Pelita Perkebunan 38(3) 2022, 155─170
DOI: 10.22302/iccri.jur.pelitaperkebunan.v38i3.517

ISSN: 0215-0212 / e-ISSN: 2406-9574

Growth and Plant Architecture of Several Introduced *Coffea canephora* Clones Under Different Shade Levels

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Received: 10 August 2022 / Accepted: 11 November 2022

Abstract

Introducing superior plants is one of the efforts to increase coffee productivity in Indonesia. Three clones from *France de Torino* (FRT), FRT 07, FRT 09, and FRT 65, have been introduced to Indonesia. However, their cultivation is not widely distributed yet. Analysis of the responses of FRT clones against differences in climate and cultivation is needed to determine the right cultivation system to produce maximum growth and productivity. This study examines the vegetative growth of FRT clones introduced at some levels of shade. The study employed a split-plot design with 36 experimental units. The primary factor was the levels of shade consisting: without shade, 25% of shade, 50% of shade, and 100% of shade. The three introduced FRT clones (FRT 07, FRT 09, and FRT 65) were used as the subplot. Observations were done on several growth variables. The results showed that shade treatment affected all growth parameters and plant architecture. Clones significiantly affected plant height, orthotropic internode length, number of leaves, and average leaf area. Increased levels of shade caused an increase in internode length, branch angle, and crown diameter but decrease in number of internodes and leaves. A low level of shade (25%) produced an optimal value on parameters related to the productivity of FRT coffee plants, such as the number of plagiotropic internodes and the number of leaves. Parameters related to vegetative growth, such as plant height, stem diameter, and internode length, showed optimal values in a moderate level of shade (50%). Treatment without shade and a heavy shade resulted in impaired growth of FRT coffee. There was no interaction between levels of shade and clone treatment on most of the variables related to plant morphology, which indicated that the three introduced FRT clones gave relatively similar response to shade; thus, the three clones can be managed with the same shade management.

Keywords: introduction, superior clones, shade, growth, and plant architecture

INTRODUCTION

The increase in coffee demand is caused by the increase in domestic coffee consumption and foreign market demand supported by government policies that encourage the export of Indonesian coffee beans to the global market (Alexander & Nadapdap, 2019). However, this high demand is not accompanied by an increase in coffee productivity; the coffee productivity in Indonesia has been around 600 kg ha^{-1} year^{-1} for the last five years. This covers an area of approximately 1.2 million hectares with no new additional areas in the last five years (BPS, 2020). This figure is still relatively low when compared to productivity in other coffee-producing countries of around 2-3 tons ha^{-1} $year^{-1}$ (Filho *et al.*, 2014).

Robusta coffee (*C. canephora*) is Indonesia's most cultivated coffee variety and accounts for 83% of the total production. South Sumatra and Lampung are the largest coffee producers in Indonesia, producing 201,400 and 118,000 tons of coffee, dominated by Robusta coffee (BPS, 2020). Intense competition between agricultural and plantation commodities for land in the lowlands (<1000 m above sea level) puts pressure on Robusta cultivation.

One way to increase the competitiveness of coffee plants is to use new varieties or clones with higher agronomic performance (Etienne *et al.*, 2018). Efforts to obtain superior planting material continue with breeding, exploration, and introduction. Exploration and breeding in Indonesia have produced varieties and clones of Robusta coffee with a production potential of 2-2.7 tons $hectare^{-1}$ (Sumirat, 2016). The use of superior planting material can be done through replanting and rejuvenation.

The Indonesian Coffee and Cocoa Research Institute introduces a new superior planting material for Robusta coffee as the result of selection by Nestlé R&D-Tours to accelerate the increase in coffee production in Indonesia. The superior planting material for Robusta coffee consists of several France de Torino (FRT) clones, namely FRT 07, FRT 09, and FRT 65, originating from South America. In Brazil, FRT coffee is cultivated in Espírito Santo and Rondônia at 10^{o}-25^{o} south latitude (Volsi, 2019), 700-1300 meters above sea level (asl.), with a monoculture system without shade (Campanha *et al.*, 2004). The cropping pattern uses a single fence system with a spacing of 3 x 1 meters, resulting in a population of 3,333 trees per hectare with the productivity of 2,379 kg ha^{-1} $year^{-1}$; and a plant spacing of 3 x 1.5 meters, producing a population of 2,222 trees ha^{-1} $year^{-1}$ with the productivity of 2,183 kg ha^{-1} $year^{-1}$ (Filho *et al.*, 2014). FRT coffee has a smaller plant habitus than Robusta coffee in Indonesia, so it has the potential to be planted with close spacing.

Differences in climate and coffee cultivation methods in Indonesia, especially those related to the use of shade plants, will certainly affect the growth and crown architecture of the introduced coffee plants. Coffee cultivation with shade is a form of mitigation that can be applied to increase the resilience of coffee plantations to climate change (Partelli *et al.*, 2014). Lower climate-related stress and lower *Cercospora coffeicola* attack on coffee plants were found in coffee cultivation under shade (Baliza *et al.*, 2012). Shade in coffee plantations can provide many benefits for coffee, including reducing air temperature, soil temperature, leaf surface temperature, and thermal amplitude; shade also plays a role in protecting coffee plants from strong winds, rain, or hail and reducing the biennial-bearing effect, and increasing and maintaining soil fertility by returning significant amounts of leaf litter into the soil as a source of organic matter, nitrogen fixation, and soil moisture retention (Neto *et al.*, 2018). It was reported that coffee cultivation under shade resulted in better photosynthetic performance, increased carbon storage capacity in the system, and yielded larger beans with improved organoleptic quality of coffee beans (Partelli *et al.*, 2014).

However, shade-grown coffee has weaknesses, including accelerated height gain, longer internodes on orthotropic and plagiotropic branches, and reduced light intensity (Partelli *et al.*, 2014). The longer internodes will affect plant height, branch length, and the number of buds in one tree (Bonomo *et al.*, 2004). Under heavy shade, *C. canephora* will produce wider and thinner leaves, which result in self-shading, causing disturbances in flower formation and a decrease in the number of coffee cherries (Tabagiba *et al*., 2010).

Therefore, a study of the growth response and architecture of introduced *C. canephora* plants (FRT 07, FRT 09, and FRT 65) at several levels of shade is indispensable as the basis for preparing standards of Good Agricultural Practices (GAP), especially in determining plant spacing and shade management.

MATERIALS AND METHOD

The research was carried out at the Wirolegi Experimental Garden of the Indonesian Coffee and Cocoa Research Institute (ICCRI) in Jember, Indonesia, with an altitude of 79 m asl. The area had with rainfall type D according to the Schmidt and Ferguson classification. The study lasted 6 months, from November 2020 to April 2021. Rainfall during the study was 238.6 mm month^{-1}, with a minimum of 13 mm month^{-1}, a maximum of 445 mm month^{-1}, and an average of 1,957 mm year^{-1}.

