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Solar Radiation Interception, Dry Matter Production and Yield among Different Plant Densities of *Arachis spp*. in Ibadan, Nigeria

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Abstract

The production of grain legumes is becoming a popular practice in the humid south western Nigeria. Apart from the decreasing trends observed in rainfall amount and duration as a result of climate change, solar radiation interception also constitutes a limitation to crop production because of persistent cloud cover. A trial was conducted at the University of Ibadan experimental site to determine the effect of different plant densities of *Arachis spp*. on solar radiation interception, dry matter production and yield in Ibadan, Nigeria with the aim of ascertaining the best practice for groundnut production in the zone. The treatments were three plant spacings (60 cm × 20 cm, 75 cm × 20 cm and 75 cm × 40 cm), and three *Arachis* varieties (Samnut 10, Samnut 21 and Pintoi) arranged in a split plot, randomized complete block design with *Arach*is varieties as the main plot while plant densities formed the subplot and replicated three times. Growth parameters (number of leaves, dry leaf weight and dry stem weight) were measured at two weeks interval while yield parameters (number of pods, dry pod weight, dry seed weight and total dry matter) were determined at harvest. Intercepted radiation by plants (PAR) was also taken along with the growth parameters. The highest light interception from 42 - 105 days after planting (DAP) among the *Arachis spp*. was recorded by Samnut 10, while at 42 - 87 DAP, plant density of 75 cm × 20 cm had the highest light interception. Dry matter production increased with light interception and was highest at 105 DAP when light interception was between 55% and 60% for all *Arachis* varieties and all plant densities. In terms of pod weight and grain yield, Samnut 10 performed better than Samnut 21 and also recorded the highest Radiation Use Efficiency (RUE) for pod, seed and total dry matter. However, *Arachis pintoi*, a sterile and forage plant with slower growth rate served as a cover crop

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capable of replenishing soil nutrients and physical properties.

Keywords

Radiation Use Efficiency, *Arachis spp.*, Plant Densities, Solar Radiation Interception

1. Introduction

Groundnut is a major crop grown in the arid and semi arid zones of Nigeria. It is either grown for its nut, oil or its vegetative residue (haulms). Groundnut production is influenced by several environmental factors, especially moisture stress and temperature as reported by several authors [1]-[4]. It is an important oil seed crop as its seed contains 44% - 56 % oil and 22% - 30 % protein on a dry seed basis [5]. The *Arachis pintoi* which is also a leguminous plant originally from Brazil is a multiple-use, prostrate, stoloniferous, perennial tropical legume [6], cultivated as a cover crop in orchards [7]. It forms a dense mat of rooted stolons that reduces weed invasion, controls erosion [8] and improves soil fertility through nitrogen fixation [9]. Unlike many other tropical legumes, *A. pintoi* is persistent and tolerant of acidic conditions, shading, drought and heavy grazing [6] [10].

Radiation Use Efficiency (RUE, $g \cdot MJ^{-1}$) is defined as the ratio of accumulated crop mass (*i.e.* dry matter) to cumulative intercepted solar radiation. It is a key factor in the determination of the photosynthetic performance of plants growing in any environment. Leaf area development is critical for maximum interception of solar radiation and the achievement of high crop productivity. Under well-watered conditions and ample nutrition, in the absence of pest and diseases, maize yield had been shown to be closely related to the amount of radiation intercepted [11] [12].

Soil water and solar energy are the basic atmospheric resources required for crop production. Plants can maximize canopy light interception by increasing both leaf surface area and the efficiency of light interception for each unit of leaf area [13]-[15]. Interception efficiency of both direct and diffuse irradiance increases on leaves with horizontal laminae (planophyllous leaf architecture) [16] [17]. In groundnut stands, interception of radiation and the efficiency of its conversion to stand biomass (Radiation Use Efficiency) decrease with increasing saturation deficit in the soil [18], and also in cells and tissues [19]. Considering the several factors that contribute to the success of *Arachis spp.*, management decisions regarding variety selection and plant spacing can have strong effects on the development and yield of the crop. The objectives of this study are therefore to determine the effects of different plant spacing on the growth, development and yield of different varieties of *Arachis* and relate the amount of solar radiation intercepted and used on dry matter production and yield in Ibadan, South West Nigeria.

