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Phenological Development and Yield of Three Groundnut Varieties as Influenced by Plant Density in a Forest-savanna Transition Zone

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ABSTRACT

Field experiments were conducted at the research fields of the University of Education, Winneba, Mampong-Ashanti campus during the 2009 and 2010 seasons to evaluate the influence of plant densities on the phenological development, pod and seed yields of three groundnut varieties. The design used was a 3×4 factorial arranged in a randomized complete block design with three replications. Azivivi, Nkosour and Shitaochi groundnut varieties were sown at 14.29, 16.67, 20.0 and 33.33 plants m^{-2}. Azivivi and Nkosour cvs. are improved 120 day maturing Virginia bunch type, while Shitaochi cv. is a widely grown local 95-100-day maturing Spanish type. Crop emergence, flowering and podding expressed in calendar days, differed significantly among the groundnut varieties in both seasons. Shitaochi cv. emerged faster, flowered and podded earlier than cvs. Azivivi and Nkosour. The thermal duration from sowing to emergence differed among varieties in both seasons with Shitaochi having the least thermal duration. In 2009, cvs. Azivivi and Nkosour produced similar but higher pod (83-113%) and seed (71-95%) yields than that produced by cv. Shitaochi. The 33.3 plants m^{-2} treatment generally produced greater pod and seed yields in 2009 under low rainfall situations. In 2010, Nkosour and Shitaochi cvs. increased seed yield by only 7-8% more than Azivivi cv. and the 16.67 and 20.0 plants m^{-2} treatments impacted better on the groundnut yields. It is recommended that Nkosour cv. at 33.3 plants m^{-2} be sown during the minor season and Nkosour or Shitaochi cv. at 16.67 or 20.0 plants m^{-2} during the major season.

Key words: Phenological development, pod and seed yields, plant density, groundnut varieties, thermal time, development rates

INTRODUCTION

Groundnut is an important subsistent and cash crop in Ghana grown mostly by smallholder farmers in pure stands and/or crop mixtures for its high protein (22-30%) and edible oil (38-50%) contents. It is also rich in minerals (calcium, potassium, phosphorus, magnesium) and vitamins (Brink and Belay, 2006; Schilling and Gibbon, 2002). The transition and Guinea savanna agroecological zones (where the crop ranks as the number one grain legume) account for almost 85% of groundnut production in Ghana, the forest zone (8%) and coastal savanna zones (7%) (Breisinger *et al.*, 2008; Naab *et al.*, 2005). The average yields of groundnuts on farmers' fields in Ghana are generally low (c. 900 kg ha^{-1}) (FAO, 2010), far below the potential yields of 1800-2800 kg ha^{-1} of the improved varieties released for cultivation in Ghana

(Adu-Dapaah *et al.*, 2004). Abiotic stresses (particularly unreliable rainfall as the crop is entirely grown as rainfed), biotic stresses (pests and diseases such as rosette viral and leaf spot diseases) as well as farmers' inability to use improved agronomic practices significantly account for the low groundnut yields in farmers' fields (Adu-Dapaah *et al.*, 2004; Naab *et al.*, 2009; Craufurd *et al.*, 2002).

The yield of a crop can be influenced significantly by the rate of progress of the crop through a sequence of developmental stages (McKenzie and Hill, 1989) and their durations are important in determining the use of resources such as water, nutrients and solar radiation. In addition, the adaptation of a crop to climate and its yield are also strongly dependent on the time to flowering and the duration of growth (Wilson and Robson, 1996). Crop management practices such as sowing date, plant density and irrigation can significantly influence the environment and the phenological development during the crop growth period which in turn affect the growth and yield of the crop (Chin Choy *et al.*, 1982; Bell and Wright, 1998; Lanier *et al.*, 2004). For instance, crop growth and yield, quality factors and pest development in groundnuts were affected by varying plant population density (Lanier *et al.*, 2004).

