VOL. 7, NO. 10, OCTOBER 2012 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

www.arpnjournals.com

THE INFLUENCE OF SOIL MOISTURE STATUS ON REPRODUCTIVE GROWTH AND DEVELOPMENT OF BAMBARA GROUNDNUT (*Vigna subterranea* (L.) Verdc) LANDRACES IN GHANA

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ABSTRACT

The increasing threat of water deficits for crop production requires evaluating potential drought tolerant crops for cultivars that can withstand and efficiently produce under moderate to low soil moisture conditions. Bambara groundnut is one such drought tolerant crop, but this trait varies among landraces with respect to its reproductive development. Experiments were therefore carried out on bambara groundnut in Ghana, to evaluate the reproductive response of two contrasting landraces; Cream-seeded and Mottled-seeded, under three soil moisture regimes, viz. 30-40%, 50-60% and ≥70%. In both landraces, days to 50% flowering, pod and seed numbers, dry matter, pod and seed yield and harvest indices were significantly higher at 50-60% soil moisture than at 30-40% and ≥70% soil moisture regimes. The 30-40% soil moisture greatly promoted early flowering and pod-filling with enhanced harvest indices of the landraces than ≥70% soil moisture. There was higher biomass production at ≥70% soil moisture, but this did not translate into higher harvest indices as compared to 30-40% soil moisture. In all three soil moisture regimes, the pod, seed and dry matter yields, and harvest indices, were higher in Cream-seeded landrace than in Mottle-seeded landrace. Cream-seeded landrace was the most soil moisture efficient cultivar, and demonstrated superiority and better adaptation to low soil moisture condition than Mottled-seeded landrace, and could be chosen in areas of inadequate rainfall. The differences in reproductive response patterns of the landraces under varying soil moisture conditions might provide basis for developing strategies towards stabilizing bambara groundnut yields in areas of low rainfall.

Keywords: bambara groundnut, cultivars, reproductive development, soil moisture.

INTRODUCTION

The increasing water deficits resulting from poor and erratic rainfall, couple with poor soils threatens water availability for crop production. The water deficit effect on crops is more pronounced during reproductive development, and this demands strategies towards minimizing its impact on crop productivity. One such strategy is research towards obtaining drought tolerant varieties that can effectively give good yields under limited soil moisture (Doku, 1995). This is particularly needed in Sub-Saharan African countries such as Ghana, where water availability for crop production is dwindling at a faster rate due to inadequate and erratic rainfall, increasing temperatures and drought.

Incidentally, crop species differ in their responses to high temperatures and water deficits, and problems of water scarcity may further reduce the few crop species the world population currently depends on for food sufficiency and caloric supply (FAO, 1996). As a result, some of those crops regarded as minor or underutilized but identified as promising under water deficit conditions are receiving attention from governments and research institutions in Sub-Saharan African countries.

Bambara groundnut is one of such underutilized crops in Sub-Saharan Africa (Doku, 1995; 1996), which has numerous agronomic attributes in reproductive development and yield potential under limited rainfall and poor soil conditions, where other crops fail (Linnemann and Azam -Ali, 1993; Collinson, *et al*., 1997; Brink, 1999; Massawe, *et al*., 2003; Mwale, *et al*., 2007). In terms of production and utilization, the crop is reported to be the third most important leguminous crop south of the Sahara, being exceeded only by cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogaea*) (Doku, *et al*., 1978; Doku, 1995).

Bambara groundnut though is drought tolerant, inadequate moisture during its reproductive development phase can affect dry matter allocation to yield components, which subsequently affect yields (Collinson, *et al*., 1996; Leport, *et al*., 1999). Moisture is therefore an important determinant of crop growth and reproductive development, and hence plays vital role in food sufficiency status of any nation. For instance, the highest proportion of yield losses in crops can be directly attributed to drought conditions during reproductive development (Mwale, *et al*., 2007). In environments where water is a limiting factor, crop water use efficiency that culminates to higher yield is of utmost importance, and therefore of great value as drought tolerant attribute.

Therefore, assessing reproductive response features of bambara groundnut landraces, using principal factors such as soil and water, which can be adjusted across a pre-determined range, will have a positive impact on subsistence farmers, especially in areas of low and erratic rainfall. This calls for evaluating reproductive development of the crop under different moisture regimes; with an aim to selecting varieties that are better equipped

VOL. 7, NO. 10, OCTOBER 2012 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

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to cope with unfavourable conditions of limited rainfall and soil moisture.

