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# Shade Trees in Cocoa Agroforestry Systems in Ghana: Influence on Water and Light Availability in Dry Seasons

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***Author's contribution***

*The sole author designed, analyzed and interpreted and prepared the manuscript.*

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## ABSTRACT

The objective of this paper was to assess the influence of single standing shade trees in cocoa agroforestry systems on soil moisture and light availability for cocoa in the dry seasons and how these environmental factors affect potential pod yields of cocoa. The research was conducted in a moist semi-deciduous forest zone of Ghana. Seven different shade trees that were commonly found in cocoa systems were selected. An effect ratio was used to compare tree sub-canopy effects to the open area effects. *Morinda lucida* (0.19), *Spathodea campanulata* (0.16) and *Ficus capensis* (0.13) showed favourable soil moisture conditions, however *Citrus sinensis* (-0.26) revealed a lower soil moisture content in the sub-canopy. *Entandrophragma angolense* and *Terminalia superba* had the highest transmitted percentage light of 69.2% and 67.1% respectively and the lowest being *Mangifera indica* (3%). The potential pod yields of cocoa were higher under *Morinda lucida* (0.40), *Terminalia superba* (0.40) and *Entandrophragma angolense* (0.35) but lowest under *Mangifera indica* (-0.55). *Morinda lucida, Spathodea campanulata, Entandrophragma angolense* and *Terminalia superba* in cocoa agroforestry systems potentially ensure higher soil moisture content and light availability in the sub-canopy, especially during the dry seasons, which could translate into higher cocoa pod yields.

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## 1. INTRODUCTION

Cocoa (*Theobroma cacao* L.) is an understorey tree and it explains why the crop is traditionally cultivated under the shade of selectively thinned forests in Ghana. The forest shade trees remaining in cocoa systems contribute to carbon sequestration, nutrient recycling, accumulation of soil organic matter, and the conservation of biodiversity [1,2]. Evapotranspiration which leads to moisture stress is reduced by shade trees during the drier seasons. This is crucial for the establishment and survival of cocoa seedlings in seasonally wet and dry environments [3]. Thus, especially in circumstances of low-input agriculture, shade trees confer sustainability (microclimatic stability) to cocoa production [4-6]. Usually, multiple species in cocoa agroforestry systems contribute functions not found in monocultures, such as the partitioning of resources, synchrony of resource use, and the capability of each species to capture and cycle nutrients [5].

Even though the favourable effects of trees in cocoa systems are widely stated [3,7,8], information on the magnitude of these effects and how they ultimately translate into effects on yield is scarce and often controversial. More precisely, it is not yet evident to what magnitude trees influence different microclimatic factors in cocoa systems and how the magnitude of effects depends on the type of shade tree, thus which specific tree traits favour or hamper cocoa growth and yields, and to what extent [9,10]. Benefits might differ between tree species and not all benefits might be equally important for cocoa growth and production. Species-specific studies support the importance of shade trees in cocoa systems for improved microclimate [11] but comparisons of more species are required to give adequate tree trait based recommendations. The study therefore seeks to evaluate the effects of tree species in cocoa agroforestry systems on the availability of soil moisture and light for cocoa in the dry seasons and how these environmental factors influence cocoa potential pod yields.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The Atwima Nwabiagya District, which is located in the Ashanti Region of Ghana, was the area where the study was conducted (Fig. 1). The District lies roughly between Latitude 6° 32'N and 6° 75'N and between Longitude 1° 45'W and 2° 00' W and covers an estimated area of 294.84 sq. km [12]. The major occupation of the people in the District is cocoa farming and hence makes the area suitable for the study. The Atwima Nwabiagya District lies within a moist semi-deciduous forest zone with dual maximum precipitation ranging between 1700 mm and 1850 mm annually. The temperature is fairly unvarying ranging between 27ºC in August and 31ºC in March. The mean relative humidity is between 87 and 91 percent. The least relative humidity typically happens in February/April [12].

### 2.2 Research Design

Seven tree species (4 replicates per species) were selected based on their relative abundance in cocoa farms. The selected shade tree species are presented in Table 1.