The materials used in this study were cuttings of *C. canephora* from *France de Torino* (FRT) 07, FRT 08, and FRT 65 clones aged six months (ready to transplant into the planting area). Other materials used were net houses with an incoming light intensity of 20-30%, 45-55%, and 70-80%. The tools used were a temperature and humidity data logger, lux meter, digital caliper, hand counter, protractor, and tape meter.

The experiment was designed in a split-pot design with four shade levels and three varieties of *C. canephora.* The main plot was the four levels of shade: without shade, 20-30% of shade, 45-55% of shade, and 60-70% of shade. The subplot was the coffee plant type, consisting of three clones: FRT 07, FRT 08, and FRT 65. From this design, 12 treatment combinations were produced with three replications.

The FRT coffee seeds used were six months old and met the standards for planting in the field. Seeds were selected based on plant height, the number of leaves, and root conditions during seedling transplantation to larger polybags (20 cm x 30 cm). The media used was soil:sand:manure with a ratio of 1:1:1. Seedling acclimatization was carried out for two months.

The sample plants were planted under a net house with a height of 2.5 meters, a width of six meters, and a length of eight meters. The net used three density levels that produced light intensity, namely N0, N25, N50, and N75. Plants were fertilized with NPK 16:16:16 fertilizer of as much as 5 g per plant per month and watered twice a week until the media was saturated with water—this was done until the end of the research activity. The light intensity in the N0, N25, N50, and N75 treatments was observed once a month using a lux meter. Meanwhile, temperature and humidity were observed using a tiny tag data logger every three hours at 00.00, 03.00, 06.00, 09.00, 12.00, 15.00, 18.00, and 21.00 from 0 to 180 days after planting (DAP).

Observations were carried out monthly on several growth variables, including plant height (cm), stem diameter (mm), the number

Table 1. Micro climate condition in several shade level of paranet house

Shade level (%)	Light intensity (lux)	Temperature (°C)			Humidity (%)		
		Max	Min	Average	Max	Min	Average
0	24.276	34.10	20.83	27.46	93.43	36.74	63.80
25	18.659	33.19	21.30	27.24	94.57	39.70	66.08
50	11.536	30.99	21.35	26.17	96.29	47.03	70.80
75	5.679	30.16	21.54	25.85	95.71	62.21	80.34

of ortho-tropic internodes, the length of ortho-tropic internodes (cm), budding frequency, budding period (days), the number of plagio-tropic branches, the length of plagiotropic branches (cm), the number of plagiotropic internodes, and the length of plagiotropic internodes (cm).

Observations were also made on the number of leaves and leaf morphology. Observations were made at 180 days after planting (DAP) with the following observed variables: average leaf area (cm^2), total leaf area (cm^2), and specific leaf area (SLA) (cm^2 g^{-1}) calculated by the formula:

$$SLA = \frac{A}{Wd}$$

In which:

A = leaf area
Wd = leaf dry weight

The branching angle (^{o}) was measured at 180 DAP using a protractor. An angle of 0^o is parallel to the main stem, with the base of the branch being the axis and the midpoint of the protractor. Branching and leaf angles are classified into 3, namely (Subekti, 2012):

Upright branch angle : $<35^o$
Medium branch angle : $35^o \leq x \leq 60^o$
Flat branch angle : $>60^o$

The crown diameter was observed at 180 DAP using the plagiotropic branch length and branching angle as the main component according to the formula:

2 (sinX*length of the plagiotropic branch), where X is the branching angle.

The data were analyzed using an analysis of variance for quantitative characters followed by an analysis of the difference in the mean value using the Duncan Multiple Range Test at α 5% confidence level using Genstat 19 software.

RESULTS AND DISCUSSION

The vegetative growth of coffee plants is dimorphic, with upright growth (orthotropic) and sideways growth (plagiotropic). Orthotropic branches or shoots make up the main stem, and water shoots with a vertical growth direction. In contrast, plagiotropic branches or shoots grow horizontally and serve as places for flowers and fruit to appear (Yuliasmara *et al*., 2016). The morphological response of the crown of FRT clones to the levels of shade will affect the cultivation pattern, especially in determining plant spacing and shade management.

Orthotropic Growth

Plant height is the primary indicator of upright or orthotropic growth. Some of the introduced FRT coffee clones responded significantly to shade on the number of orthotropic internodes, orthotropic internode length, and plant height. However, there was no interaction between shade treatment and coffee clones.

The response of FRT 07 and FRT 09 clones to the levels of shade on plant height resulted in the optimal value of plant height of 71.66 cm at 56.71% shade intensity and 73.96 cm at 47.01% shade intensity (Figure 1). In addition, the FRT 65 clone produced an optimal plant height of 84.76 cm at a shade intensity of 54.74%. The average optimal height of the three clones of *C. Canephora* occurred at a shade level of 52.61%. FRT 65 showed a faster plant height gain in the clone treatment than FRT 07 and FRT 09. DaMatta *et al*. (2008) state that environmental and genetic factors influence the height increase of coffee plants. Light is an important environmental factor for plant growth and development, because in addition to playing a dominant role in the photosynthesis process, it is also a controller, trigger, and modulator of morphogenesis responses, especially in the early stages of plant growth (Sopandie,

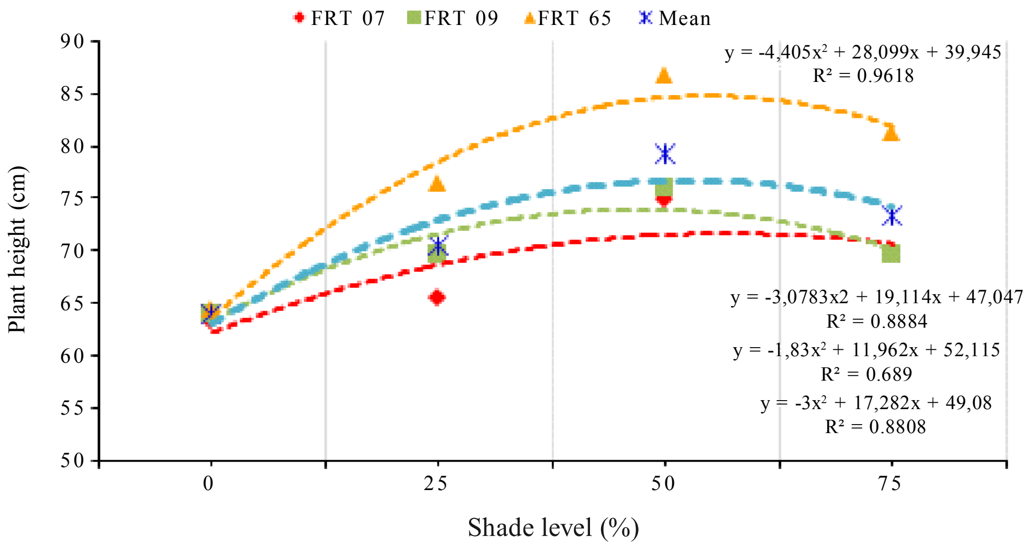


Figure 1. Relationship between shade levels and plant height of FRT clones at 180 DAP

2013). Optimal light intensity supports the efficiency of the photosynthetic process of plants, where the results of photosynthesis are a substrate for plant growth (Sholikhah *et al.*, 2015). Each type of coffee clone also has different physiological and agronomic characteristics, causing different photosynthetic activities affecting final production (Ayalew, 2018).

