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Shading effects of baobab (*Adansonia digitata* L.) stands on productivity of millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum bicolor* L.) in farmed parklands in Northern Ghana

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Abstract

An experiment was conducted to examine the effects of shade of three different baobab stands on the general biological productivity of millet and sorghum at Doba in northern Ghana in 2013. A purposive sampling technique was used to identify three natural baobab tree stands viz. Highly-clumped, moderately-clumped and isolated. Each stand type was replicated three times. The experimental plots were laid in two strata, consisting of large plots containing the three categories of baobab stands and subplots nested within the large plots containing the cereal food crops. Characteristics of the baobab trees, especially plant height and crown diameters were determined, whilst light intensities in plots were measured with the aid of hand-held light level sensor meters. Growth parameters and yield components of millet and sorghum were also assessed. The results showed that there were weak correlations among many aspects of productivity determinants and the height, crown spread and light intensity received in the three baobab stands. However, in general, the light intensities received in both the east and the west cardinal points of the three baobab stands were significantly and positively correlated with millet plants height. Also, significant differences existed in millet plants dry weight at the western flanks of the trees, seed weight of millet at the eastern flanks of the trees, panicle weight of sorghum at both eastern and western flanks and seed weight of sorghum at the eastern flanks of the baobab trees. Education of farmers to cultivate cereals at least two meters away from trunks of baobab trees whilst promoting growing of shade tolerant vegetables closer to the trunks of baobab trees could be recommended.

Keywords: *Shading effect, baobab, millet, sorghum, productivity.*

INTRODUCTION

The cultivation of cereals in mixture with crops or economic plants is a common cropping system found throughout the Upper East Region of Ghana, particularly the Kassena-Nankana East District, and around Navrongo, Doba and Vonania. Millet (*Pennisetum glaucum* L.) is usually intercropped with other cereals especially sorghum (*Sorghum bicolor* L.) and/or a legume (Spencer and Sivakumar 1986). Farmers practice this cropping system in order to maximize the use of the small landholdings and also to reduce the risk of crop failure due to the unpredictable nature of the rain-fed agriculture system practiced in the area. Additionally, the short-season millet known in the local parlance as “Nara” commonly intercropped with other cereals and crops matures fast to serve as a guarantee food supply to the farming households especially at the time when other crops have not matured and farmers are in a dire need of food.

The agricultural land-use system practiced by the people of the Kassena-Nankana East District of the Upper East Region of Ghana can be described as agroforestry because some trees are deliberately left on the fields, which of course have both ecological and economic interactions with the food crops. Farmers leave some tree species on their crop fields because of the benefits derived from them. The baobab (*Adansonia digitata* L.) tree is one of the commonest indigenous trees left on the fields on both the compound and in the bush cultivated fields. The presence of baobab on cultivated fields is a common sight even to a casual observer due to its large size and probably to its large numbers in the area.

When trees and food crops are grown together, there is inevitable competition for growth resources and the productivity of each component depends on its ability to capture light, water and nutrients and also its response to changes in the microclimate (Otsyina, 1989). The interactions between trees and crops, growing on the same field and the effects on either component have still not been fully investigated and understood (Otsyina, 1989; Kang and Vandenbeldt, 1990). Several researchers have evaluated the effects of trees on yields of food crops in the savanna ecosystem (Maiga, 1987; Kessler, 1992; Karter *et al.,* 1992; Peiler, 1994; Sanou *et al*., 2011) and reported reduced crop yields except enhanced food crop yields with *Faidherbia albida* intercrops.

Competition among plants for growth resources occurs both above-and below-ground but the former involves factors such as light, space and perhaps carbon dioxide but the principal normally limiting in above-ground competition is light (Gerardo *et al.,* 2001). Plants do not usually compete for carbon dioxide because atmospheric turbulence is so effective in replenishing supply of this resource. Also, agronomic practices such as altering distances between plants and optimum plant density per stand could minimize or eliminate space competition on agro-ecological systems. In contrast, competition for light is unique in the sense that there is no storage and thus incoming light must be used or lost (Häder and Tevini, 1987). Leaves behave towards light as individual units; when they remain for long periods below light compensation point they are not supported by export of assimilates from other parts of the plant resulting in death (Gerardo *et al.,* 2001). For this reason, competition for light is between individual leaves rather than between plants in an open area. According to Bell *et al.* (1977) individual leaves of green plants absorb photosynthetically active radiation with a high degree of efficiency and the total energy absorbed by the whole plant or plant communities depends on the number of leaves, their arrangements, structure and leaf lifespan. Photosynthesis makes a significant contribution to dry matter production and grain yield of crops and this depends on solar radiation received. The amount of photosynthesis in canopies depends on the amount of photosynthetically active radiation intercepted by the plant leaf, its distribution over the surface and hence levels of radiation per unit surface area and photosynthetic capacity per unit of such surfaces.

The above-ground interaction between trees and agricultural crops normally deals with shade of the trees on the food crops and the effect of shading depends largely on the crown size or form and to some extent, tree height. In fact, many farmers in the study area perceived baobab tree to have intense shading on associated food crops due to its large size and according to their indigenous technical knowledge, canopy shade of trees in general lasts longer in east-west axis than north-south axis of trees in every photo-period. The leaves of baobab trees sprout and develop during the cropping period from June to October and this causes a reduction in light under their canopies varying from 45 % to 65 % of the incident radiation (Belsky *el al.,* 1989). This may affect the ecology and crop productivity beneath the canopy and around the trees in general.

