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# Cacao Growth and Development Under Different Nursery and Field Conditions

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## Abstract

Experiments were conducted between 2004 and 2018 to examine cacao growth, development, establishment and yield under varying experimental conditions comprised of seed mucilage handling before sowing, sowing methods and its effects on seedling growth and development, timing of mycorrhizal inoculation on root and shoot growth and development and effects of shade and dry season drip irrigation on growth and yield of field-grown cacao. Results show that cleaning cacao seed mucilage before sowing enhanced sprouting rate and percent germination. The use of manure mixed with sawdust and loamy soil aided excellent seed germination, seedling vigor and root development. Inoculating cacao seeds with arbuscular mycorrhizal fungi (AMF) at point of sowing and early stages in the nursery aided root development and enhanced field establishment and survival during the dry season. Dense shade retarded cacao growth and development during the rainy season, while no shade enhances optimum growth and canopy development. The use of drip irrigation strategies in young cacao plantations increased seedling survival from less than 45% under no irrigation to above 95% at the end of the second dry season. This showed that irrigation during dry season can significantly enhance cacao establishment and survival.

**Keywords:** cacao, growth, irrigation, seedlings, shade

## 1. Introduction

Cacao (*Theobroma cacao* L.) is a tropical woody species which belongs to the family Malvaceae [1]. Under natural conditions the tree can attain a height of 20–25 m [2], whereas under cultivation, plant height varies from 3 to 5 m. The geographical origin of cacao is South America [3], where several wild populations can be found in the Amazon and Guyanian regions. It is considered one of the most important perennial crops with an estimated world output of 4.2 million tonnes in 2018 [4] while [5] reported an estimated annual yield of 3.2 million tonnes in 2009. Cacao is predominantly grown in the humid tropical areas of Central and South America, Asia and Africa [6]. Cocoa is propagated through the seed for plantation establishment, and the seedlings are raised in the nursery for about 3–4 months before transplanting on the field. Direct sowing or sowing at stake and vegetative propagation are also possible means of establishing the crop [7, 8].

In Nigeria, cocoa production is limited to the rainforest and savanna transition zones. At present, the level of cocoa production stands at 350,000 tonnes per annum [9], and Nigeria is endowed with vast land areas suitable for its cultivation. Adoption of good management practices can bring about increased bean production of up to 100–300% [10]. The country had its peak production of 304,000 metric tonnes of cocoa beans in 1970 [11]. However, by 1999 production had dropped to 225,000 metric tonnes. As a result of the drop in production, the federal government of Nigeria is making tremendous efforts to resuscitate this industry through programmes such as Cocoa Rebirth Program and Tree Crop Development Program in partnership with other international organizations like the World Cocoa Foundation and the International Institute of Tropical Agriculture (IITA) Sustainable Tree Crop Development in Ibadan. Their effort has led to an increase in production to 370,000 MT with average yield of 270 kg/ha [11]. The major reasons attributed to low productivity despite the huge effort of the government according to [8] were limited access to modern production technologies, limited access to input and credit facilities, low percentage of survival (less than 35%) of transplanted seedlings at the end of the second dry season due to soil moisture stress, poor field management and impact of changing climate. More so, cocoa farm sizes are relatively small ranging from 0.4 to 6.0 hectare per farmer with an estimated total cultivation area of about 2.25 million hectares. With the present ever-increasing rate of unemployment in the country, coupled with the dwindling growth in economy and increased rate of food insecurity and the attending impact of climate change on crop production, a more concerted effort is required to harness the full benefit accruable from growth (employment opportunities, climatic stability, etc.), consumption (as food and beverages locally) and exportation (for foreign exchange earnings).

Traditionally, plantains have been used by the farmers to complement the shade requirement of the freshly transplanted cacao seedlings across the cocoa-growing region of Nigeria [12]. The associated problems of this practice include lack of existing models to follow in terms of spatial arrangement of the shade plants/trees, densities and possible consequences on the plant growth and development as the relationship progresses. More so, despite the provision of shade by plantain for the young transplanted cacao seedlings, it was a known fact that the highest percentage of these seedlings died between the first and second dry seasons as a result of soil moisture deficit during the peak of dry seasons [13]. It is also established that the plantains that were planted to provide shade during this dry period do shed most of their leaves as a result of limited soil moisture in order to survive [13]. In solving the above-mentioned problems, more robust farm management strategies are therefore required.

An arbuscular mycorrhiza (AM fungi) is a type of mycorrhiza that penetrates the cortical cells of the roots of a vascular plant and aids root development and nutrient absorption. The involvement of biofertilizer in the experiment was to aid root development and water/nutrient absorption from the soil by the rapidly developing root. Also, it helps to build tolerance in the seedlings to moisture stress during the dry season as discussed by [8] that proper root development in cacao seedlings always aids nutrient and water absorption.

Nigeria agriculture like anywhere else in West Africa is completely rain-fed, and rainfall and humidity over the country as a whole have been in persistent decline since the mid-1970s [14], while temperature has also been on the increase. Given the increasing worldwide demand for cocoa and quest for obtaining sustainable production systems, it is imperative to understand the effect of some agronomic practices on the responses of cacao seedling to dry season environmental conditions especially the hydrothermal stresses [15]. Improved insights would be valuable towards the attainment of optimum seedling establishment and vigor on the field

and to compare attainable yield among agroecology conditions and growing season environmental condition.

