



## **Shade and Irrigation Effects on Growth, Flowering, Pod Yields and Cacao Tree Survival Following 5 Years of Continuous Dry Season Irrigation**

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### **Authors' contributions**

*This work was carried out in collaboration among all authors. Authors EFC, EF, IBF and SOA designed the study and wrote the protocol. Authors EFC, OPA and IBF performed the statistical analysis and wrote the first draft of the manuscript. Authors EFC and EF managed the analyses of the study and literature searches. All authors read and approved the final manuscript.*

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### **ABSTRACT**

The effects of plantain shade and dry season irrigation on the growth, field survival, flowering and pod production of cacao was investigated. Treatments were a 2 by 2 factorial combinations of shade regimes (Unshaded/open sun and shaded) and irrigation intervals (5-day and 10-day intervals) arranged in a split-plot design. There was an unirrigated but shaded control. The shade regimes constituted the main plot while irrigation intervals were the sub-plot treatments. The growth, dry season survival, flowering and pod/bean yield characters of cacao were enhanced in the unshaded (open sun) compared with the shaded plants. The open sun treatment combined with 5-day irrigation produced the largest canopy development, flowering and pod production compared with shading-irrigation combinations. The shade-irrigation ameliorated microclimate and enhanced growth and development, flowering and uniform fruiting/pod production and total bean yield and reduced dry season mortality (whole tree death, branch and twig dieback). For the non-irrigated but shaded cacao, about 30% dry season mortality (branch and twig dieback) were

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obtained. Air temperatures within the cacao field were highest for open sun cacao followed by moderate and dense shade respectively. Flowers were more profuse for unshaded (open sun) cacao compared with the shaded while the yield and yield components of cacao for each harvest dates and total pod and bean yields were significantly different between the unshaded and shaded cacao regimes. Trees that were irrigated at 5-day intervals produced significantly ( $P < 0.05$ ) higher LAI, branching, flowers and pods compared with those irrigated at 10-day intervals. The 5-day irrigation interval significantly increased percentage of trees bearing flowers and pods, and produced larger number, and heavier pods and beans compared with the 10-day interval. The drip irrigation strategy adopted ameliorated dry season terminal drought (hydrothermal stresses) in cacao. This is a veritable tool to scale up growth, survival, establishment and flower/pod production.

*Keywords: Cacao; mortality; die-back; adaptation; climate stress; heat; drought; seasons; tropics.*

## 1. INTRODUCTION

Cocoa (*Theobroma cacao* L.) is an important perennial fruit tree with an estimated annual world production of over 3.2 million tonnes (FAO, 2010). Within the cocoa-growing belt of West Africa, sale of cocoa beans is a major foreign exchange earner, the cocoa sector employs over 1000,000 smallholder farm families and contributes about 70-100% of their annual household incomes. In Nigeria, the main cocoa-producing areas are concentrated in rainforest of the western and eastern parts of Nigeria with an estimated total cultivation area of about 1.45 million hectares. Estimated productivity per hectare from cocoa fields in Nigeria is 250 kg, a yield level that is lower than those from Cote d'Ivoire and Indonesia, which have annual yield rates estimated at 600 kg and 1000 kg per hectare, respectively. In the smallholder cocoa farms of West Africa, farm sizes are small ranging from 0.5 to 5.0 hectare. About 25% of current cocoa-tree stocks are over 30 years old. Also, over 60% of cocoa farmers are currently over 50 years old, and unwilling to take extra risk in investing in yield improvement strategies due to the perceived high cost of input relative to producer price [1]. Attempts at replanting cocoa have been hampered by difficulties in re-establishment due to high cocoa seedling mortality as a result of the challenges of climate and shifts in weather patterns.

The annual total rainfall in the cocoa-growing regions of Nigeria is about 1500 mm (less than 2000 mm). The rainfall distribution pattern is bimodal from April to July and September to November. There is a short dry period from July to August during which the relative humidity is still high with overcast weather conditions. There is a main dry season from November to February-March. The four to six months of dry

weather results in soil water deficit and since irrigation is not part of the farming system, causing seedling mortality [2,3]. In bearing plants, the existence of the short dry season during main pod filling can affect bean size if it is sufficiently severe.

Given the increasing worldwide demand for cocoa, it is important to develop sustainable production systems to expand its cultivation and improve plantation establishment and productivity. To develop such systems, it is imperative to examine the value of agronomic practices for ameliorating extreme environmental conditions especially the hydrothermal stresses of the dry season on seedling and mature tree survival and productivity on the field.

