International Journal of Agricultural Research, 2010
ISSN 1816-4897

Effects of Sowing Methods and Plant Population Densities on Root Development of Cacao (*Theobroma cacao* L.) Seedlings in the Nursery

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Abstract: Effect of population densities and sowing methods were tested on root development of cacao seedlings in the nursery in 2006/2007 and 2007/2008 sowing season at the teaching and research farm of the Federal University of Technology, Akure, Nigeria. The experiments were carried out using three population densities and three sowing methods. There were no observed significant difference in the root dry weight and the numbers of lateral roots produced per plant in all the treatments. Seedlings raised in polythene pots showed a significantly higher mean difference of tap root length and girth over other sowing methods. However, seedlings sown in groves and those in broadcasting showed a significant difference in lateral root length over seedlings sown in polythene pots. The rate of plant root distribution was affected by population densities with more uniform distribution along the tap root to plant population of 104.2 seeds m^{-2} and highest concentration towards the surface in plant population of 52.08 seeds m^{-2}. Population densities of 69.5 and 104.2 seeds m^{-2} enhanced root mass density per unit volume of soil. Also, sowing in groves and by broadcasting improves root mass densities over sowing in polythene pots.

Key words: Cocoa, density, nursery, population, seedling, sowing

INTRODUCTION

The cocoa sector in Nigeria occupied a prime place in the 1960s and 1970s when cocoa was the country's largest exports. Although, now the world fourth largest cocoa producing country, its production dropped from 400,000 tones in 1970s to about 130,000 tones in the 1990s (Akinifesi *et al*., 1999). The decline was attributed to a number of constraints faced by farmers including: inadequate and limited access to production technologies and practices, high cost and limited access to inputs and credit facilities, poor/inefficient marketing channels and market power, low and inconsistent quality standards, low level of local consumption of cocoa and cocoa products in Nigeria. Others include very low percentage seedling establishment after transplanting, moribund/aged cocoa farms and high cost and limited access to highly productive hybrid seedlings (Cocoa Research Institute of Nigeria, 2002; Opeke, 2003; Gro-Cocoa, 2005).

In recent years, Government of Nigeria lunched a programme aimed at revitalizing the cocoa sector through a series of rehabilitation programmes including cocoa rebirth. In overcoming these problems, the Federal Government of Nigeria has put in place a lot of measures to increase cocoa production from the current position of 130,000 tones in the late

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1990s to 600,000 tones by 2009. As part of these, an expansion in the area planted to cocoa is planned from the current 400,000 ha effectively in production to one million hectares (Gro-Cocoa, 2005). To achieve these set target, an alternative and efficient means of producing cocoa seedlings at a relatively low cost and will give a very good percentage establishment on the field after transplanting needs to be considered.

Cocoa, as a tropical tree crop, needs to pass through a nursery stage to allow easy and good establishment on the field (Adenikinju *et al.*, 1989).

According to Centre for Coffee Research Institute seedling survival on the field is determined by seedling vigour which is a factor of height, stem girth, number of leaves and the root volume. Wilson (1999) also reported that factors for seedling survival after transplanting include vigour, which is determined by plant height, stem girth, number of leaves, leaf area and root volume. Other factors include moisture availability in the air and soil, soil water retentive capacity and soil nutrients status. Basu *et al.* (2007) stated that application of manure generally improve crop performance especially in annual crops. CABI Biosciences (2001) stated that after care activities like weed control, insect and disease management, fertilizer application and general farm management enhance establishment rate and vegetative growth of cocoa after transplanting.

The experiments were established in a field nursery to examine the effect of sowing methods (sowing in polythene pots, sowing in groves on raised beds and sowing by broadcasting on raised beds) and seed rates (52,08, 69.5 and 104.2 seeds m^{-2}) on the root development and growth of cocoa seedlings.