The proposed agronomic practices may obliterate negative effects of environmental stresses especially in the dry season and increase cacao adaptation to stressful growing environments. Such practices may enhance the resilience of cacao in plantation to the impact of weather variability. In order to develop such systems, it is imperative to examine the value of agronomic practices in the amelioration of extreme growing environmental conditions especially the hydrothermal stresses of the dry season on seedling survival on the field. Improved insights are required in order to attain optimum seedling establishment on the field. Effective management of cacao seedlings on the field using agronomic practices like dry season irrigation and optimum shading regime to enhance root development will improve plantation establishment and cacao productivity.

This write-up comprises of major findings of four different experiments conducted over 10 years on sustainable cacao production:

Experiment 1: Effects of growth media and mucilage cleaning methods on sprouting rate, seedling growth and development of cacao in the nursery.

Experiment 2: Timing of arbuscular mycorrhiza fungi (AMF) application on growth and development of cacao seedling in the nursery.

Experiment 3: Cacao developmental pattern, soil temperature and moisture variation as affected by shade and dry season drip irrigation.

Experiment 4: Effects of shade regimes and varying seasons of irrigation on survival, developmental pattern and yield of field-grown cacao (*Theobroma cacao*).

## 2. Materials and methods

### 2.1 Experiment 1: effects of growth media and mucilage cleaning methods on sprouting rate, seedling growth and development of cacao in the nursery.

This was conducted twice in Akure, Nigeria, in 2009 and 2010 to investigate the effect of mucilage cleaning methods and growth media on sprouting rate and seedling development of cacao. The trial was a 3×3 factorial experiment laid out in three replicates. Factor 1 was growth media consisting of topsoil, mixture of topsoil and sawdust at ratio of 50:50 and mixture of sawdust and poultry manure at ratio of 50:50, while factor 2 was a mucilage cleaning method which consists of cleaning with water, cleaning with cloth and no cleaning. Nursery pots were filled in accordance with the treatments and seeds from freshly harvested cacao pods from Teaching and Research Farm, Federal University of Technology, Akure (FUTA), which were subjected to mucilage cleaning treatments and planted the same day. Watering continues on a 2-day interval throughout the period of the experiment. Data were taken on date of sprouting, number of leaves, plant height and leaf area which continued for 8 weeks. Root parameters which include taproot length, number of lateral roots and longest lateral root length were collected at the termination of the experiment. The measured data were subjected to analysis of variance, and the means separated using Tukey test.

### 2.2 Experiment 2: timing of arbuscular mycorrhiza fungi (AMF) application on growth and development of cacao seedling in the nursery.

This experiment evaluates timing of arbuscular mycorrhiza fungi (AMF) inoculation on growth and root development of cacao in the nursery and in the early stage



on the field. The experiment was conducted in Akure, Nigeria, between December 2009 and April 2010 and between December 2010 and April 2011 in a completely randomized design with three replicates. The treatments were applied at 4, 8, 12 and 16 weeks after sowing and the control treatment (with no AMF). Nursery sites were prepared close to a source of water on the field under a natural shade suitable for tree crop seedling production.

Polythene pots for cacao seedlings were filled using topsoil from a virgin forest. Cacao seeds were obtained from the Cocoa Research Institute of Nigeria in Owena substation. Fifty pots were used for each treatment, and the seeds were sown immediately after pot filling, and the first treatment was applied. Other treatments were also applied at 4, 8, 12 and 16 weeks after sowing of the seeds. Agronomic practices and watering were carried out for 5 months on the seedlings. Data collected include plant height, number of leaves and stem girth at 4-week interval. Leaf area, taproot length, number of lateral root, average length of lateral root and the distribution along the taproot were taken at the end of 5 months from five selected pots from each treatment. Spore count was carried out on the soil around the cacao roots at the end of each experiment to determine the population of AMF spores in the root zone of the plants. Data collected were subjected to statistical analysis of variance, and the means separated using Tukey Test.

### **2.3 Experiment 3: effects of plantain shade and irrigation on cacao seedling establishment, vigor of growth, root development, survival and soil temperature variation on the field**

The field experiments were conducted in Akure between May 2010 and May 2012. The treatments are plantain shade alone, irrigation alone, irrigation + plantain shade and the control. The treatments were replicated three times in a completely randomized design. Cacao seedlings were raised between January and May 2010 in the nursery and were transplanted to a manually cleared forest land with 2-month-old established plantain suckers (for shade treatments) at a spacing of 3 x 3 metres on the two sites. Drip irrigation lines were laid out on the field at the base of the cacao seedlings (irrigated treatments) at the beginning of dry season (December 2010 and 2011) to enhance adequate moisture supply during the dry season. Water was applied once per week at 2 litres per plant for 4 months of dry season. The shade plant (plantain) was transplanted on the field at the ratio of one stand of plantain to one stand of cacao seedling. Growth and development of the seedlings, soil and air temperature of the experiment site and soil moisture variation both in the wet and dry seasons were monitored starting from the onset of the dry season for 5 consecutive months. The data collected include plant height, stem girth, number of leaves, number of branches, taproot length, number of lateral root, length of lateral root, percentage (%) of seedling survival and leaf area. The soil moisture was monitored using tensiometer while soil temperatures were measured using soil thermometer at the hour of 2.00-3.00 pm in the afternoon. The collected data were subjected to analysis of variance (ANOVA), and the means separated using Tukey test.

### **2.4 Experiment 4: effects of varying dry season irrigation and shade regimes on survival, development and pod yield of young cacao on the field**

This trial was conducted in Akure in 2012–2013, 2013–2014 and 2014–2015 sowing seasons. The experiment design was a 3x4 factorial experiment involving four irrigation packages that were imposed on the young cacao over a 3-year period (1:1:1, 1:1:0, 1:0:0 and 1:0:1) with 1 indicating year of irrigation and 0 indicating year

of no irrigation. The shade treatments involved dense shade (one stand of cacao to one stand of plantain), moderate shade (two stands of cacao to one stand of plantain) and no shade (open sun).

