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Effects of shade on microclimate, canopy characteristics and light integrals in dry season field-grown cocoa (*Theobroma cacao* L.) seedlings

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ABSTRACT

Effect of shade regimes on gradients of microclimate, canopy extent (leaf area index: LAI) and light integrals in dry season field-grown cocoa (cacao) seedlings was investigated in a rainforest zone of Nigeria. The shade regimes tested were: unshaded/open-to-sun, dense shade and moderate shade. Shade intensity affected solar radiation transmission through cacao canopy, photosynthetic active radiation (PAR) and canopy light attenuation (extinction coefficient, k). Intensity of transmitted radiation below the canopy from incident radiation was highest for open-to-sun, followed by moderate and dense shade, respectively. The temporal trend of intercepted radiation showed that intercepted radiation increased from December to May, and, the values were highest for open-to-sun, followed by moderate and dense shade. The ratio of transmitted (Io) to incident (I) radiation (I_O/I) was higher for open sun. Significant differences were found between open-to-sun (unshaded) and moderate and dense shade intensity for value of canopy extinction coefficient (k). The association of growing degree days (GDD), and, total leaf number (TLN) and leaf area index (LAI), were characterized by high coefficient of determination (R^2) for the respective open, dense and moderate shade treatments. Inverse of the slope of the regression of relationship between estimated thermal time (°Cdays) and corresponding total leaf number (TLN) denotes leaf appearance rate (phyllochron, in °Cdays/leaf). Rate of leaf appearance was faster in open sun compared with to that in moderate or dense shade intensity. Characteristics of the cacao canopy development were measured by leaf area index (LAI), a parameter which affects the intercepted photosynthetic active radiation (PAR). Higher LAI was obtained in no shade (open sun) compared to that in moderate or dense shade treatments. Unshaded plants had a higher radiation use efficiency (RUE) and RUE values were significantly higher compared to the other two treatments. Low light intensity and LAI for under-storey cacao had negative implications for growth and biomass development. Air temperatures within the cacao field were highest for open sun cacao, followed by moderate and dense shade, respectively; the values increased from December to April, with peak values seen in April.

Key words: Cacao, cocoa, shade, canopy, LAI, extinction, radiation, temperature, drought

INTRODUCTION

Cocoa (cacao), as a major cash crop in Nigeria, has contributed immensely to the country's economy. For instance, it has since become the second largest foreign exchange earner after crude oil (Sanusi *et al*, 2006; Oluyole and Kayode, 2010) and has provided jobs for people. In fact, the crop has engaged about ten million persons, who live and work in the cocoa belt (Sanusi *et al,* 2006).

The modest growth in Nigeria's cocoa sub-sector has, however, been traced among other things to favourable weather conditions (Kohler *et al*, 2010). Cocoa is highly susceptible to drought and, hence, its cropping pattern is related to rainfall distribution. Annual total rainfall in the cocoa growing region of West Africa is less than 2000 mmbi-modal rainfall distribution pattern (Anim-Kwapong and Frimpong, 2005). The dry and hot weather of about 3 months results in soil water deficit that can affect cocoa seedlings establishment in field. However, irrigation can be introduced during the establishment phase to minimize seedling mortality, especially, in the dry season characterized by little or no rainfall. Drip irrigation is economical and effective in water management, as, it increases soil moisture availability to meet the crop's demand for growth and yield (Anim-Kwapong and Frimpong, 2005).

Cacao is a shade-tolerant species where appropriate shading can lead to adequate photosynthetic rate, growth and seed yield (Alex-Alan *et al,* 2007). Shading also helps reduce the effects of unfavourable ecological factors such as low soil-fertility, wind velocity and excessive evapo-transpiration (Miyaji *et al*, 1997). The trees used for shade greatly contribute to the pool of soil organic matter, carbon sequestration and maintenance of biodiversity (Lobao *et al,* 2007). In regions with low access to inorganic fertilizers, specifically, the multi-strata plantation that provides shade is used for maintaining soil fertility, with subsequent increase in nutrient availability in cacao (Isaac *et al,* 2007). Trees used for shading also reduce wind speed and evapo-transpiration (Beer *et al,* 1998), consequently, decreasing humidity stress during the dry season (Anim-Kwapong, 2003). This is essential for survival and establishment of cocoa seedlings in the dry and seasonally humid environments, since, these are highly susceptible to dehydration (Alex-Alan *et al,* 2007).

Cocoa is intercropped around the world in planned systems with other species of economic value (Almeida *et al,* 2002). In Ghana and Ivory Coast, for example, 50% of the total cacao farm area is under mild shade, whilst, an average of 10% in Ghana and 35% in Ivory Coast is managed under no shade (Padi and Owusu, 1998). In a shade and fertilizer trial conducted with Amazon cocoa over a 20-year period in Ghana, yield of heavily shaded plots was about half as that under non-shade treatment (Ahenkorah *et al,* 1987). Despite this, the authors inferred that the economically viable life of an unshaded Amelonado Cocoa farm in Ghana may not be over 15 years of intensive cropping. This means that cocoa can be produced without shade (under open sun), with adequate management practices, and, water and nutrient replenishment (Alex-Alan *et al,* 2007).

Although shade is commonly used for improving the establishment and growth of crops (Beer, 1987; Pilar, 2005), there is inadequate knowledge on the combined effects of shade and irrigation on cacao in Nigeria. The specific objectives in this study were to examine the effect of shade and irrigation regime on the gradients of microclimate, canopy extent (leaf area index, LAI) and light integrals of field-grown cacao seedlings in the dry season in a rainforest zone of Nigeria.