In general, apart from the recent work by Sanou *et al.* (2011) on shade effects of baobab on millet in concentric circles around isolated tree species, there is no information on baobab tree interaction with other traditional cereal crops like sorghum. In addition, only food crops' yield with respect to cardinal directions of different tree species has been reported in literature so far without general assessment of biological productivity. No study has so far been able to systematically address these aspects in a single study. It is against this background that the study sought to examine the relationship between aspects of the baobab tree, such as height, canopy spread and light intensity that determine its shading, on crop productivity with respect to east and west cardinal points.

MATERIALS AND METHODS

Study area

The study was conducted at Doba, a community near Navrongo in the Kassena-Nankana East district of Upper East Region of Ghana. Doba is about 6 km south-east of Navrongo on the Bolgatanga-Paga main road. The community is located in the south-eastern part of the district and shares boundaries with other communities such as Nayagnia, Kandiga, Janania and Wariga. The district covers a total land area of 1657 square kilometers in the Sudan savanna zone, within latitude 10º 54' N and longitude 01º 06' W.

The vegetation of the area is Sudan savanna with short grasses interspersed with common tree species like *Vitellaria paradoxa, Ceiba pentandra, Adansonia digitata* and *Parkia biglobosa* (Taylor, 1960). Agriculture and other human activities such as firewood harvesting and bush burning did not permit the establishment of natural climax vegetation, but fire pro-climax vegetation is predominant in the district with a few species of fire-tolerant trees growing over a continuous understory of grass cover.

The climate is linked with the prevailing general air circulation affecting the West African sub-region. There are two main seasons; the rainy and the dry seasons. The rainy season extends from May to October with a mono-modal pattern while the dry season usually lasts from November to April. The mean annual rainfall is between 750 mm and 1100 mm, with high temperatures throughout the year. The area also experiences abundant sunshine with mean relative humidity values (measured at 0600

GMT) ranging between 35 % and 95 % (Ghana Meteorological Service, 2011).

Selection of experimental baobab trees

A purposive sampling technique was used to identify three natural baobab tree stands namely; highly-clumped, moderately-clumped and isolated. These classifications were based on results of tree inventory and reconnaissance survey carried out in the study area (Imoro *et al*., 2009). Thus, highly-clumped baobab trees, consisted of six trees situated within 20 m x 20 m land area with closed canopy whilst moderately-clumped trees consisted of three baobab trees situated within 20 m x 20 m land area. Also, isolated baobab tree consisted of a single tree situated within 20 m x 20 m land area in which no other tree was found. The highly-clumped baobab tree stands were identified at three different sites and same was done for both the moderately-clumped and isolated baobab stands, as these served as replicates.

Determination of the structural characteristics of the baobab stands

The structural characteristics of the baobab stands studied were tree height, trunk girth, diameter at breast height, crown diameter and basal area. Tree height was determined by the use of a clinometer while the trunk girth and the diameter at breast height were measured with a diameter tape. The crown diameter was measured by determining the average diameter of the vertical projections of canopies in North-South and East-West directions (Peiler, 1994) using surveyor's tape. The basal area was calculated.

Field layout and design

The experimental plots were laid out in two strata in the field, namely large plots containing the three categories of baobab stands and subplots nested within the large plots containing the cereal food crops. Each large plot dimension was 100 m x 100 m whilst each subplot was 5 m x 5 m. This plot arrangement was replicated thrice. Also, three large plots were laid out together with their subplots but contained no tree and served as control experiment. Each 100 m x 100 m plot (i.e. large plot) was laid in such a way that the selected baobab stands were located at its center and the plot edges were demarcated with wooden pegs. Then, within each large plot containing the baobab trees, the geographic east and west cardinal directions were determined with the aid of a hand-held compass. For the isolated baobab trees, the subplots were laid along the east-west axes of the trunk, ensuring that, plots began from one meter away from the trunk of the tree. Also, for the clumped baobab trees, the subplots were laid along the east-west axes, ensuring that, plots began from one meter away from the trunks of baobab trees in east and west. In all, three subplots were laid in east axis of the baobab tree(s) trunk(s) and similar number on the west axis of the trunk(s), giving a total of six subplots per baobab tree(s) in a single 100 m x 100 m plot. The distances between subplots within 100 m x 100 m plots were one meter apart. For the large plots, which served as the control, that is the 100 m x 100 m plots without trees, the distances between subplots were also one meter apart and oriented along east-west geographic cardinal points. A total of twelve 100 m x 100 m plots (i.e. large) together with 72 subplots (i.e. 5 m x 5 m plots) were laid in the farmed parkland in the vicinity of Doba. These plot sizes have been chosen because they could conveniently be handled in the study area and have been successfully used elsewhere (Hatheway and Williams, 1958).

The spatial distances of the subplots from the baobab tree trunks served as treatments in one case. Thus, treatments consisted of a combination of three different spatial distances and three different baobab stand types.

The cereal food crops used in the experiment were millet and sorghum because they are the main food crops grown in mixed stands in the study area. The subplots were over-planted with the food crops and thinned to the appropriate stands, 20 days after planting. Also, the intra-row and inter-row spacing between the crop plants were 30 cm and 60 cm respectively.

Determination of light intensity in the subplots

Light intensities in the subplots were determined using a hand-held light level Sensor Meter (E 30280/1 DK, Philip Harris Shenstone-England) standing in the middle of each subplot with the aid of field assistants. This was measured at the same time simultaneously in all plots. The measurements were taken three times that is when the food crops were 30, 45 and 60 days old from planting. This was done within the hours between 11.45 am and 12.15 pm, for duration of 30 minutes in each case.

Determination of productivity parameters of food crops

Plant height

Three randomly selected plants from each subplot at each sampling day were taken and their height measured using measuring tape but at the initial stages of plant growth, this parameter was determined with the aid of a twine/thread.