The plants were monitored for 3 consecutive years after transplanting to the field, and irrigation treatments were imposed as appropriate during the dry season between December and March of each year of 2012–2013, 2013–2014 and 2014–2015. The plants were irrigated using water from a nearby stream dam that was piped to an overhead storage tank. Drip irrigation pipes were laid on the field having each cacao on drip point. The pipes were connected to the water source (overhead tank), and the field was irrigated for 2 hours on a weekly basis. The amount of water coming out of the emitter was measured to be 2 liters per hour per plant. The irrigation processes continued during the dry season for 3 years. Data were measured on root development, percentage survival/mortality and pod yield. Root count was taken by using pressurized water to wash off the soils around the selected plants in order to make the root available for counting before covering back with moist soil. The collected data were subjected to statistical analysis using GENSTAT, and the means separated using Tukey test.

### 3. Results

#### 3.1 Experiment 1

**Table 1** shows the effects of growing media on leaf area development (LAD); significant difference ( $P \leq 0.05$ ) was obtained 3 and 6 weeks after planting. The topsoil growing media produced cocoa seedlings with the largest leaf area development during the weeks of the experiment, while the sawdust + poultry manure gave the least.

**Table 2** shows the combined effects of cleaning methods and growth media on leaf number development. Significant differences ( $p \leq 0.05$ ) were recorded at the second and sixth weeks after planting. Similar trend was also observed in **Table 3** where the combined effects of cleaning methods and growing media on plant height development of cacao were presented, although significant differences ( $P \leq 0.05$ ) were only recorded at the second week after sowing while other weeks showed no significant differences ( $P \leq 0.05$ ). The cacao seeds that were cleaned with water and planted in the SD + PM growing media gave the tallest cacao plant, while seeds that were not washed and planted in the topsoil growing media gave the shortest cacao seedlings.

**Table 4** shows the combined effects of cleaning methods and growing media on leaf area development of cacao. Significant differences ( $p \leq 0.05$ ) were obtained at 3 and 6 weeks after sowing; cacao seeds that were cleaned with cloth and water and were planted in the SD + PM growing media produced the largest leaf area, while

Growing media	WK2	WK3	WK4	WK5	WK6
Sawdust + topsoil	2.57a	44.10b	56.89a	62.22a	65.14b
Topsoil	2.19a	51.57ab	61.44a	63.72a	88.45a
Sawdust + poultry manure	2.59a	56.35a	60.26a	61.07a	64.21b

Mean values in the same column followed by different letter(s) are significantly different by Tukey test at  $P = 0.05$ .

**Table 1.**  
Effects of growing media on leaf area development.

Cleaning methods	Growing media	WK2	WK3	WK4	WK5	WK6
Cleaning with cloth	SD + TS	2.00b	4.00a	4.67a	5.67a	6.00b
	Topsoil	1.33b	4.33a	5.00a	6.00a	6.67a
	SD+ PM	3.00a	4.67a	5.00a	6.00a	7.00a
Cleaning with water	SD + TS	1.33b	4.00a	4.33a	5.33b	5.67b
	Topsoil	1.96b	4.12a	4.51a	6.71a	7.03a
	SD + PM	3.33a	4.00a	4.66a	5.67a	6.33ab
No wash	SD + TS	2.00b	4.33a	4.33a	5.33b	5.67b
	Topsoil	3.00a	4.33a	4.67a	6.00a	6.33ab
	SD + PM	4.00a	4.33a	4.33a	6.33a	6.33ab

Mean values in the same column followed by different letter(s) are significantly different by Tukey test at P = 0.05.  
Note: TS = topsoil; SD = sawdust; PM = poultry manure.

**Table 2.**  
Combined effects of cleaning methods and growth media on leaf number development.

Cleaning methods	Growing media	WK2	WK3	WK4	WK5	WK6
Cleaning with cloth	SD + TS	6.50b	15.80a	16.87a	17.20a	17.57a
	TS	5.17b	15.13a	16.90a	17.27a	17.93a
	SD + PM	8.73a	16.87a	17.40a	17.93a	18.30a
Cleaning with water	SD + TS	5.07b	14.40a	16.83a	17.63a	18.33a
	TS	5.20b	13.68a	15.81b	16.37a	18.00a
	SD + PM	8.80a	16.53a	17.60a	18.40a	18.97a
No wash	SD + TS	5.20b	15.43a	17.87a	18.07a	18.33a
	TS	5.20b	14.10a	15.03b	15.93b	16.27a
	SD + PM	7.83a	16.37a	17.67a	18.00a	18.87a

Mean values in the same column followed by different letter(s) are significantly different by Tukey test at P= = 0.05.  
Note: TS = topsoil; SD = sawdust; PM = poultry manure.

**Table 3.**  
Combined effects of cleaning methods and growing media on plant height development of cacao.

Cleaning methods	Growing media	WK2	WK3	WK4	WK5	WK6
Cleaning with cloth	SD + TS	3.06a	49.30b	53.79c	59.57b	60.98c
	TS	2.50b	61.98a	67.29b	68.28b	99.46a
	SD + PM	1.78c	38.64c	41.18d	41.98c	44.45
Cleaning with water	SD + TS	3.79a	42.64b	63.34b	70.80a	73.48b
	TS	0.45c	31.94c	46.76	50.95c	88.80a
	SD + PM	3.07a	72.69a	76.13a	77.78a	78.37a
No wash	SD + TS	0.86c	40.37b	53.52c	56.30c	60.97c
	TS	3.66a	66.57a	71.02a	73.06a	76.85a
	SD + PM	2.92a	57.71bc	63.47b	63.47b	69.82bc

Mean values in the same column followed by different letter(s) are significantly different by Tukey test at P = 0.05.  
Note: TS = topsoil; SD = sawdust; PM = poultry manure.