MATERIALS AND METHODS

The experiments were conducted at the Teaching and Research Farm of the Federal University of Technology, Akure in 2006/2007 and 2007/2008 sowing season respectively as a 3 x 3 factorial experiment with three replicate. The treatments combinations are: plant population (PP) of 52.08 seeds m^{-2} with Sowing in Groves (SG) on beds; PP of 52.08 seeds m^{-2} with Sowing by Broadcast (SB) on beds; PP of 52.08 seeds m^{-2} with Sowing in Polythene Pots (SP); PP of 69.5 seeds m^{-2} with SG; PP of 69.5 seeds m^{-2} with SB; PP of 69.5 seeds m^{-2} with SP; PP of 104.2 seeds m^{-2} with SG; PP of 104.2 seeds m^{-2} with SG; PP of 104.2 seeds m^{-2} with SB; and PP of 104.2 seeds m^{-2} with SP. The common sowing methods i.e sowing in polythene pot, [sowing by broadcasting and sowing in grove (for bare root transplanting)] were used (Amoah *et al.*, 1999). The site was manually cleared and tilled to produce flat beds of 2×2 m sub plots with 1m spacing between blocks and 0.5 m spacing between sub plots. Polythene pots of 12 cm diameter x25 cm length were used for the polythene pot sowing. Sowing was done immediately after tilling using seeds from freshly harvested ripped cocoa pods following the above stated sowing densities and methods. Normal agronomic practices were carried out on the seedlings for four months. Twenty plants were selected from each treatment for data collection. Seedlings were carefully uprooted with the ball of earth around the root zone and immersed in a drum of water for careful washing off of the soil preventing the fine roots from cutting off at sixteen Weeks after Sowing (WAS). Average lengths of the lateral roots were taken, tap root length, tap root girth, number of lateral root and lateral root distribution along the tap root. Other parameters taken include plant height, leaf area development and the root dry weight. Core samples were taken randomly within each sub plots. The contents were emptied into 2 mm sieve and washed carefully in large volume of water to sort out the plant root in the core. After draining, the roots were weighed to determine the fine root density/distribution (root mass/volume of soil) per treatment.

Data collected were subjected to Analysis of Variance (ANOVA) and the significant means were separated using Least Significant means Difference (LSD).

RESULTS

Effect of Interaction Between Sowing Methods (Sowing in Groves, Sowing by Broadcasting and Sowing in Poly Pot) and Population Densities (52.08, 69.6 and 104.2 seeds m^{-2}) on Shoot Growth Parameters of Cocoa Seedling in the Nursery

From Table 1 and 2, no significant difference was observed in the number of leaves produced and the stem girth value from the interaction between factor A (sowing methods) and factor B (population densities). However, at 16 weeks after sowing, the effect of interaction was observed on the plant height. Also, in the leaf are and shoot dry weight, no significant difference was observed from the interaction between the two factors (i.e. sowing methods and population densities).

Effect of Sowing Methods (Sowing in Groves, Sowing by Broadcasting and Sowing in Poly Pot) on Root Parameters

Significant differences were observed in the tap root length and tap root diameter with sowing in poly pots having the highest mean values. There were no significant differences between the mean values of sowing in poly pot and sowing in groves in term of tap root

Table 1: Mean values of root and shoot parameters for 2006/2007 experiment

Plant population	Sowing methods	Tap root length (cm)	Longest lateral root (cm)	Tap root diameter (cm)	Soil root density (g cm^{-3})	No. of root per plant	Root dry weight (g)
52.08 seeds m^{-2}	Groves	14.08	35.50	1.32	0.005	2.87	0.93
	Broadcasting	13.65	22.55	1.00	0.0073	2.90	0.99
	Polythene pot	24.85	16.50	1.33	0.005	2.53	1.07
69.5 seeds m^{-2}	Groves	14.08	29.60	0.72	0.0075	3.20	0.88
	Broadcasting	14.55	25.60	0.96	0.0087	2.97	0.95
	Polythene pot	23.11	17.60	1.25	0.0046	2.50	1.04
104.2 seeds m^{-2}	Groves	14.49	29.24	1.12	0.0079	3.33	0.91
	Broadcasting	14.43	34.30	0.92	0.01	2.80	0.80
	Polythene pot	23.83	14.50	1.40	0.0043	2.50	1.05
LSD values	Population density	NS	1.39	1.15	NS	NS	NS
	Sowing methods	3.44	1.36	1.15	NS	NS	NS
	Plant population and sowing methods	NS	2.35	0.10	NS	NS	NS

