soil temperature was carried out at 08.00, 12.00, and 16.00. The values of air temperature, humidity, and soil temperature at three different times were then averaged into one used as a representative of one day data. Measurement of light intensity was carried out using a TASI TA8131 luxmeter in the range of 200,000, measurements of air temperature and humidity were carried out using an HTC-2 thermo-hygrometer, while soil temperature measurements were carried out using a stick thermometer. Measurement of light intensity was carried out to measure light absorption as affected by shade plants. The value of light absorption is obtained from the measurement of the light intensity in the open area minus the light intensity above the cocoa canopy, which is then divided by the light intensity in the open area and multiplied by 100 %.

Soil sampling was carried out in September 2020. Soil sampling was initiated by determining the soil sample points. The soil sample points were determined in the area both with and without shade plants. Five replications of cacao stands per block were used as soil samples. Soil sampling points were taken three times at a depth of 0 cm to 50 cm on the edge of the cocoa canopy, which is 1.5 m from the cocoa stand. The soil samples was then mixed together so that a total of 20 soil samples were taken for analysis in the laboratory. The data obtained were analyzed with ANOVA at α= 5 %. If there were significant differences between treatments, the data were then tested with Duncan's Multiple Range Test (DMRT) at α= 5 %. 5Overall data analysis was performed using the SAS version 9.4 program.

RESULTS AND DISCUSSION

Light absorption

Light intensity affects photosynthetic efficiency of a plant. Cocoa-tree agroforestry patterns using various types of shade trees aims to provide optimum microclimate characteristics for cocoa. Under optimum microclimate, cocoa trees have a better pho photo-synthetic osynthesis capacity. A better photosynthetic capacity was the main factor controllingtrol maximum growth of cocoa. Light intensity transmitted to land surface was influenced by type of shade trees. The effects of different types of shade trees on amount of light absorptions are presented in Table 1.

Cocoa-tree agroforestry pattern using *C. spectabilis* shade trees showed the highest light absorption, while the lowest absorption was in control, without shade trees. The highest light absorption by *C. spectabilis* is due to the higher canopy density and leaf surface area of this tree, compared to F. *moluccana* and *C. nucifera*. The light intensity varied according to the types of shade trees. This varying light intensity affects amount of light absorption by cocoa. *C. spectabilis* had 38 % to 39 % of light absorption from September to December 2020, meaning that only 61 % to 62 % of light intensity were absorbed by cocoa.

Cocoa is C3 crop. This crop is sensitive to high light intensity due to the low level of light saturation level. High light intensity causes an increase in temperature, over than what cocoa needs. Cocoa has maximum photosynthetic rate when canopy receives 60 % of light intensity (Rubiyo and Siswanto, 2012). Cocoa without shading, or with very light shading, was unable to conduct optimum photosynthetic rate due to the high level of photorespiration. If this situation happens for long run, cocoa will be prone to low productivity (Abou-Rajab et al., 2016). Photo-synthesis is the main factor controlling growth, development, and yield (Hu et al., 2011; Jung et al., 2016; Apichatmeta et al., 2017; Lahive et al., 2018). Cocoa needs shading to overcome high light intensity. This crop only needs 30 % to 50 % direct radiation (Erwiyono, 2007). This result showed that *F. moluccana* and *C. spectabilis* shade trees were able to reduce light intensity absorbed by cocoa canopy.

Air temperature

Air temperature is one of essential climatic factors in plant growth and development. Light intensity and air temperature tend to have a positive linear relationship. Higher light intensity is followed by increased air temperature. Effects of cocoa-tree agroforestry pattern using various types of shade trees on air temperature are shown in Figure 1.

The cocoa-tree agroforestry pattern using *C. spectabilis* shade tree showed the lowest average air temperature, meanwhile control (without shading) showed the highest air temperature. Cocoa-tree agroforestry pattern using *C. spectabilis* shade tree resulted the minimum and maximum average air temperature canopy of 29 °C and 31 °C, respectively. Control (without shading) resulted in the minimum and maximum average temperature of 32 °C and 34 °C, consecutively. Monthly temperature fluctuations occurred at the research site. In September, temperature above cacao canopy was higher in all types of shade trees compared to other months. The average air

Table 1. Light absorption in the cocoa-tree agroforestry pattern using various types of shade trees

Treatments	Light absorption (%)			
	September	October	November	December
Falcataria moluccana	34 b	33 b	34 b	34 b
Cassia spectabilis	38 a	39 a	39 a	38 a
Cocos nucifera	22 c	23 c	25 c	24 c
Without shade	0 d	0 d	0 d	0 d
CV (%)	0.00	0.00	0.00	0.00

Remarks: Means followed by the same letters in the same column are not significantly different based on DMRT at α= 5 %, (*) data transformed to √(x+0.5).