2. Materials and Methods

The experimental design was a split plot in randomized complete block design. Three varieties of *Arachis* (Samnut 10, Samnut 21 and Pintoi) were the main-plot treatments while three spacings (75 cm × 40 cm, 75 cm × 20 cm and 60 cm × 20 cm) constituted the sub-plots. There were three replicates. The total land area used for the experiment was (48 m × 23 m). Each block had nine plots with a dimension of 5 m × 4 m, intra boundary spacing of 1 m, inter boundary spacing of 2 m and guard boundary of 2 m, consisting of 27 plots in all. Groundnut was sown at one seed per hole (seed viability is 100 percent) on ridges on August 01, 2011 while pintoi was planted vegetatively using stem cuttings on ridges on August 19, 2011 after the emergence of groundnut.

Soil samples at the depth of 0 - 15 cm were taken randomly on each plot before planting. The soil samples were bulked, air dried and sieved through a 2 mm and 0.5 mm sieves and analysed for pH (H_2O and KCl), Organic carbon by Walkey Black method, exchangeable base (Potassium, Sodium, Magnesium and Calcium) by flame photometer and Atomic Absorption Spectrophotometer, available phosphorous by Bray P-1 method, total nitrogen by Micro-Kjeldhal method, and extractable micronutrients (Iron, copper, Manganese and zinc) by Atomic Absorption Spectrophotometer.

Undisturbed soil samples at the depth of 0 - 15 cm were also taken on the plot with the aid of a core sampler to determine bulk density and saturated hydraulic conductivity using the constant head method. The particle size analysis was also carried out by the hydrometer method.

Plant Sampling and Analysis

Plant sample collection commenced at about 6 weeks after planting (WAP) and was done at 2 weeks interval. On each sampling occasion, one plant stand was randomly taken per plot outside the designated final harvest area. The selected plant stand was carefully uprooted, separated into leaves, stem and pods and oven dried at 70˚C to a constant weight to determine component dry weights. The leaf area per plant was determined from sampled area using a CI-202 Area Meter (CI-202, CID, Inc., USA) and used for calculating the leaf area index (LAI) per plant stand. The total numbers of leaves per plant stand were also recorded. Other data collected include daily records of solar radiation, daily incident photosynthetic active radiation (PAR), crop phenology, maximum and minimum temperature and daily rainfall.

Photosynthetic Active Radiation (PAR) was measured from six weeks after planting using 0.8-m-long Sunfleck Ceptometer (Decagon Device Inc., Pullman, WA Model #SF-80), and six readings were taken at 2 weeks interval.

Incoming PAR (I) was measured 1m above the canopy. Three transmitted measurements (T) were taken with the ceptometer positioned on ridge, below plant between two ridges and across two ridges in each plot within the final harvest area. The ceptometer was inverted 1m above the plant canopy to measure the reflected PAR (R). Daily solar radiation (SR) data was also collected at the International Institute of Tropical Agriculture (IITA) Ibadan meteorological weather station.

Radiation measurements were taken at solar noon under clear skies above and below the canopy to comprise a measurement pair of which the ratio gives the percentage PAR reaching the ground, from which the interception was calculated. The measurement sites were tagged plants within the designated final harvest area in each plot, which were taken on three plots to give a replicated treatment. The average of three transmitted PAR measurements with the ceptometer placed between, within and diagonally below the canopy of each plot was used to obtain periodic transmitted PAR measurement. The ceptometer was also inverted 1.0 m above the canopy to measure reflected PAR from the canopy-soil scene. Precautions taken and difficulties met with such equipment were as listed by Mungai *et al*. [20].

At Ibadan, the coefficient of 0.50 was used to estimate PAR from measured net radiation values recorded at the IITA weather station [21]. Daily radiation absorbed by the canopy was then determined from the calculated extinction coefficient, incoming and reflected PAR, and interpolated leaf area index estimated between radiation measurements. Accumulated dry matter (DM) is a function of accumulated daily absorbed PAR and Radiation Use Efficiency (RUE). RUE was calculated by regressing dry matter accumulation against intercepted PAR [22].

$$\mathrm{DM} = \mathrm{RUE} \times \mathrm{PAR}$$

Therefore: $\mathrm{RUE} = \mathrm{DM}/\mathrm{PAR}$

Leaf area index was measured alongside with the growth analysis every two weeks starting from the sixth week of planting to the fourteenth week.

All data collected were subjected to analysis of variance (ANOVA). Least significant difference (LSD) was used for mean separation at 5% level of significance.