MATERIAL AND METHODS

Experimental site and conditions

The experiment was conducted using one-year-old field-grown cacao seedlings that were irrigated during the previous dry season (January 2012 to April 2013) of the first year of planting. The study was carried out on the research farm of Department of Crop, Soil and Pest Management, Federal University of Technology, Akure, located in the southern part of Ondo State, Nigeria, at latitude 7°18' and longitude 5°8'.

The treatments imposed were 3 by 2 factorial combinations of shade regimes (Open sun, Dense and Moderate), and irrigation intervals of 5 and 10-days, arranged in split-plot design. The shade regime encompassed the main plot, while irrigation intervals constituted the sub-plot treatment. Twenty cacao seedlings were selected per plot at random and tagged, from the dense-shaded, open sun and moderate-shaded plots. Shade was provided by a plantain crop planted densely for the dense-shade plot, in scattered form for the moderate-shade plot, and none for the open sun plot.

A gravity-drip irrigation system was laid out in the field for application of water to the cacao seedlings at 5-day intervals. The gravity-drip irrigation system included a pumping machine with a good water source, pipes, drip lines, overhead tank (with stand) and pressure control valves, at the onset of the experiment. Irrigation water was discharged via point source emitters on drip lines laterally installed per row of the plot.

Plant leaf area and canopy extinction coefficient

The Beer–Lambert Law describes absorption of light by plant pigments in solution. This function demonstrates that absorption of light will be more or less exponential with increase in intercepting area down through the canopy. Extinction (attenuation of light through the canopy) is affected by changing availability, quality and direction of incident light and, thus, proportion of the light intercepted by the canopy.

Light extinction coefficient (k), according to the Beer–Lambert Law (as modified by Sheehy and Cooper, 1973), is:

$$k = [\log e\ (I / I_o)] / LAI \ldots\ldots\ldots\ldots 4$$

$$k = -\ln\ (I - I_o) / LAI \ldots\ldots\ldots\ldots\ldots 5$$

where

I and I_o are irradiance values upon and under the canopy, respectively, and LAI is leaf area index of leaves causing light attenuation, and k is the extinction coefficient or slope of the curve when the natural log (In) I/ I_o is plotted against LAI.

Cacao leaf area index (LAI) and canopy light integrals (incident, transmitted and absorbed radiation, the ratio of radiation measurements below and above the canopy and PAR) were measured using LAI2000 (Plant Canopy Analyzer Model, Delta T, UK) equipment. To avoid error in non-destructive LAI measurements caused by direct solar radiation, measurements with LAI2000 were conducted only at dawn, or, when the sky was completely overcast during the day. Number of leaves per plant was estimated as the product of time period (days) over which leaves were initiated, and, average rate of leaf appearance (RLA) was obtained by dividing this by total leaf number (TLN). Rate of leaf appearance (phyllochron) was calculated as inverse slope of the regression that determined leaf appearance rate (phyllochron in ^oCd/leaf).

The growing degree days (GDD) (accumulated thermal time: ^oCd) attained during growth (period of experiment) was calculated from the daily maximum (Tmax) and minimum (Tmin) temperatures measured at the Meteorological Station located 500m from the experimental site. Values for cardinal temperatures for cacao are: base (Tb) = 15°C; optimum (To) = 22°C, and maximum (Tm) = 34°C. The cardinal temperatures used were 15°C for base temperature (below which no development takes place) and 34°C for maximum temperature (above which development is zero).

Growing degree days (GDD) value was computed during the growth of cacao using the following algorithm:

$$GDD = \Sigma([T_{max} + T_{opt}] * day_{1-x} /2) - Tb \text{ ....6}$$

where

T_{max} represents maximum air temperature, T_{opt} represents optimum temperature, and T_b represents base (minimum) temperature in cacao; 1-x represents time intervals during which measurements were made (day one to the last day).

Calculation of the GDD considers a linear, ascending function between the base and optimum temperatures, and, a linear, descending function between optimum and maximum temperatures. The degree days calculated and summed over duration of the experiment (133 days from mid-December to April) gave thermal time accumulated during growth. The calculation considers a linear, ascending function between the base and optimum temperatures, and, a linear, descending function between optimum and maximum temperatures. In addition, coefficient of light extinction was computed from LAI 2000 (Plant Canopy Analyzer Model) equipment as the ratio of solar radiation measured below and above the canopy.

Growth parameters in cacao

Growth parameters on which data were collected includedd cacao seedling height measured from the base of the cacao to the apical shoot using meter rule; stem girth (collar diameter of the seedling) measured using Vernier callipers; and, number of leaves, branches and flowers per plant. Growth parameters were assessed at the onset of irrigation (December, 2013) and at the termination of irrigation (April, 2013); number of flowers per plant was assessed in February, April and June 2013, respectively. Other variables derived from measurements observed were: growing degree days (GDD), leaf area index (LAI), photosynthetic active radiation (PAR), transmitted radiation, and canopy extinction coefficient (k). Table 1 shows the activities on field, with respective dates.

Data analysis

Data collected were subjected to Analysis of Variance (ANOVA) using SPSS (16.0), and significant Means were separated by Tukey Test.