The current recommended plant density for groundnut production in Ghana is 20 plants m^{-2} (50×20, 2 plants/hill) (Adu-Dapaah *et al.*, 2004). However, typical plant population in farmers' field ranged from 8-10 plants m^{-2}. This is because many small-holder farmers either plant groundnut randomly without any defined plant spacing on the flat land or on mounds constructed haphazardly, where the plant spacing adopted are normally very wide. Thus the optimum plant population is not achieved. Few farmers plant on ridges. Various authors have indicated that maximum or optimum yields of groundnuts were obtained with higher plant density: 22-33 plants m^{-2} (Mercer-Quarshie, 1972), 18-30 plants m^{-2} (Roy *et al.*, 1980) and 3.7-16 plants m^{-2} (Mayeux and Maphanyane, 1989). As rows were narrowed from 80-40-20, the yield of peanuts increased (Buchanan and Hauser, 1980). Several authors have also indicated that reproductive development was strongly influenced by plant population density. While Wright and Bell (1992) obtained more pods m^{-2} in a 4 than 12 or 24 plants m^{-2} planting density, (Kang *et al.*, 1998) found that reproductive parameters increased with increasing row spacing but crop growth rate increased with decreasing row spacing. Mayeux and Maphanyane (1989) observed that very low plant density led to prolonged flowering, uneven maturity and low shelling proportion.

In Ghana, there are two growing seasons (major and minor seasons) in the transition zone. Groundnut is usually grown as a main cash crop in the major season or as a secondary food crop in the minor season often planted after maize. Environmental factors such as rainfall (intermittent and/or terminal drought stress are common) and temperature may change markedly in these seasons, thus variously limiting the time available for growth, reproductive development and yield formation. It is therefore, important to gain an improved understanding of the effects of plant density on the crop's development and/or variability in yield and yield components among seasons and sites to help develop efficient production and pest management options for groundnut. Thus the objective of this study was to determine the influence of different plant densities on the phenological development, rate of development and yield of three groundnut varieties grown under rainfed conditions.

MATERIALS AND METHODS

Field experiments were conducted at the Multipurpose nursery research fields of the College of Agriculture Education, University of Education, Winneba, Mampong-Ashanti campus (07°8'N,

