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SWEET POTATO (*Ipomoea batatas*) GROWTH AND TUBER YIELD AS INFLUENCED BY PLANT SPACING ON SANDY LOAM IN HUMID TROPICAL ENVIRONMENT

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ABSTRACT

The choice of appropriate plant spacing that gives optimum density of sweet potato (Ipomoea batatas* (L.) Lam*) is crucial for its productivity, considering that plant density of cover crops affects above-ground access to sunlight, degree of soil surface cover, and below-ground tuberization. The influence of plant planting and the ensuing plant density on growth and tuber yield of sweet potato in a sandy-loam soil in southern Nigeria was assessed in the 2012 and 2013 growing seasons. The field trials involved five plant spacings namely 90 × 90, 60 × 90, 60 × 60, 30 × 90, and 30 cm × 60 cm; corresponding to plant densities of 1.23, 1.85, 2.78, 3.70 and 5.56 plants m^{-2}, respectively. Data were collected on vine girth, number of leaves, leaf area, tuber weight $plant^{-1}$ and tuber yield, as well as on weed dry matter. Closer plant spacings resulted in higher number of leaves m^{-2} and leaf area index (LAI). However, tuber weight $plant^{-1}$ was highest with the second widest spacing (60 cm × 90 cm) and decreased with spacing. By contrast, tuber yield increased with spacing; the closest spacing (30 cm × 60 cm) gave the highest value (12.95 t ha^{-1}) which, however, was similar to 10.55 t ha^{-1} due to the second closest spacing (30 cm × 90 cm) which, in turn, was similar to 60 cm × 60 cm (9.55 t ha^{-1}) and 60 cm × 90 cm (8.89 t ha^{-1}). Tuber yield correlated with number of leaves ($r = 0.57^*$) and LAI ($r = 0.54^*$), suggesting that the increases in these growth variables due to denser plant population translated into greater photosynthetic activity and translocation of assimilates to the tubers, which manifested as increased tuber yield. Spacing had no influence on weed dry matter. Sweet potato growers on well-drained sandy loam and similar soils in the humid tropics should consider adopting 60 cm × 90 cm with 'intercropping' to maximize space and resource use. Alternatively, they should space sweet potato 30 cm × 90 cm in sole production to achieve the desired density (3.70 plants m^{-2}) for optimizing resource use and tuber yield.

Key words: leaf area index, number of leaves, tuber weight per plant, optimum tuber yield, sweet potato

INTRODUCTION

Among the tuber crops of the world, sweet potato (*Ipomoea batatas* (L.) Lam) ranks third in importance after Iris potato and cassava (Ikeorgu, 2003). Sweet potato is, however, the only tuber crop with a positive per capita annual rate of production in sub-Saharan Africa (Tewe *et al*., 2003). This rests on its high yield potential that may be realized within a fairly short growing season. Sweet potato tuber is a major source of carbohydrate and can be eaten without processing. The succulent vines can also be eaten as vegetable to enrich dietary intake. Its leaves and tubers are also fed to livestock. Where desired, the leaves and tubers may be processed into starch, noodles, candy, flour, desserts and alcohol for human consumption. There is advocacy for the cultivar known as orange-fleshed sweet potato for being particularly rich in β-carotene (precursor for vitamin A) (Anderson *et al*., 2007).

The world average tuber yield of sweet potato is estimated at 15 t ha^{-1}, while that of Nigeria is at 9.80 t ha^{-1} (FAOSTAT, 2012). This fairly low average yield of the crop in Nigeria could be partially addressed through specific adoption of optimum plant density. This is because plant density depends not only on cultivar and cropping system but also on climatic and soil conditions. Some researchers have reported the benefits of optimum plant density in crop production (Binalfew, 2012; Obalum *et al*., 2017).

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However, optimum plant density of sweet potato is still controversial among tropical growers. Most farmers in the humid and sub-humid tropics grow the crop at wide and random spacing because of the prevailing intercropping system. Closer spacing may be preferred for sweet potato to achieve maximum tuber yield. Plant vigour and yield increase, while weevil infestation and tuber size decrease with increase in plant density (Woolfe, 1992). The effect of intra-row spacing on sweet potato productivity has been studied indepth and documented for several varieties worldwide (Rubatzky and Yamaguchi, 1997). These studies show that plant spacing and density influences growth and tuber yield of the crop, with the recommended spacing for most varieties ranging from 23 to 40 cm (Rubatzky and Yamaguchi, 1997).