RESULTS AND DISCUSSION

The growth season was grouped into Major (April to mid August) and Minor (mid-August to December) rainy season, and, Dry (December to March) season. The minor season is characterized by more overcast sky with lower air temperatures and higher relative humidity, compared to the major rainy season (Table 1). The rainy season had

Table 1. Mean seasonal relative humidity, temperature, vapour pressure deficit, leaf area index and photosynthetically active radiation

Shaderegimes	PAR (*µmol/m²/s*)			LAI			RH(%)			VPDkPa			Temperature(°C)			Sunshinehour		
	a	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
Open sun (Unshaded)	755	957	1031	1.8	2.4	1.5	70	64	33	1.9	1.6	3.1	35	32	37	5.2	4.5	6.6
Moderate	459	648	893	1.3	2.1	1.3	72	70	35	1.5	1.3	2.8	33	31.4	34	5.2	4.5	6.6
Dense	285	423	603	1.5	1.9	1.05	76	73	36	1.3	1.2	2.6	31.6	30.7	33	5.2	4.5	6.6

Major(a) and Minor rainy season (b) and dry season (c), relative humidity (RH), temperature (T) and vapour pressure deficit (VPD), photosynthetically active radiation (PAR: µmol/m²/s), leaf area index (LAI,µmol/m²/s)

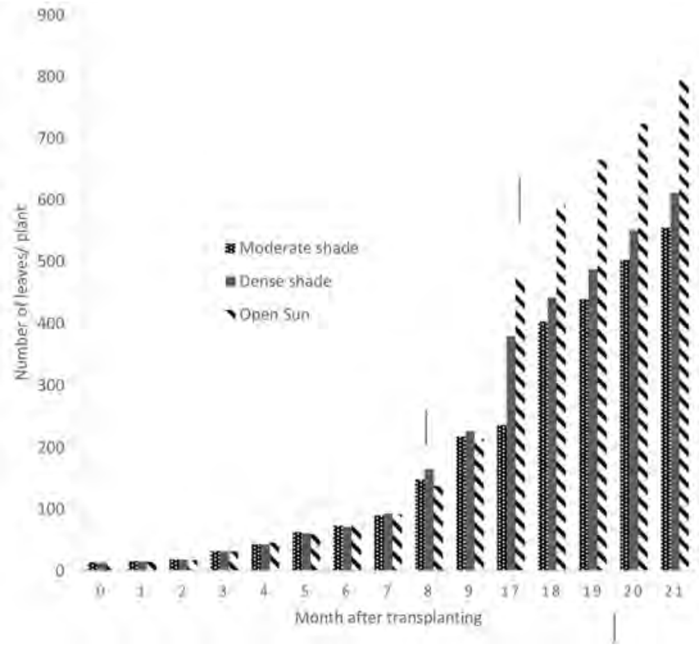


Fig 1. Effect of shade on leaf development   =LSD bar (*Pd”0.05*)

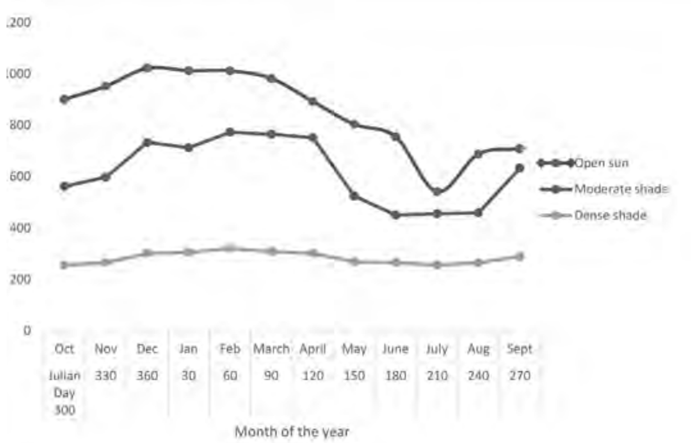


Fig 2. Temporal trends in PAR within the shaded and unshaded cacao

higher mean relative humidity (71%) and lower air temperatures (32.8^{o}C) compared to the dry season. Also, higher air temperature and VPD, and lower relative humidity, were found for the unshaded, open sun cacao compared to the shaded plants.

Effect of shade on canopy development in cacao

Effect of shade on canopy development was measured as number of leaves per plant and leaf area index (LAI). Results showed significant differences among the shade treatments for number of leaves per plant (Fig. 1). The

Table 2. Time dynamics of leaf area index (LAI) in cacao as affected by shade regime

Shade regimes	Periods of measurements		
	April 0 MAT*	August 15 MAT	December1 21MAT
Dense	1.35	1.63	1.88
Moderate	1.93	2.55	2.69
Open-to-sun (Unshaded)	3.55	3.90	4.68
LSD (0.05)	1.03	0.71	1.40

*MAT (months after transplanting)

highest number of leaves/plant was obtained in open sun over moderate or dense shade. LAI measured between 10th to 21st month after transplanting, especially in April, August and December, is presented in Table 2. This showed significant difference among treatments for LAI measured in December. Highest LAI was recorded under open sun, over moderate or dense shade. For LAI measurements made in April, the values were higher for moderate compared to the dense shade treatment.

Characteristics of solar radiation and light integrals within cacao plantation as affected by shade and irrigation regimes

The characteristics of solar radiation (light integrals), the incident and transmitted radiation, transmission through plant canopy and, in particular, photosynthetic active radiation (PAR) intensity, its interception (capture) within cocoa, and use efficiency were affected by various shade regimes. Temporal trends in radiation (and PAR) regimes within cacao are shown in Fig. 2. Results indicated that unshaded (open sun) plants had significantly higher photosynthetic active radiation (PAR) intensity compared to moderate or dense shaded plots. Moderate shade also had significantly higher PAR over dense shaded plots.