In coffee plants, plant height is closely related to the length of the orthotropic internode, the number of orthotropic internodes, the budding frequency, and the budding period. In the variable of orthotropic internode length, significant differences occurred in levels of shade and clone treatments. However, there was no interaction between levels of shade and clone treatments on the four observation variables.

The orthotropic internodes of FRT clones were getting longer as the levels of shade increased. Treatment without shade and N25 resulted in short internodes, 5.07 cm, and 5.46 cm. The N50 treatment resulted in a longer orthotropic internode of 6.26 cm. The longest internode occurred at N75, with a length of 6.94 cm. Disruption of auxin activity at high light intensity is thought to inhibit the growth process of orthotropic shoots resulting in short internode shoots. Rodríguez *et al.* (2001) support our findings, stating that an increase in internode length in orthotropic and plagiotropic or reproductive branches happens along with an increase in shade levels caused by low auxin degradation. FRT 65 clones produced longer orthotropic internodes than FRT 07 and FRT 09 clones at all levels of shade. This may be related to the genetic nature of FRT 65, which has longer internodes.

Based on the analysis of variance on the number of orthotropic internodes, budding frequency, and budding period, there was a significant difference between the shade treatments but no significant difference in clone treatments.

The number of internodes also showed a significant difference in the treatment of shade levels. N75 produced the least number of internodes compared to other treatments

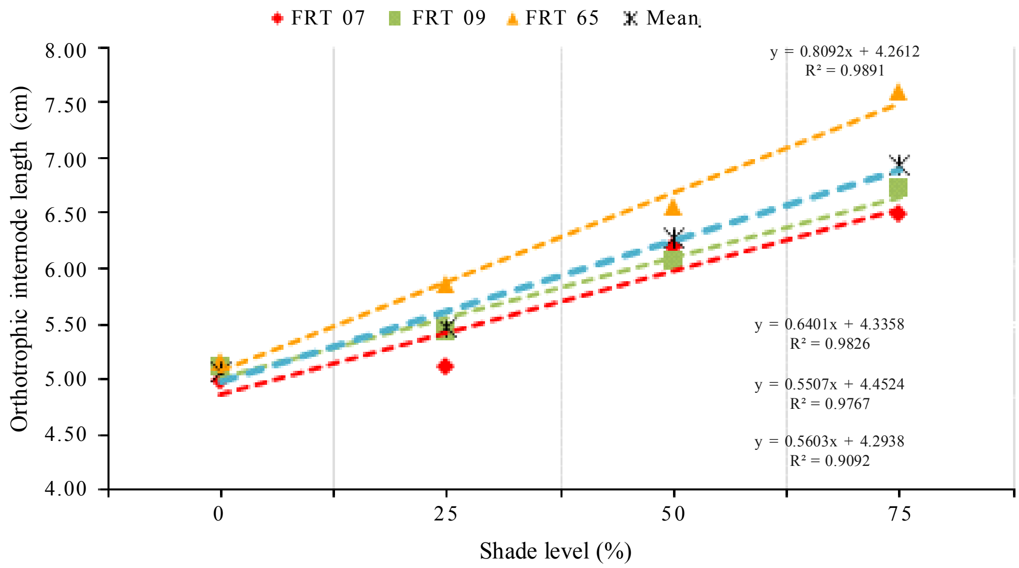


Figure 2. Relationship between shade level and orthotropic internode length of FRT clones at 180 DAP

(Figure 3). The number of internodes is related to the frequency of shoot growth. Orthotropic shoots on coffee plants occur once a month (once in 26-30 days) in a supportive environment (Espindula *et al.*, 2020). Based on observations on the number of orthotropic shoots, it was found that the treatments without shade, N25, and N50 sprouted 6.27 times, 6.38 times, and 6.22 times until the plant was 180 DAP. This shows that shoots in the treatment without shade, N25, and N50 occurred once every 28.84, 28.41, and 29.67 days. In contrast, for the N75 treatment, there was a slowdown in shoot growth, indicated by an increase of 4.18 times during 180 DAP. This shows that the budding of the N75 treatment occurred once every 43.3 days, resulting in fewer orthotropic internodes than other treatments. The low intensity of sunlight plants receive is thought to affect the formation of assimilate used for plant growth.

Two factors are thought to affect plant height and other variables that influence it related to the levels of shade: photosynthetic activity and auxin hormone activity. Optimal light intensity supports the efficiency of the photosynthetic process of plants (Sholikhah *et al.*, 2015), where photosynthesis results are a substrate for plant growth (Harjanti *et al.*, 2014). Low light intensity will reduce the rate of photosynthesis and interfere with metabolism in the plant body, which in turn will reduce plant growth (Sholikhah *et al.*, 2015). Meanwhile, high light intensity increases plant transpiration. The mechanism of stomata closure is carried out by plants to control the transpiration process, but it will reduce the photosynthetic process.

In addition, too-high light intensity can suppress the work of the auxin hormone. Auxin hormone is one of the hormones in plant growth, affecting elongation. Plant height increases at lower light intensities because auxin works well under such a condition; auxin is sensitive to damage or degradation at high light intensity (Ariany *et al.*, 2013). The inhibition of auxin activity

