International Letters of Natural Sciences
ISSN: 2300-9675, Vol. 81, pp 31-41
doi:10.18052/www.scipress.com/ILNS.81.31
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Submitted: 2020-02-24
Revised: 2020-05-20
Accepted: 2020-05-29
Online: 2021-02-25

Micro-Climate Conditions, Weed Diversity, Flowering and Yield of Young Cacao Plants as Affected by Shade Regimes

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Keywords: Cacao, cherelle, microclimate, pod, shade, temperature, weed.

Abstract. Experiments were conducted in 2015/2018 in two cacao plots established in 2012 and 2013 in Akure, Nigeria to investigate micro-climate conditions, weed densities, flowering and yield of cacao as affected by shade regimes. Established cacao plots under three plantain (*Musa spp*) shade regimes consisting of No-shade, Moderate and Dense shade were used. Air and soil temperature, relative humidity and Photosynthetic Active Radiation (PAR), weed population and species diversity, cacao flowering and pod production were measured. From the results, air and soil temperature measurements under No-shade plots had a significantly higher mean values (32^0C) and soil (28^0C) compared with moderately shaded [air, 30^0C and soil, 26.5^0C] and densely shaded [air, 30^0C and soil, 26^0C] plots in 2015 and 2016 measurements but under 2017 measurements, no significant difference in the soil temperature of the plots under dense shade, moderate and the no-shade which were ascribed to canopy close-up of the cacao that led to reduced transmitted light through the canopy to the understories species. The vigour of weeds under no-shade plots were significantly higher compared with dense and moderately shaded plots. In 2013 established cacao plot, flower production was higher significantly in no-shade compared with those in moderate and dense shaded cacao plots in 2015 and 2016 measurement. Pod production under No-shade were significantly higher compared with other treatments in 2016 and 2017. Cherelle wilt rate was higher in shaded plots compared with the no-shade plots. Pod yield parameters were significantly higher under No-shade plots compared with shaded treatments during the three years of data measurement. Air temperature between 30ºC to 33.7ºC during flowering and fruit/pod setting was found to have positive influence on bean yield in cacao. The study concluded that excessive shade decreases yield of cocoa, while increases in temperature and relative humidity boosts some physiological processes for pod production in Cocoa.

Introduction

The farming process of cocoa can damage the environment itself through conversion of existing forest vegetation (deforestation) to cocoa plantation with less plant ecosystem diversity. Global climate change, for example, causes longer drought seasons making it more difficult for farmers to plant and sustain new cocoa trees. The impact of climate conditions on agricultural productivity is confirmed by many recent studies [1], [2], [3], [4] and [5]. They reported that decrease in water availability (moisture stress) during crop growing period could play a major role in reducing productivity. [6] examined the effects of rainfall on cocoa production and concluded that there are many interactions between weather variability and cocoa production. [7], [8] and [9] emphasized the significant of use of plantain as a shade plant for soil moisture conservation, temperature reduction and ecosystem stability in cacao plantation establishment. [10] proposed that changes in climatic extremes will constitute adverse impact on productivity of fruit harvests with likely agricultural losses of between 2 and 7% of Gross Domestic Product [11]. Efforts should be geared towards characterizing weather-crop relations, adopt sustainable management of water resources via adoption of water saving technologies, increased use efficiency of rainfall and soil water and identification and use of stress tolerant species [12]. Therefore, this research emphasised the effects of shade regimes on micro-climate variation, cocoa flowering and yield in southwest Nigeria over three years (2015-2017).

Materials and Method

Experiments were conducted between 2015 and 2018 on two established cacao plantations planted in 2012 and 2013 at the Teaching and Research farm of the Federal University of Technology Akure, Nigeria (Latitude 7^0 16^1 N and longitude 5^0 12^1 E of Greenwich meridian) in the rain forest agro-ecological zone. The variety of the cacao is CRIN Tc4 (Cocoa Research Institute of Nigeria-*Theobroma cacao*) developed by Cocoa Research Institute of Nigeria. The two plantations were beside each other separated by a drive way. The size of the plots was 54 x 36 meters for both 2012 and 2013 established plots. The plots were established under three shade regimes of Moderate shade (30% shade) with one cacao row followed by one plantain row, dense shade (60% shade) with one cacao row followed by two plantain rows and No-shade (0 % shade) which is under open sun. The plantains and the cacao were planted at 3 meters apart both along the rows and across the rows. The number of cacao plant per shade treatment is 72 with the total cacao stands of 216 per experiment.

Gravity drip irrigation was installed in both fields during the dry seasons to alleviate soil moisture stress. Weeding was conducted on the fields three times annually while minor pruning takes place annually before the onset of rain. During the experiment, twenty stands of cacao were selected from each shade regime from both fields totalling 120 cacao plants and were monitored from 2015, to 2018. Ten soil thermometers were installed per shade treatment at various point on the field to take the soil temperature at one week interval while Ten thermometers were also suspended under the canopy of the tagged cacao stands to measure the air temperature within the cacao canopy at varying periods of the day. Relative humidity and Photosynthetic Active Radiation (PAR) was also monitor. The relative humidity was measured using air moisture meter. The PAR was measured using DELTA T Sunscan Canopy Analyser. Data were also measured on flowering rate, cherrelle (immature young pod) production, cherrelle wilt, total pod yield, fresh pod weight, fresh bean weight, bean number per pod, dry bean weight, and total dry bean weight per shade regime.