Fig. 3 shows the temporal trend of intercepted radiation within cacao field as affected by different shade regimes. Intercepted radiation from transmitted light through cacao canopy measured each month was highest in April. Across the months of observation (December to May), open-to-sun had the highest value for incident radiation, followed by moderate and dense shade, respectively. Transmitted radiation below the canopy from incident radiation above the canopy (shown in Fig. 3) showed no significant difference among treatments.

Effect of shade density on trends in light distribution (transmitted radiation below the canopy, Fig. 3) showed significant reduction in the quantum of light received by cacao under plantain shade and were found compared to 'no shade' (open sun) which had direct access to full solar radiation. Temporal trend of the ratio of transmitted to incident radiation is presented in Fig. 4. The trends closely followed the pattern observed by time dynamics of intercepted radiation. Under dense shaded plots, more than 60% of the transmitted light was either absorbed or reflected by the broad leaves of plantain (shade plant) (Fig. 4). Significant differences were found between moderate and dense shaded plots. Cacao, under dense plantain shade, received the least incident radiation throughout the period of measurement.

Shade regimes affected growing degree days (GDD), leaf area index (LAI), incident and transmitted radiation (light integrals), canopy extinction coefficient (k) and air temperatures within cacao

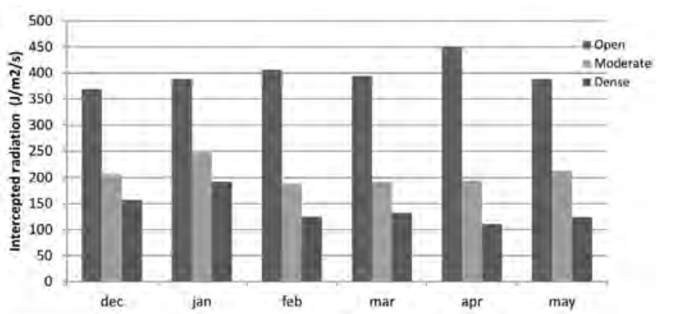


Fig 3. Temporal trends in radiation interception within cacao field as affected by shade intensity

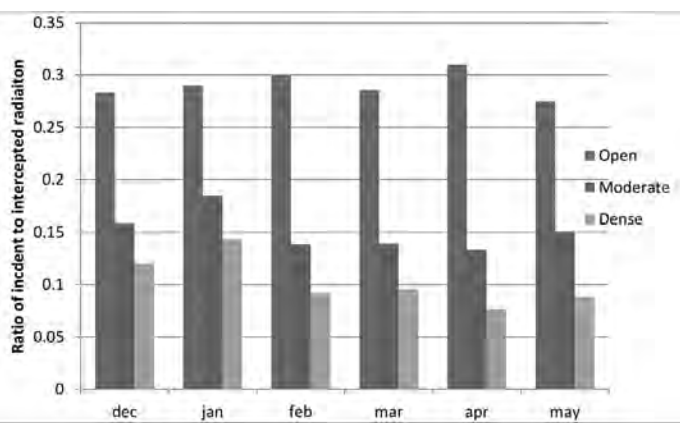
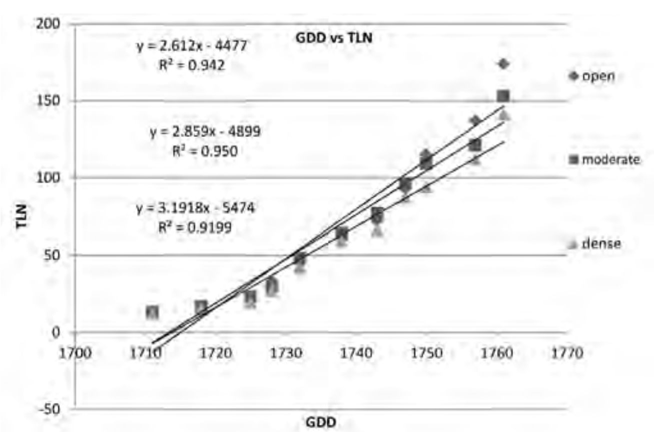


Fig 4. Temporal trends in the ratio of transmitted radiation to incident radiation within cacao field as affected by shade intensity

The summary of pattern of growing degree days (GDD), light integrals (incident and transmitted radiation), photosynthetically active radiation (PAR), leaf area index (LAI), and extinction coefficient (k) are presented in Table 2.

Accumulated thermal time (growing degree days; GDD), LAI and PAR were higher for open sun compared to dense or moderate shade. Effect of shade on cacao canopy light integrals, in particular the ratio of transmitted to incident radiation (I_O/I), was higher for open sun. Canopy light attenuation (extinction coefficient, k) was significantly lower for open sun compared to the shaded cacao. The estimated canopy PAR extinction coefficient values (k) showed significant differences among the open sun (unshaded) and the moderate and dense shade intensities.