For each selected tree, circular paired (sub canopy and open area) plots were set. The sub canopy area was the zone where the tree species had direct influence on the cocoa trees as readings were directly taken under the tree

**Table 1. Selected trees and their particulars**

| Tree name | Average age (years) | Average canopy diameter (meters) |
|---|---|---|
| *Citrus sinensis* | 55 | 6.6 |
| *Entandrophragma angolense* | 38 | 3.3 |
| *Ficus capensis* | 30 | 11.5 |
| *Mangifera indica* | 36 | 14.8 |
| *Morinda lucida* | 32 | 9.1 |
| *Spathodea campanulata* | 55 | 12.1 |
| *Terminalia superba* | 66 | 8.5 |

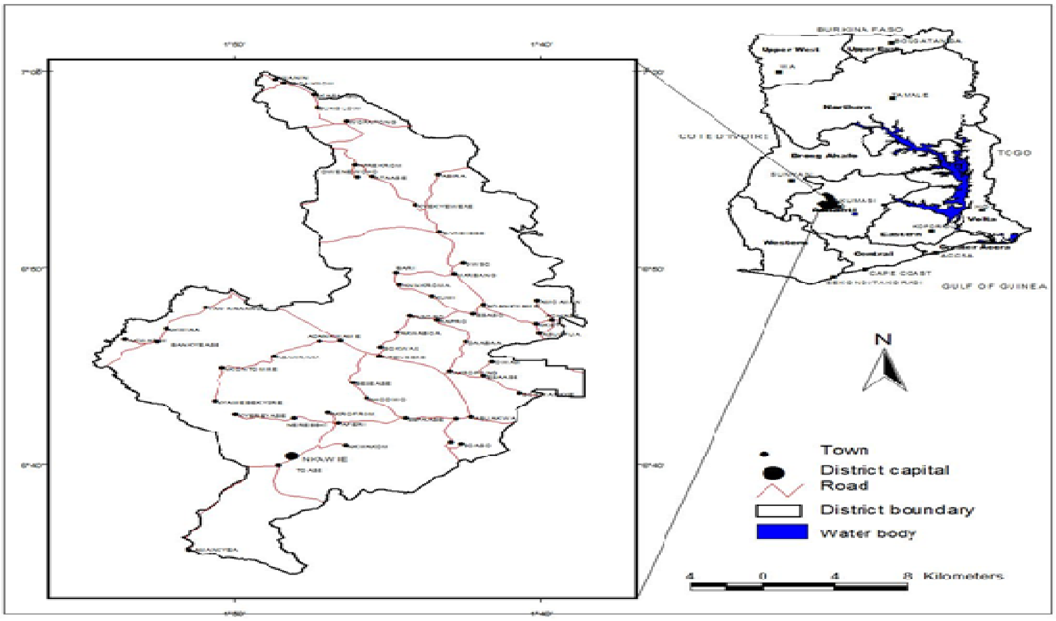


**Fig. 1. Map of Atwima Nwabiagya District in Ghana**

canopies while the open area was the zone without any tree influence serving as the control. All measurements were taken from the sub-canopy and open area circular plots which were set 50 m apart from each other. Because some of the trees had large canopy sizes, 50 m distance was selected to ensure that there is actually a true open site without any tree influence such as possiblity of shade casting during sun rise and sun set when the sun is at an angle relative to that of the tree and to help ensure a uniform distance for all trees.

## 2.3 Data Collection Method

### 2.3.1 Volumetric soil moisture content

Soil moisture measurements were done using a hand held Time Domain Reflectometry (TDR) sensors (Probe model: CD658, 20 cm rods). Eight TDR measurements were recorded in the top soils (0-20 cm) in the sub canopy area at 2 m from the centre of the tree trunk in the four cardinal directions as well as in between, that is S, SE, E, NE, N, NW, W, SW using a compass as a guide. Eight TDR readings were as well taken 2 m away from a point in the middle of the open site serving as the control. Measurements were limited to the top 20 cm as this is the active lateral root zone of cocoa [13]. Measurements were performed in late January as this is the driest month of the year.

### 2.3.2 Light availability

The Photosynthetic Active Radiation (PAR) photon flux sensors were used to determine the amount of light available to the cocoa in the sub canopy as well as in the open sun. PAR measurements were done between 10:00 to 14:00 GMT when the sun was in the zenith. Two PAR sensors were used for the light measurements. One of the two was attached to a DECAGON EM50 Logger, which was set to log at every one minute. This logger was installed in the open above the cocoa as a control to check the open sky conditions at all time. The other was attached to the Pro Check Hand held device and this was used to take eight readings in the Sub canopy above the cocoa. In the sub canopy area, readings were taken 2 m away from the centre of the tree trunk in the four cardinal directions as well as in between, thus S, SE, E, NE, N, NW, W, SW using a compass as a guide. Measurements on light were done in early November as this was the flowering period of cocoa for the minor season.

### 2.3.3 Potential cocoa pod yields

Potential yields were assessed based on the number of mature, healthy cocoa pods (above 10 cm long) and immature pods (below 10 cm long) [14] in each paired plot using the Hand Tally Counter.