There is paucity of data on plant spacing effect on sweet potato production on the sand-dominated loamy Ultisols in the rainforest of southern Nigeria, with climate typifying a humid tropical environment. Considering the well-drained status of the soils and the high evaporative demand of the climate vis-à-vis the protective cover offered by sweet potato, we reasoned that plant spacing could be an important factor in its production in the area, hence this study. The aim of the study, therefore, was to identify the plant density for optimum growth and yield of the crop under the prevailing soil and climatic setting.

MATERIALS AND METHODS

Study Area

The study was conducted at the Teaching and Research Farm of the Faculty of Agriculture, University of Benin, Benin City, Nigeria. The site is located on latitude 6° 20′ N and longitude 50° 40′ E, and is on an elevation of 500 ft above sea level. The location is characterized by a humid tropical climate. It has a mean annual rainfall of 1762 mm and daily temperature of 26.40°C. It lies within the rainforest agro-ecological zone in southern Nigeria.

The field trials were conducted twice in the rainy, growing seasons of two consecutive years – 2012 and 2013. In each year, the experiment was started early (February - April) in the growing season.

Experimental Design

The field trials involved five plant spacings namely 90 × 90, 60 × 90, 60 × 60, 30 × 90, and 30 cm × 60 cm; corresponding to plant densities of 1.23, 1.85, 2.78, 3.70 and 5.56 plants m^{-2}, respectively. They were laid out in a randomized complete block design (RCBD) with three replications. A seedbed represented a plot measuring 10 m × 1.20 m. To minimize interference, a gap of 1.00 m was left between plots in a block (replicate) and between blocks themselves. The entire experimental plots measured 34 m × 12 m.

Cultural Practices

The land was cleared of the existing vegetation, ploughed and marked out. Thereafter, seedbeds were prepared and, four weeks to planting, organic manure of cured cattle dung was incorporated into the topsoil at a rate equivalent to 20 t ha^{-1} (Uzoh *et al*., 2015). Some tubers of white sweet potato belonging to the cultivar “TIS 2535-OP-1-13” which were free from any form of infestation by pests and diseases were obtained from “Oba Market”, Benin City, Nigeria. The tubers were washed under running tap water before cutting into 50-g setts with a clean knife. The cut surfaces were treated with wood ash and dried under shade overnight. The setts were planted at one per hole on 8th February in each of the two years of 2012 and 2013. After planting out, each plant was mulched with dry leaves to conserved moisture. Setts took 5-7 days to sprout. The plots were maintained weed-free through manual hoeing done at 3, 6 and 9 weeks after planting (WAP). Whenever there was no rain for two consecutive days, the plants were watered manually to field capacity on the third day.

Data Collection and Analysis

Data were collected on five randomly selected plants from the middle row of plots at 8 WAP for growth variables including vine girth, number of leaves m^{-2}, leaf area, leaf area index (LAI) and weed dry matter. Number of leaves m^{-2} was estimated as thus;

$$\text{Number of leaves m}^{-2} = \frac{100 \times 100}{Area\ of\ spacing} \times x;$$

where x represents the number of leaves plant^{-1} for a given plant spacing of the study.

The leaf area was obtained through measurement of lengths and widths of the middle leaves of the five tagged plants in a plot. Mean of the lengths and widths of the leaves was computed and used to estimate the leaf area after Ogoke *et al.* (2003):

$$\text{Leaf area} = \text{length} \times \text{width} \times 0.45.$$

Thereafter, leaf area index (LAI) was estimated with the following equation:

$$\text{LAI} = \frac{Leaf\ area}{Land\ area}.$$

Weed dry matter was obtained by drying the weeds harvested from each plot in an oven set to 80°C until constant weight was obtained. The sweet potato tubers were harvested at 20 WAP when most leaves and vines had dried up considerably. After harvest, data were collected on tuber weight per plant^{-1} and tuber yield. Tuber weight per plant^{-1} was obtained as weight (kg) of tubers harvested from the designated five plants divided by five. For each plot, the weight of the tubers was extrapolated to its net plot (1 m^{2}) equivalent. This, regarded as tuber yield (kg m^{-2}), was expressed on hectarage basis (t ha^{-1}) by multiplying by a conversion factor of 10.