Fig. 5 and 6 show the relationship between growing degree days (GDD) and total leaf number (TLN), and, between growing degree days (GDD) and leaf area index



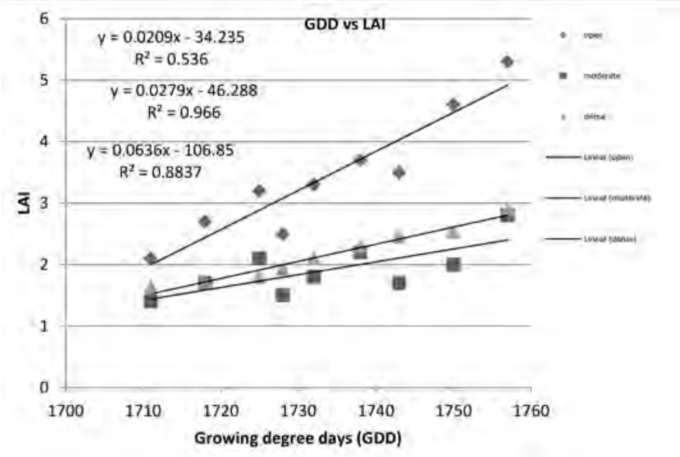
Open : Y = 3.191x – 5474
Dense : Y = 2.612x – 4477
Moderate : Y = 2.859x – 4899

R^2 = 0.919 R^2 = 0.942 R^2 = 0.950

Fig 5. Association of growing degree days (GDD) with number of leaves per plant in cacao

Table 3. Summary of patterns of growing degree days (GDD), Leaf area index (LAI), Photosynthetic active radiation (PAR), incident (Io) and transmitted (I) radiation, phyllochron, extinction coefficient (k) and air temperatures within cacao as affected by shade regimes

Shade regimes	GDD(oCd)	LAI	PAR (ì.m^{-2}.s^{-1})	Incident radiation (Io)(ì.m^{-2}.s^{-1})	Transmitted radiation (I)(ì.m^{-2}.s^{-1})	Io/IRatio	Phyllochron (^{o}Cd/leaf)	Extinctionco efficient (k)	Air Temperature (^{o}C)
Open sun(Unshaded)	183.3	3.83	623.3	1373.3	399.3	0.29	3.2	0.37	32.3
Moderate	121.4	1.91	535.8	1373.3	206.7	0.15	2.8	0.96	30.7
Dense	102.5	2.51	481.5	1373.3	140.2	0.10	2.6	0.73	29.4



Open : Y = 0.063x – 106.8
Dense : Y = 0.020x – 34.23
Moderate : Y = 0.027x – 46.28

R^2 = 0.883 R^2 = 0.536 R^2 = 0.966

Fig 6. Association of growing degree days (GDD) with leaf area index (LAI) in cacao

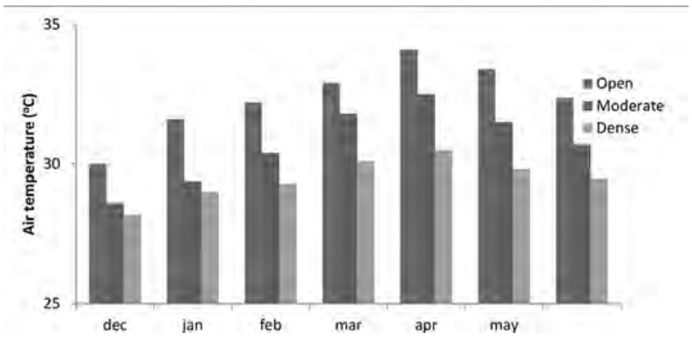


Fig 7. Temporal trends in air temperature within the cacao field

(LAI), respectively. The relationships were characterized by high coefficient of determination (R^2) for the respective open, dense and moderate shade treatments.

Inverse slope of the regression of a relationship between estimated thermal time (^{0}Cdays) and the corresponding total leaf number (TLN) denotes leaf appearance rate (phyllochron, in ^{0}Cd/leaf). Rate of leaf appearance was faster in open sun compared to that in moderate or dense shade intensity.

In Fig.7, the temporal trend of air temperature within the cacao field is presented, and open sun had the highest temperature, followed by moderate and dense shades, respectively. Air temperature in open sun was higher than that in moderate and dense shade, respectively (Fig. 7). Air temperature increased from December to April, with temperature peak in April.

Characteristics of radiant energy (availability, transmission, interception /capture) and use efficiency, leaf area index (LAI), transmitted radiation and canopy extinction coefficient (k) as affected by shade regimes

The gradients of microclimate / canopy characteristics and radiant (light) energy characteristics (incident and transmission), capture and use efficiency of PAR and dynamics of leaf area within cocoa were seen to be affected by the shade regime.

Higher intensity of solar radiation (incident and transmitted through the cacao canopy) and photosynthetic active radiation (PAR) obtained in the unshaded compared to the moderate and dense shades, appeared to have translated into better vigour of growth and canopy formation in the former treatment. Acheampong *et al* (2013) reported that biomass accumulation and overall development in cacao depended on intensity of the PAR. However, it has been reported that cacao exhibited low light compensation point and, that, light was not a major limiting factor in assimilate production in the young cacao in nursery. Maximum photosynthesis occurs in cacao at about 20% intensity of full sunlight (Hutcheon, 1976; Acheampong *et al*, 2013).

'No shade' treatment had advantage over moderate and dense shade treatments in terms of radiation energy available and its usage for dry matter accumulation during the period. In addition, Acheampong *et al* (2013) state that light penetration through cacao canopy is a factor of leaf area index (LAI) which depends on the variety, age, planting density, leaf size and whorled leaf arrangement, which can alter solar energy more into diffuse light thus promoting interception and transmitted components of incident radiation.

Despite this, shade offered by the plantain stand reduced transmitted light, PAR and photo activity of the canopy of the understory cacao and weed species. Plantain shade significantly reduced the fraction of solar radiation transmission (visible components) through the canopy to the understorey cacao plants, and, the resultant reduced growth was observed in this study.