At one week interval, average air and soil temperature were taken with the use of thermometer on the selected cacao between the hours of 1.00-3.00 pm in the afternoon. Average soil temperature changes between the hours of 1.00-3.00pm were also recorded. At one week interval, cacao flowering, number of pods, number of Cherelles, and number of wilted Cherelles were monitored by counting. For the yield parameters, ripe cocoa pods were harvested at two weeks interval from the tagged cacao stands. Total pod yield and bean yield were determined by summing up the total harvested pods and bean yield at various harvest intervals. At harvest, weight of each pod was taken using weighing balance, the pods were broken with a blunt cutlass and the beans were extracted and weighed. The extracted beans were fermented and sundried to 7 % moisture and the weights were measured. At one month interval weed density sampling were taken using a 50cm by 50cm quadrant by throwing randomly under different shade regimes and the available weeds were sorted and classified into ephemeral, annual and perennial weeds. The total averages were recorded at the end of each experiment year. Microbial population (nematode, fungi and bacterial) within the soil under the varying shade regimes were also monitored during the experiment (2015, 2016 and 2017). Soil samples were from each shade regimes were analysed in the laboratory for nematode, fungi and bacterial. The total viable bacteria and fungi colonies were counted per gram of the soil samples while nematode count was carried out using Bearmann funnel method. The measured data were subjected to analysis of variance using MINITAB and the mean was separated using Tukey test.

Results

Figure 1 shows the effects of shade regime on monthly air temperature variation within the plots between May, 2015 and Nov. 2017. From the result, air temperature was significantly higher under no-shade compared to dense shade and moderately shaded cacao plots. No shade plots exhibits a significantly higher air temperatures during the months of October-December and February-May across the years of the experiment which was also associated with reduced soil moisture percentage. During the month of June –September and December/January, no significant different in the temperature under the three shade regimes across the three years of experiment, though with a slight increase in temperature trends.

Figure 2 shows the effects of shade regime on monthly soil temperature variation from May, 2015 to November, 2017. There were significant differences among no-shade, dense shade and moderately shaded cacao. From the result, temperatures in no-shade plots were significantly higher than those of moderate and dense shaded cacao plots across the three years under consideration. A higher significant soil temperature means were recorded during the months of June/July, September/November and February/April with No shade plots showing a significantly higher difference over moderate and dense shaded plots.

Table 1 shows the effects of shade regimes on flower production during 2015-2018. From the results, flower productions were significantly higher under no-shade treatment throughout the three year under consideration (2015, 2016 and 2017 experiments) compared to the moderate and dense shade cacao. During the period of three years of data measurement, no significant difference was recorded between moderately and densely shaded plots at the period of flower flushing (onset of raining season) but were significantly lower in flower production compered to no-shade plots. The result also indicated that flower production diminishes as rainy season gets established and was also based on the carrying capacity of each cacao stand to sustain pod/cherelle growth and development.

Beginning from the month of August, monthly flower productions dropped by an average of 70% across the three years under consideration in all the shade treatments. Similar trend was also obtained in 2016 experiment. The only notable difference was in the number of produced flower per plant per month which was a function of plant age. Flower production increases with age of the cacao across the three treatments.

Figure 3 represents the effects of shade regimes on pod yield from 2015 to 2017. In general sense pod production was found to increase with age of the cocoa plant. In 2015, pod production was significantly higher under no shade plots compared to those recorded in moderate and densely shaded plots. Similar trends were recorded in 2016 and 2017production seasons. In addition, no shade plots had the highest significant pod yield followed by moderate and the least significant pod yield from densely shaded plots throughout the three years of measurement.

Table 2 represents the effects of shade regimes on cherelle production during 2015-2018 experiments. From the results, no shade treatment plots converted higher number of flower produced to cherelles and to mature pods compared to moderate and densely shaded plots. The numbers of cherelles developed on a monthly basis between April and November of the three years under consideration across the two plantations increases at the first two months and later decrease along the month from June. In 2015 observations, peak of cherelles production was noticed in June while those of 2016 and 2017 were noticed in April/May. It was also observed that cherelles production in no shade treatments were continuous round the year with a minimum cherelles count of 15.3, 25.4 and 34.0 in the year 2015, 2016 and 2017 respectively compared to that of 1.0, 15.7 and 22.4 for 2015, 2016 and 2017 respectively for densely shaded treatments.

Table 3 represents the effects of shade regimes on cherelle wilt rate. The results indicated that no-shade was significantly lower in cherelle wilt rate compared to moderate and dense shaded cacao plots although there was no significant difference between moderate and densely shaded plots in 2015 measurements. In 2016 measurements, beginning from April through July, cherelle wilt rate were significantly lower in no shade treatment plots compared to those of moderate and densely shaded plots.