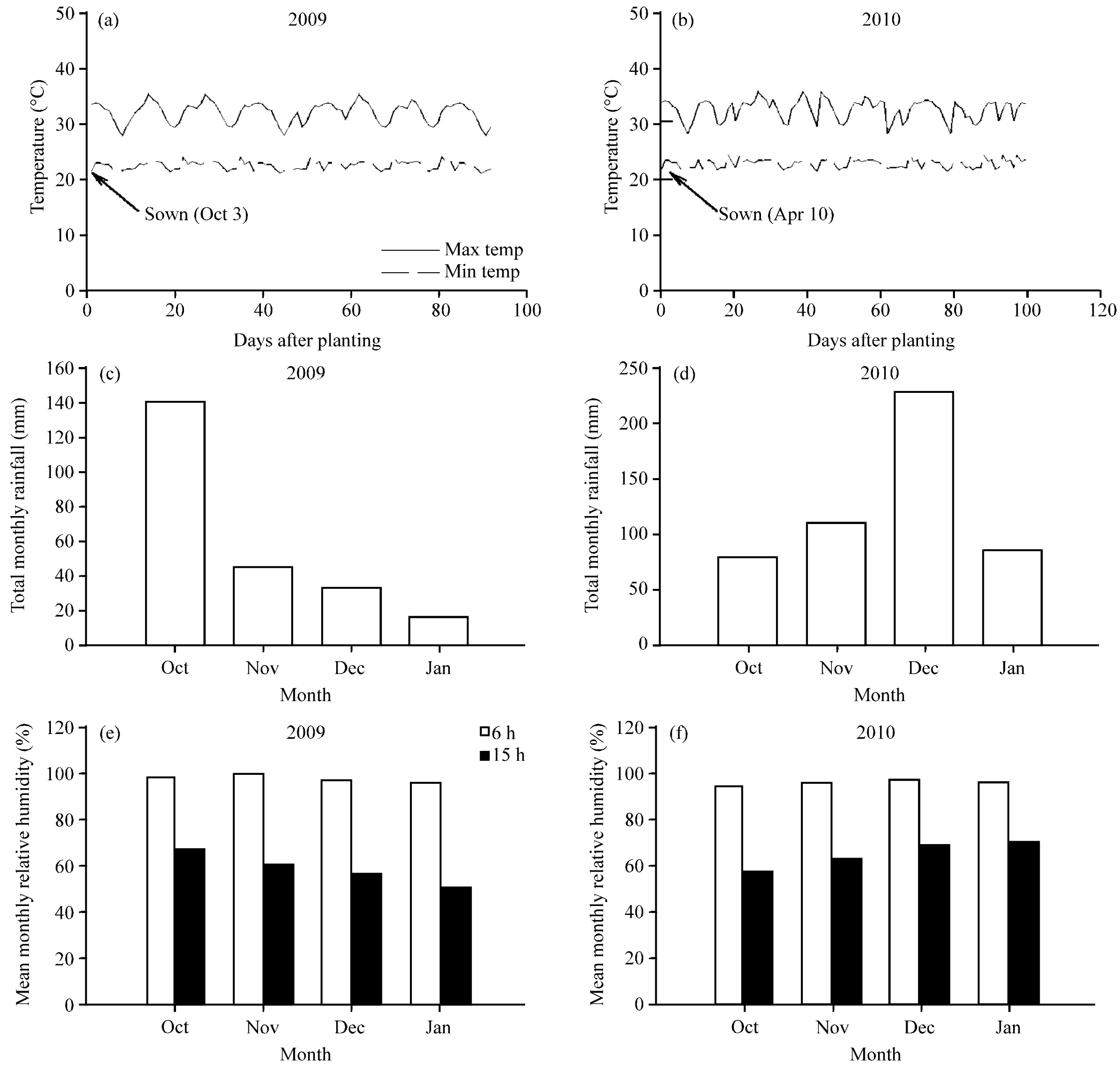

Fig. 1(a-f): (a) Mean daily minimum and maximum temperatures in 2009, (b) Mean daily minimum and maximum temperatures in 2010, (c) Total monthly rainfall in 2009, (d) Total monthly rainfall in 2010, (e) Mean monthly relative humidity in 2009 and (f) Mean monthly relative humidity in 2010

01°24'W and 456 m above sea level) during the 2009 minor season (from October, 2009 to January, 2010) and the 2010 major season (from April, 2010 to July, 2010). The soil at the experimental site was a deep sandy-loam with pH of 5.5-6.5 and belongs to the Bediase series and classified as Chromic Luvisol (Asiamah *et al.*, 2000; FAO, 1988). The area is within the forest-savanna transition agro-ecological zone and the monthly total rainfall, maximum and minimum temperatures and humidity are presented in Fig. 1.

The experimental design used was a 3×4 factorial arranged in a Randomized Complete Block Design (RCBD) with three replications. The factors studied were three varieties of groundnut [(1) Azivivi (2) Nkosour and (3) Shitaochi] and four plant densities [(1) 14.29 (2) 16.67 (3) 20.0 and (4) 33.33 plants m^{-2}]. The plant spacings used which correspond with the above plant densities were 70×20, 60×20, 50×20 and 60×10, respectively. Azivivi and Nkosour are improved 120 day maturing Virginia bunch type groundnut varieties reportedly tolerant to the rosette virus disease, while Shitaochi is a widely grown local 95-100-day maturing Spanish type groundnut variety reportedly susceptible to the rosette virus disease (Adu-Dapaah *et al.*, 2004, 2007). Seed for all the groundnut varieties used was obtained from the CSIR-Crop Research Institute, Fumesua, Kumasi, Ghana. Each plot size consisted of six ridges, with each ridge measuring 4 m long.

The land was prepared by slashing, ploughing and ridges constructed. Two seeds per hill were sown at a planting depth of about 3-5 cm on the 3 October, 2009 and 10 April, 2010 for the two seasons, respectively. Weeds were controlled manually using hoes and plots were weeded two times at 3 and 6 weeks after planting in the first season and three times at 2, 4 and 6 weeks after planting in the second season. Earthen up was done during weeding to protect developing pegs and pods. Supplementary irrigation was applied to the first (minor) season crop, because of intermittent drought, in November and December 2009. There were three applications each in both November and December and 341 of water was applied per plot at each watering period.

Phenological development was measured in calendar days, thermal time (°C days) and rate (or progress) of development from sowing to emergence, flowering and podding. The days to 50% emergence and flowering were determined as the number of days when 50% of the plants within the two harvestable middle rows had emerged or had at least one open flower. Days to podding was estimated by inspecting ten randomly selected plants every two days for pod development one week after flowering. The days to podding was determined when at least five of these plants were seen with a developing pod. The thermal time or duration between any two phases was calculated as the time interval integral of mean temperature above a base temperature (T_b) as:

$$[(T_{max}+T_{min})/2]-T_b$$

where, T_{max} and T_{min} are the maximum and minimum daily temperatures. A T_b of 10°C was adopted for the thermal durations of all phases (Bell and Wright, 1998; Ong, 1986). The rate of development during these phases was also calculated as 1/d, where d is the duration, in days, of each respective developmental phase. Linear regression analyses were used to relate the rates of development from emergence to flowering and flowering to podding to the thermal durations.