Shade-irrigation treatments significantly reduced soil temperature within the cacao field. This finding is supported by the report of Acheampong *et al* (2013) that density of the shade plant on cacao canopy plays a major role in temperature regulation within a cacao field. The high shade-density led to reduced soil temperature, while, un-shaded plots registered higher temperatures. This condition may have increased the evapo-transpiration and moisture loss from soil and leaf surface, consequently, leading to young shoot dieback and wilting. The significantly higher soil-moisture content recorded under moderate and dense shade treatments owing to soil cover would have aided moisture conservation (reduction in soil evaporation). Shade conserves soil moisture and reduces soil temperature and surface evaporation (Beer, 1987; de Almeida and Valle, 2007; Kohler *et al*, 2010; Moser *et al*, 2010).

Open-to-sun cocoa was better in terms of leaf development [measured as leaf area index (LAI)] and transmitted radiation, but with low extinction coefficient (k). This result is consistent with reports of Chazdon *et al* (1996) and Beer *et al* (1998) which state that shaded crops in agro-forestry systems are at a disadvantage in growth and yield characteristics under circumstances of low-intensity radiation. Robinson (1996) and Lobao *et al* (2007) also found shaded crops to have lower photosynthesis rate than exposed leaves due to lower transmitted PAR. Leaf area index (LAI) in this study was higher in open-to-sun, and this observation agrees with Israeli *et al* (1995) and Turner (1998) wherein LAI was lower in shaded crops compared to that in open-to-sun. Improved leaf area in the plant and leaf area index (LAI) and, radiation use efficiency and low extinction coefficient (k), enhanced growth and vigour of young cacao in the field (Carr, 2011; Acheampong *et al*, 2013).

Values for canopy extinction coefficient (k) were higher for shaded regimes compared to that in open-to-sun, supporting Turner (1998), Korner (2002) and Carr (2011), who stated that canopy light attenuation (canopy extinction coefficient) depended on the amount of light transmitted through canopies (diffuse radiation). Higher extinction coefficient value was obtained in the shaded cacao compared to open-to-sun, due to lower transmitted light (diffuse radiation). The estimated values for canopy extinction coefficients (k) support the fact that shade intensity affects attenuation of light and other radiation characteristics within a canopy. Goudriaan and Monteith (1990) affirmed that low extinction coefficient enhanced growth when the plant canopy was fully developed and distributed uniformly.

Tree canopy and canopy size are known to strongly influence radiation intensity above the canopy and transmission within the canopy layers; tree canopy characteristics relate to effectiveness at reducing the radiant energy load in a vegetated community. Thus, canopy characteristics determine the extent of radiation-load reduction, evaporative demand, and, the subsequent cooling effect. Vegetation and, hence, canopy size determine the surface roughness of landscapes, air movements and the cooling effect by heat/thermal dissipation (Monteith and Unsworth, 1990; Kuttler, 2008). Canopy, via absorption of radiation, enhances convective heat transfer and heat exchange, with little heat storage (low heat capacity/low sensible heat storage). The properties of a vegetation in terms of canopy extent and size can bring about changes in the ratio of sensible to latent heat of vaporization (Monteith and Unsworth, 1990). A large canopy enhances evaporation and transpiration from plants (ET), vapour release and cooling effect (Kutter, 2008)

The relationship between growing degree days (GDD) and total leaf number (TLN) and leaf area indices (LAI) affirms that as GDD increases, TLN and LAI increase. This result is in support of reports of Kuttler (2008) and Ruttanapreserr *et al* (2013) who point that growing degree days (GDD) is a weather characteristic of agricultural value. GDD plays an important role in accelerating growth, maturity and yield in crops. The open-to-sun treatment gave the highest values for LAI per GDD, a result consistent with reports of Ruttanapreserr *et al* (2013) and Sruthi *et al* (2014) who used LAI as a tool for determining physiological quantity and vegetative canopy structure in plants.

The time course of the incident radiation within the cocoa field showed that open-to-sun had higher values across the months of experiment, compared to moderate and dense shades, respectively. This is in support of Anim-Kwampong and Frimpong (2005). In addition, the trends of ratio of transmitted to incident radiation on the cacao field showed that open-to-sun had an advantage over moderate and dense shade, respectively, across the months of the experiment. Ofori-Frimpomg *et al* (2007) and Acheampong *et al* (2013) affirmed the importance of light in a cacao field. Time dynamics of air temperature within the cacao field followed the trend obtained in radiation interception by cacao for the shade intensities evaluated. Open-to-sun cacao had the greatest values compared to that in the shaded regimes. Air temperature is a measure of how hot or cold the air is. Miranda *et al* (1994) and Tschoegi (2000) stated that air temperature affected growth and reproduction in cacao, with warmer temperature promoting biological growth.

The capability of plants for producing dry matter depends largely upon availability, capture and use efficiency (or degree of exploitation) of radiant energy (solar radiation). Development of plant leaf area and, hence, leaf area index (LAI) are important to light interception. However, efficiency of light interception resulting from any given LA1 is influenced by leaf characteristics (canopy architecture) such as type, size, shape, and display of leaves. Efficiency of light transmission through leaves alters light interception efficiency. Practically speaking, due to overlapping of leaves, LA1> 1 is required to cover the land surface (Anim-Kwampong and Frimpong, 2005) when leaves intercept the most light, while, efficiency is dependent upon the degree of its transmission through leaves. At high LA1 values, mutual shading occurs; leaves at the bottom of the canopy receive very low light intensity while the uppermost leaves are exposed to light far above that required for maximal photosynthesis (light saturation).