Table 4 shows effects of shade regimes on pod weight, bean number, bean weight, and dry bean weight between 2015- 2018. From the results, average weight of pods under no shade treatment was significantly higher compared to dense and moderately shaded cacao plots. More so, no shade showed a significantly higher mean values over densely shaded plots in term of number of bean per pod, pod wet and dry weight. No significant difference exist in the pod wet weight mean values between no shade and the moderately shaded plots, number of bean per pod and the fermented bean dry weight for the two plots as shown in table 4

Table 5 represents the effects of shade regimes of the density of weed species within the cacao plantation. The results indicated that no shade treatment enhances a significantly higher weed densities across the three years of data measurement compared to moderate and densely shaded plots. More so, throughout the period of data measurement (2015-2017), weeding regimes were significantly higher in no shade which in turn increases the cost of field management and control compared to moderate and densely shaded plots. Densities of weed on a monthly measurement were not different significantly among the three shade regimes between the months of November to April but with marked significant differences between April and September as shown in table 5.

Table 6 represents the microbial population within the plots in 2015, 2016 and 2017. From the results, shade was found to enhance microbial population build up across the three years of data measurement. More so, cacao age tends to have a positive impact on the fauna population due to canopy development which assist in the covering of the exposed surface within the plantation.

Figure 4 a, b and c shows the impact of shade regimes on photosynthetic active radiation and light penetration within the cacao canopies. From the results, higher shade densities were found to significantly influence light penetration through the canopies of the cacao thereby reducing the PAR that is available for growth, development and yield of the cacao. More so, dense shade plots were found to have the lowest PAR which translated to its inability to produce enough assimilates for flower and pod production compared to no shaded plots that has unhindered access to insolation which influenced flowering, increase pod yield and quality. In addition, the trends of variation in the performance of the cacao across the three shade regimes reveals that PAR plays an important roles in virtually all aspect of cacao growth and development.

The higher microbial activities under dense and moderately shaded plots compared to those in no shade plots were as a result low amount of transmitted light through the cacao canopy due to interference by closed canopies of the shade plant and the cacao canopies.

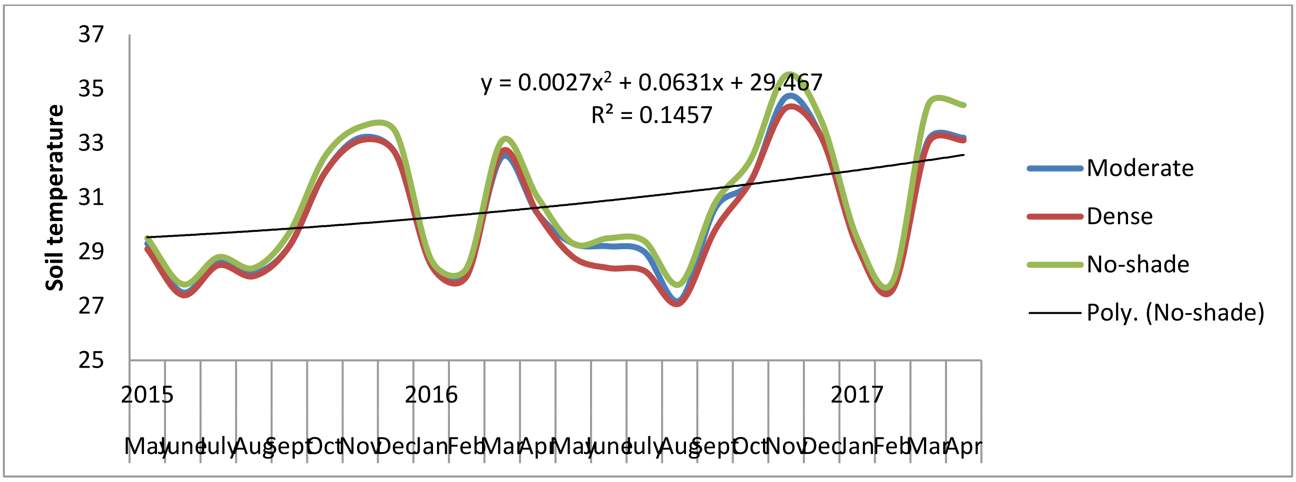

Figure 1: Air temperature variations within cacao plots as influenced by shade regimes for 2015-2017