3. Results and Discussion

3.1. Soil and Weather Situations

The values of the physical and chemical properties of the soil used for experiment are shown in **Table 1**. The soil belongs to the textural class of loamy sand with 838 g·kg^{-1} s and, 79 g·kg^{-1} silt and 83 g·kg^{-1} clay, with good drainage which is ideal for groundnut production and harvesting [23]. The soil chemical analysis result gave total nitrogen of 1.7 g·kg^{-1} which is medium, soil pH (H_2O) of 6.0 (medium acid), organic carbon of 16.3 g·kg^{-1} is high while available phosphorus of 34 mg·kg^{-1} is also high. Soil potassium is 0.3 cmol·kg^{-1} in the medium availability range and calcium of 33.8 cmol·kg^{-1} which is high [24]. The values of soil nutrients are in the available forms to sustain a good crop of groundnut without additional nutrient supply to the soil [23], hence there was no soil nutrient amendment application to the trial.

The weather condition during the cropping season of 2011 is shown in **Table 2**. The range of the mean monthly maximum air temperature between August and November were ideal for the growth, development, maturity and harvest of groundnut at Ibadan [25]. Warm night temperature range of 21˚C to 24˚C with adequate moisture observed during the growing season ensured good growth and development of groundnut (**Table 2**).

Table 1. Physical and chemical properties of soil at experimental site.

Parameter	Value
pH (H_2O) 1:1	6.0
Total Nitrogen ($g \cdot kg^{-1}$)	1.7
Organic Carbon ($g \cdot kg^{-1}$)	16.3
Available Phosphorus ($mg \cdot kg^{-1}$)	34
Extractable Micronutrients ($mg \cdot kg^{-1}$)	
Fe	165
Mn	354
Zn	14
Cu	6
Exchangeable bases ($cmol \cdot kg^{-1}$)	
K	0.3
Na	0.6
Ca	33.8
Mg	2.8
Particle Size Distribution ($g \cdot kg^{-1}$)	
Sand	838
Silt	79
Clay	83
Textural Class (USDA)	Loamy Sand
Bulk Density ($Mg \cdot m^{-3}$)	1.36
Saturated Hydraulic Conductivity ($cm \cdot sec^{-1}$)	4.72×10^{-3}

Table 2. Monthly mean values of solar radiation, maximum and minimum air temperatures, monthly total rainfall, and rainfall days for the year 2011.

Month	Radiation ($MJ \cdot m^{-2} \cdot day^{-1}$)	Maximum Temperature (˚C)	Minimum Temperature (˚C)	Total Rainfall (mm)	Rainfall Days
January	5.2	32.9	19.4	0.0	0
February	6.8	33.7	22.9	134.6	6
March	6.3	33.8	23.7	72.3	5
April	3.9	32.8	23.1	103.0	6
May	3.9	32.3	22.8	146.1	14
June	3.1	30.5	22.5	224.4	18
July	3.2	28.1	21.8	156.4	22
August	2.4	27.8	21.1	314.9	16
September	8.6	29.6	22.2	280.9	14
October	6.9	30.0	21.7	262.4	21
November	10.7	32.4	23.6	8.0	2
December	16.1	33.5	19.7	0.0	0
Total				1703.3	124

Source: International institute of tropical agriculture (IITA), (2011).

Total energy (Solar radiation) intercepted during the season in Ibadan was 77.1 MJ·m^{-2}·day^{-1} as shown in **Table 2**. The average solar radiation was 6.43 MJ·m^{-2}·day^{-1} with 16.1 and 2.4 MJ·m^{-2}·day^{-1} as the highest and lowest recorded values respectively. Solar radiation was very low within the month of August when planting was done but later rose steadily until it reached its highest value (16.1 MJ·m^{-2}·day^{-1}) in December. The occurrence of heavy rainfall and persistent cloud cover in August would have been responsible for the observed mean low solar radiation value (2.4 MJ·m^{-2}·day^{-1}). Incident solar radiation was generally lower than required by groundnut in Ibadan during the cropping season as compared to the less humid northern Nigeria (>16.1 MJ·m^{-2}·day^{-1}) where groundnut has shown better adaptation and is grown extensively [26].