**Table 4.**  
Combined effects of cleaning methods and growth media on leaf area development of cacao.

Growing media	Cleaning methods	Day 10	Day 14	Sprouting (%)
Topsoil alone	No wash	2d	19d	63.3
	C/cloth	5c	23c	76.7
	C/water	7c	28b	93.3
Topsoil + sawdust	No wash	2d	26b	86.7
	C/cloth	12b	28b	93.3
	C/water	15a	30a	100
Poultry manure + sawdust	No wash	7c	26b	86.7
	C/cloth	13b	30a	100
	C/water	14a	30a	100

Mean values in the same column followed by different letter(s) are significantly different by Tukey test at  $P = 0.05$ .

**Table 5.**  
*Cacao seed sprouting rate in day after sowing and in percentage.*

cacao seeds that were cleaned with cloth and planted in the SD + PM growing media had cacao seedlings with the smallest leaf area at 6 weeks after sowing.

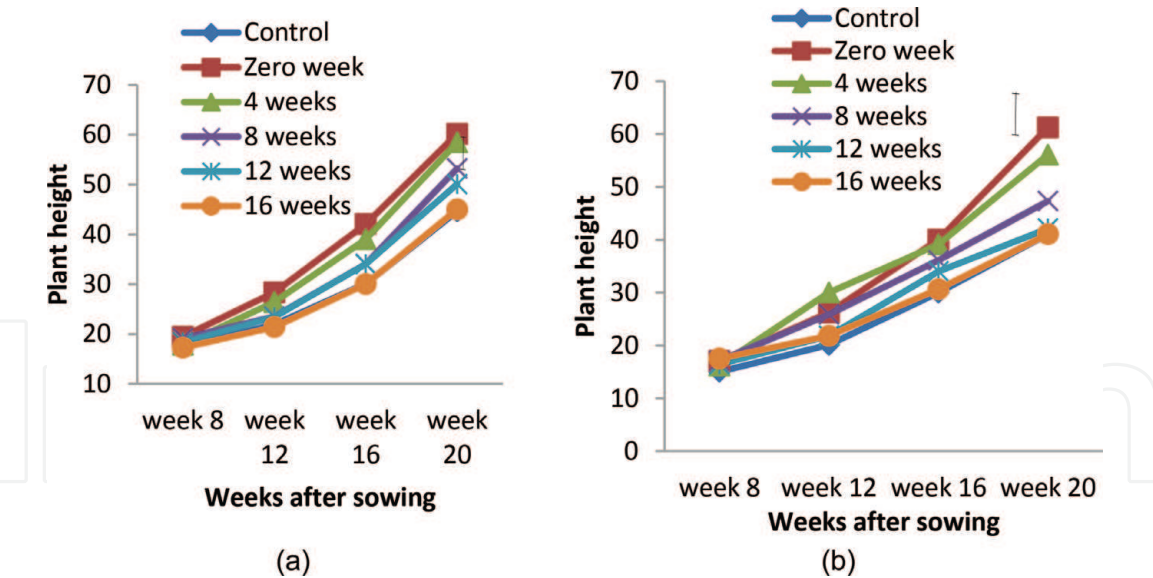
**Table 5** represents cacao seed sprouting rate in numbers of day after sowing and in percentage. Seeds that had its mucilage cleaned with water and cloth had a highest and fastest sprouting rate of about 48–50% at day 10 after sowing in both soils mixed with sawdust + poultry manure and topsoil + sawdust, while those that had their mucilage intact had a delayed sprouting with less than 25% sprouting at 10 days. At 14 days after sowing, seeds that were cleaned with water and cloth sowed in combination of topsoil + sawdust and poultry manure + sawdust had above 98% germination, while those with mucilage sowed in topsoil had less than 65% germination under topsoil mix. There was a significant difference between germination rates among seeds washed with water and those cleaned with cloth over those with their mucilage intact. More so, the mixtures of topsoil + sawdust and poultry manure + sawdust supported early sprouting rate and higher germination percentage than topsoil substrate.