Dry weight

This exercise commenced when the plants were about twenty-five-day old from emergence. Three randomly selected plants from each subplot were taken at each sampling day and divided into root and shoot components. The plant samples were put in labeled envelopes and dried in an oven set at 80^{o}C for 48 hours until a constant weight was achieved as described by Sharma *et al.* (1996). The dry weight was determined with the aid of an electronic balance.

Leaf area

The leaf area of three randomly selected plants in each subplot at each sampling day was measured by scanning the leaves as computer images and then measured the area by using image analysis software to calculate the individual leaf area. Based on the leaf area, leaf area ratio and average leaf areas per plant were calculated for each plant species.

Leaf area index (LAI)

The population of plants in each plot was manually counted. The number of leaves per plant was also counted in the same manner and the leaf area index (LAI) for each species was then determined using the relationship described by Shortall and Liebhardt (1975) as: $LAI = Y \times N \times A_L \times (A_p)^{-1}$, where: Y = Population of plants per plot, N = Average number of leaves, A_L = Average area per leaf, A_p= Area of plot.

Yield

At maturity, the plants were harvested and randomly sampled yield components weighed with the aid of electronic balance. For sorghum and millet, panicles randomly collected were weighed for each subplot. After threshing the panicles to obtain the grains or seeds separately, ten, hundred and thousand grains (for both sorghum and millet) were picked randomly from each subplot's plants and their weight determined with the electronic balance for both fresh and dry weights. Number of seeds borne by each panicle was also counted and recorded.

Harvest index

Harvest index for each crop was determined as the ratio of economic yield to biological yield as described by White and Wilson, (2006). For the economic yield, the dry weights of only the grains/seeds of randomly selected plants were determined while, the biological yield was determined by the total dry weight of the shoot, roots and empty panicles of the randomly harvested plants. That is all the components dry weight of the plants except the seeds.

Data Analysis

The normality of the data of the baobab stands' parameters was checked using normal probability plots and in general the data were found to be normally distributed. The results of the baobab tree data are expressed as means ± standard error. The data on baobab characteristics were analyzed using a one-way analysis of variance (ANOVA). Also, the data on millet and sorghum productivity were analyzed using correlations and multiple regressions found in the General Statistical Software Package of GenStat, 2007.

RESULTS

Structural characteristics of the three baobab stands

The mean heights of the three different baobab stands were similar (F = 0.90, df = 30, P = 0.418). Thus, the results showed that the height of the baobab trees at the various stands ranged between 11.3 ± 1.06 m and 14.2 ± 2.20 m. The mean crown diameter did not also differ (F = 1.734, df = 30, P = 0.196). The mean crown diameters recorded for the isolated, moderately-clumped and highly-clumped trees ranged between 15.5 ± 2.19 m and 22.3 ± 2.59 m (Table 1).

Table 1: Structural characteristics of the baobab stands

Table 1: Structural characteristics of the baobab stands

Baobab - stand type	Stands height (m)	Stands girth (m)	Stands diameter at breast height (m)	Stands crown diameter (m)	Stands basal area (m^2/ha)
Isolated baobab stands	14.2 ± 2.20	8.2 ± 1.42	2.6 ± 0.46	22.3 ± 2.59	5.68 ± 1.06
Moderately-clumped stands	11.3 ± 1.06	5.8 ± 0.92	1.5 ± 0.20	15.5 ± 2.19	6.09 ± 0.23
Highly-clumped stands	11.5 ± 0.81	6.5 ± 0.44	2.1 ± 0.14	16.3 ± 1.42	21.67 ± 2.44

Values are means ± S.E.

Millet production with respect to the cardinal directions of the three baobab stands.

Relationship of height, crown spread and light intensity of baobab stands to plant height of millet with respect to east and west cardinal directions.

In general, the light intensities received in both the east (R^2 = 0.6131, P = 0.013) and the west (R^2 = 0.5476, P = 0.023) cardinal points of the three baobab stands were significantly and positively correlated with millet plants height. Also, there was no difference between the height of millet plants growing in the inner subplots in both the eastern (F = 2.58, P = 0.190) and the western (F = 1.11, P = 0.460) flanks with respect to tree height, crown spread and light intensities of the three baobab stands. The trend indicated that the height of millet plants in the eastern flanks generally recorded slightly higher values as compared to the corresponding western flanks especially in the subplots at the isolated and the moderately-clumped stands. This trend however, was not exhibited in the subplots under the highly-clumped stands (Table 2). Similarly, no differences existed among the millet plants height in the middle subplots under the three different stands with respect to the east (F = 3.66, P = 0.118) and the west (F = 3.70, P = 0.116) cardinal directions. The same trend was observed for the outer subplots in the east (F = 3.81, P = 0.092) and the west (F = 3.42, P = 0.109) cardinal directions under the three baobab stands.

Table 2: Relationship of height, crown spread and light intensity of baobab stands to plant height of millet with respect to east and west cardinal directions.