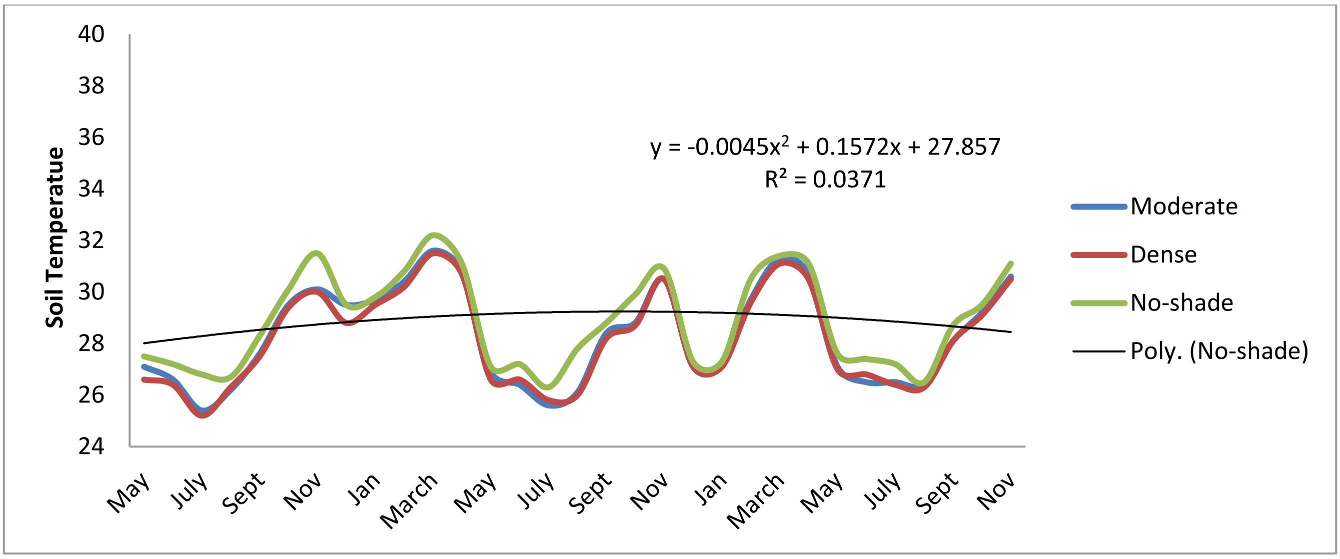

Figure 2: Soil temperature variations in cacao plots as influenced by shade regimes for 2015-2017

Table 1: Effects of shade regimes on flower production of 2015, 2016 and 2017

Year	Shade regimes	2013 established cacao plot							2012 established cacao plot						
		April	May	June	July	Aug.	Sept.	Oct.	April	May	June	July	Aug.	Sept.	Oct.
2015	Moderate	92.5b	220.8b	7.40b	14.4b	7.4a	3.5a	4.2a	189.6b	616.4a	226.0b	122.2a	21.0a	35.4a	30.2a
	Dense	69.3b	282.6b	35.6ab	28.6a	6.0a	6.7a	5.5a	175.6b	684.0a	395.0a	104.6a	21.8a	22.8a	25.4a
	No Shade	225.7a	411.6a	122.0a	22.6ab	15.4a	23.4a	20.4a	605.4a	590.0a	474.0a	35.0b	14.6a	55.8a	63.4a
2016	Moderate	511.2a	712.5a	558.5a	251.2a	102.4a	21.5a	4.2a	1514.2a	1335.2a	855.6a	312.5a	65.3a	22.1a	9.5a
	Dense	457.9a	526.4a	425.6a	130.5b	65.5b	13.0a	2.5a	1558.2a	1103.9a	623.0b	122.8a	38.9b	12.0a	16.2a
	No Shade	369.5a	665.0a	502.7a	440.5a	231.3a	45.7a	15.0a	1754.6a	1680.5a	1103.5a	281.9a	92.2a	19.1a	12.5a
2017	Moderate	698.6b	1256.2a	850.0a	320.0b	87.4b	20.8a	6.6a	4157.3a	2945.6a	1691.2a	568.4a	111.5b	14.1a	22.3a
	Dense	705.2b	1054.2b	545.5b	265.3b	37.0b	18.1a	8.0a	3887.4a	2557.3a	912.4b	212.3b	31.0c	23.1a	13.0a
	No Shade	875.3a	1641.0a	980.8a	556.2a	144.6a	39.4a	28a	4336.8a	3516.5a	1992.4a	704.5a	201.6a	55.4a	42.5a

Means in the same column for same year followed by same letter (s) are not significantly different @ $p \leq 0.05$ by Tukey Test.