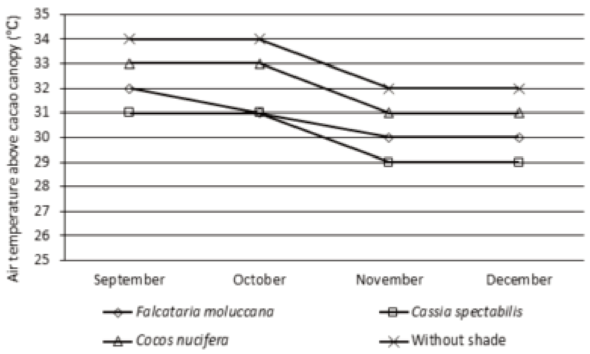

Figure 1. Air temperature above cacao canopy

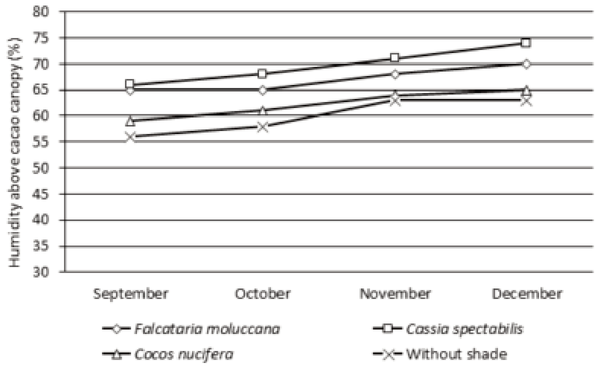

Figure 2. Humidity above cacao canopy

temperature decreased from October to December due to the transition from dry season (September to October) to rainy season (November to December).

Control (without shading) had higher air temperature compared to others treatment because of 100 % of light intensity able to reach cocoa canopy. Cocoa-trees agroforestry with *F. moluccana* and *C. spectabilis* shade trees had lower air temperatures since only 60 % of light intensity was able to reach cocoa canopy. A part of light intensity was absorbed by trees canopy. This condition decreased air temperature around cocoa with shading. Growth and development of cocoa were controlled by air temperature, including vegetative growth, flowering, and fruit formation. Air temperature was controlled by light intensity. Based on some references, ideal air temperatures for cocoa in general were 30–32 °C (maximum) and 18–21 °C (minimum). Air temperatures outside the range had possibilities to inhibit several metabolic activities of cocoa. Some enzymes were damaged due to abnormal air temperature, therbey significantly decreasing metabolic activities. Cocoa-trees agroforestry with *F. moluccana* and *C. spectabilis* shade trees resulted in optimal air temperatures, optimizing that the growth and development of cocoa. Meanwhile, cocoa without shade trees, especially during dry season, were exposed to stress condition. Stress condition disturbed metabolic activities of cocoa, and in long run decreased growth and yield.

Relative humidity

Air temperature was negatively correlated with relative humidity. High air temperatures decreased relative humidity, and vice versa. Effects of cocoa-tree agroforestry pattern using various types of shade trees on humidity are presented in Figure 2.

Cocoa-tree agroforestry pattern using *C. spectabilis* shade trees showed the highest humidity, while control (without shade trees) showed the lowest one. Cocoa-tree agroforestry pattern using *C. spectabilis* shade trees resulted in the relative humidty values of 66 % (minimum) and 74 % (maximum). Meanwhile, control (without shading) showed relative humidity of 56 % (minimum) and 63 % (maximum). *C. spectabilis* shade trees were able to increase relative humidity in area of cocoa because this type of trees absorbed part of light intensity. The shade trees reduced penetration of light to cocoa canopy so that leaf