MATERIALS AND METHOD

Two contrasting bambara groundnut cultivars, Cream-seeded (early and bunch) and Mottled-seeded (late and spreading), were selected among landraces cultivated in Ghana, and used as planting materials. Soil was collected from University of Ghana Experimental Farm at 0-15 cm depth. Samples were taken from collected soil and analyzed in triplicates using standard procedures and methods (Chapman and Pratt, 1982; AOAC, 1990), for their physical and chemical properties as shown in Table-1.

Table-1. Physical and chemical characteristics of soil used for the study.

Physical					
	% Sand	**% Silt**	**% Clay**	**Water holding capacity** (%)	**Bulk density** ρ_b (g/cm^3)
Value	73.2	5.7	21.1	60.5	1.72

Chemical								
	pH In H_2O	**pH In $CaCl_2$**	**% Org. carbon**	**% Org. matter**	**Nitrogen (%)**	**Tp ppm**	**Op ppm**	**Ap ppm**
Value	5.6	4.3	0.4	0.5	0.1	79.5	34.7	7.4

	Exchangeable cations (Meq/100 g Soil)			
	Na^+	**Mg^{2+}**	**K^+**	**Ca^{2+}**
Value	0.7	3.9	1.1	12.4

Tp = Total phosphorus, Op = Organic Phosphorus, Ap = Available phosphorus

The remaining soil was air-dried and homogenized before perforated plastic pots, 144 in number, were each filled with 8kg of the soil. The pots were arranged in Randomized Complete Block Design (RCBD) in open conditions on raised benches in four plastic houses as replicates. Each replicate has 36 pots. The pots were each inserted with two calibrated electrical resistance (Gypsum) blocks, before they were saturated with water and left till field (pot) capacity. At field capacity, the pots were weighed and their corresponding moisture content measured with moisture meter through gypsum blocks electric cables, before planting four seeds of each landrace per pot. The pots were kept at field capacity till two weeks after planting (WAP), before plants were thinned to two per pot and mulched.

Water treatment of ≥70%, 50-60% and 30-40% soil moisture (Pot capacity) were then imposed in the third week after planting and maintained; through pot weighing, soil moisture content reading through electrical resistance blocks cables, and watering, till first harvest at 7 WAP for Cream-seeded and 9 WAP for Mottled-seeded; and subsequent harvest at two weeks interval until final harvest at maturity, 11 weeks for Cream-seeded and 13 weeks for Mottled-seeded. The above experiment was repeated the following year. The monthly average climatic data recorded within the study period is presented in Table-2.

Table-2. Monthly mean climatic data recorded within experimental period.

Month	**Temperature min-max** (°C)	**Relative humidity min-max** (%)	**Sunshine** (hours/day)
March	25.3 - 33.8	60-75	8.5
April	25.1 - 32.5	65-90	7.5
May	24.9 -31.8	68-91	8.1
June	25.4-29.7	63-85	8.3

Crop data on eight plants (i.e., four pots) per treatment were collected on number of days to 50% flowering; number of pods and seeds; pods and seed dry weights and total dry matter. The harvested pods per plant were counted, sun-dried, weighed and shelled for the seeds. The seeds were counted per plant and sun-dried to 11-12% moisture before seed weights were determined.

Analysis of variance (ANOVA) was performed on crop data of the two experiments separately and combined, using the Genstat Statistical Package computer software program (Lawes Agricultural Trust, Rothamsted Experimental Station, U.K). Differences between treatment effects reflecting in the soil moisture and

VOL. 7, NO. 10, OCTOBER 2012 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

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landrace means were separated by least significant difference (LSD) at 5% probability.

RESULTS

Soil moisture and reproductive development of bambara groundnut landraces

The two different experimental periods produced similar reproductive development data of the landraces; and were not significantly different in examined parameters. There were however, significant differences between examined parameters within each experimental period, and the combined data results are presented in Table-3.

There were significant (LSD 5%) differences between soil moisture and landrace types on days to flowering, pod and seed production, as well as their dry weights and harvest indices (Table-3). Depending on soil moisture level, about 50% of the plants in Cream-seeded landrace flowered between 32-37 days, and in Mottled-seeded, between 40-51 days after planting (DAP), but after at least 5 days of first flower appearance in Cream-seeded landrace, and about 10 days in Mottled-seeded landrace.