Worldwide, changing growing environment manifests as variations in the patterns of precipitation, elevated temperatures, atmospheric dryness, drought and dry spell intensities. Soil moisture deficit and high-temperature stresses of the dry season have been reported as the cause of the massive seedling and fruiting tree mortality [4,3]. Climate Change (temperature and rainfall) scenarios for the rainforest of Nigeria have been variously constructed using process-based methods that rely on the General Circulation Models (GCM) in conjunction with Simple Climate Models (SCM) [5,6]. The results have indicated projected decline in mean annual rainfall and elevated maximum and minimum temperatures, such scenarios will exacerbate soil moisture conditions during the dry season (November to March) and aggravate the vulnerability of crops to adverse climatic conditions [2]. Cocoa is highly sensitive to changes in climate from hours of sun, to rainfall and application of water, soil conditions and particularly to temperature due to effects on evapotranspiration. Cocoa is susceptible to

drought in terms of growth and yield, and the pattern of cropping of cocoa is related to rainfall distribution [4].

The changing growing environmental conditions (marginal soils and extreme weather events) impose constraints on cocoa growth and productivity, hence the need to develop climate-stress adaptive strategies for the fruit tree-based agroforestry systems of the humid tropics.

Agronomic practices such as dry season irrigation, optimum shading regimes or intensities could enhance field establishment, tree survival and productivity. Good shade management may bring about a reduction in soil water evaporation and ameliorate microclimatic conditions via the reduction in radiation load within cocoa field.

Traditionally, plantain has been in use by the farmers to complement the shade requirement of the freshly transplanted cocoa seedlings across the cocoa-growing region of Nigeria [7,3]. Although the provision of shade using plantain and other shade-tree species for transplanted cocoa seedlings is recommended, a high percentage of transplanted seedlings died between first and second dry season on the field as a result of soil moisture deficit and high-temperature stresses of the dry season [7,3]. The author also reported that plantain planted to provide shade during the dry season shed its leaves or die out due to the hydrothermal stresses of the season. Irrigation has been recommended for alleviating dry-season climatic stress especially for the fruit tree-based farming systems of the humid [8,2].

The goal of the study is to evaluate the effects of densities of plantain shade (moderate and dense shades) and irrigation regimes (5- and 10- day intervals) during the dry season on cocoa tree survival, flowering and pod/bean production. The findings would improve understanding of the influence of shade and irrigation regimes on the development, field establishment and gradient of weather and soil factors of growth within cocoa plantation. The results will contribute to the development of shade and irrigation management guidelines for sustainable cocoa production for smallholder farmers.

## 2. MATERIALS AND METHODS

### 2.1 Experimental Site and Conditions

Experiment was conducted using one year-old cocoa seedlings on the field which were

previously irrigated during dry season (January, 2012 to April, 2013) of the first year of planting. The study was carried out on the research farm of the Department of Crop, Soil and Pest Management Federal University of Technology Akure located in the southern part of Ondo State Nigeria on latitude: 7° 18', Longitude: 5° 8'.

The treatments were 3 by 2 factorial combinations of shade regimes (Open sun, moderate and dense shades) and irrigation intervals of 5 and 10-day arranged in a split-plot design. The shade regime constituted the main plot while irrigation intervals were the sub-plot treatment. There was a shaded no-irrigation control. Twenty (20) cocoa seedlings were selected randomly from the shaded, open sun and shaded no-irrigation control plots for sampling and measurements. Shade was provided by the plantain crops planted to form moderate and dense shades and none in the open sun.

### 2.2 Irrigation Strategies

A drip irrigation system (drip irrigation) was laid out on the field including. This 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 project. The irrigation strategy consisted of water application at 5-day and 10-day intervals using gravity-drip irrigation system and water was discharged via point source emitters on the drip lines which were laterally installed per row of the plot.

The air temperature was measured using ordinary mercury in glass thermometer which was suspended at 1.5 meters above the ground level at different locations within the canopy of the different shade regimes at 2.30 - 3.00 pm.

### 2.3 Leaf Area Dynamics

Cocoa leaf area index (LAI) and canopy light integrals (incident, transmitted and absorbed radiation, the ratio of radiative measurements below and above the canopy and PAR) were measured using LAI2000 (Plant Canopy Analyzer Model, Delta T, UK) equipment. To avoid errors in non-destructive LAI measurements caused by direct solar radiation, measurements with the LAI 2000 were conducted only at dawn or, if the sky was completely overcast, during the day.

## 2.4 Cacao Growth Parameters

The growth parameters were assessed at the onset of the irrigation (December, 2016) and at the termination of irrigation (May, 2017). The assessment of the number of flowers and pods per plant commenced in January and at monthly intervals until August. Ripened cacao pods were harvested at weekly intervals (from February to August), fresh beans were extracted and bean weight measured per harvest.

## 2.5 Data Analysis

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

## 3. RESULTS

### 3.1 Weather Conditions during the Period of Study for the Shaded and Irrigated Cacao

The late (minor) rainy season (mid August to December) is characterized by high cloud overcast (overcast sky), low air temperatures and higher relative humidity compared with the major rainy season (April to mid August) and the dry season (Table 1). On the average, the rainy season had higher mean relative humidity averaged (71%) and lower air temperatures (32.8°C) compared with the dry season (December to March). Also, higher air temperature and VPD and lower relative humidity were found for the unshaded open sun cacao compared with the shaded plants.