Baobab- stand type	Mean stands height (m)	Mean stands crown spread(m)	Subplot orientation towards trunk(s)	Light intensity (10^3 lux)		Mean millet height (cm) at end of growing season	
				East	West	East	West
Isolated	14.2±2.20	22.3±2.59	close	3.74±0.09	3.52±0.04	124.4±19.25	123.4±19.59
			middle	4.64±0.12	4.42±0.10	142.1±8.48	141.9±8.45
			outside	5.67±0	5.67±0	144.2±5.59	143.7±5.30
Moderately-clumped	11.3±1.06	15.5±2.19	close	3.72±0.05	3.60±0.07	97.8±3.41	94.4±3.01
			middle	4.55±0.03	4.64±0.11	145.3±41	144.1±1.47
			outside	5.67±0	5.67±0	136.1±2.44	136.3±2.12
Highly-clumped	11.5±0.81	16.3±1.42	close	3.49±0.01	3.80±0.04	84.9±1.64	84.4±2.26
			middle	4.42±0.10	4.53±0.04	94.9±2.06	94.7±1.86
			outside	5.67±0	5.67±0	119.8±7.81	119.4±7.81

Relationship of height, crown spread and light intensity of baobab stands to plant dry of millet with respect to east and west cardinal directions.

The light intensities in both the east (R^2 = 0.2663, P = 0.155) and the west (R^2 = 0.1624, P = 0.283) cardinal points of the three baobab stands had weak positive correlation with the dry weight of millet plants. Also, there was no difference in the dry matter accumulated by millet plants in the subplots closer to the trunks of the three baobab stands with respect to the east (F = 1.27, P = 0.410) and the west (F = 2.02, P = 0.257) cardinal directions. The trend showed that plant dry weight in the inner subplots under the isolated and highly-clumped baobab stands recorded the same values at the corresponding eastern and western flanks of the trees. However, under the moderately-clumped stands, the eastern flanks recorded relatively higher dry weight values of the millet plants than their corresponding western flanks (Table 3). Similarly, there were no differences in the millet plant dry weight in the middle subplots with respect to the east (F = 1.67, P = 0.315) and the west (F = 1.58, P = 0.334) cardinal directions of the various baobab stands. The observable trend however, showed that the dry weight of millet plants in those plots under the isolated and the moderately-clumped stands indicated relatively higher values in the eastern flanks as compared to their corresponding western flanks but this trend was not the same for those plots under the highly-clumped stands (Table 3). Contrarily, there was a significant difference of dry weight accumulated by millet plants in the outer subplots at the western flanks (F = 6.67, P = 0.034) with respect to the three baobab stands. However, there was no difference in the dry matter accumulated in the eastern flanks (F = 3.28, P = 0.117) with respect to the three baobab stands. The results indicated that the dry matter accumulated in the eastern flanks of both the isolated and highly-clumped stands showed relatively higher values as compared to their corresponding western flanks but the dry matter values of the millet plants were the same under moderately-clumped stands (Table 3).

Table 3: Relationship of height, crown spread and light intensity of baobab stands to plant dry weight of millet with respect to east and west cardinal directions.

Baobab-stand type	Mean stands height (m)	Mean stands crown spread(m)	Subplot orientation towards trunk(s)	Light intensity(10^3 lux)		Mean dry matter accumulated by millet (g) at end of growing season	
				East	West	East	West
Isolated stands	14.2±2.20	22.3±2.59	close	3.74±0.09	3.52±0.04	21.7±3.56	21.7±3.66
			middle	4.64±0.12	4.42±0.10	25.6.1±2.71	24.9±2.68
			outside	5.67±0	5.67±0	25.1±1.11	24.2±1.26
Moderately-clumped stands	11.3±1.06	15.5±2.19	close	3.72±0.05	3.60±0.07	18.0±0.59	17.8±0.55
			middle	4.55±0.03	4.64±0.11	27.6±0.45	26.9±0.44
			outside	5.67±0	5.67±0	23.5±1.41	23.0±1.52
Highly-clumped stands	11.5±0.81	16.3±1.42	close	3.49±0.01	3.80±0.04	14.6±0.71	14.6±0.75
			middle	4.42±0.10	4.53±0.04	17.2±1.16	17.0±1.16
			outside	5.67±0	5.67±0	20.2±0.97	19.8±0.84

Relationship of height, crown spread and light intensity of baobab stands to seeds weight of millet with respect to east and west cardinal directions.

The light intensities in both the east (R^2 = 0.0146, P = 0.756) and the west (R^2 = 0.1901, P = 0.241) cardinal points of the three baobab stands had weak positive correlation with the seeds weight of millet plants. There was however, difference in the seeds weight in the inner subplots of the baobab tree trunks at the eastern (F = 8.16, P = 0.033) cardinal point. Contrarily, there was no difference in the seeds weight in the inner subplots at the western (F =0.49, P = 0.748) flanks of the baobab trees. The results showed that the seeds weight of millet plants grown under the various baobab stands in the inner subplots was in the order: isolated stands > highly-clumped stands> moderately-clumped stands in both the eastern and western flanks of the trees (Table 4). Also, there were no differences in seeds weight of millet in the middle subplots in both the east (F = 3.22, P = 0.142) and the west (F = 2.14, P = 0.240) cardinal directions of the stands. Similarly, the seeds weight produced from the outer subplots had no differences with respect to the eastern (F = 2.31, P = 0.193) and the western (F = 1.55, P = 0.312) cardinal directions of the three baobab stands. The observable trend was that the eastern flanks of the isolated and the highly-clumped stands recorded relatively higher values than their corresponding western flanks of the baobab trees (Table 4).

The outer subplots under the moderately-clumped stands, however, did not show any value difference between the east and the west.

Table 4: Relationship of height, crown spread and light intensity of baobab stands to seeds weight of millet with respect to east and west cardinal directions.