One-way analysis of variance (ANOVA) suitable for an RCBD experiment with blocking was carried out on the data, whereby the data for the two years were combined and averaged before analysis. This was achieved using the software Genstat 3, 7.2 Ed. (VSN Int. Ltd., Hemel Hempstead, UK). With this, the least significant difference was used to infer on significant differences between means at 5% level of probability, designated $LSD_{0.05}$. Pearson correlations were used to test for relationships among growth variables and tuber yield of sweet potato.

RESULTS

Influence of Plant Spacing and Ensuing Density on Above-Ground Growth of Sweet Potato

The influence of plant spacing and density on some growth variables of sweet potato as evaluated 8 WAP is shown in Table 1. Plant density had no significant ($p < 0.05$) influence on vine girth of the plant. However, plant density significantly ($p < 0.05$) influenced number of leaves m^{-2} and LAI. Both variables showed lowest values in plots where the plants were spaced 90 cm × 90 cm which was the widest spacing and lowest density. They also showed highest values in plots where the plants were spaced 30 cm × 90 cm which was the second closest spacing and highest density. Notably, these two variables tended to progressively increase as plant spacing became closer and hence plant density higher up till the second closest spacing and highest density; thereafter, they showed a drop in values in plots with the closest spacing and highest density.

Influence of Plant Spacing and Ensuing Density on Tuberization Indices of Sweet Potato

The influence of plant spacing and density on tuberization of sweet potato was evaluated using tuber weight $plant^{-1}$ and tuber yield, data of which are presented in Table 2. The data show that plant spacing significantly ($p < 0.05$) influenced the yield component of tuber weight $plant^{-1}$, such that values were similar in plots where the plants were spaced 90 cm × 90 cm, 60 cm × 90 cm, and 60 cm × 60 cm. Also, the values were similar in plots where the plants were spaced 60 cm × 60 cm, 30 cm × 90 cm, and 30 cm × 60 cm. Generally as the plant spacing became closer and plant density higher, tuber weight $plant^{-1}$ decreased.

By contrast, tuber yield, which was significantly ($p < 0.05$) influenced also by plant spacing, increased progressively as plant spacing became closer and hence plant density higher. The tuber yield was lower in plots where the plants were spaced 90 cm × 90 cm compared with those where the plants were spaced 60 cm × 90 cm, 60 cm × 60 cm, and 30 cm × 90 cm; all three in which tuber yield indicated similar values.

Table 1: Influence of plant spacing and density on some growth variables of sweet potato grown on a sandy-loam Ultisol at 8 weeks after planting

Plant spacing[†]	Vine girth (cm)	Number of leaves m^{-2}	Leaf area index, LAI
90 cm × 90 cm (1.23)	5	62	2.35
60 cm × 90 cm (1.85)	4	111	7.14
60 cm × 60 cm (2.78)	5	128	9.52
30 cm × 90 cm (3.70)	5	267	36.42
30 cm × 60 cm (5.56)	3	161	17.36
$LSD_{(0.05)}$	Ns	42	6.73

[†]Numbers in parenthesis represent the corresponding plant density (plants m^{-2}). $LSD_{(0.05)}$ - least significant difference between means at 5% level of probability; ns - not significant

Table 2: Influence of plant spacing and density on tuberization of sweet potato grown on a sandy-loam Ultisol

Plant spacing[†]	Tuber weight (kg $plant^{-1}$)	Tuber yield (t ha^{-1})
90 cm × 90 cm (1.23)	0.40	5.00
60 cm × 90 cm (1.85)	0.48	8.89
60 cm × 60 cm (2.78)	0.34	9.55
30 cm × 90 cm (3.70)	0.28	10.55
30 cm × 60 cm (5.56)	0.23	12.95
$LSD_{(0.05)}$	0.15	2.57