### 3.2 Effects of Shading Regime on Flowering, Pod Production, Bean Yield and Survival on Field-grown Cacao

The time course (yearly pattern) of tree mortality showed that the shade without complimentary dry season irrigation had the highest number of dead trees per plot across the measurement dates (Fig. 1). Irrigation promoted tree survival for both the unshaded and moderate and dense shade treatments.

Similar to the time course of tree mortality across treatments, the number of trees bearing dead branches and twigs was highest for the un-irrigated but shaded cacao plots. The 5- and 10-day irrigations reduced death of branches and twigs for the unshaded and moderate and dense shade treatments (Fig. 2). Following the

commencement of the rains, leaf flush production was noticed with an increasing trend in leaf flush production was obtained from DOY 40 to 165. The lowest number of trees bearing leaf flushes was obtained for the un-irrigated but shaded cacao plots, in contrast, irrigation enhanced leaf flush production for the unshaded and shaded treatments (Fig. 3). 135 to 210 the time course of flower showed that cacao trees bear flower throughout the year (Fig. 4) with the peak in flowering obtained between DOY 135 and 210 with sharp decline numbers between DOY 285 and 75, a period characterized by low rainfall and soil moisture and high temperatures. Pod production commenced early in the year around DOY 40 with increasing trend which peaked between DOY 165 and 225 followed by sharp decline in production between DOY 285 and 75 (Fig. 5). Increases in air temperatures were observed across the shaded and unshaded cacao plots from January and peak in values were obtained in April. Highest air temperatures were found for the unshaded and lowest for the dense shade treatment (Fig. 6).

### 3.3 Effects of Irrigation and Shade on Pod and Bean Yields of Cacao

The effects of shade regimes on pod and bean yields of cacao is presented in Table 2. For each harvest date, significantly higher and heavier weights of pods and beans were obtained for the unshaded (open sun) compared with the shaded cacao (Table 2) while across harvest dates, unshaded cacao out-yielded the shaded (both moderate and dense shade) in terms of number and weights of pods and beans per tree. Pod and bean yields were significantly different under the irrigation and shade regimes (Table 3). The 5-day irrigation produced a larger number, and heavier pods and beans compared with the 10-day interval. Similarly, the 5-day irrigation combined with the moderate and dense shades produced significantly higher number and weights of pods and beans compared with the 10-day irrigation interval (Table 3). Across the shade and non-shade treatments, 5-day irrigation interval had significant effect on pod and bean yields compared with the 10-days irrigation. The bean yield was significantly higher under no shade with irrigation treatment compared to shaded cacao (Table 3). The open sun cacao that was subjected to 5-day irrigation interval produced significantly higher number and heavier pods and beans and total bean weight over the 10-day irrigation combined with shade treatments. Irrigation alleviated soil moisture deficit related constraints to cacao performance.

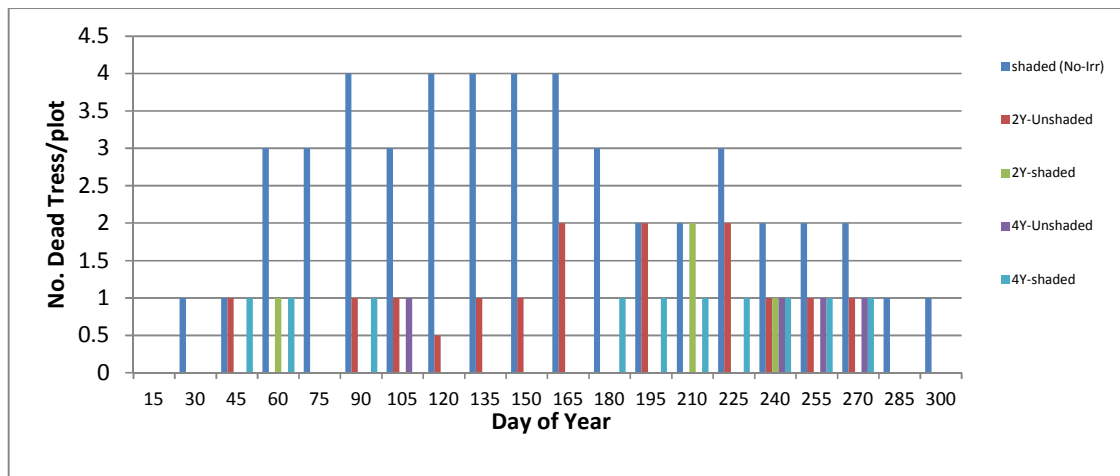
The continuous growth during the rainy season was assisted by the dry season irrigation across the treatment may explain the non-significance of most of the measured growth, flowering and pod

yield variables of cacao. Across the shade and non-shade treatments, 5- day irrigation interval produced a significantly higher number of pods compared with the 10- days irrigation.