### 3.2 Experiment 2

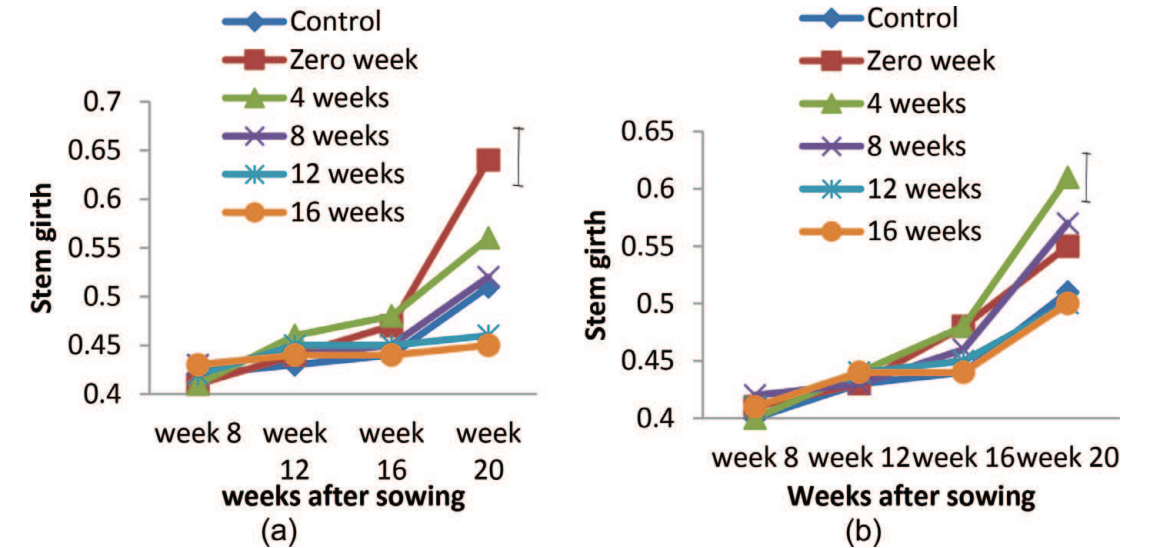
#### 3.2.1 Results

**Figure 1a** and **b** represents the effects of timing of AMF inoculation on plant height from point of sowing (0 week after sowing) in nursery for 2009 and 2010. Inoculating cacao seeds at the point of sowing to 4 weeks after sowing showed significant effects on seedling height development over other periods of inoculation. No significant difference was observed among inoculating with AMF at the 12th week and 16th week after sowing and the control treatment. Similarly, **Figure 2a** and **b** represents the effects of varying time of AMF inoculation on stem girth development; the obtained results indicated that early inoculation (0–8 weeks) aided cacao stem girth growth and development significantly compared to late inoculation dates (10–20 weeks). More so, the numbers of leaves produced by the seedlings under early inoculation dates were significantly higher than those obtained with late inoculation dates (10–20 weeks after sowing) as shown in **Figure 3a** and **b**. The effects of timing of inoculation on root, shoot and leaf area development were shown in **Table 6a** and **b**; the results indicated that early inoculation at 0–4 weeks after sowing enhances leaf area development compared to other





**Figure 1.**  
(a and b) Effects of time of AMF inoculation on height development of cacao seedlings in the nursery (2009–2010, 2010–2011).



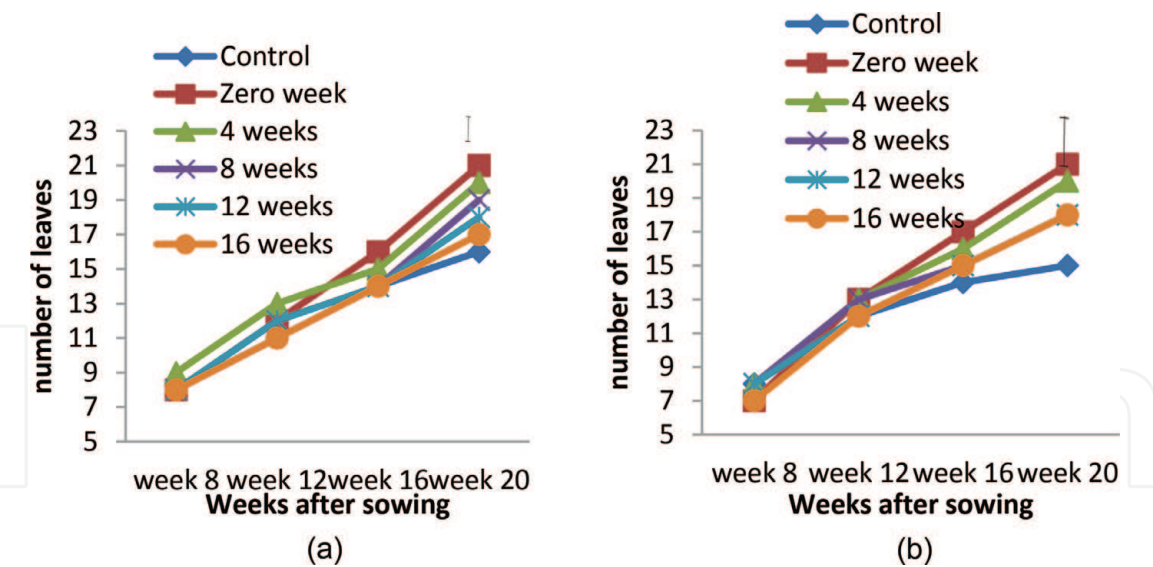
**Figure 2.**  
(a and b). Effect of AMF inoculation on stem girth of cacao seedlings in the nursery (2009–2010, 2010–2011).

periods of inoculation. In addition, root development was higher significantly when cacao seedlings were inoculated at 0–8 weeks in terms of the number and length of lateral root and the taproot length compared with those inoculated later as shown in Table 6a and b.

### 3.3 Experiment 3

**Effects of shade and AMF inoculation on vigor of growth and establishment of cacao seedlings on the field.** Effects of combined use of plantain shade and AMF inoculation from nursery and at the point of transplanting were further studied to monitor growth, development, establishment and survival of field transplanted cacao seedlings in 2011–2012. The results obtained are as shown below.

Table 3 indicates the effects of treatments on the number of leaves produced by the cacao seedlings with treatments having AMF inoculation combined with plan-tain shade having the highest significant mean values over treatment at shade alone, AMF alone at transplant and the control. In addition, no significant difference was



**Figure 3.**  
(a and b). Effects of time of AMF inoculation on inoculation on leaf development in cacao seedlings in the nursery (2009–2010, 2010–2011).