[†]Numbers in parenthesis represent the corresponding plant density (plants m^{-2}). $LSD_{(0.05)}$ - least significant difference between means at 5% level of probability

It is noteworthy that, of these three plant spacings, only the 30 cm × 90 cm tuber yield (10.55 t ha^{-1}) that was comparable to the highest value recorded in plots with the closest plant spacing of 30 cm × 60 cm (12.95 t ha^{-1}). Therefore, our data show that the duo of 30 cm × 90 cm and 30 cm × 60 cm representing the second closest and the closest plant spacings, respectively not only had similar tuber weight $plant^{-1}$, but also produced similar tuber yield of sweet potato.

Influence of Plant Spacing and Ensuing Density on Weed Infestation in Sweet Potato Field

Plant spacing and ensuing plant density did not significantly ($p > 0.05$) weed infestation evaluated by weed dry matter in the sweet potato field. In the plots under the various plant spacings of 90 cm × 90 cm, 60 cm × 90 cm, 60 cm × 60 cm, 30 cm × 90 cm, and 30 cm × 60 cm, the values for the weed dry matter were 10.60, 13.60, 16.40, 15.80 and 14.00 t ha^{-1}, respectively. Without prejudice to the fact that these values are similar, the data show an initial increase in weed dry matter with closer spacing and hence higher plant density up till the 60 cm × 60 cm spacing, beyond which the weed dry matter started decreasing.

Table 3: Correlation matrix of growth variables, tuber weight plant^{-1} and tuber yield of sweet potato grown with various plant spacings on a sandy-loam Ultisol

	Vine girth	Number of leaves	Leaf area index, LAI	Tuber weight plant^{-1}
Number of leaves	0.18	-		
Leaf area index, LAI	0.29	0.97*	-	
Tuber weight plant^{-1}	0.43	-0.37	-0.54*	-
Tuber yield	0.21	0.57*	0.54*	0.06

*the correlation was significant at or less than 5% level of probability.

Relationships among Growth Variables and Tuberization Indices of Sweet Potato

The relationships among the growth variables and the two indices of tuberization of the sweet potato plant (tuber weight plant^{-1} and tuber yield), represented by coefficients of their correlations, are shown (Table 3). Number of leaves showed a near-perfect positive correlation with LAI ($r = 0.97^*$). Tuber weight plant^{-1} and tuber yield had negative and positive correlations, respectively with LAI. Furthermore, tuber yield had a positive correlation with number of leaves. All these correlations were significant ($p < 0.05$).

In this study, vine length was also measured; however, plant spacing did not influence it neither was there any clear trend. For this reason, we decided not to present the data for the vine length. Similarly, there were consistently no correlations between this vine length and other growth variables and tuberization indices of sweet potato. Hence the data are excluded also from the correlation coefficients in Table 3.

DISCUSSION

The results of this study show that plant spacing and the ensuing plant density influenced the growth and yield of sweet potato on a well-drained sandy loam belonging to the soil order of Ultisols in Benin, located in the rainforest belt in southern Nigeria typifying a humid tropical environment. These field trials over a two-year period demonstrate that planting at close spacing and hence increasing the plant density could increase the tuber yield of this tuberizing crop. The mean of the tuber yields achieved here approximates the national average in Nigeria, which is estimated at 9.80 t ha^{-1} (FAOSTAT, 2012).

In this study, the tuber yield achieved with closest plant spacing of 30 cm × 60 cm was highest and similar only to that achieved with the second closest spacing of 30 cm × 90 cm. The yield values under each of these two plant spacings exceed the African average tuber yield of sweet potato, which is estimated at 7.00 t ha^{-1} (FAOSTAT, 2012). This implies that farmers who plant in rows at such specific close spacing could have yields higher than the average in Africa as opposed to those who adopt arbitrary plant spacings. Similar to our observation, Sen *et al.* (1990) reported higher tuber yields of sweet potato where the vine cuttings were closely planted.