In both seasons, maturity was estimated from visual observation of the onset of senescence characterized by the yellowing and browning of leaves. The two middle rows of each plot were harvested at maturity for pod and seed yield determination. Harvesting was done manually by hoe digging and hand pulling of dug plants. Pods were ripped from plants, sun-dried for 10 and 14 days in 2009 and 2010, respectively and weighed. The pods were then shelled and the seeds weighed for seed yield determination. The moisture level of seeds was taken using a Protimeter moisture meter after sun-drying in both seasons and was about 10-13% for all samples.

All data were analyzed using standard analysis of variance technique for a factorial RCBD experiment with the SAS/STAT statistical package (SAS, 2010).

RESULTS AND DISCUSSION

Weather: Temperature, rainfall and relative humidity changes during the two seasons are shown in Fig. 1. The average monthly maximum and minimum temperatures in the 2009 growing season ranged from 29.4-33.6°C and 22.1-23.1°C, respectively. In 2010, maximum and minimum temperatures ranged from 29.4-34.3°C and 21.7-23.4°C, respectively (Fig. 1a, b). Temperature

Table 1: Main effects of variety and plant density on days to 50% emergence, flowering and podding of groundnut during 2009 and 2010

Treatment	Days to 50% emergence		Days to 50% flowering		Days to podding	
	2009	2010	2009	2010	2009	2010
Variety (V)						
Azivivi	7.8	10.4	31.3	31.7	50.8	45.7
Nkosour	7.5	10.1	31.2	31.5	50.8	45.8
Shitaochi	6.0	9.5	28.8	30.8	45.8	40.8
SED (DF = 22)	0.38	0.33	0.54	0.44	2.17	0.99
Plant density (D) (plants m^{-2})						
14.29	7.7	10.0	30.8	31.0	51.1	44.1
16.67	7.3	10.4	30.2	31.8	50.0	43.4
20.0	6.4	10.0	30.1	31.4	47.8	44.9
33.3	6.9	9.6	30.4	31.1	47.8	44.0
SED (DF = 22)	NS	NS	NS	NS	NS	NS
V×D interaction	NS	NS	NS	NS	NS	NS

NS: Not significant ($p>0.05$)

changes were similar for both seasons. In the 2009 growing season, monthly rainfall ranged from 14.7-138.6 mm with October as the wettest month. Rainfall during the growing period totalled 331.2 mm. In the 2010 growing season, rainfall ranged from 77.3-225.8 mm. Total rainfall during the growing season was 547.5 mm, about 65% more rainfall than the growing period in 2009 (Fig. 1c, d). Mean monthly relative humidity in 2009 was 54-97% and in the 2010 growing season varied from 50-98% (Fig. 1e, f).

Phenological development: Crop phenological development (emergence, flowering and podding), expressed in calendar days, differed significantly among the groundnut varieties but was not significantly influenced by plant density in both seasons (Table 1). There was also no significant variety×plant density interaction effects on the crop phenological development. Shitaochi cv. which is an early maturing variety, as expected, emerged faster, flowered and podded earlier than Azivivi and Nkosour cultivars in both seasons. Generally, the varieties emerged faster (about 3-4 days earlier) but podded late (about 5 days later) in 2009 than in 2010 (Table 1). The faster emergence in 2009 (6-8 days) might be attributed to adequate soil moisture during the first four days that seeds were sown compared with the short dry spell experienced immediately after sowing in 2010 causing seeds to emerged in 10-11days. De Waele and Swanevelder (2001) have reported that in moist and warm soils, groundnut seeds emerge within 7 days after sowing, while in dry and cooler soils emergence might take up to two or more weeks. However, the late podding in 2009 compared with 2010 could be due to the regular intermittent drought spells that occurred during the growth period in 2009. The 2010 season crop received regular well distributed rainfall during the season. Boote and Ketring (1990) noted that the start of flowering as well as pod formation in peanut could be delayed by moisture stress.

The durations from sowing to 50% emergence, 50% flowering and podding in both seasons ranged from 6-10, 29-32 and 41-51 days, respectively (Table 1). The number of days from sowing to maturity was 92-96 days for Shitaochi cv., 115-118 days for Nkosour cv. and 115-122 days for cv. Azivivi in both seasons (data not shown).