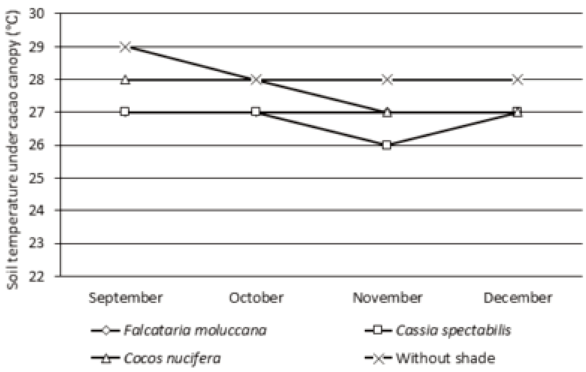

Figure 3. Soil temperature under cacao canopy

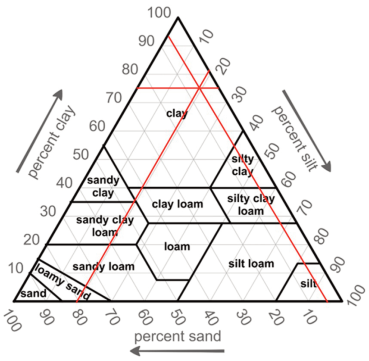

Figure 4. Soil texture triangle

transpiration decreased. This situation saved water stock in soil, increasing water availability. Optimum relative humidity for cacao is around 80 % (Rubiyo and Siswanto, 2012), meaning that the relative humidity in cocoa-tree agroforestry pattern using *C. spectabilis* shade trees is optimum for cacao plantation.

Soil temperature

Soil temperature is an important soil property directly affecting growth, soil moisture, aeration, soil structure, and microbial activity. Effects of cocoa-tree agroforestry pattern using various types of shade trees on soil temperature are shown in Figure 3.

Control treatment (without shading) showed a higher soil temperature when compared to cocoa with shade trees. Cocoa-tree agroforestry pattern using *C. spectabilis* and *F. moluccana* shade trees resulted in the lowest soil temperature from September to December. However, in November, cocoa-tree agroforestry pattern using *F. moluccana* shade trees resulted in a lower soil temperature compared to *C. spectabilis* shade tree. Cocoa-tree agroforestry pattern using *F. moluccana* shade trees resulted in the average soil temperature of 27 °C (minimum) and 27 °C (maximum). Cocoa-tree agroforestry pattern using *C. spectabilis* shade trees resulted in average soil temperature of 26 °C (minimum) and 27 °C (maximum). Meanwhile, control treatment (without shading) showed the average soil temperature of 28 °C (minimum) and 29 °C (maximum). Soil temperature was affected by the amount of light intensity absorbed by soil surface. Control treatment (without shading) had the highest soil temperature because more light intensity was absorbed by soil surfaces (Table 1). Meanwhile, cocoa-trees agroforestry with *C. spectabilis* and *F. moluccana* shade trees had the lowest soil temperature due to the ability of the shade trees to absorb more light intensity. This condition decreased total light intensity reaching soil surface so that soil temperature significantly dropped (Table 1).

Soil texture

Soil texture is composition of soil fractions, expressed as a relative proportion (%) of sand, silt, and clay. Soil texture in cocoa-tree agroforestry pattern using various types of shade trees are presented in Figure 4. Soil texture was affected by parent material and pedogenetic processes. Soil at the research site is Latosol, which has undergone intensive weathering and commonly found in high rainfall. Based on the analysis using soil texture triangle, the soil in the research site belongs to clay texture class. Latosol at the resarch site contains clay fraction of 73.40 % to 76.20 % from total fraction.

Bulk density, permeability, and soil moisture

Soil is important living component of crops. The main function of soil is to support crops to grow upright. Crop growth and development are highly dependent on soil fertility, especially soil physical properties. Physical properties of soil are related to sufficient air and water for crops in addition to nutrients. Effects of cocoa-tree agroforestry pattern using various types of shade trees on the soil bulk density, permeability, and soil moisture are presented in Table 2.

Cocoa-tree agroforestry pattern using *C. spectabilis* shade trees resulted in the highest bulk density, while *C. nucifera* shade trees showed the

Table 2. Bulk density, permeability, and soil moisture in the cocoa-tree agroforestry pattern using various types of shade trees

Treatments	Soil physical properties		
	Bulk density $g.cc^{-1}$	*Permeability ($cm.h^{-1}$)	Soil moisture (%)
Falcataria moluccana	1.08 b	5.60 a	35.16 a
Cassia spectabilis	1.14 a	6.20 a	36.81 a
Cocos nucifera	1.02 c	5.80 a	28.49 b
Without shade	1.11 ab	6.80 a	26.11 b
CV (%)	5.67	18.62	19.34

Remarks: Means followed by the same letters in the same column are not significantly different based on DMRT at α= 5 %, (*) data transformed to √(x+0.5).