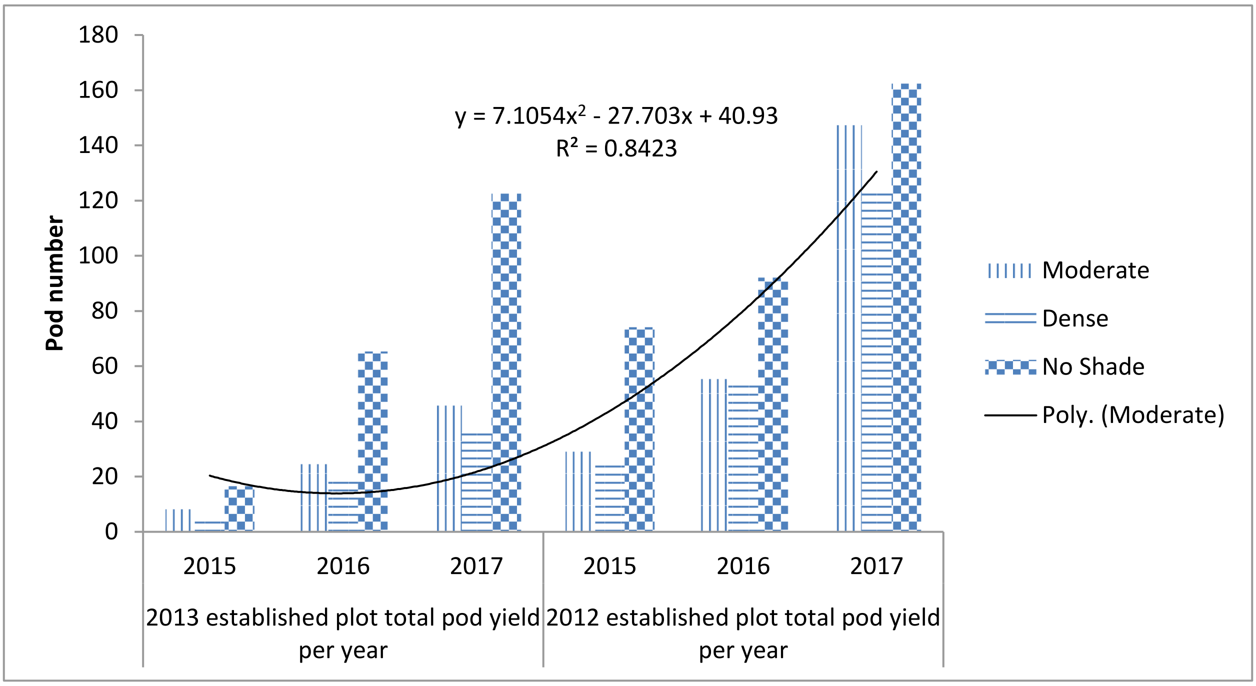

Figure 3: Effects of shade regimes on pod yield 2015, 2026 and 2017

Table 2: Effects of shade regime on cherelle production 2015, 2016 and 2017

Year	Shade Regime	2013 plot April	May	June	July	Aug.	Sept.	Oct.	Nov.	2012 plot April	May	June	July	Aug.	Sept	Oct.	Nov.
2015	Moderate	0.0d	6.8c	45.4b	12.0a	3.6b	0.8d	1.2c	1.0b	13.0b	33.0c	63.6b	21.8c	5.2c	7.2c	5.4d	1.0d
	Dense	1.0d	11.4c	33.6bc	16.4a	3.8b	1.4c	1.8c	3.2a	10.0b	28.0c	48.0b	32.8b	14.0b	11.8b	5.5d	1.0d
	No-shade	0.0d	7.0c	72.2a	6.8b	5.4b	3.4b	3.5b	5.2a	24.0a	62.0b	109.6a	52.8a	6.2c	9.2bc	15.8c	9.5c
2016	Moderate	18.2c	48.0b	26.5c	11.0a	7.9a	0.0e	5.5b	0.0c	56.5	78.9b	55.0b	25.6c	15.6b	9.6bc	18.6b	15.3b
	Dense	21.4c	52.4b	22.8c	5.8c	15.2a	5.6b	11.6a	2.0b	45.6	85.0ab	61.3b	39.3b	28.4a	18.2a	12.6c	15.7b
	No-shade	68.2b	108.1a	25.0c	13.8a	3.8b	25.4a	13.0a	3.5a	75.0	106.2a	53.4b	34.2b	18.6b	13.8b	23.6b	25.4b
2017	Moderate	78.5b	43.5b	35.2b	6.1c	12.3a	2.4c	4.0b	0.0c	120.5	68.1b	39.7c	21.3c	20.4a	11.3b	22.1b	35.1a
	Dense	65.0b	69.4b	46.7b	11.5a	10.0a	6.0b	5.0b	1.0b	104.0	60.2b	32.1c	12.8d	14.8b	8.7c	12.4c	22.2b
	No-shade	155.1a	145.5a	50.4a	5.0c	3.0b	38.2a	3.2b	0.0c	135.6	103.5a	55.6b	25.8b	24.6a	22.7a	35.8a	34.0a

Means in the same column followed by same letter (s) are not significantly different @ p≤ 0.05 by Tukey Test.

Table 3: Effects of shade regime on cherelle wilt rate 2015, 2016 and 2017

Year	Shade regime	2013 plot April	May	June	July	August	Sept.	2012 plot April	May	June	July	August	Sept.
2015	Moderate	0.0d	0.0d	0.0d	2.0b	2.8a	2.8a	7.00c	2.6c	9.4b	5.4a	4.6b	11.8b
	Dense	0.4d	0.4d	1.0c	5.8a	3.2a	3.2a	9.4bc	3.4c	11.8b	7.4a	13.8a	18.0a
	No Shade	0.0d	0.0d	1.0c	2.0b	1.0b	1.4b	5.2c	3.8c	8.8bc	1.4b	5.8b	7.8c
2016	Moderate	6.5b	3.8b	10.0b	1.6c	2.3a	0.0c	16.5b	15.5b	13.5b	4.2b	3.4b	4.2c
	Dense	8.4b	6.8b	12.5a	3.4a	2.5a	1.0b	10.2b	28.4a	21.2a	6.3a	5.5b	4.1c
	No Shade	3.1c	2.5c	5.4b	3.5a	1.0b	3.5a	5.5c	24.0a	2.5d	2.3	2.0c	2.0d
2017	Moderate	12.5a	12.1a	16.8a	4.5a	1.0b	1.0b	26.1a	23.3a	6.4c	5.8a	3.6b	3.5c
	Dense	16.0a	6.5b	15.0a	3.5a	1.0b	1.0b	30.0a	27.9a	11.5b	7.0a	5.4b	3.8c
	No-shade	7.3b	3.2b	11.0a	1.5c	0.0c	2.5a	13.0b	20.2a	7.9c	2.0b	1.0c	1.0d

Means in the same column followed by same letter (s) are not significantly different @ p≤ 0.05 by Tukey Test.