### 2.4 Data Processing and Statistical Analysis

An effect ratio comparing the sub-canopy effects to the open sun effects was used to test for differences between the individual tree species. The tree effect ratio is expressed as; (Sub-Open)/ (Sub+ Open), where a positive output means the tree sub-canopy effects are bigger, a negative output means the open sun (control) effects are bigger and a zero output means there are no effects.The averages of the individual tree sub-canopy and open area readings were calculated to represent their respective replicate values.

Data were analyzed as one-way analysis of variance (ANOVA) using the R Statistical Package, version 3.2.2 (The R Foundation for Statistical Computing Platform). For each variable, normal distribution was tested using the Shapiro-Wilk normality test for homogeneity of variances. Significant ANOVAs were subsequently assessed using Tukey's Honestly Significant Difference (HSD) test and probability was set at 0.05 for the statistical tests.

## 3. RESULTS AND DISCUSSION

### 3.1 Effect of Tree Species on Soil Moisture Content in a Cocoa System

Table 2 presents the differences between the individual tree species in terms of their ability to conserve soil moisture in cocoa agroforestry system in the dry season. Soil moisture effect was highest in the sub-canopies of *M. lucida* (0.19), *S. campanulata* (0.16) and *F. capensis* (0.13) with the least being *C. sinensis* (-0.26) (Table 2). Tree species with positive soil moisture effects might have the ability to reduce evapotranspiration and therefore increases soil moisture content for cocoa. According to Beer [3], shade trees decrease evapotranspiration and therefore moisture stress during the dry seasons. These tree species have the potential to conserve soil moisture in cocoa agroforestry especially in the dry seasons. Belowground competition for water may be reduced by planting shade tree species which shed their leaves during the dry season [15], or which take up their water from different soil zones than crops [16,17]. Thus, leafing phenology and rooting depth could be responsible for the favourable soil moisture effect as most of the tree species were deciduous and deep rooting as well. On the other hand, tree species with negative soil moisture effects may be as a result of the shallow rooting and/or evergreen features [17].

### 3.2 Effect of Tree Species on Percentage Transmitted PAR to Cocoa

The effects of the different tree species on percentage PAR availability to the understorey cocoa are presented in Table 3. *Entandrophragma angolense* and *T. superba* had the highest transmitted PAR of 69.2% and 67.1% respectively, and the lowest being *M. indica* (3%) (Table 3). With regards to light transmission to the understorey cocoa, Rich et al. [18] reported that the higher PAR recorded in the dry season for all the species could be due to a higher irradiance usually received by the canopy during the dry season, as a result of reduced cloud and leaf cover. *Entandrophragma angolense* and *T. superba* are deciduous trees and elevated above the cocoa and therefore the

**Table 2. Effect of tree species on soil moisture content in a cocoa agroforestry system during the dry season**

| Tree species | % soil moisture content | | Moisture effect |
|---|---|---|---|
| | **Sub-canopy** | **Open area** | |
| *M. lucida* | 8.06 ± 2.25 | 5.33 ± 1.23 | 0.19 ± 0.08 $^{a}$ |
| *S. campanulata* | 9.80 ± 2.38 | 7.56 ± 2.12 | 0.16 ± 0.08 $^{a}$ |
| *F. capensis* | 12.69 ± 2.29 | 9.24 ± 1.22 | 0.13 ± 0.06 $^{a}$ |
| *T. superba* | 10.79 ± 0.61 | 10.24 ± 0.95 | 0.03 ± 0.03 $^{ab}$ |
| *M. indica* | 6.43 ± 0.65 | 6.06 ± 0.30 | 0.02 ± 0.07 $^{ab}$ |
| *E. angolense* | 12.64 ± 2.47 | 13.47 ± 2.77 | -0.03 ± 0.02 $^{ab}$ |
| *C. sinensis* | 4.75 ± 1.67 | 7.31 ± 1.77 | -0.28 ± 0.12 $^{b}$ |

*Values with superscripts followed by the same letters are not significantly different at P≤ 0.05 level using Tukey's HSD range test* understorey cocoa receives much light directly when the sun is at an angle relative to the sub-canopy. This is in line with a study by Zuidema et al*.* [19] who reported that cocoa under tall trees receive much PAR during the mornings and late afternoons when the sun is at an angle relative to the tree sub-canopy. *Mangifera indica* and *C. sinensis* are evergreen tree species and they were not elevated above the cocoa species which resulted in the low PAR transmission to the understorey cocoa (Table 3). Cocoa is highly sensitive to light availability [19] and because there is limited available PAR irrespective of the angle (relative to the sub-canopy) of the sun during the day, these species when used in cocoa systems could adversely affect flowering leading to lower yields.