Treatments	Leaf area (cm <sup>2</sup> )	Number of lateral root (cm)	Lateral root length (cm)	Taproot length (cm)	
(a) First trial					
Control	105.03c	29c	7.1b	20.14b	
0 week	186.17a	83a	11.4a	26.45a	
4 weeks	182.11a	85a	11.6a	26.33a	
8 weeks	165.04b	80a	10.5ab	27.15a	
12 weeks	149.12b	71b	9.5ab	20.08b	
16 weeks	121.33c	65b	9.1b	21.12b	
Treatments	Leaf area (cm <sup>2</sup> )	Number of lateral root	Lateral root length (cm)	Taproot length (cm)	Number of AMF spores
(b) Second trial					
Control	98.92c	22c	6.3b	18.4b	0c
0 week	176.5a	96a	11.0a	23.6a	117a
4 weeks	188.3a	104a	10.4a	26.4a	109a
8 weeks	162.5ab	88b	10.1a	22.4a	101b
12 weeks	143.5b	80b	8.3b	20.0b	91b
16 weeks	114.3c	69b	6.9b	20.2b	76b

Mean values in the same column followed by different letter(s) are significantly different by Tukey test at P = 0.05.

**Table 6.**  
Effects of time of AMF inoculation on growth of cacao seedlings in the nursery (a, first trial and b, second trial).

observed between treatment of AMF alone from nursery and those with combined use of AMF and shade.

AMF inoculation from the nursery combined with plantain shade showed significantly higher mean values of stem girth development over other treatments. Other treatments except the control with a significantly lower mean value were not significantly different from each other in terms of plant height development as shown in **Table 7**.

Treatments	At transplant	Week 4	Week 8	Week 12	Week 16	Week 20	Week 24
Shade + AMF at nursery	8a	10a	13a	16a	17a	18a	21a
Shade + AMF at transplant	8a	11a	13a	14a	16a	18a	20a
Shade alone	9a	10a	12a	13b	14b	15b	17b
AMF alone at nursery	8a	11a	13a	15a	15a	17a	20a
AMF alone at transplant	8a	11a	12a	14a	14b	15b	18b
Control	9a	12a	13a	14a	14b	15b	16c
Means in the same column followed by the same letter(s) are not significantly different at 5% probability.							

**Table 7.**  
Effects of treatments on the number of leaves produced during the first rainy season (0–7 months after transplanting) (2011 experiment).

Treatments	At transplant	Week 4	Week 8	Week 12	Week 16	Week 20	Week 24
Shade + AMF at nursery	1.81a	1.88a	1.95a	2.06a	2.32a	2.35a	2.51a
Shade + AMF at transplant	1.78a	1.82a	1.93a	2.02a	2.22a	2.29a	2.33b
Shade alone	1.82a	1.83a	1.90b	1.99ab	2.08b	2.22b	2.24b
AMF alone at nursery	1.83a	1.84a	1.89b	1.94b	1.98b	2.07c	2.38b
AMF alone at transplant	1.81a	1.84a	1.87bc	1.96b	2.03b	2.20b	2.35b
Control	1.75a	1.83a	1.85c	1.91c	1.97c	2.05c	2.10c
Means in the same column followed by the same letter(s) are not significantly different at 5% probability.							

**Table 8.**  
Effects of treatments on stem girth development (cm) during the first rainy season (0–7 months after transplanting) (2011 experiment).

**Effects of shade and AMF inoculation on plant height development.** The results on **Table 8** show that treatments of AMF combined with shade and AMF alone from nursery were not significantly different from each other in terms of plant height development. It was also observed from the result that as the age of the inoculated cacao seedlings increases, the better the influence of AMF on them. This was evident in **Table 8** as the plant age increases the gap between treatments of AMF decreases.

**Tables 9 and 10** show that the plant growth and developmental measurement at the beginning of the first dry season after transplanting with shade + AMF from the nursery and AMF alone at transplant have the highest significant mean values over others in terms of plant height development. No significant mean difference was recorded among the treatment combinations. Similar trend was followed in stem girth development with control treatment having the lowest mean values. The percentage survival at the onset of the first dry season was not significantly different among treatments.

**Table 10** shows the results of the plant growth and developmental measurement at the end of the first dry season in April. The result indicated that inoculating with AMF from the nursery significantly increases the survival rate of the transplanted seedling with 64.7% survival compared with other treatments. Results also show

Treatments	Plant height (cm)	Number of leaves	Number of branches	Stem girth (cm)	Percentage (%) survival
Shade + AMF at nursery	67.5a	20.6a	1a	1.51a	100a
Shade + AMF at transplant	62.4b	18.3b	0a	1.33ab	95a
Shade alone	60.3b	22.5a	0a	1.24b	95a
AMF alone at nursery	64.3b	22.3a	2a	1.38ab	95a
AMF alone at transplant	66.3a	25.1a	0a	1.35ab	100a
Control	58.2b	17.3b	0a	1.10c	95a

**Table 9.**  
*Treatment effects on growth and survival of cacao at the onset of the first dry season 7 months after transplanting (December 2011).*

Treatments	Plant height (cm)	Number of leaves	Number of branches	Stem girth (cm)	Percentage (%) survival
Shade + AMF at nursery	85.42a	60.6a	5.1a	2.2a	64.7a
Shade + AMF at transplant	83.18a	48.3b	4.6a	2.0a	50.3b
Shade alone	71.44b	32.5c	5.2a	1.4a	36.1c
AMF alone at nursery	69.20b	32.3c	5.1a	1.8a	29.4c
AMF alone at transplant	70.10b	45.1b	4.3a	1.7a	28.3c
Control	64.50c	9.3d	2.1b	1.1a	9.0d

*Means in the same column followed by the same letter(s) are not significantly different at 5% probability.*

**Table 10.**  
*Treatment effects on growth and survival at the end of the first dry season 7 months after transplanting (April 2011).*

that shade alone is grossly inadequate to scale up the survival percentage of transplanted cacao seedling during the first dry season. Percentage survival of control treatment which is at 9% recorded the significantly lowest mean followed by AMF alone at transplant; AMF alone from the nursery and shade alone were not different significantly.