lowest one. Soil bulk density in cocoa-tree agroforestry pattern was in moderate category, ranging from 1.06 $g.cm^{-3}$ to 1.47 $g.cm^{-3}$. Shade plants are plants that can be used as a source of organic matter, in which the source of this organic matter can come from leaves and twigs that fall to the soil surface. Organic matter is the material that has the least proportion in the composition of the soil but has a very large function in the soil. Organic matter can increase the pore space of the soil and form a crumb soil structure so that it can reduce soil bulk density. Soil bulk density was affected by pore space of soil, soil structure, root growth, microbial activity, and organic matter. Soil bulk density was affected by pore space of soil, soil structure, root growth, microbial activity, and organic matter. Application of organic matter to soil decreased bulk density. Brito-Vega et al. (2018) found that in cocoa agroforestry dominated by clay texture, the average bulk density value was 1.19 $g.cm^{-3}$. Clay with high organic matter had a bulk density ranging from 1.0 $g.cm^{-3}$ to 1.3 $g.cm^{-3}$.

Cocoa-tree agroforestry pattern using all types of shade trees resulted in the same soil permeability due to the similar bulk density in all types of shade trees. Soil permeability in cocoa-tree agroforestry pattern was in the medium category, ranging from 2.0 $cm.h^{-1}$ to 6.25 $cm.h^{-1}$. Soil bulk density could affect permeability of soil, in which soil with high bulk density has low level of permeability, and vice versa.

Cocoa-tree agroforestry pattern using *F. moluccana* and *C. spectabilis* shade trees showed the highest moisture content. Cocoa-trees agroforestry with coconut shade trees and control (without shading) showed low level of soil moisture. Cocoa-trees agroforestry with *F. moluccana* and *C. spectabilis* shade trees had higher soil moister than others due to the low level of light intensity reaching soil surface, low level of air and soil temperatures, and high level of relative humidity (Figure 1).

Organic C and soil pH

Soil chemical properties are related to all chemical reactions that occur in soil, controlling the properties and characteristics of soil, including soil fertility in particular. Soil chemistry was able to explain chemical reactions involving nutrient problems. Effects of cocoa tree agroforestry pattern using various types of shade trees on organic C and pH are presented in Table 3.

Table 3. Organic C and soil pH in the cocoa-tree agroforestry pattern using various types of shade trees

Treatments	Organic C (%)	pH H_2O
Falcataria moluccana	1.54 b	5.45 bc
Cassia spectabilis	1.58 b	5.70 a
Cocos nucifera	1.52 b	5.49 b
Without shade	1.66 a	5.34 c
CV (%)	6.94	3.51

Remarks: Means followed by the same letters in the same column are not significantly different based on DMRT at α= 5 %, (*) data transformed to √(x+0.5).

Control treatment (without shading) showed the highest organic C content. Meanwhile, cocoa-trees agroforestry pattern using *F. moluccana*, *C. spectabilis*, and *C. nucifera* shade trees produced the lowest organic C content. Soil organic C content in all cocoa-tree agroforestry pattern was in the low category, ranging from 1 % to 2 %. Low level of soil organic matter in this case, especially cocoa-trees agro-forestry with many types of shade trees, was caused by high decomposition and mineralization rate of organic matter in soil when soil samples were collected. In this research, soil samples were collected during dry season, and within this season, there were no addition of organic matter from pruning. Addition of organic matter from pruning of the shade trees mostly happens during rainy season, when shade trees growth faster. If soil samples were collected during dry season, most of organic matter had decomposed five months after the addition of organic matter to soil. This condition leads to the low level of organic C content in all treatments including agroforestry system with many types of shade trees. However, soil nutrient content in cocoa-tree agroforestry with *C. spectabilis* shade trees was higher than in control. The soil nutrient contents were higher in agro-forestry model than in control due to the addition of nutrient from mineralization process of organic matter. Indonesia is a tropical rain forest country, which has high temperatures with high rainfall, in which this condition accelerates both decomposi-tion and mineralization rate of organic matter.

Cocoa-tree agroforestry pattern using *C. spectabilis* shade trees showed the highest pH, while control (without shading) had the lowest one (Table 3). Cocoa-tree agroforestry shaded by *C. spectabilis* resulted in the highest pH due to massive decomposition and mineralization of organic matters. This model produced more organic matter from both cocoa and *C. spectabilis*. Massive activities of decomposition and mineralization of organic matter produced many organic acids and also nutrients able to increase soil pH. Organic matter decomposition produces basic cations increasing soil pH. Addition of organic acids and cations to soil increases soil pH and decreases exchangeable Al (Sari et al., 2017). Soil pH in cocoa-tree agroforestry pattern using *F. moluccana* and *C. nucifera* shade trees and control (without shading) were in acidic category, ranging from 4.5 to 5.5. Meanwhile, soil pH of cocoa-tree agroforestry with *C. spectabilis* shade trees was slightly acidic, ranging from 5.5 to 6.5.