Table-3. Soil moisture and reproductive growth and development of bambara groundnut landraces (Values are means per plant)

Land-race	Soil water (%)	Reproductive development							Reproductive Growth							Harvest index (H_I)*
		Days to 50 % flower	Number of pods (WAP)			Number of seeds (WAP)			Pod dry weight (g) (WAP)			Seed dry weight (g) (WAP)			Total dry matter (g)	
			7	9	11	7	9	11	7	9	11	7	9	11		
Cream-seeded	≥70	36.6	1.2	8.3	14.2	0.5	5.6	13.9	0.1	2.8	5.1	0.1	1.8	4.7	10.8	0.42
	50-60	33.7	3.7	12.2	24.6	1.9	10.3	23.8	0.7	5.4	9.9	0.3	4.9	9.4	16.5	0.57
	30-40	31.5	1.9	5.1	9.7	0.8	3.4	7.5	0.2	2.4	3.4	0.1	2.1	3.5	8.2	0.43
Within Cream-seeded	Mean	33.9	2.3	8.6	16.2	1.1	6.5	15.2	0.4	3.6	6.2	0.3	3.2	5.9	11.9	0.48
	LSD5 %	2.6	2.0	2.9	5.9	1.3	2.8	4.3	0.2	0.9	2.5	0.1	0.7	2.2	1.5	0.11
			(WAP)			(WAP)			(WAP)			(WAP)				
Mottled-seeded			9	11	13	9	11	13	9	11	13	9	11	13		
	≥70	51.7	0.3	4.3	8.4	0	1.8	4.9	0	0.5	1.8	0	0.1	1.4	8.4	0.17
	50-60	44.7	1.8	7.9	15.5	0	3.7	11.6	0	1.4	4.6	0	0.2	4.3	12.9	0.33
	30-40	40.5	0.6	3.5	6.5	0.3	1.2	3.7	0.1	0.5	1.7	0.1	0.4	1.5	6.5	0.23
Within mottle-seeded	Mean	45.6	0.9	5.2	10.2	0.1	2.3	6.7	0	0.8	2.7	0	0.3	2.4	9.3	0.24
	LSD5 %	2.7	0.3	1.9	2.4	0.2	1.2	2.7	0	0.4	1.2	0	0.3	0.8	2.8	0.10
Among	LSD5 %	3.2	1.4	3.2	4.1	0.5	3.7	8.8	0.2	2.3	2.4	0.2	2.2	1.5	0.7	0.10

*H_I is seed dry weight as proportion of total dry weight

The average days to 50% flowering in the landraces were 34 days in Cream-seeded and 46 days in Mottled-seeded, but with similar and consistent days to 50% flowering intervals of about 4-5 days between soil moisture regimes (Table-3). The Mottled-seeded landrace had plants with at least 4-6 flowers at maturity (95 DAP) whilst Cream-seeded landrace rarely had flowers at maturity (72 DAP). The prolong flower production in Mottled-seeded landrace plants was prominent at ≥70% than at 30-40% soil moisture regimes, resulting in delayed pod production and maturity.

Pod initiation started 7 weeks after planting (WAP) in Cream-seeded landrace and 9 WAP in Mottled-seeded landrace, and increased steadily to the peak at maturity (11 WAP in Cream-seeded landrace and 13 WAP in Mottled-seeded landrace). During pod formation, 30-40% soil moisture recorded more pods per plant in Cream-seeded landrace, than in Mottled-seeded landrace. At maturity, pod production was higher at 50-60% moisture, with Cream-seeded landrace producing on the average, 25 pods per plant, and Mottled-seeded landrace 6 pods per plant. Under each soil moisture regime, and among landraces, total number of pods and seeds per plant were significantly (LSD 5%) higher in Cream-seeded than in Mottled-seeded landrace (Table-3).

Seed formation in both Cream-seeded and Mottled-seeded landraces started 5-9 days after pod initiation, agreeing with Norman and Chongo (1992) that, seed formation in bambara groundnut starts about 6 days after pod initiation. There were significant differences (LSD 5%) between landraces on seed production from early pod development to maturity. Though there were more immature pods in Mottled-seeded landrace, most of the pods in either landraces at maturity had seeds in them, and seed numbers were not significantly different from pod numbers.