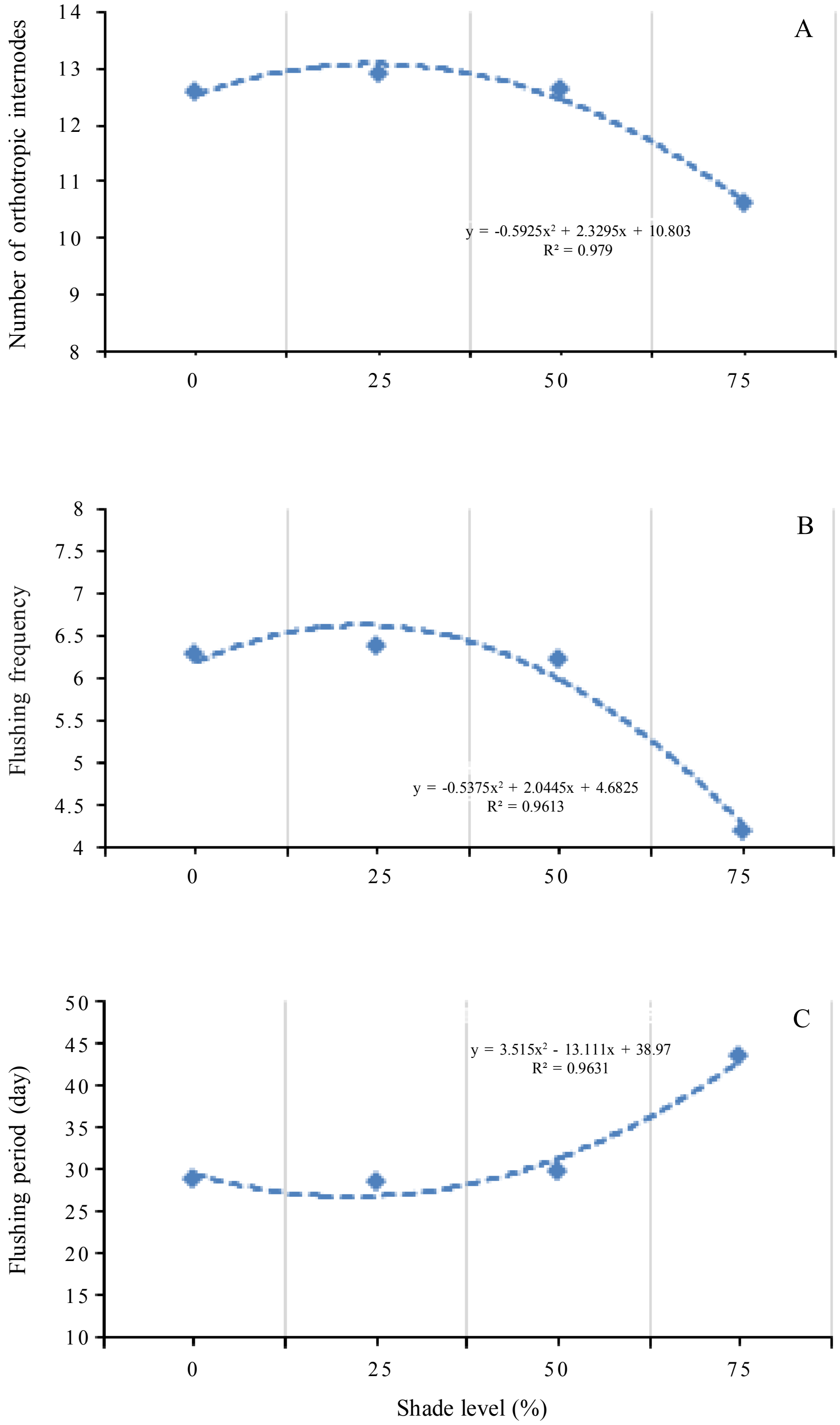


Figure 3. Relationship between shade level and number of orthotropic internodes (A), flushing frequency (B), and flushing period (C) of FRT clones at 180 DAP

in conditions without shade disrupts shoot growth, inhibiting internode increase and height gain.

Based on the analysis of variance in stem diameter, there was a significant difference and interaction between the shade treatment and FRT clones at 180 DAP (Table 2). The stem diameter at FRT 07 produced an optimal value of 10.32 mm, which occurred at a shade intensity of 38.52%. The effect of shade intensity on FRT 09 and FRT 65 on stem diameter was 10.22 mm at 50.56% shade intensity and 10.89 mm at 42.01% shade intensity, respectively. In observing the stem diameter of the FRT clones, it was found that the optimal stem diameter occurred at a moderate shade level from 38.52% to 50.56%. Optimal values for stem diameter occurred at light-moderate shade levels, indicating that 25% and 50% shade produced an optimal microclimate for stem diameter growth. In the 25% and 50% shade treatments, FRT 65 produced the largest stem diameter compared to FRT 07 and FRT 09. If it was associated with plant height, FRT 65 in the N25 and N50 shade treatments produced larger and taller plants.

The stem diameter of the FRT clones decreased in the no-shade conditions. FRT 65 showed the heaviest growth pressure symptoms compared to FRT 07 and FRT 09 on stem diameter in no-shade conditions. In general, *C. canephora* experiences growth disorders due to exposure to high-intensity sunlight, which results in photorespiration, mechanical damage as indicated by chlorosis, leaves wilt and fall with yellowish color (Arisandi, 2015) as well as disruption of the activity of auxin. The inhibition of auxin activity results in the disruption of shoot growth due to the high intensity of sunlight, so assimilate is allocated for storage in the stem and lateral growth of the plant.

N75 showed a decrease in stem diameter for FRT 07 and FRT 65, indicating a disturbance in growth due to limited light. However, FRT 09 in the N75 shade treatment showed better adaptability, so the resulting diameter did not significantly differ from the N25 and N50 treatments. Higher growth, with long internodes and small stem diameters shown by FRT clones under shade N75, was similar to the symptoms shown by plants that experienced branch etiolation, in

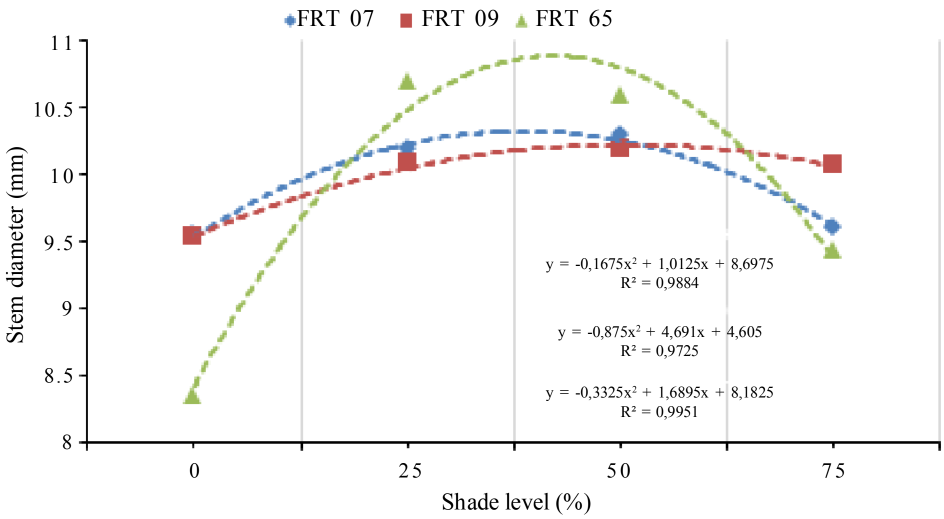


Figure 4. Relationship between shade level and stem diameter of FRT clones at 180 DAP

which the highest value for plant height has been caused by internode elongation due to low radiation (Partelli *et al*., 2014). These results indicate that an increase in plant height and a decrease in stem diameter under shade is an adaptation mechanism for coffee plants to maximize light interception by individual leaves (Ayalew, 2018).

Plagiotropic Growth

The plagiotropic branch is where flowers and fruit appear on the coffee plant, called the production branch. The morphology of the plagiotropic branch is a growth parameter related to the potential of coffee plant production. The analysis of variance on the number of plagiotropic branches, the length of the plagiotropic branches, the number of internodes of a plagiotropic branch, and the length of the internode of the plagiotropic branch showed a significant difference but no interaction between the levels of shade and FRT clones (Table 2).