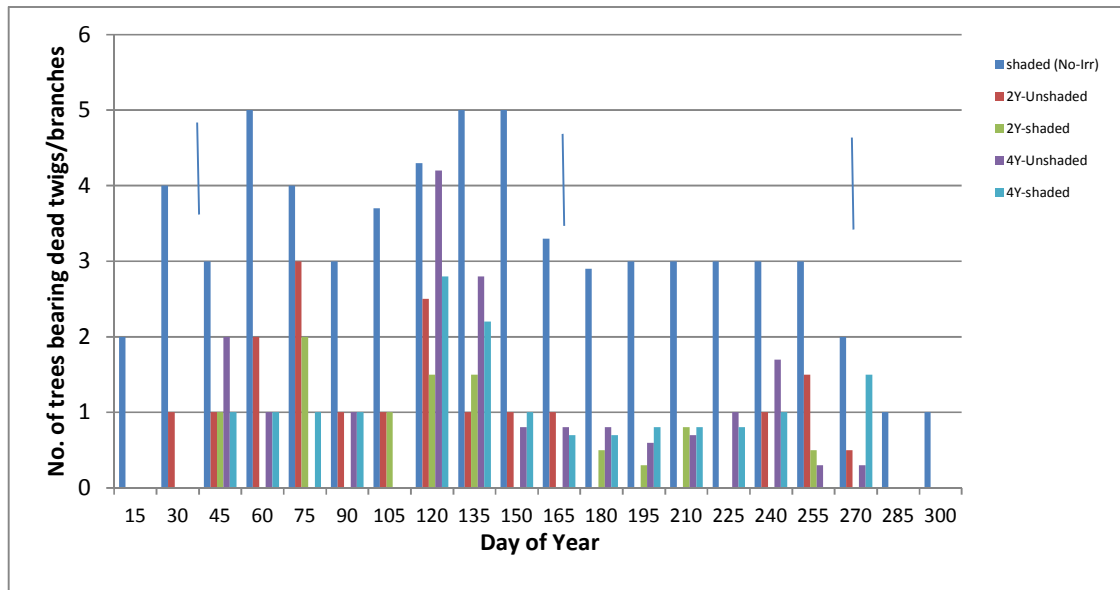
**Table 1. Seasonal trends in weather variables and photosynthetically active radiation (PAR) of shaded and irrigated cacao**

Treatments	PAR ( $\mu\text{mol}/\text{m}^2/\text{s}$ )			RH (%)			VPD (kPa)			Temp. ( $^{\circ}\text{C}$ )			Sunshine hour		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Shaded+Irrigation	681	982	831	71	78	59	1.6	1.3	2.4	30	32	33.3	5.2	4.5	6.6
Unshaded+Irrigation	951	1523	1229	65	72	51	1.9	1.5	3.2	35	32	37	5.2	4.5	6.6
Shaded alone	528	669	974	70	75	54	1.7	1.4	2.7	31	32.7	34.2	5.2	4.5	6.6

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



**Fig. 1. Time dynamics of number of dead trees for the unshaded and shaded cacao combined with irrigation**



**Fig. 2. Time dynamics of number of trees with dead branches/twigs for unshaded and shaded cacao as affected by irrigation**