Crop durations in terms of thermal time for Sowing to Emergence (S-E), Emergence to Flowering (E-F), Flowering to Podding (F-P) and Sowing to Podding (S-P) are presented in

Table 2: Thermal time for sowing to emergence (S-E), emergence to flowering (E-F), flowering to podding (F-P) and sowing to podding (S-P) for three groundnut varieties as affected by plant density in 2009

	Thermal time (°C days) (T_b = 10 °C)							
	2009				2010			
Treatment	S-E	E-F	F-P	S-P	S-E	E-F	F-P	S-P
Variety (V)								
Azivivi	129.1	457.3	294.7	881.1	179.9	378.8	244.8	803.5
Nkosour	124.6	416.6	337.2	878.5	174.2	382.3	249.6	806.1
Shitaochi	100.7	401.1	292.0	793.8	163.6	380.2	174.4	718.2
SED (DF = 22)	6.36	NS	NS	36.24	5.90	NS	20.34	17.46
Plant density (D) (plants m^{-2})								
776.4	14.29	128.3	465.1	292.2	885.6	172.5	374.8	229.2
16.67	122.1	403.9	341.4	867.4	180.4	380.1	203.7	764.1
20.0	114.6	414.6	296.5	825.7	164.9	384.5	224.4	773.8
33.3	107.4	416.4	301.9	825.7	172.5	382.5	234.5	789.5
SED (DF = 22)	7.34	NS	NS	NS	NS	NS	NS	NS
V×D interaction	NS	NS	p = 0.0398	p = 0.0271	NS	NS	NS	NS

NS: Not significant

Table 2. The thermal duration for the S-E phase differed among varieties in both seasons with Shitaochi having the least thermal duration for S-E. On the average, the accumulated thermal time for S-E in 2010 (172.6°C days) was about 46% higher than that for 2009. The trend in thermal accumulation at the S-E phase was strongly associated with the period of time taken by the varieties to emerge, with cv. Shitoachi having emerged faster accumulated the least thermal duration compared with the other two varieties which had similar thermal durations. The thermal duration for E-F phase in both seasons was not influenced by variety, plant density or variety×plant density interaction. These responses for the E-F phase might reflect the similarities between the two seasons in mean maximum and minimum air temperatures (i.e. 29.4-33.6 and 22.1-23.1°C for 2009 and 29.4-34.3 and 21.7-23.4°C for 2010, respectively). Flowering in grain legumes is reported to be highly influenced by temperature and photoperiod (Wallace *et al*., 1995; Summerfield *et al*., 1991; Squire, 1990). Variation in photoperiod at the experimental location during the two seasons was generally negligible.

In 2009, there was significant variety×plant density interaction effects on the thermal durations for the F-P and S-P phases. While the thermal durations for F-P and S-P were similar for all plant densities under cv. Shitaochi, groundnut planted at 16.67 and 14.29 plants m^{-2} accumulated the highest thermal durations under cvs. Azivivi and Nkosour, respectively, in both seasons (Table 2). However, in 2010, these two phases differed only among the varieties with Shitoachi cv. having the least thermal durations, while the other two varieties accumulated similar thermal periods (Table 2). The thermal durations for the F-P phase varied among the seasons with the 2009 season crop accumulating 36-68% more thermal times than the 2010 crop, mostly due to the delays in flowering and pod formation as a result of the intermittent drought stress in 2009 (Boote and Hammond, 1981; Boote and Ketring, 1990). Phenological development of groundnut responds primarily to heat unit accumulation (Leong and Ong, 1983; Bell *et al*., 1991; Bell and Wright, 1998). On the average, the accumulated thermal times of 543 and 851°C days obtained for sowing to flowering and sowing to podding in this study were similar to the 538 and 720°C days obtained by Leong and Ong (1983) for the same phases, respectively.

Table 3: Rates of development (1/day) from emergence to flowering and flowering to podding of three groundnut varieties as affected by plant density in 2009 and 2010

	Rate of development (day^{-1})			
	Emergence to flowering		Flowering to podding	
Treatment	2009	2010	2009	2010
Variety (V)				
Azivivi	0.0427	0.0473	0.0638	0.0781
Nkosour	0.0426	0.0468	0.0537	0.0724
Shitaochi	0.0441	0.0470	0.0640	0.1050
SED (DF = 22)	NS	NS	0.0097	0.0111
Plant density (D) (plants m^{-2})				
14.29	0.0435	0.0478	0.0576	0.0840
16.67	0.0440	0.0470	0.0585	0.0939
20.0	0.0424	0.0468	0.0613	0.0817
33.3	0.0427	0.0466	0.0646	0.0811
SED (DF = 22)	NS	NS	NS	NS
V×D interaction	NS	NS	NS	NS