Leaf area index (LAI) and canopy dynamics, leaf appearance rate and light interception

Effect of temperature and light on leaf expansion has been reported in crops (Spitters, 1990). Canopy development (leaf area index) is influenced by thermal time. The number of fully expanded leaves is a product of thermal time elapsed since leaf emergence, (viz., leaf appearance rate (phyllochron). The pattern and rate of leaf appearance were different in shade and irrigation treatments; however, greater thermal time is required to initiate leaves under a non-shaded cacao. Vegetative growth and development rate depends upon the prevailing weather conditions for growth. In particular, hydrothermal regimes following seedling transplanting and establishment affect the subsequent rate of leaf appearance. Cacao developed comparatively large leaf area despite a dwindling soil moisture status during the dry season. This trait is essential to its survival and growth.

Thermal environment for growth is usually expressed in units of thermal time. Total number of leaves/plant (TLN) and leaf area index (LAI) were found to be related to thermal time. The relationships were characterised by high R^2 value. The supra-optimal temperature environment of the dry season appears to have raised optimum temperature for leaf emergence. This shows that more thermal time is needed to produce a leaf, hence, the decreased thermal energy efficiency of dry-season cacao. Cacao leaf appearance rate is affected by temperature and soil, and, air draughts and shade enhanced the differences in radiation energy (light intensity) (Tschoegl, 2000).

CONCLUSIONS

Gradients of microclimate and canopy (LAI) and radiant energy (incident and transmission) characteristics within cacao, interception (capture) and use efficiency of photosynthetic active radiation (PAR), and canopy extinction coefficient (k) differed under the shade and irrigation regimes imposed. The characteristics of solar radiation within cacao field which include incident and transmitted radiation and photosynthetic active radiation (PAR) were better for open-to-sun compared with moderate or dense shade. Unshaded + irrigated plants had higher radiation use efficiency (RUE) compared to shaded + irrigated; RUE values were significantly high compared to moderate and dense shade treatments. Transmitted radiation below the canopy was highest for open-to-sun, followed by moderate and dense shade treatments, respectively. The ratio of transmitted (Io) to incident (I) radiation (I_O/I) was higher for open-to-sun. Canopy development affected intercepted photosynthetic active radiation (PAR): higher LAI was obtained for 'no shade' (open-to-sun) compared to moderate or dense shade treatments. Intercepted radiation from transmitted light through cacao canopy for each month was highest in April. Across the months of observation (December to May), open-to-sun had the highest value for incident radiation, followed by moderate and dense shade, respectively. Temporal trends of the ratio of transmitted to incident radiation followed closely the pattern observed in time dynamics of intercepted radiation. Inverse of the slope of regression of the relationship between estimated thermal time (^{o}Cdays) and corresponding total leaf number (TLN) denote the leaf appearance rate (phyllochron in ^{o}Cd/leaf). Rate of leaf appearance was faster in open-to-sun compared to moderate or dense shade. Temporal trends in values of air temperature showed an increase from December to April, peaking in April. Moderate and dense shade improved soil moisture content and reduced the soil temperature during dry season, compared to 'no shade' treatments combined with irrigation. Air temperature within the cacao canopy under shade was lower than that in open-to-sun. Low light intensity and LAI for the under-storey in cacao had a negative implication for growth and biomass development.

REFERENCES

Acheampong, K., Hadley, P. and Daymond, A. 2013. Photosynthetic activity and early growth of four cacao genotypes as influenced by different shade regimes under West African dry and wet season conditions. *Exptl. Agri.*, **49**:31-42. ISSN 0014-4797 doi:10.1017/S0014479712001007

Ahenkorah, V., Halm, B.J., Appiah, M.R., Akrofi, G.S. and Yirenkyi, J.E.K. 1987. Twenty years' results from a shade and fertilizer trial on Amazon cocoa (*Theobroma cacao*) in Ghana. *Exptl. Agri.*, **23**:31-39

Alex-Alan, F. de Almeida, A-AF., Raul R. And Valle, R.R. 2007. Ecophysiology of the cacao tree. *Brazilian J. Pl. Physiol.*, **19**:234-342

Almeida, A-AF, Brito, R.C.T, Agular M.A.G. and Valle, R.R. 2002. Water relations aspects of *Theobroma cacao* L. clones. *Agrotropica*, **14**:35-44

Anim- Kwapong, G.J. 2003. Potential of some neotropical *Albizzia* species as shade trees when replanting cacao in Ghana. *Agroforestry Systems*, **58**:185-193

Anim-Kwapong, G.J. and Frimpong, E.B. 2005. Vulnerability of agriculture to climate change: Impact of climate change on cocoa production. Cocoa Research Institute, New Tafo Akim, Ghana

Beer, J.W. 1987. Advantages, disadvantages and desirable characteristics of shade trees for coffee, cocoa and tea. *Agroforestry Systems*, **5**:3-13

Beer, J., Muschler R., Kass, D. and Somarriba, E. 1998. Shade management in coffer and cacao plantations. *Agroforestry Systems*, **38**:139-164

Carr, M.K.V. 2011. The water relations and irrigation requirement of oil palms (*Elaeis guineensis*): A review. *Exptl. Agri.*, **47**:629-652

Chazdon, R.L., Pearcy, R.W., Lee D.W. and Fetcher, N. 1996. Photosynthetic responses of tropical forest plants to contrasting light environment. In: Chazdon, R.L., Mulkey, S.S., Smith, A.P. (eds.). Tropical Forest Plant Ecophysiology. Chapter 1, ISBN 0-412- 03571-5675p, Chapman & Hall, London, England

Daymond, A.J. and Hadley, P. 2004. The effects of temperature and light integral on early vegetative growth and chlorophyll fluorescence of four contrasting genotypes of cacao (*Theobroma cacao*). *Anna. Applied Biol.*, **145**:257-262

de Almeida, A-AF and Valle, R.R. 2007. Ecophysiology of the cocoa tree. *Brazilian J. Pl. Physiol.*, **19**:425–448