Total N, P, K, Mg, Ca, and B

Nutrients in soil are in available and unavailable form. Unavailable nutrients are usually found in clay minerals as nutrients absorbed by clay minerals or soil organic matter that are not mineralized. Unavailable nutrients are nutrient reserves in soil. These available and unavailable nutrients are total nutrients in soil. Effects of cocoa-tree agroforestry pattern using various types of shade trees on total N, P, K, Ca, Mg, and B are presented in Table 4.

Cocoa-tree agroforestry pattern using *C. spectabilis* shade trees resulted in the highest total N, P and K. Cocoa-tree agroforestry using *C. spectabilis* shade trees had high level of total N and P. This was due to the ability of *C. spectabilis* shade trees to produce high quality of organic matter compared to other shade trees. It means that biomass from shade trees directly becomes source of nutrient to soil after decomposition and mineralization processed.

Cocoa-tree agroforestry pattern using *C. spectabilis* shade trees tended to have the highest total K when compared to others. Total K are obtained from organic matter produced by cocoa and shade trees. Mineralization of organic matter from cocoa

Table 4. Total N, P, K, Ca, Mg, and B in the cocoa-tree agroforestry pattern using various types of shade trees

Treatments	Total nutrients					
	N (%)	P (%)	*K (%)	Ca (%)	Mg (%)	B (ppm)
Falcataria moluccana	0.124 b	0.110 b	0.048 a	0.034 b	0.042 a	193.20 a
Cassia spectabilis	2.438 a	0.132 a	0.056 a	0.040 b	0.040 a	191.20 a
Cocos nucifera	0.126 b	0.128 ab	0.042 a	0.048 a	0.040 a	193.20 a
Without shade	0.124 b	0.088 c	0.042 a	0.048 a	0.036 b	199.00 a
CV (%)	17.44	22.48	1.55	21.98	12.00	7.55

Remarks: Means followed by the same letters in the same column are not significantly different based on DMRT at α= 5 %, (*) data transformed to $\sqrt{(x+0.5)}$.

leaves was faster when mixed with organic matter from *F. moluccana* and *C. spectabilis* leaves due to the high N content in leaves of legume family. Cocoa leaves have a high C/N ratio, while *F. moluccana* and *C. spectabilis* leaves have lower C/N ratio. Combination between organic matter with low and high levels of C/N accelerated decomposition and mineralization processed. According to Asigbaase et al. (2021), cacao-tree agroforestry pattern system enhances leaf litter decomposition and nutrient mineralization so that more essential nutrients become available to support crop growth and yield.

Cocoa-tree agroforestry pattern using coconut shade trees and control (without shading) resulted in the highest total Ca. High level of total Ca in *C. nucifera* shade trees and control were caused by low absorption rate of Ca. This condition led to the highest total Ca in both treatments. Cocoa-tree agroforestry pattern using coconut shade trees and control (without shading) had the lowest absorption rate of Ca from soil due to the low level of soil moisture in both treatments. Low level of soil moisture inhibited transpiration rate of crops. One of the nutrient transport mechanisms in crops is mass flow. Mass flow is movement of nutrient solutions (water and minerals) to root surface driven by transpiration. Low rate of transpiration inhibits mass flow and then decreases Ca absorption by cocoa.

Cocoa-tree agroforestry pattern using *F. moluccana*, *C. spectabilis*, and *C. nucifera* shade trees showed the highest total Mg content, while control (without shading) showed the lowest one. Control treatment (without shading) had low level of total Mg in soil due to the low supply of organic matter in control treatment.

Cocoa-tree agroforestry pattern using various types of shade trees resulted in the same total B content in the soil. Total B was similar due to the similar value of soil pH. Optimum availability of B is achieved if the soil pH is around 5 to 7. Acidic mineral soils or alkaline mineral soils have low boron level because boron is bound to Fe, Al, and Ca oxides/hydroxides of soil. Normally, total B in soil ranges from 20 ppm to 200 ppm (Riwandi et al., 2017).