Baobab-stand type	Mean stands height (m)	Mean stands crown spread (m)	Subplot orientation towards trunk(s)	Light intensity (10^3 lux)		Weight of 1000 seeds (g) of millet	
				East	West	East	West
Isolated stands	14.2±2.20	22.3±2.59	close	3.74±0.09	3.52±0.04	8.53±0.12	8.59±0.19
			middle	4.64±0.12	4.42±0.10	9.14±0.12	9.14±0.12
			outside	5.67±0	5.67±0	9.14±0.12	9.07±0.08
Moderately-clumped stands	11.3±1.06	15.5±2.19	close	3.72±0.05	3.60±0.07	8.32±0.07	8.31±0.07
			middle	4.55±0.03	4.64±0.11	8.80±0.05	8.76±0.06
			outside	5.67±0	5.67±0	8.83±0.08	8.83±0.08
Highly-clumped stands	11.5±0.81	16.3±1.42	close	3.49±0.01	3.80±0.04	8.49±0.05	8.48±0.05
			middle	4.42±0.10	4.53±0.04	9.02±0.09	9.02±0.09
			outside	5.67±0	5.67±0	8.97±0.11	8.96±011

Relationship of height, crown spread and light intensity of baobab stands to harvest index of millet plants with respect to east and west cardinal directions.

The light intensities in both the east (R^2 = 0.3697, P = 0.083) and the west (R^2 = 0.0484, P = 0.569) cardinal points of the three baobab stands had weak positive correlation with the harvest indices of millet plants. Also, there were no differences among the harvest indices of millet plants grown in the inner subplots in the east (F = 0.26, P = 0.887) and the west (F = 0.43, P = 0.785) cardinal directions. The observable trend showed that the eastern flanks of the isolated baobab stands recorded relatively higher values than its corresponding western flanks while, the opposite trend occurred under highly-clumped stands. However, under the moderately-clumped stands, the two opposite sites recorded the same harvest index values (Table 5). Also, there were no differences in the harvest indices in the middle subplots with respect to the eastern (F = 0.25, P = 0.897) and the western (F = 1.06, P = 0.479) cardinal directions of the stands. The observable trend was that the eastern flanks of the isolated baobab stands recorded relatively higher harvest index values than the corresponding western flanks while the same values were recorded at the moderately-clumped and the highly-clumped stands in both cardinal directions. Also, there were no differences among harvest indices in the outer subplots with respect to the east (F = 0.85, P = 0.521) and the west (F = 1.17, P = 0.407) cardinal directions of the baobab stands.

Table 5: Relationship of height, crown spread and light intensity of baobab stands to harvest index of millet plants with respect to east and west cardinal directions.

Baobab-stand type	Mean stands height (m)	Mean stands crown spread (m)	Subplot orientation towards trunk(s)	Light intensity (10^3lux)		Harvest index (HI)of millet	
				East	West	East	West
Isolated stands	14.2±2.20	22.3±2.59	close	3.74±0.09	3.52±0.04	0.13±0.01	0.12±0.01
			middle	4.64±0.12	4.42±0.10	0.14±0.01	0.13±0.003
			outside	5.67±0	5.67±0	0.13±0.01	0.13±0.003
Moderately-clumped stands	11.3±1.06	15.5±2.19	close	3.72±0.05	3.60±0.07	0.11±0.01	0.11±0.01
			middle	4.55±0.03	4.64±0.11	0.12±0.003	0.12±0.01
			outside	5.67±0	5.67±0	0.13±0.003	0.13±0.01
Highly-clumped stands	11.5±0.81	16.3±1.42	close	3.49±0.01	3.80±0.04	0.11±0.01	0.12±0.01
			middle	4.42±0.10	4.53±0.04	0.12±0.003	0.12±0.01
			outside	5.67±0	5.67±0	0.13±0.003	0.13±0.01

Sorghum production with respect to the cardinal directions of the three baobab stands.

Relationship of height, crown spread and light intensity of baobab stands to leaf area index of sorghum plants with respect to east and west cardinal directions.

The light intensities in both the east (R^2 = 0.0361, P = 0.625) and the west (R^2 = 0.0576, P = 0.534) cardinal points of the three baobab stands had weak positive correlation with the leaf area index of sorghum. There were no differences in the leaf area indices of sorghum plants in the inner subplots in both the east (F = 2.78, P = 0.173) and the west (F = 0.92, P = 0.530) cardinal directions. The observable trend showed that the leaf area index values in the eastern flanks were relatively higher than their corresponding sides at the western flanks under both isolated and the moderately-clumped stands but the reverse trend occurred under the highly-clumped stands. Similarly, there were no differences in the leaf area indices of sorghum in the middle subplots in both the east (F = 0.92, P = 0.530) and the west (F = 0.75, P = 0.606) cardinal directions of the various baobab stands. Also, there were no differences in the leaf area indices of sorghum plants in the outer subplots in the eastern (F = 0.62, P = 0.630) and western (F = 0.88, P = 0.513) flanks of the baobab trees. The observable trend showed that the eastern flanks under the isolated baobab stands recorded relatively lower values as compared to the western flanks while the reverse trend occurred under both moderately-clumped and the highly-clumped stands (Table 6).

Table 6: Relationship of height, crown spread and light intensity of baobab stands to leaf area index of sorghum plants with respect to east and west cardinal directions.

Baobab-stand type	Mean stands height (m)	Mean stands crown spread (m)	Subplot orientation towards trunk(s)	Light intensity (10^3 lux)		Leaf area index of sorghum	
				East	West	East	West
Isolated stands	14.2±2.20	22.3±2.59	close	3.74±0.09	3.52±0.04	2.09±0.06	2.07±0.12
			middle	4.64±0.12	4.42±0.10	2.01±0.05	1.97±0.01
			outside	5.67±0	5.67±0	2.05±0.13	2.17±0.03
Moderately-clumped stands	11.3±1.06	15.5±2.19	close	3.72±0.05	3.60±0.07	1.98±0.01	1.96±0.01
			middle	4.55±0.03	4.64±0.11	2.12±0.10	2.03±0.03
			outside	5.67±0	5.67±0	2.13±0.07	2.07±0.03
Highly-clumped stands	11.5±0.81	16.3±1.42	close	3.49±0.01	3.80±0.04	2.02±0.04	2.06±0.07
			middle	4.42±0.10	4.53±0.04	2.13±0.09	2.07±0.07
			outside	5.67±0	5.67±0	2.17±0.09	2.13±0.03

Relationship of height, crown spread and light intensity of baobab stands to panicle weight of sorghum plants with respect to east and west cardinal directions.