Treatments without shade, N25, and N50 produced more plagiotropic branches than treatment N75. The number of plagiotropic branches was optimal at N50 and was significantly different from other treatments. N75 produced the least number of plagiotropic branches with all tested FRT clones. The response of FRT clones to the number of plagiotropic branches did not show a significant difference between treatments. The plagiotropic branches grew at the internode of orthotropic stems, so it was related to the number of internodes of orthotropic stems, which also experienced growth inhibition at N75.

The analysis of the variance of plagiotropic branch length, the number of internodes, and plagiotropic internode length at 180 DAP showed a significant difference but no interaction between the shade treatment and the FRT clones (Table 2). The length of the plagiotropic branch is influenced by the number and length of the internodes of the branch. Treatment without shade resulted in the shortest plagiotropic branch length and the shortest internode length but the highest number of internodes compared to shade treatment. In the N25 treatment, FRT coffee produced long plagiotropic branches and many internodes with short internodes. This condition resulted in a higher number of internodes so that it had the potential to produce more optimal coffee cherries compared to other treatments. Meanwhile, the treatment without shade and N50 resulted in long plagiotropic branches and long internodes, resulting in fewer internodes than treatments without shade and N25. N75 produced long plagiotropic branches but with fewer internodes due to the longer internodes produced compared to other treatments.

Previous studies mention that shade-grown coffee cultivation causes decreased productivity (Morais *et al*., 2006), an accumulation of decreases in the number of productive

Table 2. Effect of shade level on plagiotropic branches of FRT clones at 180 DAP

Treatment	Plagiotropic branch number	Plagiotropic internode number	Plagiotropic internode length (cm)	Plagiotropic branch length (cm)
Shade level				
0%	11.62 b	5.81 c	5.56 a	32.23 a
25%	11.69 b	5.44 c	6.37 b	34.66 b
50%	12.49 c	4.81 b	7.48 c	35.88 b
75%	10.59 a	4.05 a	8.69 d	35.10 b
Signifikansi	**	**	**	*
C. canephora clone				
FRT 07	11.07 a	5.27 a	6.79 a	35.17 a
FRT 09	11.90 a	5.00 a	7.10 a	34.60 a
FRT 65	11.82 a	4.81 a	7.19 a	33.63 a
Signifikansi	ns	ns	ns	ns

Notes : Figures in the same treatment group and the same column followed by the same letter are not significantly different at α 5% to according to DMRT.

branches, the number of buds per branch, and the number of cherries per bud, leading to a decrease in the number of cherries per tree (Yuliasmara, 2017). The differences in morphology of plagiotropic branches in several treatments in this study were related to the excess of auxin in the heavy shade, causing the elongation of internodes or branches; in addition, auxin inhibition due to the presence of shade causes the internodes or branches to be shorter (Arisandi, 2015).

Leaf Number and Morphology

The analysis of variance showed a significant effect of shade treatments and clone treatments on the number of leaves. However, there was no interaction between the two treatments tested.

Under dark shade (N75), FRT coffee produced the least number of leaves in one tree compared to other shade conditions. N25 produced the highest number of leaves, followed by N50. In addition, the treatment without shade resulted in the number of leaves being less than N25 but more than N75. This is different from Arisandi (2015), stating that Robusta coffee planted without shade tends to have fewer leaves than those planted under shade. FRT 09 produced the highest number of leaves compared to FRT 07 and FRT 65. Coffee leaves grow on each plagiotropic and orthotropic branch; coffee plants with more internodes will produce more leaves than those with few. These results indicate that the introduced coffee clones may have a higher tolerance for direct sunlight intensity than Robusta coffee in Indonesia.

The analysis of variance showed a significant effect of shade treatments and clone treatments on average leaf area. However, there was no interaction between the two treatments tested.

The leaf area of Conilon coffee increases with the increase in the levels of shade. Treatment without shade will produce thick yet narrow leaves. This is in line with the research results stating that excessive light intensity causes stunting of plant stems and leaves. Under shaded conditions, leaf cells are larger and thinner, endodermis, cuticle, and walls are more developed, and chloroplasts are more numerous and larger (Baliza *et al*., 2012). Wider leaves under shaded conditions represent one of the adaptation

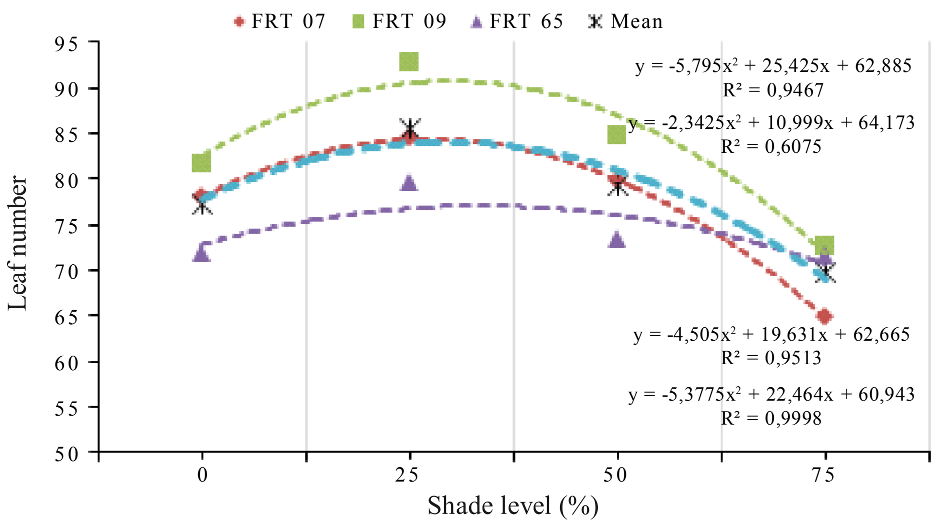


Figure 5. Relationship between shade level and leaf number of FRT clones at 180 DAP