Plant population	Sowing methods	Root/Shoot (g)	Leaf area (cm^3)	Root weight/ Leaf area (g cm^{-2})	Shoot dry weight	Lateral root fresh weight (g)
52.08 seeds m^{-2}	Groves	0.36	34.25	0.027	2.58	1.17
	Broadcasting	0.35	39.92	0.025	2.80	0.56
	Polythene pot	0.36	46.00	0.023	3.01	0.38
69.5 seeds m^{-2}	Groves	0.33	37.02	0.024	2.64	0.25
	Broadcasting	0.33	39.40	0.024	2.88	0.59
	Polythene pot	0.29	51.45	0.020	3.59	0.31
104.2 seeds m^{-2}	Groves	0.33	37.46	0.024	2.72	0.59
	Broadcasting	0.32	32.46	0.025	2.53	0.39
	Polythene pot	0.30	48.44	0.022	3.54	0.36
LSD values	Population density	NS	NS	NS	NS	0.097
	Sowing methods	NS	13.26	NS	1.92	0.097
	Plant population and sowing methods	NS	NS	NS	NS	0.062

NS: Not significant

Table 2: Mean values of root and shoot parameters for 2007/2008 experiment

Plant population	Sowing methods	Tap root length (cm)	Longest lateral root (cm)	Tap root diameter (cm)	Soil root density (g cm^{-3})	No. of root per plant	Root dry weight (g)
52.08 seeds m^{-2}	Groves	16.77	38.20	1.33	0.0055	2.82	0.90
	Broadcasting	16.20	23.00	1.04	0.0075	2.91	1.11
	Polythene pot	20.70	15.80	1.31	0.0049	2.50	0.99
69.5 seeds m^{-2}	Groves	15.00	29.10	0.81	0.0077	3.20	0.85
	Broadcasting	17.97	26.30	0.99	0.0084	2.99	0.94
	Polythene pot	21.70	18.20	1.30	0.0045	2.60	1.03
104.2 seeds m^{-2}	Groves	15.23	30.20	1.15	0.0079	3.35	0.90
	Broadcasting	13.90	36.30	1.00	0.0096	2.76	0.76
	Polythene pot	20.80	15.20	1.35	0.0046	2.5	0.97
LSD values	Population density	NS	1.36	0.15	NS	NS	NS
	Sowing methods	8.06	1.36	0.15	NS	NS	NS
	Plant population and sowing method	NS	2.35	0.1	NS	NS	NS

Plant population	Sowing methods	Root/Shoot ratio (g)	Leaf area (cm^3)	Root weight/Leaf area (g cm^{-2})	Shoot dry weight	Lateral root fresh weight (g)
52.08 seeds m^{-2}	Groves	0.31	35.89	0.025	2.79	1.23
	Broadcasting	0.39	37.93	0.029	2.92	0.68
	Polythene pot	0.26	47.83	0.021	2.96	0.33
69.5 seeds m^{-2}	Groves	0.31	31.93	0.027	2.76	0.21
	Broadcasting	0.39	34.26	0.027	2.40	0.61
	Polythene pot	0.26	54.60	0.019	3.98	0.32
104.2 seeds m^{-2}	Groves	0.32	38.14	0.024	2.85	0.60
	Broadcasting	0.28	35.58	0.021	2.76	0.40
	Polythene pot	0.25	50.16	0.019	3.86	0.36
LSD values	Population density	NS	NS	NS	NS	0.97
	Sowing methods	NS	19.29	NS	1.97	0.97
	Plant population and sowing method	NS	NS	NS	NS	0.62

NS: Not significant

diameter. The mean value of the lateral root length was significantly higher under sowing in groves and sowing by broadcasting which was having a much lower value in poly pot method. The soil volume: root density ratio, number of lateral root per plant, root dry weight, root: shoot ratio and root weight: leaf area ratio were not significantly different among the three sowing methods. The lateral root fresh weight was significantly higher in value under sowing in groves and sowing by broadcasting than sowing in poly pot (Table 1, 2).

Effect of Plant Population Densities on Root Parameters

There were no significant differences in the mean value of tap root length, soil volume: root density ratio, number of lateral root per plant, root dry weight and root weight: shoot weight ratio. Also, no difference was observed in the leaf area, root weight: leaf area ratio and shoot dry weight among the three population densities (i.e. 52.08, 69.5 seeds m^{-2}, 104) at both trials. Plant population of 104.2 seeds m^{-2} was significantly higher in value of lateral root length compared to other population of 69.5 and 52.08 seeds m^{-2}. However, for the tap root diameter and lateral root fresh weight, population density of 52.08 seeds m^{-2} has a significantly higher value over population of 69.5 and 104.2 seeds m^{-2} in both 2006/2007 and 2007/2008 trials (Table 1, 2).

Effect of interactions between sowing methods (sowing in groves, sowing by broadcasting and sowing in poly pot) and population densities (52.08, 69.5 and 104.2 seeds m^{-2} on root parameters.