Table 4: Effects of shade regime on pod weight, bean number, bean wet weight, and bean dry weight for 2015, 2016 and 2017

Year	Shade Regime	2013 plot Average total number of pod /tree/yr	Average pod weight(g)	Bean number/ pod	Wet bean weight / pod	Dry bean weight/ pod	2012 plot Average total number of pod /tree/yr	Average pod weight(g)	Bean number/pod	Wet bean weight/ pod	Dry bean weight/ pod
2015	Dense	5.5f	481.3c	44.0b	152.5c	52.8b	25.4e	501.3c	45.2b	155.3d	54.d
	Moderate	8.2f	486.2c	46.2b	159.6c	64.7a	29.1e	516.0bc	46.4b	160.4c	65.2bc
	No-shade	16.5de	560.4a	49.0a	165.1b	68.6a	74.2c	585.1a	50.6a	168.9c	69.4b
2016	Dense	20.2d	485.9c	46.3b	164.5b	60.2a	54.6d	489.7c	46.5b	169.4c	61.5c
	Moderate	24.6d	477.3c	46.5b	164.8b	60.5a	55.4d	511.5bc	47.2a	173.2b	65.3bc
	No-shade	65.4b	555.6a	48.2a	173.6a	62.7a	92.1c	579.4a	49.0a	189.7a	71.0a
2017	Dense	36.2c	503.4b	46.0b	164.6b	59.8b	124.7b	525.6b	47.3a	179.2b	66.8b
	Moderate	45.8c	513.2b	45.0b	164.8b	58.5b	147.5a	533.9b	47.5a	178.6b	66.1b
	No-shade	122.5a	567.2a	48.5a	185.8a	63.1a	162.4a	592.7a	49.4a	191.4a	72.7a

Means in the same column followed by same letter (s) are not significantly different @ p≤ 0.05 by Tukey Test.

Table 5: Effects of shade regimes on weed biomass (g/m^2) in 2015, 2016 and 2017 experiments

	Shade regimes	2013established plot			2012 plots		
		March	June	August	March	June	August
2015	Moderate	120.60a	144.40ab	122.60b	100.00b	119.00a	90.60ab
	Dense	118.20a	91.80c	54.60d	47.00d	42.00e	38.00e
	No shade	132.00a	162.40a	134.00a	126.00a	83.20c	49.80d
2016	Moderate	116.20a	124.50b	102.60c	107.00b	79.00cd	60.60c
	Dense	113.00ab	110.90b	94.60c	67.00c	51.00b	35.00e
	No shade	122.80a	132.70b	124.00b	116.00ab	103.20b	99.80a
2017	Moderate	88.40b	74.50cd	62.60d	97.00b	99.00b	80.60b
	Dense	51.20c	49.80e	34.60e	67.00c	41.00e	39.00de
	No shade	116.20a	92.40c	74.00d	106.00b	83.20c	69.80bc

Means in same column followed by same letters are not significantly different at $P \leq 0.05$ by Tukey Text

Table 6: Microbial population in the soils under 2012 and 2013 established cacao plots

Organism	2013 established plots			2012 established plots		
	Moderate shade	Dense shade	No shade	Moderate shade	Dense shade	No shade
Criconemella	-	-	-	20	20	40
Discocriconema	-	-	-	30	10	-
Helicotylenchus	40	50	10	-	140	30
Hemicycliophora	-	20	-	-	-	-
Heterodera	40	50	50	40	-	40
Meloidogyne	70	-	20	50	40	-
Longidorus	20	10	20	40	60	20
Paratylenchus	50	20	-	50	50	40
Hirschmanniella	-	-	30	30	10	-
Tylenchus	-	-	-	-	10	-
Rotylenchus	-	-	10	-	20	-
Scutellonema	-	-	-	40	-	-