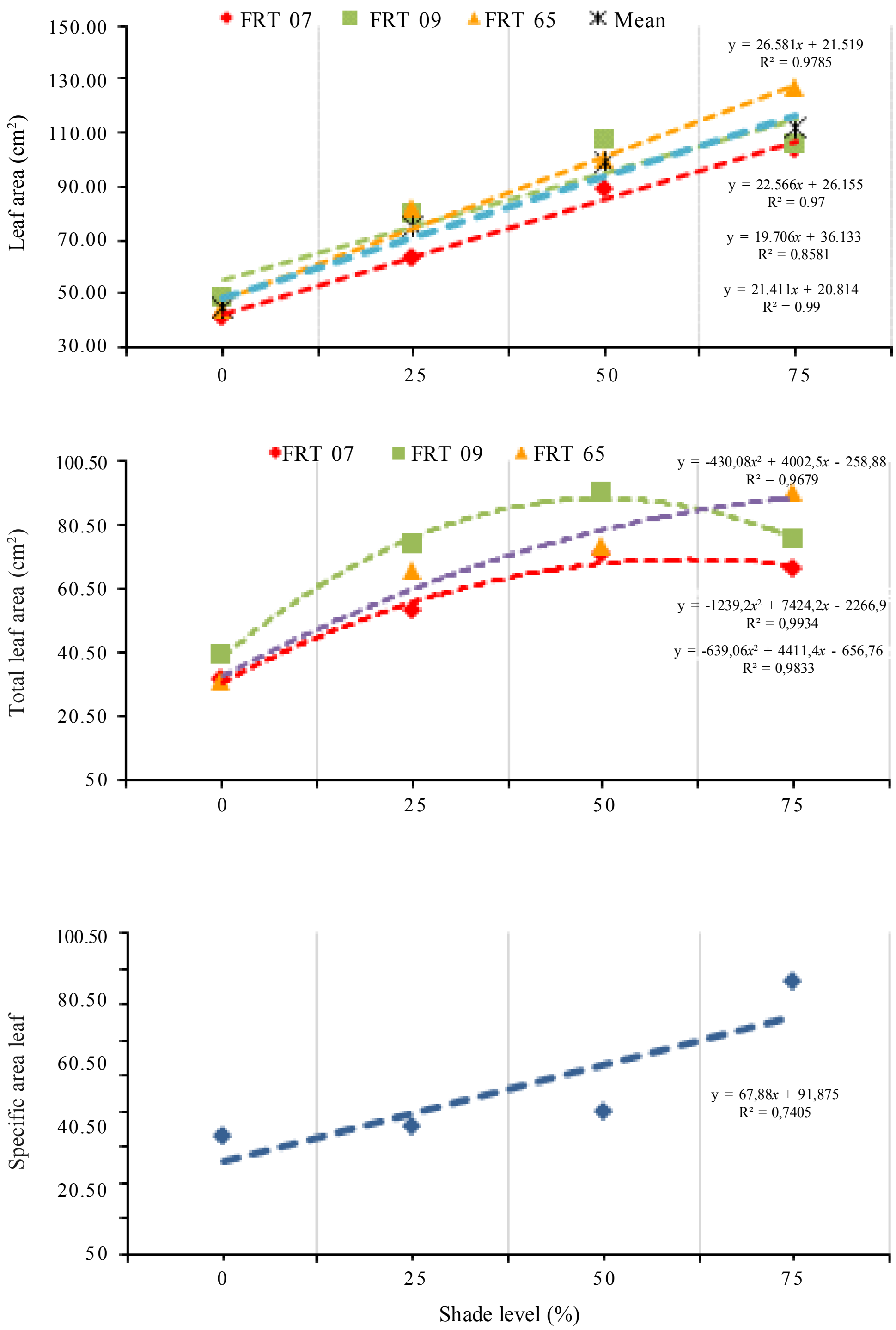


Figure 6. Relationship between shade level and the average of leaf area, total of leaf area, and specific leaf area of FRT clones at 180 DAP

efforts of plants to stress due to low light intensity to increase the light capture area (Partelli *et al.,* 2014).

FRT 65 clone had wider leaves than FRT 07 and FRT 09 in medium (N50) and heavy (N75) shades. FRT 07 had the narrowest leaf size compared to other clones tested. The relative size of the leaves of a coffee plant relates to a genetic trait influenced by environmental conditions, including shade. Several superior clones of Robusta coffee have a leaf length of 20.61 to 24.11 cm with a leaf width of 9.19 to 11.48 cm (Ramadiana *et al*., 2018), while Conilon coffee has a leaf length of 14.12 to 16.13 cm with a width of 5.75 to 6.63 (Ramalho *et al*., 2014).

The analysis of variance showed a significant effect of shade treatments and clone treatments on the total leaf area. FRT 07 gave a total leaf area growth response following the equation $y = -639.1x^2 + 4411.4x - 656.7$, with R^2 of 0.983, and the optimal value of total leaf area of 8269 cm^2 at 61.29% shade intensity. The effect of shade intensity on FRT 09 on the total leaf followed the equation $y = -1239.2x^2 + 7424.2x - 2266.9$ with R^2 of 0.968. The optimal total leaf area of FRT 09 occurred at a 49.88% shade level of 8852 cm^2. The total leaf area of FRT 65 increased along with the increase in the levels of shade following the equation $y = -430.1x^2 + 4002.5x - 258.9$ with a value of R^2 = 0.967. An increase in individual leaf area, along with an increase in shade intensity, leads to an increase in the total leaf area in one plant.

The analysis of variance showed a significant effect of shade treatments on specific leaf areas. However, clone treatments showed no significant difference in specific leaf areas.

The value of specific leaf areas increases as the levels of shade increase. Treatment without shade also produced leaves with the smallest average leaf area and the lowest value of specific leaf area. A low value of specific leaf areas indicates that the leaves are compact or thick, while a high value of specific leaf areas indicates that the leaves have a thin morphology. Shaded plants have a higher value of specific leaf areas, so they also have a higher potential relative growth rate than plants with a lower value of specific leaf areas. It is likely that the increase in specific leaf areas and the development of dark green leaf color in coffee plants under a shade has a major contribution to the increase in photosynthesis under shaded conditions (Poorter & Werf, 1998).

Crown Architecture

The crown architecture was observed on two variables: the branch angle and the crown diameter. The branching angle is related to the light distribution on the coffee crown, while the crown diameter determines the spacing when the coffee plant is planted in the field.

The analysis of variance showed no interaction between shade treatments and FRT coffee clones on the branching angle and crown diameter (Table 3).

The branching angle increases as the shade increases. Treatment without shade and N25 resulted in a small branching angle compared to treatments N50 and N75. The branching angle is related to the intensity of light received by the plant. The decrease in the value of the branching angle in conditions without shade is a form of plant response to increasing light interception. The vertical arrangement of leaves in the crown will increase light interception when the incidence angle of the sun is low, such as in the morning or evening, and reduce interception at midday when radiation is very high (Utami, 2018).

Tabel 3. Interaction between shade level plagiotropic branch of FRT clones at 180 DAP

Treatment	Branching angel(°)	Canopy diameter (cm)
Shade level		
0%	60 a	57.30 a
25%	61 a	60.31 a
50%	74 b	68.89 b
75%	80 c	68.80 b
Significance	**	**
C. canephora clones		
FRT 07	70 b	62.54 a
FRT 09	65 a	60.20 a
FRT 65	73 b	64.57 a
Significance	**	ns

Notes: Figures in the same treatment group and the same column followed by the same letter are not significantly different at α 5% to according to DMRT.

The branching angle is also influenced by the genetic factors of the plant. FRT 07 and FRT 65 have a larger branching angle than FRT 09, which indicates that the branching is more horizontal. Plants with vertical leaf angles and branching have good tolerance to high light intensity and drought (Tubur *et al*., 2012).