The increase in number of leaves per m^2 and LAI with increasing plant density indicates an increase in leaf photosynthetic activity due to closer plant spacing (Law-Ogbomo and Osaigbovo, 2014). In the present study, plant spacing influenced both tuber weight per plant and tuber yield, in an inverse manner though. The increase in tuber weight per plant with a decrease in plant density was probably due to less intra-specific competition for growth resources among plants. In plots with low densities and showing high tuber weight per plant, unrestricted access to such resources might have even prevailed. Muoneke and Asiegbu (1996) reported decreases in some yield components of okra including pod yield per plant as density increased.

Since leaf is a photosynthetic organ, changes in number of leaves and LAI would affect crop yield. Both variables increased with plant density, leading to better interception of solar radiation and enhanced photosynthesis that favoured sweet potato tuberization (Law-Ogbomo and Egharevba, 2008). Contrary to these results, higher tuber yields of early potato at low than at high plant density had been reported from a Mediterranean environment (Mauromicale *et al.,* 2003). However, results similar to the data in discourse were reported for fluted pumpkin in another sandy-loam Ultisol in southeastern Nigeria (Obalum *et al.*, 2017).

The rather contrasting results for tuber weight per plant and tuber yield can be explained thus; in plots with high plant densities, low tuber weight per plant was compensated for by high tuber yield due to more plant stands (Beukema and Van der Zaag, 1990). This implies that crop yield depends on the number of plants involved per unit area rather than on the potential of individual plants (Ariyo *et al.*, 1991).

The results for tuber weight does not necessarily imply a decrease in mean tuber size with plant density; instead, it reflects the fact that average tuber weight decreases as the number of plants involved increases. The similarity in tuber yield between 30 cm × 90 cm and the second widest spacing (60 cm × 90 cm) which showed the highest tuber yield per plant is remarkable. In practical terms, this offers the grower the chance to consider 60 cm × 90 cm with intercropping. This cropping system which is common in the farming culture of tropical Africa has many benefits, including improvements in soil physical properties of especially sandy-loam Ultisols (Obalum and Obi, 2010).

Plant spacing had no influence on weed biomass, implying that higher plant density could not suppress weed growth. This appears somewhat strange and is contrary to Law-Ogbomo and Egharevba (2008) for tomato. The present results suggest, however, that the surface cover due to the sweet potato even in the plots with widest spacing was enough to suppress weeds.

The near-perfect correlation of number of leaves and LAI implies that plant spacing influences number of leaves as much as it influences LAI. Therefore, either of these two variables could be used to index the influence of spacing on sweet potato performance, more so as both growth variables also showed similar degree and direction of correlations with tuber yield.

Considering that LAI increased with plant density, the negative correlation of tuber weight per plant and LAI buttresses the aforestated greater intra-specific competition for growth resources with an increase in plant density. Abdissa *et al.* (2011) reported decreases in tuber weight with less access to photosynthetic light. This shows that the lower the plant density and hence competition for especially photosynthetic light the higher are the chances of partitioning of assimilates to the storage organ which, in the case of sweet potato, is the tuber (Wubanechi, 2014).

CONCLUSIONS AND RECOMMENDATIONS

Plant spacing is an important factor in sweet potato production on especially sand-dominated loamy soils in the tropics. The ensuing plant density could influence growth variables, components of yield, and economic yield of the crop. As shown by our data, the closer the planting spacing and hence plant density, the better is the above-ground growth of sweet potato which ultimately translates into higher tuber yield; with optimum yield occurring at 30 cm × 90 cm that gives 3.70 plants per m^2 (37,000 plants per ha).

Although the emphasis here is on sweet potato, the grower can choose to diversify via intercropping. In this case, our data support the adoption of a wider spacing of 60 cm × 90 cm which could also produce as much tuber yield as 30 cm × 90 cm. We recommend, therefore, that sweet potato be spaced 60 cm × 90 cm and 'intercropped' to maximize space and resource use or 30 cm × 90 cm for optimum sole production. This recommendation applies to sandy-loam soils mainly in the rainforest belt of southern Nigeria and more generally to soils having similar textural and drainage characteristics in other humid tropical environments.

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