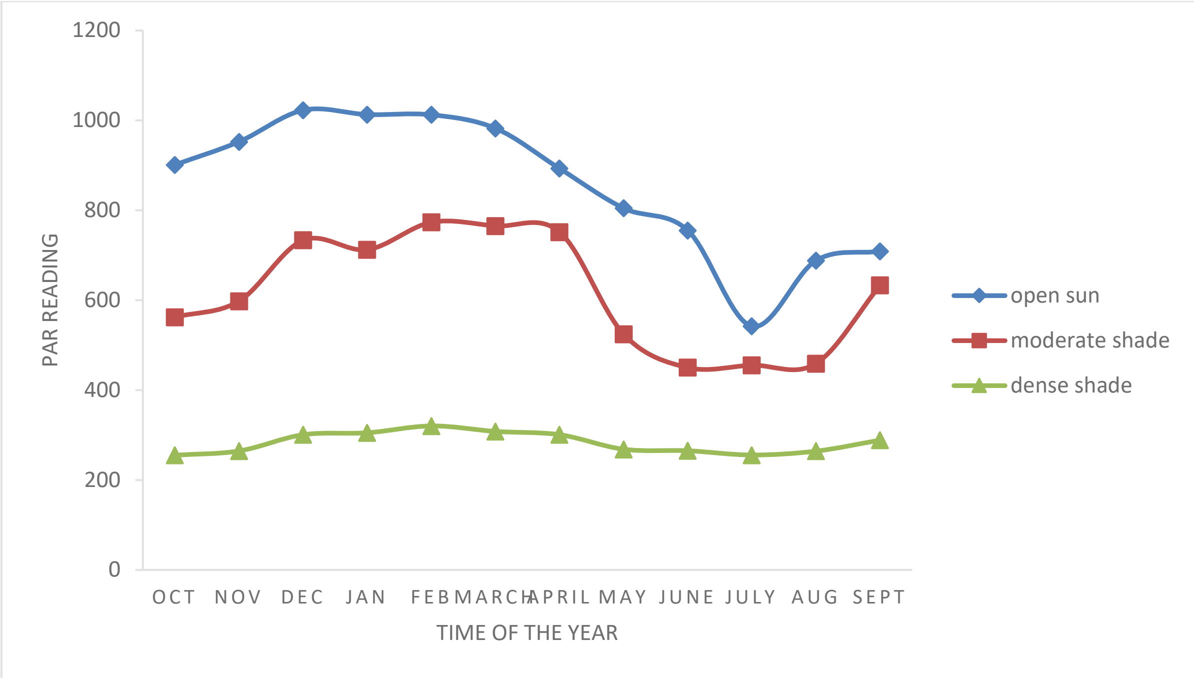

Figure 4a: Light penetration through the canopy showing the photosynthetic active radiation at different period of the year 2015/2016

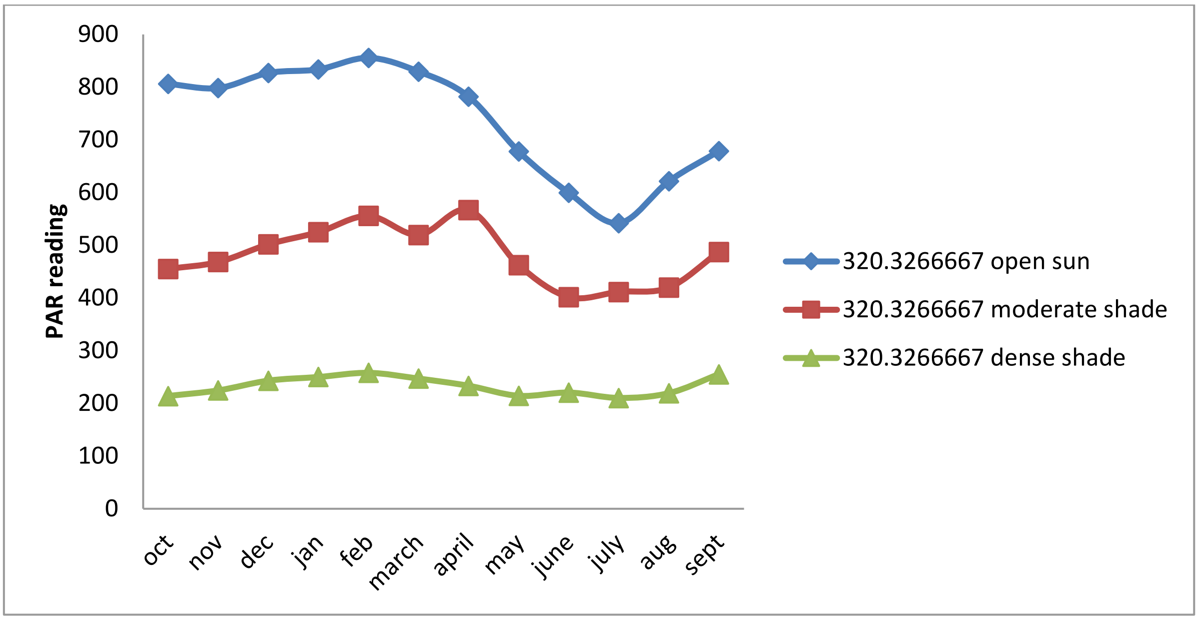

Figure 4b: Light penetration through the canopy showing the photosynthetic active radiation at different period of the year 2016/2017