The interaction between population of 52.08 seeds m^{-2} and sowing in groves favours lateral root development both in the lengthy and fresh weight showing a significantly higher value over other two treatment combinations for the two trial period of 2006/2007 and 2007/2008 trials. When sowing by broadcasting was considered there was a proportional increase in the mean values of tap root length and lateral root weight with increase in population density. These resulted in significantly higher differences among the three treatment combinations with 104.2 seeds sown by broadcasting showing the highest value in both Table 1 and 2.

Effects of Sowing Methods and Population Densities on Root Morphology of Cacao Seedlings

The values of the root density varied with sowing densities, plant population of 104.2 seeds m^{-2} has the highest value followed by that of 69.5 seeds m^{-2} while plant population of 52.08 seeds m^{-2} had the lowest root density. Also the values for the three methods varied, sowing by broadcasting had the highest followed by sowing in groves and sowing in polythene.

Plant population of 104.2 seeds m^{-2} has the highest lateral root length mean value of 78.04cm compared with 74.55 and 72.60 cm of 9.5 and 52.08 seeds m^{-2} respectively. Sowing in groves has the highest mean value of lateral root length followed by sowing through broadcasting and lastly sowing in polythene pots with the values of 94.34, 82.45 and 48.60 cm, respectively. The mean value of lateral root weight the plants decreases with increase in population density. Plant population of 104.2 seeds m^{-2} has the lowest value followed by 69.5 and 52.08 seeds m^{-2} with the values of 2.11 g, 1.50 kg and 1.345 g, respectively. Also for the sowing methods, sowing in groves has the highest value followed by broadcasting and lastly sowing in polythene pots with values of 2.013, 1.540 and 1.054 g, respectively.

Among the three population densities, plant population of 52.08 seed m^{-2} has the highest mean value of tap root diameter followed by plant population of 104.2 seeds m^{-2} and plant population of 69.5 seeds m^{-2} with the values of 3.65, 3.44 and 2.93 cm, respectively. In addition, the plants sown in polythene pot method have the highest mean value of taproot followed by sowing in groves and lastly by sowing in polythene pots (Table 1, 2).

Figure 1 and 2 show the effect of plant population on seedling stem girth with no significant difference among the treatments. Also, no significant difference was recorded in term of stem girth under the various sowing method (Fig. 3, 4).

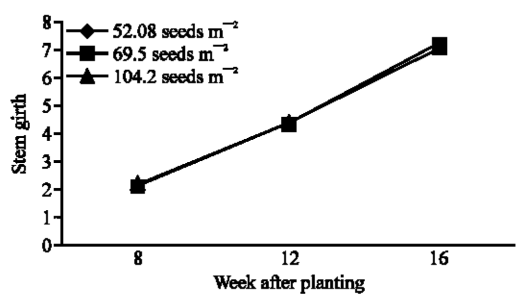

Fig. 1: Effect of plant population on stem girth of the seedling (1st trial)

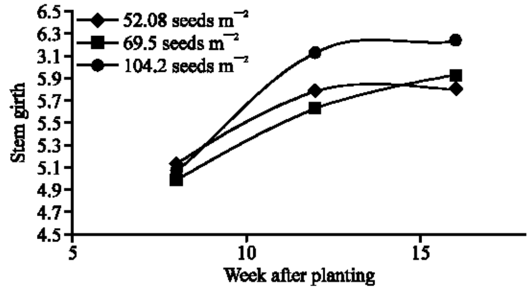

Fig. 2: Effect of population densities on seeding stem girth 2nd trial

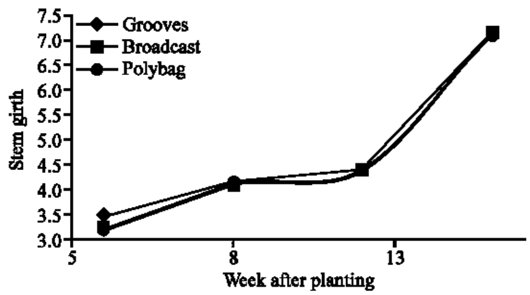

Fig. 3: Effect of sowing methods on seeding stem girth 1st trial

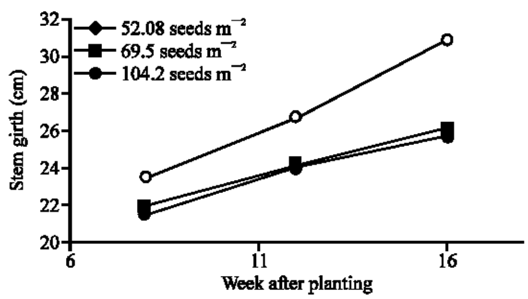

Fig. 4: Effect of sowing methods on seeding stem girth of cacao (2nd trial)