Available N, P, K, Mg, Ca, and B

Available nutrients are nutrients that are ready to be absorbed by plants. This type of nutrients is from total nutrients that have undergone a mineralization process, separated from clay absorption. The nutrients available in the soil are similar to those in crops. Crops nutrients are highly dependent on soil nutrients status. Effects of cocoa-tree agroforestry pattern using various types of shade trees on soil nutrient status, availabilities of N, P, K, Ca, Mg, and B, are presented in Table 5.

Cocoa-tree agroforestry pattern using various types of shade trees showed similar available P. This result shows that all types of shade trees in cocoa agroforestry patterns have similar ability to affect the availability of P. This was due to the ability of cocoa to produce cocoa leaf litter as a source of organic matter that could affect P solubility in soil. Most of P in cocoa ecosystem was found in vegetation, and leaf litter from vegetation have little effect on P displacement. According to Hartemink (2005), fertilization of inorganic fertilizers of less than 1,430 $kg.ha^{-1}$ in a cocoa-tree agroforestry pattern changes P balance in soil. However, P fertilizer has no significant effects on P content in organic matter. This condition caused similar levels of available P in all treatments.

Cocoa-tree agroforestry pattern using C. spectabilis tree showed high nutrient content of available K, Ca, Mg, and B in soil. High content of

Table 5. Available P, K, Ca, Mg, and B in the cocoa-tree agroforestry pattern using various types of shade trees

Treatments	Total nutrients				
	P (%)	*K (%)	Ca (%)	Mg (%)	B (ppm)
Falcataria moluccana	119.60 a	90.60 b	326.00 b	179.80 b	1.46 bc
Cassia spectabilis	121.60 a	113.40 a	416.00 a	207.20 a	2.45 a
Cocos nucifera	127.40 a	55.60 c	401.60 a	134.00 c	1.61 ab
Without shade	130.00 a	48.20 c	333.00 b	127.20 c	0.97 c
CV (%)	11.19	14.55	12.84	10.85	20.00

Remarks: Means followed by the same letters in the same column are not significantly different based on DMRT at α= 5 %, (*) data transformed to √(x+0.5).

available K, Ca, Mg, and B was due to good quality of organic matter produced by *C. spectabilis*. Cocoa combined with *C. spectabilis* could provide higher quality of organic matter than others treatment. According to Partey et al. (2018), C. spectabilis has higher NPK contents than river tamarind and gliricidia. River tamarind tree contains N, P, and K of 24.0 $g.kg^{-1}$, 1.90 $g.kg^{-1}$, and 19.0 $g.kg^{-1}$, respectively, and gliricidia contains N, P, and K of 27.7 $g.kg^{-1}$, 2.90 $g.kg^{-1}$, and 18.0 $g.kg^{-1}$, respectively. Meanwhile, *C. spectabilis* contains N, P, and K of 28.9 $g.kg^{-1}$, 2.50 $g.kg^{-1}$, and 23.0 $g.kg^{-1}$, consecutively. According to Beer et al. (1998), *C. spectabilis* is recommended as a cocoa shade tree because it produces good quantity and quality of organic matter equivalent to 97 kg Urea, 7 kg SP-36, 66 kg Potassium chloride, 51 kg Dolomite, and 12 kg Kiesrite per ha per year, with a population of 400 trees per ha. High nutrient content in *C. spectabilis* caused optimum nutrient content for cocoa when mixed. According to Bachtiar (2017), the increase in soil fertility under shade trees is thought to be impact from organic matter.

High quantity and quality of organic matter produced by cocoa was indirectly influenced by *C. spectabilis* when mixed. *C. spectabilis* provided optimum microclimate characteristics, such as light intensity, air temperature, and relative humidity around cocoa. *C. spectabilis* optimized the transpiration rate of cocoa due to ideal air and soil temperature, humidity, and soil moisture under integration between both species. Cocoa has high transpiration rate when mixed with *C. spectabilis* due to changes in microclimate and soil characters. One of nutrient transport mechanisms in crops is mass flow. Mass flow is movement of nutrient solutions (water and minerals) to root surface driven by transpiration. Optimal transpiration rate causes optimal nutrient uptake by cocoa, thereby increasing nutrient contents in cocoa leaves. Cocoa used the nutrients for optimum growth and development.

CONCLUSIONS

F. moluccana and *C. spectabilis* were able to improve microclimate characteristics in area of cocoa plantation when mixed under agroforestry model, especially light absorption, air and soil temperature. Cocoa tee agroforestry pattern using *C. spectabilis* shade trees optimized soil moisture content, pH, total N and P, and availabilities of K, Ca, Mg, and B in soil.

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