Pod dry weight increased from 7-11 WAP in Cream-seeded and 9-13 WAP in Mottled-seeded landrace (Table-3). The pod and seed dry weights were significantly higher at 50-60%, than at ≥70% and 30-40% soil moisture regimes; and there were no significant difference between latter moisture regimes. The total pod dry weight per plant in Cream-seeded at 50-60% soil moisture was about 60% of the total dry matter, while that of Mottled-seeded was 42% of the total dry matter. That of 30-40% moisture was 41.5% in Cream-seeded and 30.9% in Mottled-seeded. Harvest indices were significantly higher at 50-60% moisture, with Cream-seeded recording an average value of 0.57, and in Mottled-seeded, 0.33. The ≥70% moisture though recorded on average higher total dry matter than 30-40% soil moisture, the harvest indices of both landraces were lower at ≥70% than at 30-40% soil moisture (Table-3). The low yields obtained at ≥70% soil moisture goes to support the reports by Stanton, *et al*., (1966) that bambara groundnut yields are reduced by high amount of water, and are therefore not effectively grown in the forest zones of Africa where rainfalls are high.

Generally, the ≥70% soil moisture recorded somewhat higher values in measured parameters than 30-40% soil moisture; but the differences were not significant (Table-3). The 50-60 soil moisture recorded higher and significant values than in both 30-40% and ≥70% soil moisture regimes. The above results indicate that, although soil moisture is an important determinant for reproductive performance of bambara groundnut, the type of landrace or variety and level of soil moisture are crucial components.

DISCUSSIONS

The level of soil moisture and type of landrace can influence differences in reproductive performance of bambara groundnut. The differences in response of the landraces to days of flowering would suggest that there are differences in their photoperiodic sensitivity to flowering, with the response by Cream-seeded being consistent with quantitative short day photoperiodic sensitivity, and of more grouped flowering compared with Mottled-seeded. According to Karikari (2000), the landraces with grouped flowering could sufficiently have time for the maturation of the pods and seeds before the appearance of the bad season. There are reports indicating that some days are required after flower fertilization for mature pods and seed production in bambara groundnut (Doku and Karikari, 1970), but this days may vary depending on the soil moisture status and variety cultivated.

Though there may be some bambara groundnut varieties that are unaffected by day-length (Linnemann, 1994), temperature and photoperiod can influence flowering and pod production (Linnemann and Azam-Ali, 1993). Therefore differences in observed flowering days in both landraces, especially in Mottled-seeded landrace, could have been influenced by variations in climatic data recorded in Table-2. Both Cream-seeded and Mottled-seeded had early flower production in 30-40% soil moisture than at 60-70% and ≥70% soil moisture regimes; probably as a coping mechanism to reproduce under low soil moisture. Therefore, while the patterns of flowering are similar in both landraces, the time of flowering may differ under different moisture regimes.

The Cream-seeded landrace had more pod development than Mottled-seeded, which implies that more assimilates, were channeled to pod production in Cream-seeded than in Mottled-seeded. The Cream-seeded (bunched) landrace with shorter reproduction cycle is more productive than the Mottled-seeded (spreading) landrace with long reproduction cycle, similar to observations of Karikari and Tabona (2004). The low pod production at 30-40% soil moisture could have been due to reduced flowering and less peg development or death of some pegs before they could initiate pods. This showed that under the adverse conditions such as the lack or decrease water availability, the output of Bambara groundnut can reduce considerably.

This finding agrees with literature that number of pods and pod-filling per plant is reduced by decreased water availability (Elia and Mwandemele, 1986; Collinson *et al*., 1996; Collinson, *et al*., 1997 Mwale *et al*., 2007). The low yield usually obtained by farmers in the semi-arid areas of Africa, may be attributed to inadequate moisture supply, particularly during the period of rapid growth (i.e., between early pod formation to mid-pod filling) (Collinson, *et al*., 1997).

Cream-seeded landrace was earlier in maturity without further flowering than mottled-seeded, indicating that cream-seeded landrace is more of a determinate flowering type, whilst that of Mottled-seeded has spread out flowering, as reported by Doku and Karikari, (1970). Though late flower induction has been reported to give higher pod yield, the late flowering in Mottled-seeded landrace could not translate into pod formation. This is because late flowering that gives high yield occur in a more synchronized reproductive development stage and hence pods maturity (Linnemann, 1987). In Mottled-seeded landrace, pods do not arrive in maturity all whole because of their indefinite flowering, which lead to low seed counts and weights. Even though, delayed pod formation could have resulted in less mature pod numbers recorded in mottled-seeded landrace, leaving plants for the immature pods to mature before harvest may result in early-formed and matured pods being rotten; as indicated by Goli and Ng (1988).