3.4 Experiment 4

**Table 11** shows the impacts of varying shade regimes on cacao stand survival under the tested growing seasons of 2012–2013, 2013–2014 and 2014–2015. The results indicated that the sole use of shade does not guarantee optimum stand survival and establishment of cacao in the studied area as stand survival decreases with season having 99.5% decreased to 48.4% under dense shade, 99.9–40% under moderate shade and 100% to 27.1% under no shade. It was also recorded that the mortality rate after the end of the first dry season was least under no shade as plant stand survival and establishment are getting stabilized.

Shade	2012–2013		2013–2014		2014–2015	
	Onset of dry season	End of dry season	Onset of dry season	End of dry season	Onset of dry season	End of dry season
Dense	99.5a	68.2a	68.0a	52.1a	51.0a	48.4a
Moderate	99.9a	60.1a	58.9b	44.2b	44.2b	40.0b
No shade	100.0a	31.4b	31.4c	27.1c	27.1c	27.1c

Mean values in the same column followed by different letter(s) are significantly different by Tukey test at P = 0.05.

**Table 11.**  
Effects of shade regimes on percentage (%) survival of cacao at the onset and end of dry seasons.

Irrigation treatment	2012–2013		2013–2014		2014–2015	
	Onset of dry season	End of dry season	Onset of dry season	End of dry season	Onset of dry season	End of dry season
Three season irrigation	99.8a	99.8a	98.5a	98.5a	98.5a	98.5a
Two season irrigation	99.8a	99.8a	99.8a	99.8a	99.8a	65.4b
One season irrigation	99.5a	99.5a	99.5a	75.2b	75.2b	55.5c

Mean values in the same column followed by different letter(s) are significantly different by Tukey test at P = 0.05.

**Table 12.**  
Effects of varying seasons of irrigation on percentage (%) stand survival of cacao at onset/end of dry seasons.

**Table 12** represents the effects of seasons of irrigation on survival of cacao at the onset and end of 2012–2013, 2013–2014 and 2014–2015 seasons. The results indicated that no significant difference was observed in the stand survival of the cacao during the 2012–2013 season. In 2013–2014, plots without the second dry season irrigation were significantly lower in percent stand survival under the three shade regimes. During 2014–2015 season, plots with three seasons of irrigation had the highest percentage survival above 97%, while those with two seasons of irrigation had a significantly lower surviving rate of about 63% which is significantly higher than those subjected to only one season irrigation. It was observed that percentage survival of cacao tends to improve under no shade after two seasons of dry season irrigation. It was also observed that moisture stress tolerance of cacao stands under no shade tends to increase after irrigation in the first two dry seasons.

**Table 13** indicates the combined effects of shade regimes and varying dry season irrigation on pod yield of cacao during the main and midcrop harvest. Combination of no shade + two dry season irrigation and no shade + three dry season irrigation produced a significantly higher pod yield during the first main crop harvest (14th–18th month after transplant) over those combinations of moderate and dense shades. More so, between January and April, covering the 19th–22nd month after transplanting, combination of dense and moderate shade with two and three seasons of irrigation favored pod yield over those exposed to only one season irrigation. During the second main crop harvest, the 25th–29th month after transplant,



Shade treatment	Irrigation treatment	2012–2013		2013–2014		2014–2015	
		Onset of dry season	End of dry season	Onset of dry season	End of dry season	Onset of dry season	End of dry season
Dense shade	Three season irrigation	99.8a	99.8a	99.5a	99.5a	96.5a	98.5a
	Two season irrigation	99.8a	99.8a	99.5a	99.5a	99.5a	85.5b
	One season irrigation	99.5a	99.5	99.5a	73.5b	73.0b	54.7c
Moderate shade	Three season irrigation	99.8a	99.8a	97.6	97.5a	97.5a	97.5a
	Two season irrigation	99.7a	99.7a	99.5a	97.5a	97.5a	83.5b
	One season irrigation	100.0a	100.0	99.0a	73.5b	73.5b	52.5c
No shade	Three season irrigation	100.0a	100.0a	99.5a	99.5a	99.5a	99.5a
	Two season irrigation	100.0a	100.0a	98.0a	97.0a	97.5a	89.5b
	One season irrigation	100.0a	100.0a	99.0a	77.0b	57.0b	56.5c

Mean values in the same column followed by different letter(s) are significantly different by Tukey test at P = 0.05.

**Table 13.**  
*Effects of shade regimes and varying seasons of irrigation on percentage survival of cacao at the onset and end of dry seasons.*



**Figure 4.**  
*Cacao seedlings facing moisture stress under no shade at the peak of the first dry season.*

no-shade plots + two and three seasons of irrigation produced a significantly higher pod yield over those with dense and moderate shades.

**Figures 4–6** present cacao response to varying environmental conditions of shade and no shade with or without AMF inoculation.



**Figure 5.**  
*Cacao seedling with AMF under no shade at the peak of the first and second dry season.*



**Figure 6.**  
*Plantain shade + AMF at nursery at the onset of the first dry season.*

#### 4. Discussion

The results obtained indicated that plant height, number of leaf and leaf area of cacao plants were significantly influenced by both methods of mucilage removal and substrate mix used. In general, the best results, in terms of development of plant height, number of leaf, leaf area and percentage sprouting rate, were obtained from poultry manure mixed with sawdust and topsoil growing media whose cacao seeds were cleaned with water or cloth. This was a result of ease of sprouting in the absence of the mucilage coat on the seeds which was in conformity with the findings of [16].