NS: Not significant

The onset of flowering and podding of the groundnut crop in both seasons appeared to be highly influenced by temperature based on the strong linear relationships between thermal time and the rates of development from E-F and F-P (data not shown). The rates of development from E-F and F-P had significant and negative linear relationships with thermal time, with the standard partial regression coefficients slightly higher for F-P than E-F. This indicates that temperature had more influence on the rate of development to podding than on the rate of development to flowering in this study. This might also explain the similarities in the rate of development from E-F for the varieties, plant density or their interaction in both seasons (Table 3). The standard partial regression coefficients were also similar for each developmental phase for each season, indicating no significant differences in maximum and minimum temperatures between the two seasons. Cox (1979) identified temperature as a dominant factor for controlling the rate of development of groundnut.

Development rates: The rate of development or progress from E-F did not differ significantly among the varieties, plant densities or their interaction in both seasons (Table 3) and ranged from 0.042-0.044 day^{-1} in 2009 and from 0.047-0.048 day^{-1} in 2010. However, the rate of progress from F-P varied significantly among the varieties in both years, with a faster development rate in Shitaochi cv., especially in 2010 (0.105 day^{-1}) and a slower rate of progress in Nkosour cv. in 2009 (0.054 day^{-1}). There was no significant effect of plant density and variety×plant density interaction on rate of development from F-P in both seasons (Table 3).

The standard partial regression coefficient for thermal duration (estimated to determine the relative contribution of thermal time in explaining the variation in rate of development from E-F and F-P) were slightly higher for E-F than F-P (Table 4). However, the partial regression coefficients were similar for each of the growth stages for 2009 and 2010. The standard errors of the regression coefficients were generally low, suggesting the sampling errors in estimating the occurrence of the phenological stages was minimal.

Table 4: Standard partial regression coefficients for regression of rates of development from E-F and F-P on mean accumulated thermal times for groundnuts grown at different plant densities in 2009 and 2010 growing seasons

Variables	Coefficients	Standard errors	r^2	p- values
2009				
E-F				
Constant	0.0887	0.00282		
Thermal time	-0.00011105	0.00000686	0.96	<0.0001
F-P				
Constant	0.1527	0.01145		
Thermal time	-0.00030621	0.00003770	0.87	<0.0001
2010				
E-F				
Constant	0.0957	0.00238		
Thermal time	-0.00012798	0.00000624	0.98	<0.0001
F-P				
Constant	0.1911	0.01134		
Thermal time	-0.00047138	0.00004858	0.90	<0.0001

Table 5: Main effects of variety and plant density on pod and seed yields of groundnut in 2009 and 2010

	Pod yield (kg ha^{-1})		Seed yield (kg ha^{-1})	
Treatment	2009	2010	2009	2010
Variety (V)				
Azivivi	488	2785	305	1860
Nkosour	567	2911	347	2028
Shitaochi	266	2980	178	2176
SED (DF = 22)	75	NS	49	102
Plant density (D) (plants m^{-2})				
14.29	423	2917	263	2020
16.67	418	3009	267	2088
20.0	374	2806	236	1978
33.3	547	2824	341	2000
SED (DF = 22)	NS	NS	NS	NS
V×D interaction	NS	NS	NS	NS

Pod and seed yield: There were no significant effects of plant density or variety×plant density interaction on pod and seed yields in both seasons (Table 5). However, pod and seed yields differed significantly among the varieties in both seasons, except for pod yield in 2010. In 2009, a season characterized by regular intermittent drought stress conditions, Azivivi and Nkosour cultivars produced similar pod and seed yields (488-567 and 305-347 kg ha^{-1}, respectively) but these were 83-113 and 71-95% more than the pod and seed yields produced, respectively, by Shitaochi cultivar (Table 5). Naab *et al.* (2009) similarly observed that Manipinter (120 days duration cultivar) produced significantly greater haulm, pod and seed yields than Chinese (90 days duration cultivar) at Wa in the northern Guinea savanna zone of Ghana. In 2010, Nkosour and Shitaochi cultivars increased seed yield by only 7-8% more than cv. Azivivi. There were no differences in seed yield between the Nkosour and Shitaochi cultivars. In general, pod and seed yields produced in 2010 among the varieties ranged from 2785-2980 and 1860-2176 kg ha^{-1}, respectively and these were about five to eleven times higher than the yields produced in 2009.