Generally, the light intensities in both the east (R^2 = 0.0066, P = 0.836) and the west (R^2 = 0.0250, P = 0.685) cardinal points of the three baobab stands had weak positive correlation with the panicles weight of sorghum plants. These did not reach significant levels. However, there were differences in the inner subplots with respect to sorghum panicle weight in both the eastern (F = 7.90, P = 0.035) and the western (F = 127.25, P = 0.001) cardinal directions. The results indicated that the eastern sides of both the isolated and moderately-clumped stands recorded higher panicle weights than their respective corresponding western sides but the reverse trend occurred under the highly-clumped baobab stands (Table 7). Contrarily, there was no difference in the middle subplots with respect to the sorghum panicle weight in both the eastern (F = 6.30, P = 0.051) and the western (F = 1.24, P = 0.421) cardinal directions of the tree stands. Also, there was no difference in the sorghum panicle weight in the outer subplots in both the east (F = 3.32, P = 0.114) and the west (F = 4.72, P = 0.064) cardinal directions of the baobab stands. The observable trend indicated that the western flanks of the trees recorded relatively higher panicle weight as compared to their corresponding eastern sides in the three baobab stands (Table 7).

Table 7: Relationship of height, crown spread and light intensity of baobab stands to panicle weight of sorghum plants with respect to east and west cardinal directions.

Baobab-stand type	Mean stands height (m)	Mean stands crown spread (m)	Subplot orientation towards trunk(s)	Light intensity (10^3 lux)		Mean panicle weight (g) of sorghum	
				East	West	East	West
Isolated stands	14.2±2.20	22.3±2.59	close	3.74±0.09	3.52±0.04	23.16±1.32	22.76±0.28
			middle	4.64±0.12	4.42±0.10	24.75±2.02	24.07±1.62
			outside	5.67±0	5.67±0	23.29±0.61	23.57±0.75
Moderately-clumped stands	11.3±1.06	15.5±2.19	close	3.72±0.05	3.60±0.07	22.32±1.22	21.93±1.10
			middle	4.55±0.03	4.64±0.11	22.09±1.47	21.78±1.60
			outside	5.67±0	5.67±0	21.91±1.56	21.96±1.54
Highly-clumped stands	11.5±0.81	16.3±1.42	close	3.49±0.01	3.80±0.04	20.36±0.21	20.44±0.21
			middle	4.42±0.10	4.53±0.04	20.82±0.94	21.59±1.02
			outside	5.67±0	5.67±0	21.34±1.19	21.52±1.17

Relationship of height, crown spread and light intensity of baobab stands to seeds weight of sorghum plants with respect to east and west cardinal directions.

The light intensities in both the east (R^2 = 0.0876, P = 0.439) and the west (R^2 = 0.1568, P = 0.291) cardinal directions of the three baobab stands had weak positive correlation with the seeds weight of sorghum. There was no difference in seeds weight of sorghum plants in the inner subplots in both the eastern (F = 0.72, P = 0.621) and the western (F = 1.11, P = 0.462) cardinal directions of the baobab stands. The observable trend indicated that the eastern side of the isolated baobab stands produced relatively higher seed weight values than its corresponding western side while this trend is reversed under both moderately-clumped and the highly-clumped stands respectively. However, there were differences in the seeds weight in the middle subplots in the eastern (F = 26.99, P = 0.004) cardinal direction but the seeds weight in the western (F = 1.23, P = 0.424) flanks of the stands showed no differences at all. The results thus indicated that the seeds weight in the eastern flanks of the isolated baobab stands was relatively lower than the corresponding sites at the western flanks while this trend reversed under both moderately-clumped and the highly-clumped stands (Table 8). The outer subplots also showed no differences in the seeds weight in both the east (F = 0.37, P = 0.778) and the west (F = 0.95, P = 0.484) cardinal directions of the baobab tree trunks. The observable trend showed that the eastern flanks of both the isolated and the highly-clumped stands recorded relatively lower seeds weight as compared to their corresponding western sides but the trend reversed under the moderately-clumped stands (Table 8).

Table 8: Relationship of height, crown spread and light intensity of baobab stands to seeds weight of sorghum plants with respect to east and west cardinal directions.

Baobab-stand type	Mean stands height (m)	Mean stands crown spread (m)	Subplot orientation towards trunk(s)	Light intensity (10^3 lux)		Weight of 1000 seeds (g) of sorghum	
				East	West	East	West
Isolated stands	14.2±2.20	22.3±2.59	close	3.74±0.09	3.52±0.04	18.92±0.08	19.44±0.26
			middle	4.64±0.12	4.42±0.10	18.65±0.23	19.22±0.14
			outside	5.67±0	5.67±0	18.75±0.20	19.08±0.003
Moderately-clumped stands	11.3±1.06	15.5±2.19	close	3.72±0.05	3.60±0.07	20.58±0.27	19.60±0.12
			middle	4.55±0.03	4.64±0.11	19.98±0.06	19.58±0.26
			outside	5.67±0	5.67±0	19.12±0.08	19.10±0.03
Highly-clumped stands	11.5±0.81	16.3±1.42	close	3.49±0.01	3.80±0.04	21.06±0.06	20.92±0.23
			middle	4.42±0.10	4.53±0.04	21.07±0.02	20.98±0.04
			outside	5.67±0	5.67±0	20.83±0.23	20.84±0.10

Relationship of height, crown spread and light intensity of baobab stands to grain yield of sorghum plants with respect to east and west cardinal directions.