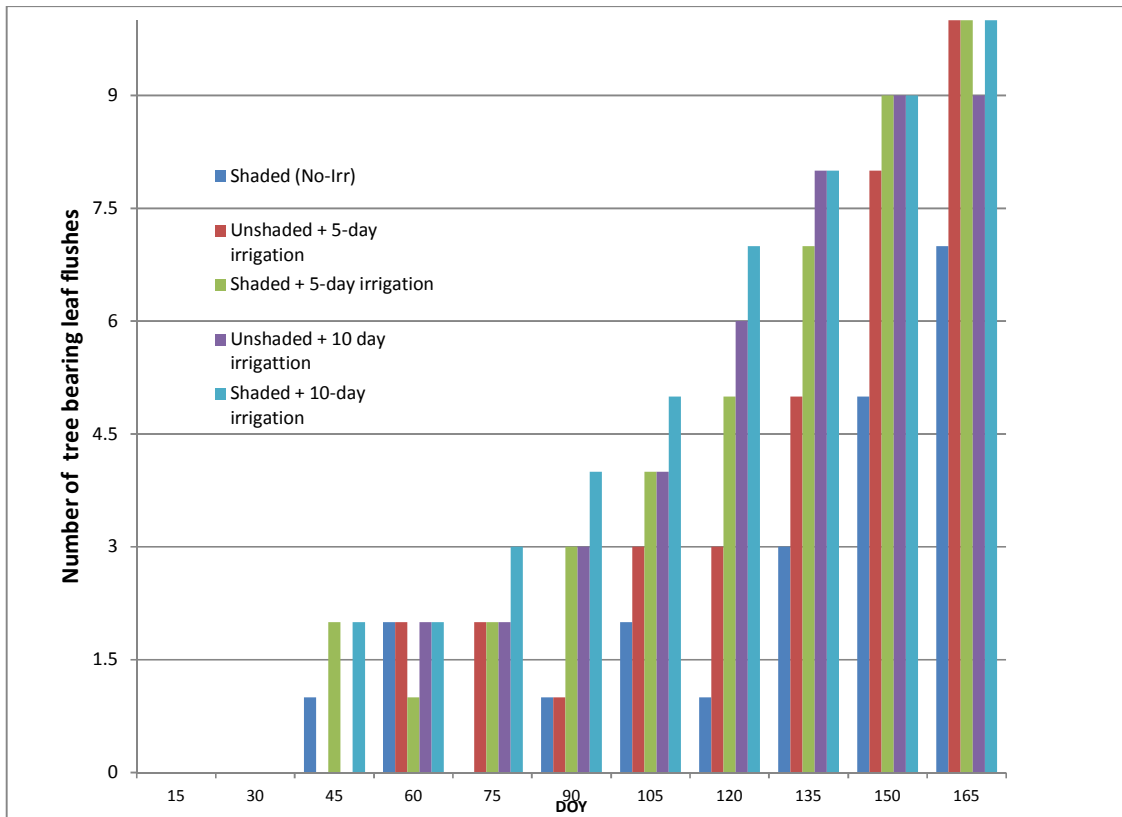


Fig. 3. Number of trees bearing leaf flushes per plot

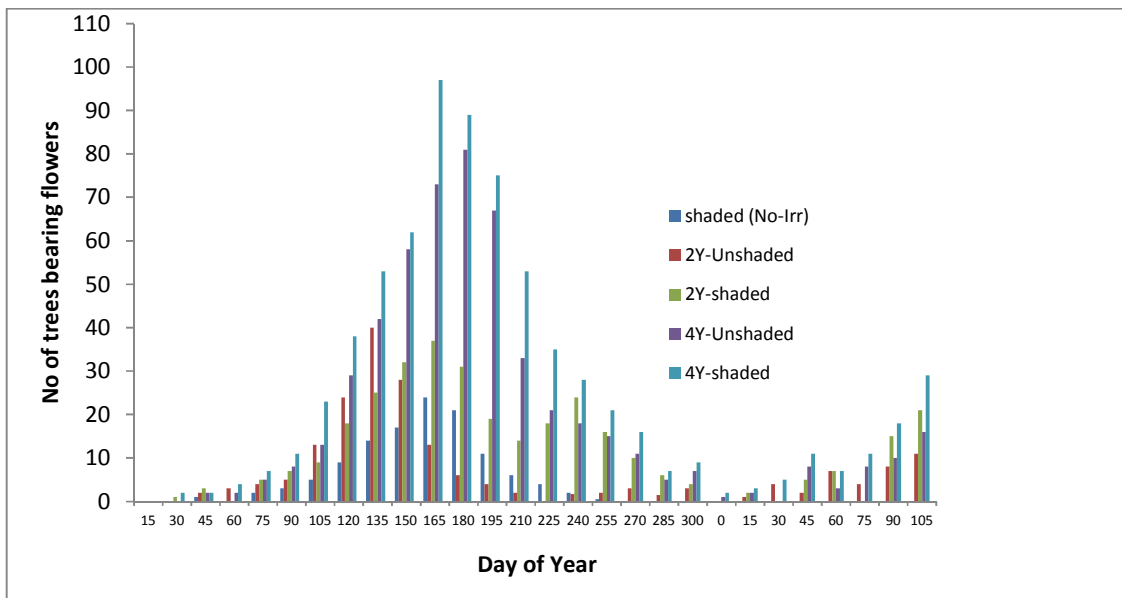
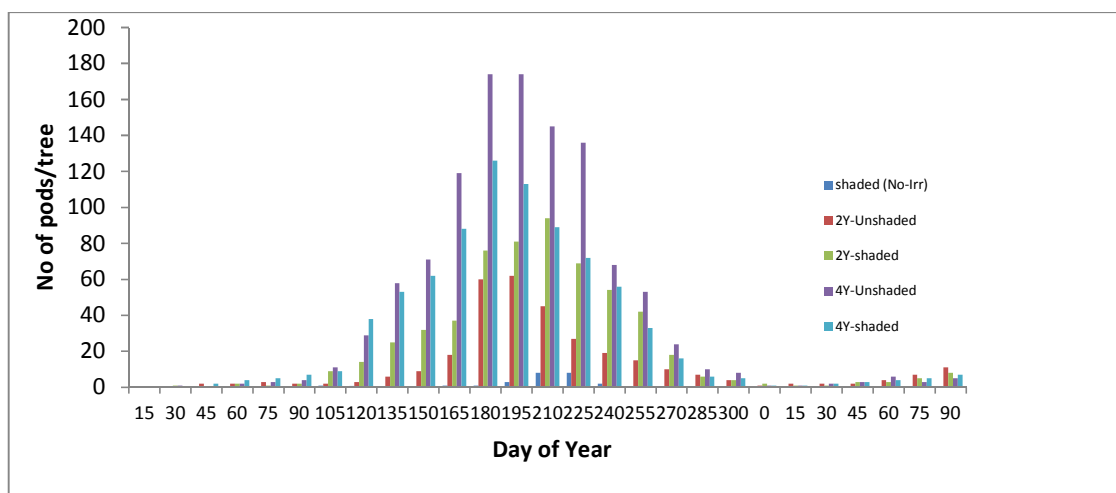
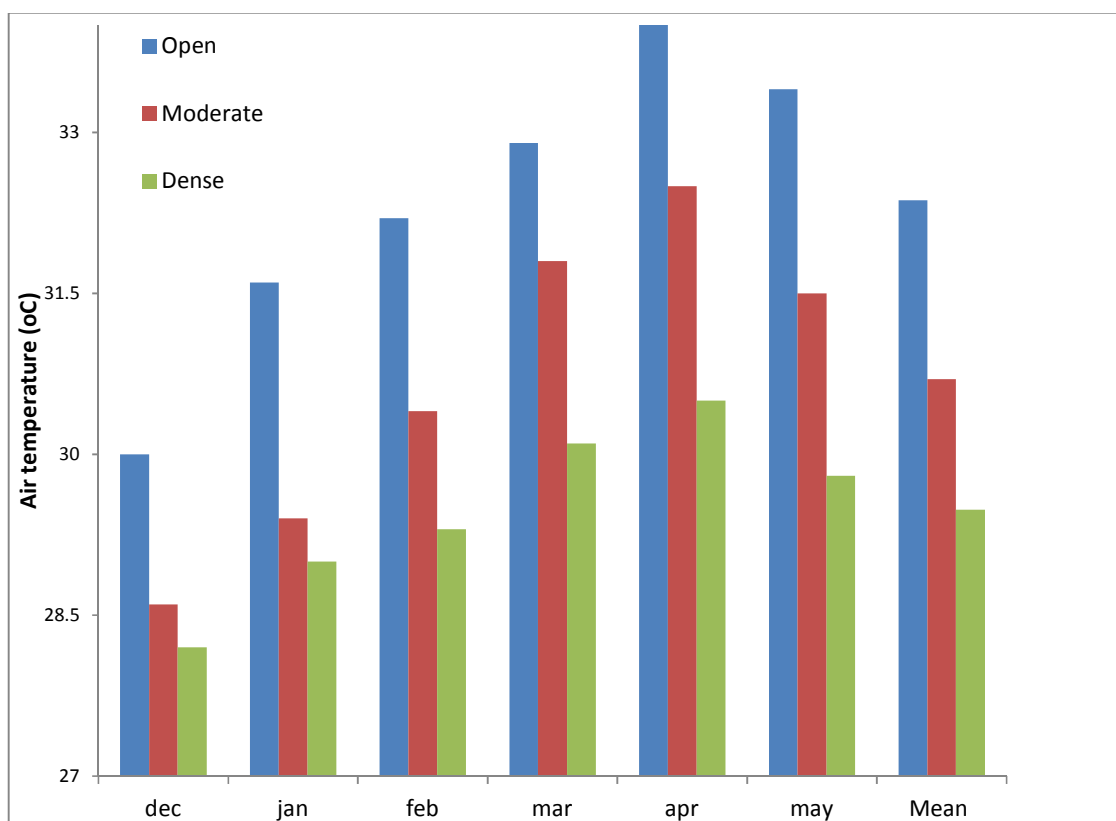


Fig. 4. Time dynamics of number of trees bearing flowers for unshaded and shaded cacao as affected by irrigation



**Fig. 5. Time dynamics of number of trees bearing pods for unshaded and shaded cacao as affected by irrigation**



**Fig. 6. Temporar trends of air temperatures in unshaded and shaded cacao plots**

### 3.4 Effects of Irrigation and Shade Cacao Canopy Development and Tree and Branch Dieback

Open sun treatment combined with 5- and 10-day irrigation intervals produced significantly

higher number of branches at each sampling dates (28 to 45 MAT) compared with the shade-irrigation combinations (Table 4). The shade regimes combined with irrigation produced significant effects on branch and leaf (canopy: LAI) development compared with that of