The improved performance of Shitaochi cultivar in 2010 (a season with well-distributed rainfall and more favourable moisture conditions) compared with 2009 suggests its high susceptibility or vulnerability to moisture stress that resulted in its poor performance in 2009. Although a stability analysis was not performed, it could be deduced from the analysis of the pod and seed yields in both seasons that Nkosour cv. was a more highly stable variety which performed well under both unfavourable (2009) and favourable (2010) conditions, while Shitaochi (the local variety) performed well only under favourable conditions. Azivivi cultivar had an intermediate stability. Shitaochi cv. had a higher rate of development from F-P in 2010 (Table 3) and this might have also contributed to its high pod and seed yields in that season. Total rainfall received during the growing seasons was 331.2 and 547.5 mm in 2009 and 2010, respectively. Weiss (2000) observed that a favorable climate for groundnut is a well-distributed rainfall of at least 500 mm during the crop-growing season and with abundance of sunshine and relatively warm temperature. He noted that a rainfall of 500-1000 mm will allow commercial production, although the crop can be produced on as little as 300-400 mm of rainfall, similar to the rainfall conditions observed in both seasons in this study. An analysis of the relationship between simulated groundnut yield and climate in Ghana showed that yield was predominantly influenced by rainfall from flowering to maturity (Christensen *et al*., 2004). Rainfall or moisture has been noted as the most significant climatic factor affecting groundnut production, as 70% of the crop area is under semi-arid tropics characterized by low and erratic rainfall (Reddy *et al*., 2003). Reddy *et al*. (2003), Zeyong (1992) and Camberlin and Diop (1999) have also reported that low rainfall and prolonged dry spells during the crop growth period were mainly responsible for low average yields in most of the regions of Asia (e.g., in India and China) and several parts of Africa. The seed yields produced in 2010 by the varieties in this study (1860-2176 kg ha^{-1}) were well within the potential yields of 1800-2800 kg ha^{-1} of the improved varieties released for cultivation in Ghana (Adu-Dapaah *et al*., 2004, 2007).

There were no significant differences in pod and seed yields in both seasons among the plant densities. However, in the drier season of 2009, the highest plant density (33.3 plants m^{-2}) tended to increase pod and seed yields by 29-46 and 28-44%, respectively, over the lower plant densities; indicating that in drier seasons higher plant density might be an advantage in moisture conservation once crop canopy closure was achieved. In 2010, under favourable conditions this advantage was eroded, with the low (14.29 plants m^{-2}) and medium (16.67 plants m^{-2}) plant densities having only 4-7% greater pod and seed yields over the 20 and 33.3 plants m^{-2} densities. Naab *et al*. (2005) observed at Wa in the northern Guinea savanna zone of Ghana that the lowest pod and seed yields in groundnuts were obtained in lowest sowing density (8 plants m^{-2}) compared with medium (12 plants m^{-2}) and high (20 plants m^{-2}) sowing densities. There were no differences in pod and seed yields between the medium and high densities. They observed that sowing at the medium density increased pod yield by 8-10% when compared with the low sowing density. Ahmad *et al*. (2007) also reported 16% higher pod yield in narrow-row planting compared with traditional wide-row cropping. While, Roy *et al*. (1980) obtained optimum pod yield with plant density ranging from 18 to 30 plants m^{-2}, Mayeux and Maphanyane (1989) observed that the yields of a Spanish variety were highest at a density of 16.6 plants m^{-2} and lowest at 3.7 plants m^{-2}. Buchanan and Hauser (1980) similarly observed that the yield of peanuts increased as rows were narrowed from 80-40-20 cm. Thus yield increased with increasing population.

CONCLUSION

The study showed that the Nkosour variety performed better in terms of growth, development and yield in both seasons. The 33.3 plants m^{-2} (60×10 cm) plant density was found to be ideal for groundnuts under low rainfall situations, while under favourable rainfall conditions, the 16.67 plants m^{-2} (60×20 cm) and 20.0 plants m^{-2} (50×20 cm) plant densities impacted better on the groundnut varieties. It is therefore, recommended that, groundnut producers in the transitional agro-ecological zone could rely on Nkosour during the minor season production or under low rainfall conditions because the variety had high total pod and seed yield compared with Azivivi and Shitaochi. In the major season, Shitaochi or Nkosour may be selected but Nkosour could be preferred for its quality large-seed sizes and high haulm production for animal feed.