3.2. Light Interception and Dry Matter Production

The trend of light interception for the three *Arachis* varieties used for the experiment is shown in **Figure 1**. At 42 DAP, Samnut 10 had the highest percentage light interception, followed by Samnut 21, and least by Pintoi which is a forage plant that establishes slowly and intercepts solar radiation at a lower rate when compared to the other *Arachis species* [27]. However the highest percentage light interception from 70 - 105 DAP indicated that Samnut 10 recorded the highest percentage light interception, followed by Samnut 21, and least by Pintoi (**Figure 1**). The trend of Total dry matter production by the *Arachis spp* was also a function of total intercepted radiation [28], which determined their capacity to store photosynthates for development. Samnut 10, showed a greater tendency of producing more vegetative parts than the other *Arachis* varieties (Samnut 21 and Pintoi).

The trend of light interception for the three plant densities is shown in **Figure 2**. At 42 DAP, plant density of 75 cm × 20 cm had the highest percentage light interception, followed by 60 cm × 20 cm and least by the widest spacing of 75 cm × 40 cm. However, at 56 DAP, plant density of 75 cm × 40 cm had the highest percentage of light interception from early cover spread, closely followed by 75 cm × 20 cm, and least by 60 cm × 20 cm. The highest percentage light interception from 70 - 87 DAP showed that plant density of 75 cm × 20 cm recorded the highest light interception, and it was significantly higher than 75 cm × 40 cm and 60 cm × 20 cm at 70 DAP. Also at 105 DAP, plant density of 75 cm × 40 cm had the highest percentage light interception, followed by 60 cm × 20 cm, and least by 75 cm × 20 cm. The population density had a moderate effect on the conversion of intercepted radiation to dry matter, but the influence on production seem to be mainly through leaf area index [29].

The interactive effects between three varieties and three plant densities on light interception (**Figure 3**) showed that Samnut 10 and Samnut 21 were not different from each other but were both significantly higher than Pintoi for the plant density of 60 cm × 20 cm at 70 DAP. However, for the plant density of 75 cm × 20 cm, Samnut 10 was significantly higher in intercepted radiation than Samnut 21 and Pintoi, while for the plant spacing of 75 cm × 40 cm, the three *Arachis* varieties showed no difference. The Samnut 10, which is late maturing showed a better adaptation to the moist humid zone of western Nigeria with higher light interception capability at relatively wide spacing to produce the highest dry matter among the three *Arachis spp.* [21].

The trend of dry matter production for *Arachis* varieties (**Figure 4**) indicated the highest total dry matter production values from 42 - 105 DAP by Samnut 10, followed by Samnut 21, and both groundnut varieties were significantly higher than Pintoi. Dry matter production generally increased with percentage light interception and was highest at 105 DAP when the *Arachis spp.* were at maturity [27].

The effect of planting density on trend of dry matter accumulation is shown in **Figure 5**. At 42 and 56 DAP, plant density of 60 cm × 20 cm was significantly higher than 75 cm × 20 cm and 75 cm × 40 cm, while 75 cm × 20 cm was also significantly higher than 75 cm × 40 cm. Plant density of 60 cm × 20 cm was not different from 75 cm × 20 cm but was significantly higher than 75 cm × 40 cm at 70 and 87 DAP. However, at 105 DAP, plant density of 60 cm × 20 cm was different from 75 cm × 20 cm and 75 cm × 40 cm. Dry matter production for plant densities also increased with percentage light interception and was highest at 105 DAP. Although incident incoming solar radiation values were generally low (**Table 1**), the trend of dry matter accumulation over time was with increasing interception of solar radiation.

The trend of LAI for *Arachis* varieties is shown in **Figure 6**. The two groundnut varieties (Samnut 10 and Samnut 21) had similar leaf area indices and were significantly higher than Pintoi throughout the duration of crop life cycle. However, the trend of LAI for plant densities (**Figure 7**) was highest at 42 and 56 DAP for the plant density of 60 cm × 20 cm, closely followed by 75 cm × 20 cm; while both were significantly higher than was observed for 75 cm × 40 cm spacing. At plant physiological maturity (105 DAP), plant densities of 60 cm × 20 cm and 75 cm × 20 cm were significantly higher in LAI than 75 cm × 40 cm spacing.