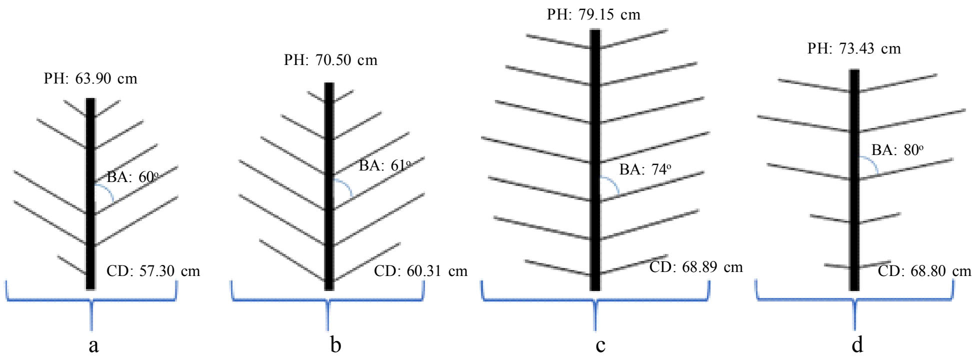
The shade treatment of 50% and 75% resulted in a wide crown diameter of 68.89 and 68.80 cm, followed by the N25 treatment with a crown diameter of 60.31 cm. The wide crown in shaded conditions aims to widen the capture area for limited light. The horizontal arrangement of leaves and branching in the plant crown will also cause interception to occur throughout the day, especially at midday. Treatment without shade resulted in the smallest crown diameter of 57.3 cm due to smaller leaf angles and less than optimal growth of plagiotropic branches (Utami, 2018). The branch architecture of *C. canephora* at several levels of shade is shown in Figure 7.

FRT coffee in the treatment without shade had a more compact habitus, shorter plants, short internodes, and narrow crown diameters. In the 25% shade treatment, there was an increase in plant height of 10.33% and crown width of 4.99% compared to the treatment without shade. The N50 treatment produced plants with the highest habitus, with an increase of 23.87% and an increase in crown diameter of 20.22% compared to the treatment without shade. The 75% shade treatment produced higher plants than the treatment without shade by 15.91%. The crown diameter in this treatment increased by 20.06% due to the plagiotropic branch length and large branching angle, resulting in a horizontal branching direction.

The crown width affects plant spacing. Both no shade and light shade produce a small crown diameter with a small branching angle allowing plants to be planted in high-density planting (HDP). Meanwhile, in shaded conditions, the crown diameter of the FRT coffee is wider with a large branching angle so that the spacing is tight, which can result in overlapping of leaves and branching.

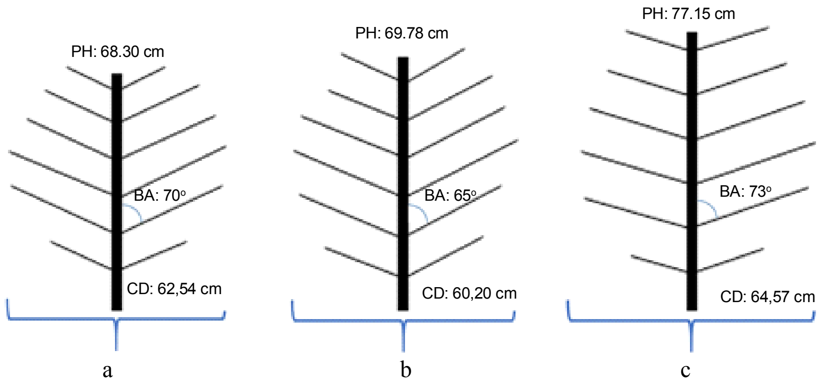
In the clone treatment, FRT 09 had the smallest leaf angle but had a crown diameter with no significant difference compared to FRT 07 and FRT 65. Small branch angles and small leaves are one of the characteristics of plants that are tolerant of environmental stresses, especially drought and high light intensity (Tubur *et al*., 2012). FRT 65 at 180 DAP showed jagur plant habitus, the plant was taller, but the crown diameter was not significantly different from other FRT clones tested.

Levels of shade significantly affect all orthotropic and plagiotropic growth parameters,



Notes : Scale 1:20; PH (plant height); CD (canopy diameter), and BA (branching angle).

Figure 7. Canopy architecture at different shade level at 180 DAP: without shade (a), 25% shade (b), 50% shade (c), and 75% shade (d)



Notes: Scale 1:20; PH (plant height); CD (canopy diameter), and BA (branching angle).

Figure 8. Canopy architecture of FRT clones at 180 DAP: (a) FRT 07, (b) FRT 09, and (c) FRT 65

leaf number and morphology, and plant architecture. Significant differences in clone treatments occurred in several variables of plant height, orthotropic internode length, number of leaves, and average leaf area. The interaction between treatments of shade and FRT clones occurred in stem diameter and total leaf area. However, interactions did not occur in most of the variables observed in this study. This shows that there is no need for a particular cropping pattern and management for the three introduced FRT clones in terms of the levels of shade. Observations of plant growth and architecture in this study were carried out in the immature plant phase, therefore further research is needed to obtain information about the effect of shade on the flowering and fruiting phase of FRT coffee.

CONCLUSIONS

An increase in the levels of shade in FRT coffee caused an increase in internode length, branch angle, and crown diameter but a decrease in the number of internodes and leaves. Light shade (25%) resulted in optimal values for parameters related to FRT coffee productivity, such as the number of plagiotropic internodes and the number of leaves. In contrast, parameters related to vegetative growth, such as plant height, stem diameter, and internode length, showed optimal values at a moderate shade level (50%). Treatment without shade and heavy shade resulted in growth disturbance of FRT coffee. The three introduced FRT clones gave relatively the same response to the levels of shade so that they could be managed with the same standard of shade management.

REFERENCES

Alexander, I. & H.J. Nadapdap (2019). Analisis daya saing ekspor biji kopi Indonesia di pasar global tahun 2002-2017. *JSEP*, 12(2), 1–16.

Ariany, S.P.; N. Sahiri & A. Syukur (2013). Pengaruh kuantitas cahaya terhadap pertumbuhan dan kadar antosianin daun dewa. *Agrotekbis,* 1(5), 413–420.

Arisandi, D.P. (2015). *Respon Karakteristik Fisiologi dan Pertumbuhan Bibit Kopi Robusta* (*Coffea canephora*) *Klon BP 358 dan BP 308 pada Berbagai Tingkat Naungan*. Skripsi. Universitas Jember, Jember, Indonesia.

Ayalew, B. (2018). Impact of shade on morpho-physiological characteristics of coffee plants, their pests and diseases. a Review. *African Journal of Agricultural Research*, 13(39), 2017–2024.

BPS (2020). *Statistik Kopi Indonesia 2020*. Badan Pusat Statistik. Jakarta.