DISCUSSION

The enhanced taproot development that was observed under sowing in poly pot was due to shape of the polythene pot used. This does not permit extensive lateral root growth as noticed under sowing directly on raised beds. However, the extensive lateral root development under sowing in groves and sowing by broadcasting was justified in the poly pot method by extensive taproot growth. Diver and Greer (2001) reported that size and the type of soil used for potted seedlings determine rate of shoot growth and root development. The lack of significant difference in the stem girth and dry root weight among the treatments for the two trials (2006/2007 and 2007/2008) was due to the production of equal amount of assimilates by the leaves which were partitioned to the root zones but were used either for lateral root development (sowing in groves and by broadcasting) or taproot development (sowing in polythene pots).

The longer taproot length observed in the plant sown in polythene pots was also related to the downward movement of water and nutrients in the polythene pot during watering because of the shape of the poly pot which does not allow horizontal water flow. Also higher soil temperature in the root zone (due to black colour of the potting material) of the polythene pots treatment is also responsible for the downward growth of the root (Landis *et al*., 1990). The variation in the leaf area development was as a result of high assimilates partitioning to root system for the plant to cope with competition for nutrients and water in the soil. This was related to the findings of Famaye *et al*. (2003), who reported that closely spaced cocoa seedlings produced a smaller leaves area than a well spaced ones due to competition that exist below the soil and above the soil. Opeke (2006) stated that the effect of population does not manifest on seedling at the early stage of growth when the growing medial has adequate nutrients needed.

Sowing in polythene pots positively affects cocoa seedling plant height than sowing in groves and sowing by broadcasting. This finding is related to an earlier work by Diver and Greer (2001) and Famaye *et al*. (2003) that potted seedling provide a favourable condition for growth. Roots of seedlings raised in polythene pots were associated with coiling and recoiling of roots in the pots. According to Steve and Lane (2003), coiling of roots in the container cause the plant to be root-bound which is detrimental to establishment and rapid development after transplanting on the field. Also, Rattin *et al*. (2006) advocated the use of plug plastic tray instead of the commonly polystyrene trays which would let avoid the damage to root system when seedlings were transplanted.

The effect of sowing method on number of lateral roots development was more obvious with sowing in groves and sowing by broadcasting. This was related to the findings of Famaye *et al.* (2003) and Diver and Greer (2001) that sowing on beds favour lateral root development which aid field establishment. The relatively high values of fine root density in the soil under high density sowing of 104 seeds m^{-2} indicates the level of competition among the plant roots in search for nutrients and water. Development of very good root network is a factor for establishment by tree crop seedling (Heusa and Stinson, 1989).

In addition, higher fine root densities that were obtained under sowing by broadcasting and in groves could have emanated from their freedom to grow towards any direction in the soil unlike the potted type that are restricted into the pot soil volume. The length of lateral root development under higher population density also appeared to be due to below ground competition for water and nutrients.

This was also applicable to sowing in groves and broadcasting which had enhanced fine root and lateral root development over sowing in polythene pots. The weight of the lateral root which was highest under the population of 52.08 seeds m^{-2} was due to larger spacing between the plants and the resultant less competition in the root zone. Significant taproot diameter development under sowing in polythene pots is possibly due to the natural/shape of soil column in the container, greater pulverization of the soil and improvement in soil moisture regimes.

CONCLUSION

The results showed that raising cocoa seedlings on beds either by making groves or by broadcasting the seeds uniformly on beds are effective methods of raising cocoa seedling for plantation establishment. Also, increasing the seed population density up to 104.2 seeds m^{-2} did not have any detrimental effect on the seedling performance in term of root and shoot development though this depends largely on soil nutrient status and the stage of growth before transplanting.

The study also shows that lateral root development was favoured by raising cocoa seedling on beds rather than polythene pots. It was also revealed that using polythene pots for the raising of cocoa seedling has a negative effect on the root development. Particularly lateral root is affected leading to root coiling and subsequent slow establishment after transplanting to the field.

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