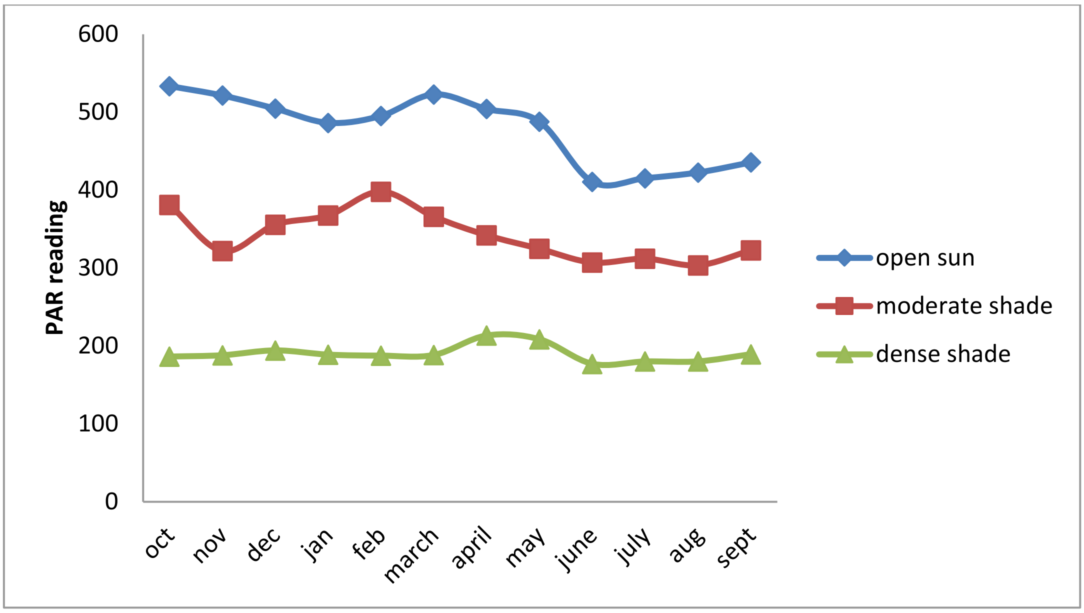

Figure 4c: Light penetration through the canopy showing the photosynthetic active radiation at different period of the year 2017/2018

Discussion

The significantly higher temperature recorded under no-shade cacao plot for 2 and 3 years is as a result of exposure to open sun which made the plot to have direct access to sunlight without any interference to reduce the direct impact of the sun. This inform a higher photosynthetic rate, higher assimilate production and partitioning for enhanced pod formation and development. Increase in temperature leads to increase in yield (due to increased photosynthesis). This agrees with [13] that if minimum temperature increases by one percent, cocoa output will increase by 3.29 percent.

Also, the significantly higher temperature in No-shade of 2 and 3 years old cacao plantation was due to increase in temperature which leads to increase in pollination and rapid increase in flowering of cacao. The relationship between temperature and cocoa productivity has been observed by [14] to be positive. The growth, development and yield rate of cocoa are highly dependent on temperature, which mainly affects the vegetative growth, flowering and fruit development of cacao. Low light intensities of sunlight however suppress flower production, having a considerable depressing effect on cocoa production [15]. This was in line with the higher yield recorded under no-shade plots compared with those under shaded plots.

Furthermore, Cherelle production was higher in No-shade regime because high light intensity enhance rapid development of flowers to Cherelle, and also enhance development of Cherelle to mature pod as a result of increased assimilate production and improve photosynthetic activities. The significantly higher cherrelle wilt recorded under densely and moderately shaded plots may be traced to the inability of the cacao canopy to produce enough assimilates to nurture the produced cherrelles to mature pods due to reduced/low PAR which is a factor of shade interference with the sunlight penetration within the cacao canopies.

More so, the significantly higher number of pods produced under No-shade of 2 and 3years cacao plots was as a result of direct access to sunlight. The high temperature resulting from high sunshine is advantageous as it is needed for ripening of cocoa pods and also for drying of cocoa beans, hence a boost to overall cocoa yield. This was supported by the findings of [16]. The yield quality that were higher in terms of bean weight, and number under no shade treated plots were traced to availability of more assymilates for pod development and bean filling which was affirmed by the submission of [17].

Also, the significantly higher weight of bean in No-shade regime is as a result of unhindered access to sunlight which enhances photosynthetic activities and assimilates production for proper seed filling. The significantly higher mean values recorded in flora population and density of the weed species under the no shade plots were traced to the higher amount of transmitted light through the cacao canopies as a result of no interference by shade plant canopies, which was found to exacerbate rapid weed development under no shade plots compared to low weed population, density and growth under the shaded plots. This scenario also placed an additional maintenance cost in term of weed control. This was in tandem with the findings of [18], that inclusion of shade plant in the establishment of new cacao plantation enhances efficient light utilization and reduced weed problems within the plantation. In addition, the fauna population and diversity were significantly higher in shaded plots due to low light penetration through the canopy to the soil surface thereby enhanced the build-up of microorganism and multiplication within the soil. More so, the quantity of litters within the shaded plots were also found to be responsible for the significantly higher microbial population within the shaded plots compare to the no shade treatments as the shade plants also add to the quantity of the available litters within the shaded plots. The above were in line with the findings of [19], [20], [21], [22] and [23].

Conclusion

Growing cacao under no shade was found to improve flowering, pod yield and quality in terms of average bean weight and bean yield. Higher soil and air temperature within the canopy favours reduced pest infestation. Dense shade enhances high rate of cherelle wilt there by leading to reduced pod yield. Low light penetration through the canopies under dense shade treatment amount to reduced air and soil temperature which enhances multiplication of pest and diseases pathogens that are responsible for cocoa black pod disease. Enhancement of the microclimate conditions within the canopies were better under shaded plots which in turns favours sustainability of the ecosystems.

Acknowledgements

My sincere appreciation goes to Mrs D.Y.Famuwagun and staffs of Teaching and Research Farm of The Federal University of Technology, Akure, Nigeria for their support towards the success of this research studies.

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