The light intensities in both the east (R^2 = 0.6352, P = 0.010) and the west (R^2 = 0.6561, P = 0.008) cardinal points of the three baobab stands were significantly and positively correlated with sorghum grain yield. There was also no difference in the seed yield by sorghum plants in the inner subplots in both the eastern (F = 0.35, P = 0.836) and the western (F = 0.30, P = 0.865) cardinal directions of the various stands. The observable trend showed that the eastern side of the isolated and the moderately- clumped baobab stands produced relatively higher yield values than their corresponding western sides while this trend is reversed under the highly-clumped stands. Similarly, there were no differences in seed yield of sorghum in the middle subplots in both the eastern (F = 0.45, P = 0.769) and the western (F = 0.58, P = 0.696) cardinal directions of the three baobab stands. Also, there was no difference in seed yield of sorghum in the outer subplots in both the eastern (F = 4.32, P = 0.074) and the western (F = 0.38, P = 0.773) cardinal directions of the three baobab stands. The observable trend however, showed that the western side of the isolated stands produced relatively higher yield values than the eastern side but under the moderately- clumped and the highly-clumped stands, the opposite trend occurred (Table 9).

Table 9: Relationship of height, crown spread and light intensity of baobab stands to grain yield of sorghum plants with respect to east and west cardinal directions.

Baobab-stand type	Mean stands height (m)	Mean stands crown spread (m)	Subplot orientation towards trunk(s)	Light intensity (10^3 lux)		Grain yield (kg/ha) of sorghum	
				East	West	East	West
Isolated stands	14.2±2.20	22.3±2.59	close	3.74±0.09	3.52±0.04	467.0±49.2	461.7±41.5
			middle	4.64±0.12	4.42±0.10	721.3±18.6	720.7.±10.0
			outside	5.67±0	5.67±0	691.7±34.9	715.0±9.9
Moderately-clumped stands	11.3±1.06	15.5±2.19	close	3.72±0.05	3.60±0.07	406.0±7.2	400.0±8.4
			middle	4.55±0.03	4.64±0.11	699.7±8.0	685.0±18.9
			outside	5.67±0	5.67±0	685.3±13.6	683.7±18.1
Highly-clumped stands	11.5±0.81	16.3±1.42	close	3.49±0.01	3.80±0.04	445.3±25.9	447.3±32.0
			middle	4.42±0.10	4.53±0.04	707.3±11.9	708.0±16.4
			outside	5.67±0	5.67±0	719.3±15.7	712.3±29.3

Discussion

Millet production with respect to the cardinal directions of the three baobab stands.

In general, plant dry weight, seed dry weight and harvest index of millet had weak correlation with baobab height, canopy spread and light intensity received in the subplots. Light however, is known to enhance crop productivity in general especially cereals like millet that undergoes C_4 photosynthesis. Since weak correlation exists among the various baobab stands parameters and light intensity in the subplots with respect to the crops productivity, it can be suggested that the influence of light may be counteracted by the other factors such as the tree height and the crown diameter in the multiple regression which neutralized the impact of light as a factor. In spite of the fact that these aggregate or multiple factors have weak correlation with millet productivity, an increasing trend of the yield parameters were observed from the middle subplots. Similarly, in a study using concentric zones designated as zones A, B and C around the baobab trees, Sanou *et al.* (2011) reported yields of millet for zones A, B and C as 648.9 ± 113 kg/ha, 908.8 ± 162.19 kg/ha and 860.7 ± 89.25 kg/ha respectively. Thus, indicating higher yield values in the middle concentric zones than values obtained in the other zones. This implies the current findings agreed with the earlier work by Sanou *et al.* (2011) and this could be due to the fact that trees generally, and baobabs in particular, increase nutrients under their canopies in addition to amelioration of the microclimate beneath the canopies which culminated in higher yields. Indeed, several tree-crop studies have reported that tree shading is not generally accompanied by crop yield reductions, provided below-ground competition is minimized (Singh *et al.,* 1989; Lawson and King, 1990; Daniel *et al.,* 1991). Thus, the higher yields obtained in the middle subplots within the canopy- influenced region could also be attributed to the fact that baobab tree roots may not compete with cereal food crops for growth resources despite its general superficial nature. On the contrary, millet is a C_4 plant and therefore sensitive to tree shade and many studies reported decrease in yield of the millet plants cultivated under tree crowns as compared to those in the open (Maiga, 1987; Kessler, 1992; Boffa, 1999; Bayala *et al.,* 2002).

The harvest index of millet in this study ranged from (0.11 ± 0.01 - 0.14 ± 0.01) at the eastern sides of the various baobab stands to (0.11 ± 0.01 – 0.13 ± 0.01) at the western sides. Sanou *et al.* (2011) also reported harvest index of millet under baobab stands in Burkina Faso as (0.10 ± 0.01). The values obtained in the current study are relatively higher than the one obtained in the earlier study and could be attributable to differences in climatic and other edaphic factors at the two study sites. In general, climatic and other factors that enhance plant growth and development are relatively better in northern Ghana (particularly the study area with Sudan type of vegetation) as compared to those in Burkina Faso with Sahelian type of vegetation. This might give rise to better harvest index of millet produced under northern Ghanaian conditions than those produced under Burkina Faso conditions. However, Andrews and Kumar, (2006) obtained better harvest index (0.15-0.20) of millet than what was obtained in the current study and this might also be attributed to the better soil fertility at their site as compared to current study site.