Gourdriaan, J. and Monteith, J.L. 1990. A mathematical function for crop growth based on light interception and leaf area expansion. *Anna. Bot.*, **66**:695-701

Hutcheon, W.V. 1977. Growth and photosynthesis of cocoa in relation to environmental and internal factors. In: *Procs. 5th Int'l. Cocoa Res. Conf.*, Ibadan, Nigeria, pp. 222–232

Isaac, M.E., Timmer, V.R. and Quasiesam, S.J. 2007. Shade tree effects in an 8-year old cocoa agroforestry system: biomass and nutrient diagnosis of *Theobroma cacao* by vector analysis. *Nutrient Cycling in Agroecosystems*, **78**:155-165

Israeli, Plaut Z. and Schwartz, A. 1995. Effect of shade on banana morphology, growth and production. *Sci. Hortic.*, **62**:45-46

Kohler, M., Schwendenmann, L. and Holscher, D. 2010. Through-fall reduction in a cacao agroforest: tree water use and soil water budgeting. *Agril. Forest Meteorology*, **150**:1079-1089

Kutter, W. 2008. The Urban Climate - Basic and Applied Aspects. In: J.M. Marzlluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, U. Simon and C. Zumbrunnen (eds). Urban Ecology - An international perspective on the interaction between humans and nature. Springer, New York, USA, Chapter 3, pp. 233-248

LobÎo, D.E., Setenta, W.C., LobÎo, E.S.P, Curvelo, K. and Valle R.R. 2007. Cacao Cabrucal, sistema agrossilvicultural tropical. In: Valle R.R. (ed). *Cinencia, Tecnologia e Manejo do Cacaueiro*, pp. 290-323, Grafica e Editora Vital Ltda, Ilheus

Miranda, R.A.C., Milde, L.C.E., Bichara, A.L. and Cornell, S. 1994. Daily characterization of air temperature and relative humidity profiles in a cocoa plantation. *Pesq. Agropec Brasilia*, **29**:345- 353

Miyaji, K.I., Silva, W.S. and lvim, P.T. 1997. Longevity of leaves of a tropical tree, *Theobroma cacao* grown under shading in relation to emergence. *New Phytol.*, **135**:445-454

Monteith, J.L. and Unsworth, M.H. 1990. Principles of environmental physics. 2nd Edition. Edward Arnold, New York, pp. 53-54

Moser G., Leuschner, C., Hertel, D., Hölscher, D., Köhler, M., Leitner, D., Michalzik, B., Prihastanti, E., Tjitrosemito, S. and Schwendenmann, L. 2010. Response of cocoa trees (*Theobroma cacao*) to a 13-month desiccation period in Sulawesi, Indonesia. *Agroforestry Systems*, **79**:171–187

Ofori-Frimpong A.A., Afrifa, S. and Acquaye, A.A. 2010. Impact of shade and cocoa plant densities on soil organic carbon sequestration rate in a cocoa growing soil of Ghana. *African J. Envir. Sci. Technol.*, **4**(9):621-624

Ofori-Frimpong K., Asase, A., Mason, J. and Danku, L. 2007. Shaded versus unshaded cocoa: implications on litter fall, decomposition, soil fertility and cocoa pod development. In: *Procs. 2nd Int'l. Symp. on Multistrata Agrofestry Systems with Perennial Crops*: Making ecosystem services count for farmers, consumer and the environment, 17-21 September, CATIE, Turrialba, Costa Rica (http://web.ctie.ac.cr/AFS/symposium)

Oluyole, A. and Kayode, A. 2010. The effect of weather on cocoa production in different agro-ecological zones in Nigeria. *World J. Agril. Sci.,* **5**(5):609-614

Padi, B. and Owusu, J.K. 1998. Toward an integrated pest management for sustainable cocoa production in Ghana. Workshop held in Panama during 30th March-2nd April, 1998. Smithsonian Institution, Washington, D.C., USA

Pilar Castro-Diez, Javier Navarro, Ana Pintado, Leopoldo G. Sancho and Melchor Maestro. 2005. Interactive effects of shade and irrigation on the performance of seedlings of three Mediterranean *Quercus* species. *Tree Physiol.,* **26**:389-400

Sanusi, R.A., Badejo, C.A. and Yusuf, B.O. 2006. Measuring household food insecurity in selected LGAs of Lagos and Ibadan, Nigeria. *Pakistan J. Nutr.,* **5**:62-67

Sheehy, J.E. and Cooper, J.P. 1973. Light interception: Photosynthetic activity and crop growth rate in canopies of six temperate forage grasses. *J. Appl. Ecol.,* **10**:239-250

Spitters, C.J.T. 1990. Crop growth models: their usefulness and limitations. *Acta Hort.,* **267**:349-368

Sruthi Narayanan, Robert M. Aiken, Vara Prasad, P.V., Zhanguo Xin, George Paul and Jianming Yu, X. 2014. A simple quantitative model to predict leaf area index in sorghum. *Agron. J.,* **106**:219-226

Tschoegl, N.W. 2000. Fundamentals of equilibrium and steady state thermodynamics. Elsevier, Amsterdam, The Netherlands. ISBN 0- 444- 50426- 5, p 88

Turner, D.W. 1998. Ecophysiology of bananas: The generation and functioning of the leaf canopy. *Procs. Int'l. Symp. Banana in Subtropics*. V. Galan Sauco (ed.). *Acta Hort.,* **490**:211- 221

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