The rapid growth and development that was recorded on the sawdust growing media at the early stage may be attributed to the high root aeration and porous soil media that allow easy root penetration and the presence of macrospores. This agree with [17] that there exist a higher numbers of macrospores (>100 mm) and high percentages of water retention (60%) in sawdust than composted media.



He further explained that the high amount of macrospores of sawdust specifies high air space (56.9%) and enhances root growth of seedlings.

From the results, the significant differences observed in AMF application at planting and at 4 weeks after sowing were a result of early colonization of the cacao roots and the formation of mycelium growing along depressions between epidermal cells of the roots. This was in line with the findings of [18] that inoculation of crops with mycorrhiza at early stages of growth aided quick colonization and subsequent nutrient absorption and development. More so, the significant mean values recorded under AMF inoculation at 0, 4 and 8 weeks after sowing were attributed to efficient nutrient absorption and partitioning of assimilates to the root and shoot region of the seedlings which was used for lateral root and shoot development. These findings were supported by [8] that cacao seedling growth, development and establishment are determined by the volume of the lateral roots/root hair of the seedlings.

The lower significant mean values recorded under inoculation at 12 and 16 weeks and the control in terms of number of leaves produced, stem girth development, lateral root length and number and taproot length were a result of late/no inoculation [19]. Early inoculation favored multiplication of the organism as supported by the result which also favors root and shoot development and subsequent field establishment.

The combined effects of moderate and dense plantain shade with continuous 3-year irrigation enhance field survival and establishment of cacao but with a significantly negative effects on some growth parameters like stem girth, branch number and canopy size compared to cacao with continuous 3-year dry season irrigation under no shade (open sun). This was in conformity with the findings of [20] that high-density shade impedes young cacao growth and developments as shade plant competes with both water and light, thereby leading to reduced photosynthetic rate and low assimilate production.

More so, [21] reported that fruit trees generally combined well with cacao though farmers said they provided fewer ecological services to cacao plants. Shade is not the most valuable feature according to farmers.

[22, 23] resolved that soil evaporation decreases proportionally over the growing seasons as the ground surface is increasingly shaded by crops and shade plant canopy. These facts validated the significant effects of shade treatments on increased percentage survival of cacao on the field after transplanting. Provision of water through dry season irrigation and unhindered access to sunlight positively enhanced early establishment, survival, development and speedy canopy development in the no-shade treatments which gave it a hedge over the shaded plots in shoot development and early production. This further confirms the early study of [13] that no-shade cacao under irrigation performed better than the shaded ones. Cacao requires shade during its early stages of growth. This may be provided by temporary plants or by mature trees. There is no absolute requirement for shade once the cacao tree is established, unless there is no irrigation, in which case shade trees preserve soil moisture. The significantly higher height of cacao plants under moderate shades came with a thinner stem girth than those under open sun (no shade) with a thicker girth, higher branch number, and better canopy sizes at first and second growing season was as a result of competition between the cacao and the shade plants. Meanwhile, that mortality were highest under plots of dense and moderate shades without irrigation in the second and third dry season (67%), followed by those without irrigation only in the second dry season (58%) and (52%) in those without irrigation in only the third dry season was as a result of diminishing soil moisture and shallow root development/penetration in the soil. This was in line with the findings of [24–26].

The reduction in stand mortality under moderate and dense shaded plots was traced to improved microclimate conditions occasioned by shade plants that aided reduced air and soil temperature, reduced moisture loss through evaporation and increased activities of microbial organism under shaded microclimate.

More so, the early canopy cover from individual cacao plant under no-shade plots may have contributed to reduced moisture loss to the atmosphere via evaporation which thereby helped in soil moisture conservation which thereby increase the amount of available moisture for growth and development. Irrigation may be implicated for the non-significant effects of shade on percent seedling survival at the end of the first dry season. Irrigation enhanced soil moisture availability during the dry season. These results were supported by [27, 28] that moisture is the principal requirement for crop survival during the dry season to supplement soil moisture loss due to transpiration, evaporation and diminishing soil water due to dry and hot air.

Soil evaporation decreases proportionally over the growing season as the ground surface is increasingly shaded by the crop canopy. The effect of both crop transpiration and soil evaporation is integrated into a single crop coefficient ( $K_c$ ) incorporating crop characteristics and average effects of evaporation from the soil [22].

## 5. Conclusion and recommendation

Finally, results of this study have indicated that poultry manure mixed with sawdust proved to be a faster germination medium than topsoil mixed with sawdust and topsoil alone irrespective of the cleaning methods. In addition, the seeds cleaned with water sprouted faster than seeds cleaned with cloth and mucilage intact seeds irrespective of the media. Thus, adopting cleaning mucilage with water combined with using sawdust mixed with poultry manure will give a better sprouting rate and enhance seedling development.

It was concluded that cacao field establishment, growth and pod yield will improve significantly if dry season irrigation is provided for the first 3 years of establishment.

More so, stand mortality as a result of dry season soil moisture deficit in the first, second and third dry season can be avoided through dry season irrigation.

Shade can be considered to ameliorate the cocoa micro-environment.

It is therefore recommended that farmers who want to embark on cacao nursery production should adopt cleaning the mucilage of the seeds with water and using sawdust mixed with poultry manure, so as to reduce seed wastage.

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