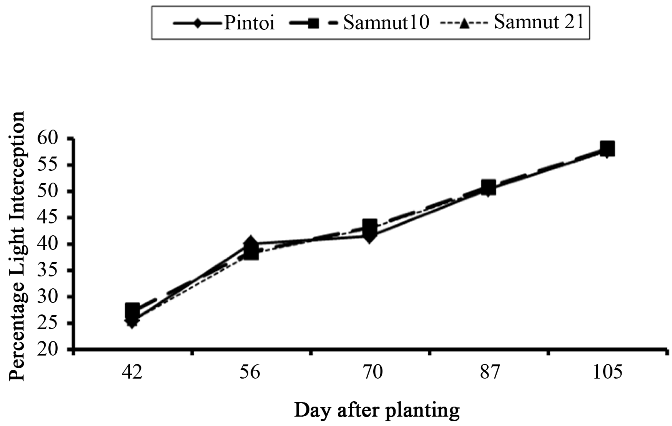

Figure 1. Trend of light interception for the three *Arachis* varieties (Pintoi, Samnut 10 and Samnut 21) during 2011 rainy season at Ibadan.

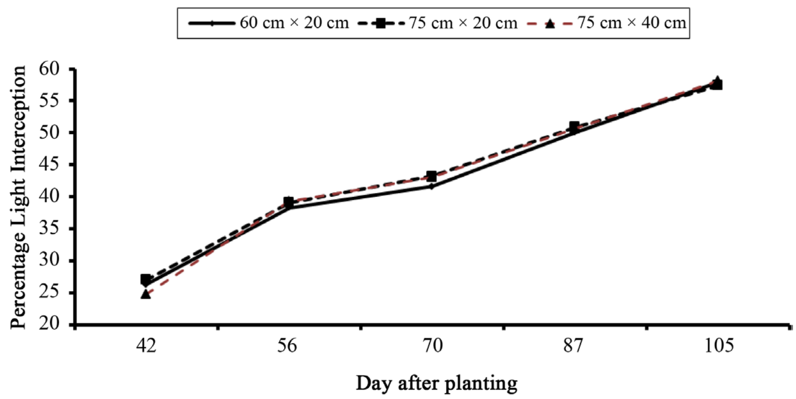

Figure 2. Trend of light interception for the three plant spacings (60 cm × 20 cm, 75 cm × 20 cm, 75 cm × 40 cm) of *Arachis* varieties during 2011 rainy season in Ibadan.

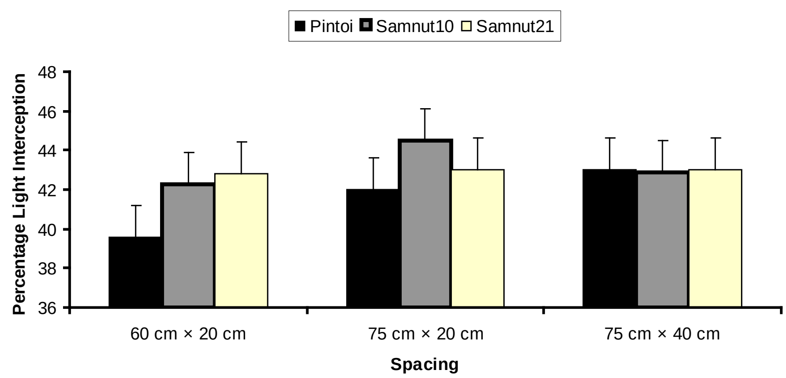

Figure 3. Variety × Spacing interaction for percentage light interception at 70 days after planting during 2011 rainy season. Extended vertical lines on bars represent LSD ≤ 0.05.

The interactive effects of variety and spacing on LAI at 56 DAP showed that Samnut 10 and Samnut 21 were significantly higher than Pintoi for the three plant densities (60 cm × 20 cm, 75 cm × 20, 75 cm × 40 cm) (**Figure 8**). Although the production of grain is more important that total dry matter from economic point of view, grain yield is always related to dry matter production over time. The generally low seasonal values of LAI, low dry matter production and pod yield s are expected from the *Arachis spp* which are C3 legume plants. These are

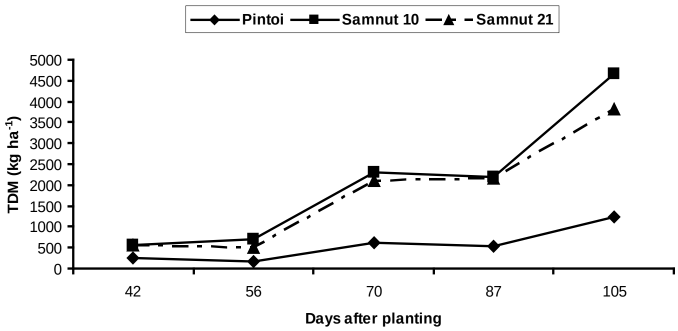

Figure 4. Trend of Total Dry Matter (TDM) accumulation (kg·ha^{-1}) for *Arachis* varieties during 2011 rainy season.