Baliza, D.P.; R.L. Cunha; R.J. Guimarães; J.P.R.A.D. Barbosa; F.W. Ávila; A.M.A. Passos (2012). Physiological characteristics and development of coffee plants under different shading levels. *Revista Brasileirade Ciencias Agrarias*. 7(1), 37–43.

Bonomo, P.; C.D. Cruz; J.M.S. Viana; A.A. Pereira; V.R. Oliveira & P.C.S. Carneiro (2004). Avaliaa o de proginies obtidas de cruzamentos de descendentes do Hibrido de Timor com as cultivares Catuai Vermelho e Catuai Amarelo. *Bragantia*, 63, 207–219.

Campanha, M.M.; R.H.S. Santos; G.B.D. Freitas; H.E.P. Martinez; S.L.R. Garcia & F.L. Finger (2004). Growth and yield of coffee plants in agroforestry and monoculture systems in Minas Gerais Brazil. *Agroforestry System*, 63,75-82.

DaMatta, F.M.; C.P. Ronchi; M. Maestri & R.S. Barros (2008). Ecophysiology of coffee growth and production. *Brazilian Journal of Plant Physiology*, 19(4), 485–510.

Neto, D.S.F.J.; K.P.G. Morinigo; N.De F. Guimarães; D.S. Gallo; M.D.B. De Souza; R. Stolf & A. Fontanetti (2018). Shade Trees Spatial Distribution and Its Effect on Grains and Beverage Quality of Shaded Coffee Trees. .

Espindula, M.C.; L.F.B. de Araújo; R. Schmidt; J.R.M. Dias & R.B. Rocha (2020). Early induction of orthotropic shoots in *Coffea canephora*. *Revista Ceres,* 67, 281–287.

Etienne, H.; D. Breton; J.C. Breitler; B. Bertrand; E. Déchamp; R. Awada; P. Marraccini; S. Léran; E. Alpizar; C. Campa; P. Courtel; F. Georget & J.P. Ducos (2018). Coffee somatic embryogenesis: How did research, experience gained and innovations promote the commercial propagation of elite clones from the two cultivated species?. *Frontier Plant Science*, 9, 1–21.

Filho, A.C.V.; M.A. Tomaz; R.G. Ferrão; M.A.G. Ferrão; A.F.A. Fonseca & W.N. Rodrigues (2014). Conilon coffee yield using the programmed pruning cycle and different cultivation densities. *Coffee Science*, 9(4), 489–494.

Harjanti, R.A.; Tohari & S.N.H. Utami (2014). Pengaruh takaran pupuk nitrogen dan silika terhadap pertumbuhan awal tebu (*Saccharum officinarum* L.) pada inceptisol. *Vegetalika*, 3(2), 35–44.

Morais, H.; P.H. Caramori; A.M.A. Ribeiro, J.C. Gomes & M.S. Koguishi (2006). Microclimatic characterization and productivity of coffee plants grown under shade of pigeon pea in Southern Brazil. *Pesquisa Agropecuária Brasileira*, 41, 763–770.

Neto, D.S.F.J.; K.P. G. Morinigo; N.De F. Guimarães; D.S. Gallo; M.D.B. De Souza; R. Stolf & A. Fontanetti (2018). Shade trees spatial distribution and its effect on grains and beverage quality of shaded coffee trees. *Journal of Food Quality*, 8(1), 1-8.

Partelli, F.L.; A.V. Araújo; H.D. Vieira; J.R.M. Dias; L.F.T. Menezes & J.C. Ramalho (2014). Microclimate and development of 'Conilon' coffee intercropped with rubber trees. *Pesqui Agropecu Bras*, 49(11), 872–881.

Poorter, H. & V.A. Werf (1998). Is inherent variation in RGR determined by LAR at low irradiance and by NAR at high irradiance? p.309–336. ***In:*** *Inherent Variation in Plant Growth: Physiological Mechanisms and Ecological Consequences*. H. Lambers, H. Poorter & M.M.I. van Vuuren (Eds.). Backhuys Publishers. Leiden, Netherlands.

Ramadiana, S.; D. Hapsoro & Y. Yusnita (2018). Morphological variation among fifteen superior Robusta coffee clones in Lampung Province, Indonesia. *Biodiversitas,* 19(4), 1475–1481.

Ramalho, A.R.; R.B. Rocha; W. Veneziano & M.M. Santos (2014). Cultivar de cafeeiro Conilon brs ouro preto: características agronômicas e agroindustriais. *Embrapa Comun. Técn*, 396, 1–9.

Rodríguez, L; J. Verdecia; L. Arias; R. Medina & E. Velasco (2001). Growth, relative water content, transpiration and photosynthetic pigment content in coffee trees (*C. arabica* L.) growing at different sunlight regimes. *Cultivos Tropicales*, 22(4), 37–41.

Sholikhah, U.; D.A. Munandar & A. Pradana (2015). Karakter fisiologis klon kopi Robusta BP 358 pada jenis penaung yang berbeda. *Agrovigor*. 8(1), 58–67.

Sopandie, D. (2013). *Fisiologi Adaptasi Tanaman terhadap Cekaman Abiotik pada Agroekosistem Tropika*. Penerbit IPB Press. Bogor.

Subekti, N.; A. Syafruddin; R. Efendi & S. Sunarti (2012). *Morfologi Tanaman dan Fase Pertumbuhan Jagung*. Balai Penelitian Tanaman Serealia, Marros.

Sumirat, U. (2016). Plasma nutfah kopi p. 39–50. ***In*****:** *Kopi: Sejarah, Botani, Proses Produksi, Pengolahan, Produksi Hilir dan Sistem Kemitraan*. (Wahyudi, T, Pujiyanto dan Misnawi, Eds). Gadjah Mada University Press. Yogyakarta.

Tabagiba, S.D.; E.A. Santos; J.E.M. Pezzopane & E.F. Reis (2010). Coffea canephora seedlings in the under shading and full sun. *Engenharia na Agricultura*, 18(3), 219-226.

Tubur, H.W.; M.A. Chozin; E. Santosa & A. Junaedi (2012). Respon agronomi varietas padi terhadap periode kekeringan pada sistem sawah. *Jurnal Agronomi Indonesia*, 40, 167–173.

Utami (2018). *Pengaruh Cahaya Terhadap Pertumbuhan Tanaman*. Fakultas Pertanian Universitas Udayana.

Volsi, B. (2019). The dynamics of coffee production in Brazil. *Plos One*,14(7), 1–15.

Yuliasmara, F. (2017). El Nino effect on coffee growth and productivity on several agroforestry systems in Gumitir Mountain coffee farms, East Java, Indonesia. *Pelita Perkebunan*, 33(3), 168–179.

Yuliasmara, F.; Suhartono & R. Hulupi (2016). Pemangkasan tanaman kopi. p. 195–216. ***In:*** Kopi: *Sejarah, Botani, Proses Produksi, Pengolahan, Produksi Hilir, dan Sistem Kemitraan*. (T. Wahyudi, Pujiyanto & Misnawi, Eds). Gadjah Mada University Press. Yogyakarta,

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