10-day irrigation with or without shade (Table 4). The no-shade with 5-day irrigation interval had significantly ( $P < 0.05$ ) higher LAI leaf production compared with other treatments. There were no significant differences in the number of jurquette branches under shade-irrigation combinations. The no-shaded combined 5- and 10-days irrigation producing a significantly higher number of jurquette branches compared to shaded plus with 5- or 10- day irrigation intervals. Open sun combined with 5- and 10-day irrigations produced higher LAI at each sampling dates (35 to 45 MAT) compared with the shaded and 5- and 10-day irrigation combinations (Table 5). However, the

shaded without irrigation had lowest LAI within the sampling dates (Table 5). The 5-days irrigation intervals significantly increased branch and LAI compared with the 10-days irrigation. Irrigation and shading affected tree mortality, branch and twig die-back between the onset and end of the dry seasons. Compared with the non-irrigated but shaded plants, shade plus irrigation produced significantly better branching and canopy development (LAI). There were significant differences in the percentage of dead trees and trees bearing dead branches and twigs survival between the shaded but non-irrigated and the open sun and shaded plus irrigation.

**Table 2. Time course (harvest dates) of cacao yield and yield components as affected by shading regimes (\* a,b and c are the harvest dates of cacao pods)**

Harvest date	Treatments	pod wt	no.pods	no.beans	bean wt/pod
A: 27-10-16	Unshaded	2270	5.3	42	154.1
	Shaded	2101	3.2	35	135.3
	Shaded	1933	2.3	23	107.6
	LSD (0.05)	8.45	1.83	1.45	3.67
Harvest date	Treatments	pod wt	no. pods	no. beans	bean wt/pod
B: 23-11-16	Unshaded	4633	5.83	44.4	147.4
	Shaded	2215	3.33	39.1	135.1
	Shaded	1900	7.14	39.6	117.1
	LSD (0.05)	26.03	0.96	1.23	5.41
Harvest date	Treatments	pod wt	no. pods	no. beans	bean wt/pod
C: 20/12/2016	Unshaded	654	4.8	42.7	128.1
	Shaded	514	3.4	31.4	93.8
	Shaded	409	3.3	21.3	58.4
	LSD (0.05)	7.51	0.38	1.15	3.50
Mean across harvest dates	Treatments	pod wt	no. pods	no. beans	bean wt/pod
	UnShaded	2005.21	1279.4	37.18	174.71
	Shaded	1770.14	1161.8	32.94	134.55
	Shaded	1248.53	854.2	25.75	121.42
	LSD (0.05)	13.45	10.21	0.45	1.36

**Table 3a and b. Effects of irrigation regimes yield and yield components of shaded and unshaded cacao**

3a. Well watered treatment (5-day irrigation intervals)	pod wt	no. pods	no. beans	bean wt/pod
Unshaded	7517.33	13.9	129.8	384.3
Shaded	6167.33	9.3	115.3	408.41
Shaded	4429.67	5.2	78.2	284.42
LSD (0.05) 27.06		2.08	2.07	5.06
3b. Mild stress treatment (10-day irrigation intervals)	pod wt	no. pods	no. beans	bean wt/pod
Unshaded	5782.56	10.7	92.2	295.38
Shaded	4744.12	7.2	80.7	231.46
Shaded	3102.07	3.1	81.8	271.17
LSD (0.05) 23.73		1.82	1.81	4.43



**Table 4. Effects of shade and irrigation on branch development of cacao**

Shade regimes	Irrigation intervals	Months after transplanting					
		28	30	34	38	42	45
Open Sun (no shade)	5 days	44.33	50.67	55.67	58.67	60.33	63.67
	10 days	38.17	40.83	51.83	53.83	55.17	58.83
Shaded	5 days	26.50	32.00	36.33	40.33	42.50	46.00
	10 days	25.00	28.67	31.33	35.33	38.00	41.67
LSD (0.05)		3.12	4.34	6.24	5.24	4.12	3.54

**Table 5. Effects of shade regimes on leaf area index (LAI) of cacao**

Shade regime		Months after transplanting			
		35	38	42	45
Shaded	5 Days irrigation	4.09	4.72	5.18	5.64
	10 Days irrigation	3.35	3.95	4.42	4.82
No shade (Open sun)	5 Days irrigation	4.65	5.02	5.69	6.21
	10 Days irrigation	4.13	4.74	5.04	5.82
Shaded, No irrigation		3.31	3.74	4.05	4.33

## 4. DISCUSSION

### 4.1 Effects of Shade and Irrigation on Cacao Growth, Flowering and Pod Production and Field Survival

The significantly taller cacao plants produced under The 5- day irrigation interval more frequently replenished soil moisture throughout the dry period compared with 10-day irrigation, and enhanced growth, flowering, pod and bean yields and survival during the dry season.