This implies that under field conditions, first flowers of plants in rainy season can benefit from rains, whereas those which appear later may not profit from rain, thus causing their drying up and pod malformation, and consequently, output reduction. As a result, Karikari (1972) reported that bunch cultivars of bambara groundnut flower early, mature early and have high number of pods and seeds per plant, which are characters mostly correlated with seed yield of the crop.

There were higher dry matter production but low harvest indices under ≥70% soil moisture, as compared with 30-40% soil moisture, and this could be that under low soil moisture, there is possible overnight rehydration of plants which can enhance the whole plant senescence and therefore improve remobilization of pre-stored carbon reserves (Yang, *et al*., 2000; Yang, *et al*., 2001). The gains from improved harvest indices in low soil moisture may outweigh any possible biomass loss due to shortened photosynthetic period during pod filling. Therefore, low soil moisture could have made the plants to efficiently utilize carbon reserves and water, resulting in enhanced harvest indices (Zhang and Yang, 2004), and thereby improving their chances of survival in water-limited conditions.

Generally, the landraces studied appear to use available soil water thriftily, and conserve sufficient water for survival through the productive periods and produce some yield. So, the observed significant differences in pod and seed counts, pod and seed weights, as well as harvest indices of landraces, could be due to their genotypic differences in outputs. These reproductive parameters could be indicated as components whose output depends mainly on the type of bambara groundnut, and when the values of these parameters are high the seed yield is often high (Ofori, 1996; Karikari, 2000; Ouédraogo, *et al*., 2008). However, variations in levels of soil moisture, could lead to different reproductive development periods and yield potentials of a particular bambara groundnut genotype.

The reduction in reproductive development and yield at 30-40% soil moisture than that of 50-60% soil moisture may imply that, relatively moderate soil moisture exist for bambara groundnut genotype to give maximum yield. Therefore the ecological and environmental conditions which characterize the 50-60% soil moisture regime will greatly favour Cream-seeded landrace (bunched type) than Mottled-seeded (spreading type). Under low soil moisture of 30-40%, the Cream-seeded landrace is more efficient and superior to Mottled-seeded in reproductive development and seed yield, and could be chosen for farmers in agro-ecologies where rainfall is inadequate. In areas where rainfall is unpredictable, long term regulation may mean that Cream-seeded landrace will be able to detect low soil moisture and respond by regulating its stomata better than Mottled-seeded landrace.

CONCLUSIONS

Soil moisture status has significant effect on days to flowering, pod and seed development and dry matter production of Cream-seeded and Mottle-seeded bambara groundnut landraces. The landraces reproductive development responses favoured 50-60% soil moisture than ≥70% and 30-40% soil moisture regimes. Though the ≥70% soil moisture recorded late flowering and higher biomass production than 30-40% soil moisture, this did not enhance its harvest indices, as compared with that of 30-40% soil moisture.

The early maturity of Cream-seeded landrace than Mottled-seeded landrace at 30-40% soil moisture could mean that the Cream-seeded landrace has different stomata regulatory mechanisms and faster rate of growth during reproductive development; which are vital for moisture deficit avoidance and/or escape. The Cream-seeded landrace also had better harvest indices, which indicates its enhanced water used efficiency than Mottle-seeded. Since the landraces harvest indices are significantly different, efficient utilization of water by plants appears to be an inherited parameter in bambara groundnut.

In areas where rainfall is unpredictable, cultivar's ability to detect low soil moisture and respond by regulating its stomata for early and short reproductive development could be an indication of drought tolerance. Therefore, the variations in the reproductive responses of the bambara groundnut landraces to varying soil moisture could be practically exploited in its improvement studies.

ACKNOWLEDGEMENTS

We thank Prof. Samuel G. K. Adiku of Soil Science Department, University of Ghana, Legon, for his immense contributions. We also thank messrs A. Tonyigah, W. A. Asante, S. Haruna, and M. S. Elegba, all of Legon, for their technical support during various stages of the research.

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