**Table 3. Effect of tree species on percentage transmitted PAR to cocoa**

| Tree species | Transmitted PAR (%) |
|---|---|
| *E. angolense* | 69.22 ± 5.63 [a] |
| *T. superba* | 67.14 ± 5.24 [a] |
| *F. capensis* | 33.75 ± 3.77 [bcde] |
| *M. lucida* | 23.33 ± 3.01 [bcdef] |
| *S. campanulata* | 18.23 ± 5.13 [cdef] |
| *C. sinensis* | 5.63 ± 1.70 [ef] |
| *M. indica* | 2.95 ± 0.81 [f] |

*Values with superscripts followed by the same letters are not significantly different at P≤ 0.05 level using Tukey's HSD range test*

## 3.3 Effect of Tree Species on Potential Pod Yields of Cocoa

The yield effect of cocoa was highest under *M. lucida* (0.40), *T. superba* (0.40) and *E. angolense* (0.35), and lowest under *M. indica* (-0.55) (Table 4). Higher yields in the sub-canopy could be attributed to low shade because the canopy heights were well elevated above the cocoa and were mainly deciduous. Tree species of this nature manipulate PAR to the understorey cocoa during the day [19] to enhance flowering and increase yields of cocoa. Moreover, the species are mainly deep rooting and hence they take up water deep down from the soil and this minimizes below ground competition for soil moisture with the understorey cocoa [20]. *Mangifera indica* (-0.55) and *C. sinensis* (-0.26) may have lower yields because they are mainly evergreen and not elevated above the understorey cocoa leading to lower light transmission and thereby limiting PAR availability to the sub-canopy cocoa trees. Moreover, the trees species are mainly shallow rooting which adversely affect water availability to the understorey cocoa as a result of competition for moisture and nutrients. Because cocoa is highly sensitive to water and light availability [19], any tree species that do not enhance optimum light and water availability will eventually have an adverse effect on cocoa yield. The results from this study confirms an investigation by Koko et al*.* [14] who reported that the yields of cocoa intercropped with *C. sinensis* were significantly lower than the monocrop yield. However, because these are mainly fruit trees and farmers are likely to include them in the system for food and/ or extra income, appropriate planting distances that minimize detrimental microclimatic effects should be adopted. Koko et al*.* [14] proposed planting distance between the cocoa and the fruit trees of 10.6 m to minimize adverse effects of trees and ensure optimum yield of cocoa.

**Table 4. Effect of tree species on potential pod yields in a cocoa agroforestry system**

| Tree species | Number of pod yields | | Pod yield effect |
|---|---|---|---|
| | Sub-canopy | Open area | |
| *M. lucida* | 10.90 ± 1.80 | 4.50 ± 1.18 | 0.40 ± 0.17 [a] |
| *T. superba* | 8.23 ± 0.80 | 3.83 ± 1.42 | 0.40 ± 0.14 [a] |
| *E. angolense* | 15.87 ± 1.47 | 11.67 ± 1.42 | 0.35 ± 0.11 [a] |
| *S. campanulata* | 15.87 ± 1.47 | 11.67 ± 1.42 | 0.15 ± 0.10 [ab] |
| *F. capensis* | 5.60 ± 0.60 | 7.42 ± 3.42 | -0.03 ± 0.22 [ab] |
| *C. sinensis* | 6.93 ± 3.70 | 11.25 ± 5.64 | -0.26 ± 0.02 [ab] |
| *M. indica* | 3.58 ± 1.68 | 10.04 ± 1.63 | -0.55 ± 0.15 [b] |

*Values with superscripts followed by the same letters are not significantly different at P≤ 0.05 level using Tukey's HSD range test*

## 4. CONCLUSION

Soil moisture content was higher under the sub-canopies of *M. lucida, S. campanulata and F. capensis*, but significantly lower in the sub-canopies of *C. sinensis* due to belowground competition with cocoa for soil moisture in the dry seasons. *Enthandrophragma angolense* and *T. superba* transmitted higher light to the cocoa sub-canopy in the dry seasons. Potential yields of cocoa were higher in the sub-canopies of *M. lucida, T. superba and E. angolense* but lower in the sub-canopies of *C. sinensis* and *M. indica.* Because *M. indica* and *C. sinensis* are fruit trees and farmers may include such trees in cocoa systems, further research should be directed at determining appropriate planting distances between the cocoa and the fruit trees to ensure favourable microclimatic interactions leading to improved yield of cocoa.

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## COMPETING INTERESTS

Author has declared that no competing interests exist.

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