The enhancement of leaf development and its leaf area duration by 5-day irrigation compared with the 10-day irrigation intervals probably conferred the benefit of soil moisture replenishment while shade reduced soil temperature and evaporation and water loss. Mutual shade and canopy cover from individual cacao plant may have contributed to reduced moisture loss to the atmosphere via evaporation which thereby helped in soil moisture conservation. The benefit of shade was optimized by irrigation enhanced replenishment of soil moisture while the 5 and 10-days irrigation regimes, would have reduced severe moisture stress in the open sun (un-shaded) plots compared to when no irrigation occurred. The development and duration of leaf area and tree survival differed between the irrigation treatments imposed (5 and 10 days irrigation intervals) in combination with dense, moderate or no shade, can be ascribed to the benefit listed above. The shade-irrigation treatments reduced soil evaporation and crop transpiration (moisture loss from the soil and leaf surface) [9,10]. The shade-irrigation treatments also reduced tree shoot

(branch) dieback, flower droppings, fruit failure, and enhanced pod and bean yields [10,3].

Irrigation maybe implicated for the non-significant effects of shade on percent seedling survival at the end of the first dry season. Irrigation enhanced soil moisture status which replenished moisture loss due to transpiration, evaporation with the consequent reduction in soil and air temperatures. The accompanied enhanced plant performance observed conform to the reports of Joly [11], Zuidema et al. [4] and Agele et al. [2] that moisture is the principal requirement for tree survival of the climate stress of the rainless dry season. The overall better performance of no shade cacao subjected to 5-day irrigation intervals might have resulted from the higher status of moisture and high sunlight intensity.

The more favourable condition appeared to have enhanced cacao ability to optimize development in term of plant height, stem girth, number of jouquette branches and leaf number. Also, the underground development (root development) was at its best since all favourable conditions were in place throughout the year (both in wet and dry season). The above findings were supported by the findings of Lobao et al. [12], Kohler et al. [9] and Famuwagun et al. [3] reported that tree growth and function will continue throughout the year especially if the climate stress conditions of the dry season is ameliorated.

The reduction in the values of plant height, stem girth, number of leaves and branches in the moderate and dense shaded plots combined with the irrigation regimes (5 and 10 days) compared

with the open sun is presumably due to reductions in the transmitted light and PAR by shade conferred by plantain. The enhanced tree vigour (greater branching and LAI) under no shade (open-sun) treatment which agree with the findings of Opeke [1] and Ofori-Frimpong et al. [13] that growing cacao without shade promoted branching and canopy development.

The non-significant difference recorded in the survival rate of transplanted seedlings at 4,9,17 and 21MAT across the shade-irrigation treatments might have resulted from higher soil moisture availability and shade-moderation of extreme weather conditions [14,13,3]. The irrigation regimes combined with shade densities maintained favourable soil moisture status (5-day irrigation interval) and temperatures and enhanced the growth and survival of the cacao during the dry season. The significantly higher pod production under shade-irrigation regimes may be due to high vigour that was recorded for these treatments. The higher branching and LAI appeared to have promoted assimilate production and possibly its partitioning and utilization for pod development [9,8]. The efficiency of root architecture and canopy (number/leaf arrangement on the tree) may play major roles in nutrient and water absorption from the soil and the subsequent production of assimilates for organ development in cacao as reported by Zuidema et al. [4]. Isaac et al. [15] reported that pod production in cacao is a function of tree biomass development. Though non-significant, the differences in cacao vigour (number of branches and LAI) between densely and moderately shaded plots which favoured the latter may be ascribed to reduced intensity of light and hence assimilate production and partitioning for development in the cacao.

#### **4.2 Effects of Shade and Irrigation on Cacao Growth, Flowering and Pod Yield and Field Survival**

The duration and extent of plant leaf area (LAI) and profuse flowering under the shade-irrigation treatments maybe attributed to enhanced soil moisture status and modified microclimate during the dry season. The significantly higher proportion of trees bearing flowers and pods in the open sun compare with the moderate and dense shade treatments might have resulted from the advantage of improved vigour of growth between the open sun and shade treatments. Lobao et al. [12], Opeke, [7] and Kohler et al. [9] reported that flower development in cacao is

determined predominantly by the vigour of growth and biomass accumulation.

### **5. CONCLUSIONS**

The effects of plantain shade and dry season irrigation (5- and 10- days irrigation intervals) was profound on cacao growth, flowering, pod production, tree mortality and branch /twig dieback especially during the terminal drought situation of the dry season. The irrigated unshaded (open sun) cacao had best results in term of growth, flowering and fruiting/pod production and bean yields. The drip irrigation strategy adopted ameliorated dry season terminal hydrothermal stresses in cacao, promoted growth, development, flowering and fruiting/pod production and survival dry. The no shade strategy in combination with irrigation appeared as the best compromise in ameliorating dry season hydrothermal stresses, tree survival and productivity. For cacao fields established without shade (open sun cacao), provision should be made for dry season irrigation. The advantage of dry season irrigation in terms of supplementation of soil moisture in the dry season and enhanced cacao growth, flowering and pod/bean yields is established. Findings from this study will find use in the development of sustainable cacao production practices and development of shade and irrigation management guidelines for smallholder farmers, especially for the amelioration of the hydrothermal stress of the dry season.

### **COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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