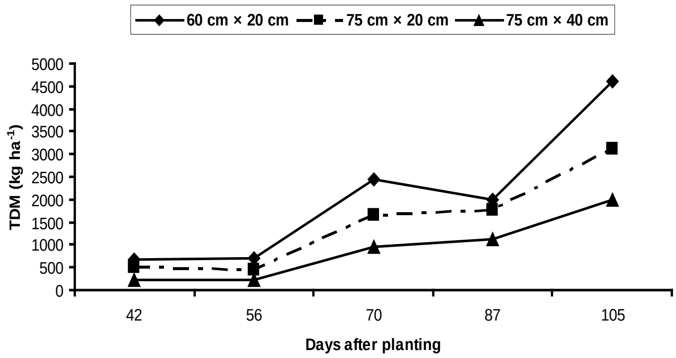

Figure 5. Trend of Total Dry Matter (TDM) accumulation (kg·ha^{-1}) for plant spacings during 2011 reason season.

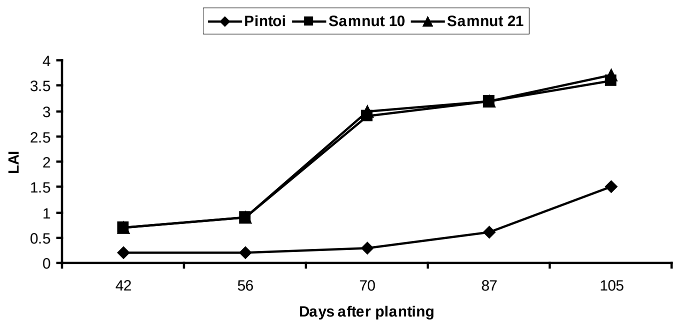

Figure 6. Trend of Leaf Area Index (LAI) for *Arachis* varieties during 2011 rainy season.

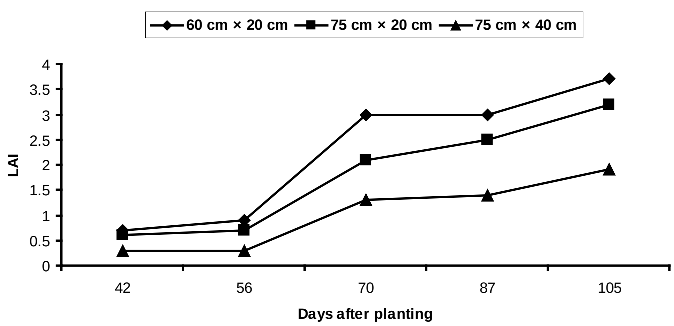

Figure 7. Trend of Leaf Area Index (LAI) for plant density during 2011 reason season.

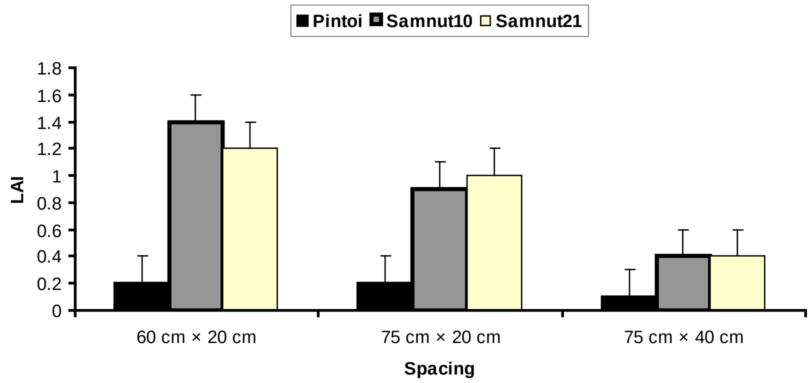

Figure 8. Variety × Spacing interaction for LAI at 56 days after planting during 2011 rainy season. Extended vertical lines on bars represent LSD ≤ 0.05.

justified with the low levels of incident radiation from excessive cloud cover in the humid environment of Ibadan and low levels of radiation intercepted during the cropping season [30] [31].