Sorghum production with respect to the cardinal directions of the three baobab stands.

The yield of sorghum in this study on the eastern flanks of the baobab stands ranged from 406 ± 7.2 kg/ha to 721.3 ± 18.6 kg/ha whilst the western flanks yielded from 400 ± 8.4 kg/ha to 720.7 ± 10 kg/ha in millet intercrop. Rao (1981) reported that sorghum intercropped with pigeon pea, soybean and groundnut obtained yields of 32.4 ± 1.4 kg/ha, 32.2 ± 1.8 kg/ha and 32.1 ± 1.8 kg/ha respectively as compared with sole cropping of sorghum with yields of 35.8 ± 1.9 kg/ha, 33.0 ± 1.9 kg/ha and 33.8 ± 2.7 kg/ha respectively. Also, in a four-year study of sorghum by Rao (1981), he reported average yields of the plants as 27.40 kg/ha, 27.30 kg/ha, 22.80 kg/ha and 22.70 kg/ha. The results obtained in this study thus indicated higher yields of sorghum as compared with the previous study and yields of food crops generally depend on several factors. For instance, soil fertility differences at the study sites could result in variations in yields. Also, climatic regimes, for example, rainfall, temperature and humidity differences could bring about variations in yields. Furthermore, variety differences of the species in addition to agronomic management practices could all account for the variations in yield among the current and previous studies.

In this study there were generally lower sorghum yield values obtained in the subplots closer to the baobab trunks in the three baobab stands in both the east and the west cardinal points as compared to the middle and the outer subplots. However, the middle and outer subplots did not give clear-cut differences in yield values. But according to Peiler (1994), sorghum grain yield increased significantly with respect to the growing distance from both *Vitelllaria paradoxa* and *Parkia biglobosa* trunks to the open fields. Yields in the inner plots (at a distance of between 0-1 m) from the *Vitelllaria paradoxa* tree trunks were 41 % - 45 % lower than those in the control plots. The grain yields according to four different distances to the trunks, i.e. 0-1 m, 1-2 m, 2-3 m and 3-4 m, were 432 kg/ha, 565.2 kg/ha, 620.8 kg/ha and 691.7 kg/ha, respectively under *Vitelllaria paradoxa* trees. Thus, the lower yield values obtained in subplots closer to the trunks and for that matter in a more intense shade regime as compared with the other subplots could be attributed to the influence of the canopy's shade. Sorghum is known to be a C_4 plant and does not undergo any serious photorespiration and hence dislike intense shade because its photosynthetic capacity rate is in excess of 200 mg CO_2 cm^{-2} S^{-1} (Eastin, 1968; Rawson *et al.* 1978). Fischer and Wilson (1976) also reported an average rate of 122 mg CO_2 cm^{-2} S^{-1} for sorghum leaves in plant stands best illuminated in the canopy.

One thousand seed weight of sorghum in the eastern flanks of the various baobab stands ranged from 18.65 ± 0.23 g to 21.07 ± 0.02 g while on the western flanks of the stands the value ranged from 19.08 ± 003 g to 20.98 ± 0.04 g. Mercer-Quarshie (1972) reported thousand seed weight of sorghum at two different sites in northern Ghana, thus Nyankpala and Damongo as 25.1 g and 17.8 g respectively. Thus, the results obtained in the present study did not agree with the earlier study and this might probably arise due to differences in site conditions especially with respect to soil fertility. Also, variations in the weight of the seeds might be dependent on the varieties used in both studies. Mercer-Quarshie (1972) found no correlation between 1000-seed weight and grain yield of sorghum plants. Although the present study used multiple factors against grain yield of sorghum, there was no correlation in those factors and the grain yield and thus confirms the earlier study by Mercer-Quarshie (1972).

The weight of sorghum panicles on the eastern flanks of the various baobab stands ranged from 20.36 ± 0.21 g to 24.75 ± 2.02 g, whilst on the western flanks the panicles weight ranged from 20.44 ± 0.21 g to 24.07 ± 1.62 g. Although there was weak correlation between the panicle weight and baobab stands' height, crown spread and light intensity with respect to both cardinal directions, these values seem quite optimal for the species. But many researchers reported reduction in panicle weight of sorghum under both *Vitelllaria paradoxa* and *Parkia biglobosa* trees (Maiga, 1987; Kessler, 1992; Kater *et al.,* 1992; Peiler, 1994).

CONCLUSION

The biological productivity of the cereals grown in general did not correlate well with the three different baobab stands' height, crown spread and light intensities received in the plots with respect to the east and west cardinal directions. The generally observed trend was that the millet plants' height in the eastern flanks produced slightly higher values than the corresponding western flanks especially in the subplots at the isolated and the moderately-clumped stands. Seed dry weight of millet plants grown under the various baobab stands in the inner subplots was in the order: isolated stands > highly-clumped stands> moderately-clumped stands in both the eastern and western flanks of the trees. In addition, the eastern flanks of the isolated baobab stands recorded relatively higher harvest index values of millet than its corresponding western flanks whilst the opposite trend occurred under highly-clumped stands.

The leaf area index values of sorghum in the eastern flanks were relatively higher than their corresponding sides at the western flanks. Furthermore, the observed trend was that the eastern side of the isolated and the moderately- clumped baobab stands produced relatively higher sorghum yield values than their corresponding western sides.

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