3.3. *Arachis* Yield Parameters, Yield and RUE

Comparison of means of yield parameters and yield are shown in **Table 3**. For the *Arachis* varieties used for the experiment, significant differences were observed for number of plants per metre square, leaf number, number of pods per plant, pod weight and haulm weight. However, the different plant densities did not have effect on yield and yield parameters of the groundnut varieties (except for the number of plants per metre square). Among the three plant spacings, 60 cm × 20 cm was significantly higher than 75 cm × 20 cm and 75 cm × 40 cm at ($P < 0.05$) for number of plants per metre square, while for number of leaves, pods per plant, pod weight, grain weight, haulm weight and harvest index, no difference was observed.

The Radiation Use Efficiency (RUE) as the slope of the regression for dry weight ($g \cdot m^{-2}/kg \cdot ha^{-1}$) and a function of the cumulative interception of stand biomass against cumulative interception absorbed by the stand are shown in **Table 4**. The higher amount of light intercepted corresponded to a higher tendency of the *Arachis* varieties to store up photosynthesis [32]. Hence Samnut 10 which had the highest percentage light interception stored more photosynthates as indicated by the highest TDM produced [33]-[35].

Table 3. Yield and yield parameters of *Arachis spp*. as affected by plant density during 2011 growing season.

Variables	Plants/m^2	Number of Leaves	Pods/Plant	Pod Weight (kg/ha)	Grain Weight (kg/ha)	Haulm Weight (kg/ha)	Harvest Index	Threshing Percentage
Variety								
Pintoi	4	486	-	-	-	373	-	-
Samnut 10	11	706	508	1124	255	1367	0.17	22.3
Samnut 21	5	964	315	686	188	1669	0.16	30.5
LSD	2.04	208	119.2	300.2	81	315.4	0.03	9.4
F. Prob.	***	**	**	**	ns	***	ns	ns
Spacing								
60 cm × 20 cm	9	653	514	1064	243	1074	0.17	24.6
75 cm × 20 cm	6	695	384	776.4	198	976	0.18	26.8
75 cm × 40 cm	5	808	338	813.7	223	1359	0.15	27.8
LSD	2.04	208.2	146.0	367.7	99.3	315.4	0.04	11.5
F. prob	**	ns	ns	ns	ns	ns	ns	ns

***Significant at $P < 0.001$, **significant at $P < 0.01$, ns: not significant at $P < 0.05$.

Table 4. Radiation Use Efficiency (RUE) of *Arachis* varieties grown at different densities in Ibadan in 2011.

	Arachis Varieties			
RUE (kg·MJ^{-1})	Pintoi	Samnut 10	Samnut 21	LSD
Pod	-	3.8**	2.3**	1.0
Seed	-	2.2**	1.3**	0.6
Total Dry Matter (TDM)	0.8***	4.8***	4.2***	1.2
	Plant Spacing			
	60 cm × 20 cm	75 cm × 20 cm	75 cm × 40 cm	
Pod	2.4	1.9	1.8	ns
Seed	1.3	1.1	1.0	ns
Total Dry Matter (TDM)	3.4	2.9	3.5	ns

***Significant at $P < 0.001$, **Significant at $P = 0.01$, ns: not significant at $P < 0.05$; Sterile plant (pod not produced).

Samnut 10 recorded the highest RUE value for pod and seed, followed by Samnut 21. However, the Pintoi variety used is sterile and did not produce pods or seeds. Samnut 10 also recorded the highest RUE value for total dry matter (TDM), followed by Samnut 21, and least by Pintoi.

4. Conclusions

The results obtained showed that no significant difference was found among the three plant densities used for the experiment with respect to yield.

Higher solar radiation intercepted increased Radiation Use Efficiency (RUE), dry matter production as well as yield among the different varieties of *Arachis* planted and the plant densities used. However, Samnut 10 recorded the highest RUE, dry matter as well as yield.

It can be concluded that out of the two groundnut varieties (Samnut 10 and Samnut 21) used for this experiment, Samnut 10 was significantly higher than Samnut 21 in terms of number of plants per meter square and yield (number of pods per plant and pod weight) and also had the highest harvest index, therefore it is recommended for planting in this agroecological zone.

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