REFERENCES

Adu-Dapaah, H.K., J.Y. Asibuo, O.A. Danquah, H. Asumadu, J. Haleeguah and B. Asafo-Adjei, 2004. Farmer participation in groundnut rosette resistant varietal selection in Ghana. Proceedings of the 4th International Crop Science Conference, September 26-October 1, 2004, Brisbane, Australia.

Adu-Dapaah, H.K., H. Asumadu, J.N.L. Lamptey, J. Haleegoah and B. Asafo-Adjei, 2007. Farmer participation in groundnut varietal selection. Proceedings of the 18th African Crop Science Society Conference, Volume 8, October 27-31, 2007, El-Minia, Egypt, pp: 1435-1439.

Ahmad, N., M. Rahim and U. Khan, 2007. Evaluation of different varieties, seed rates and row spacing of Groundnut, planted under agro-ecological conditions of Malakand Division. J. Interacad., 9: 178-183.

Asiamah, R.D., T. Adjei-Gyapong, E. Yeboah, J.O. Fening, E.O. Ampontuah and E. Gaisie, 2000. Soil characterization and evaluation of four primary cassava multiplication sites (Mampong, Wenchi, Asuasi and Kpeve) in Ghana. Soil Research Institute (SRI) Technical Report No. 200, Kumasi, Ghana.

Bell, M.J. and G.C. Wright, 1998. Groundnut growth and development in contrasting environments. 2. Heat unit accumulation and photo-thermal effects on harvest index. Exp. Agric., 34: 113-124.

Bell, M.J., B. Harch and G.C. Wright, 1991. Plant population studies on peanut (*Arachis hypogaea* L.) in subtropical Australia. I. Growth under fully irrigated conditions. Aust. J. Exp. Agric., 31: 535-543.

Boote, K.J. and D.L. Ketring, 1990. Peanut. In: Irrigation of Agricultural Crops, Steward, B.A. and D.R. Nielson (Eds.). ASA/CSSA/SSSA, Madison, USA.

Boote, K.J. and L.C. Hammond, 1981. Effect of drought on vegetative and reproductive development of groundnut. Proceedings of the Meeting of American Peanut Research and Education Society, July 21-24, 1981, Savannah, Georgia.

Breisinger, C., X. Diao, J. Thurlow and R.M. Al-Hassan, 2008. Agricultural development in Ghana: New opportunity and challenges. International Food Policy Research Institute (IFPRI) Discussion Paper 00784. http://www.ifpri.org/publication/agriculture-development-ghana?print.

Brink, M. and G. Belay, 2006. Plant Resources of Tropical Africa (PROTA): Cereals and Pulses. Foundation and Buckhuys Publishers, Wageningen, Netherlands, pp: 20-25.

Buchanan, G.A. and E.W. Hauser, 1980. Influence of row spacing on competitiveness and yield of peanuts (*Arachis hypogaea* L.). Weed Sci., 28: 401-409.

Camberlin, P. and M. Diop, 1999. Inter-relationships between groundnut yield in Senegal, interannual rainfall variability and sea-surface temperatures. Theor. Applied Climatol., 63: 163-181.

Chin Choy, E.W., J.F. Stone, R.S. Matlock and G.N. McCauley, 1982. Plant population and irrigation effects on Spanish peanuts (*Arachis hypogaea* L.). Peanut Sci., 9: 73-76.

Christensen, J.H., J.E. Olesen, O.H. Feddersen, U.J. Andersen, G. Heckrath, R. Harpoth and L.W. Andersen, 2004. Application of seasonal climate forecasts for improved management of crops in Western Africa. Danish Climate Centre, Report No. 03-02, pp: 1-33. http://www.dmi.dk/dmi/dkc03-02.pdf

Cox, F.R., 1979. Effect of temperature treatment on peanut vegetative and fruit growth. Peanut Sci., 6: 14-17.

Craufurd, P.Q., P.V. Prasad and R.J. Summerfield, 2002. Dry matter production and rate of change of harvest index at high temperature in peanut. Crop Sci., 42: 146-151.

De Waele, D. and C.J. Swanevelder, 2001. Groundnut. In: Crop Production in Tropical Africa, Romain, H.R. (Ed.). DGIC, Belgium, pp: 743-763.

FAO, 1988. FAO/Unesco soil map of the world revised legend with corrections and updates. World Soil Resources Report 60 FAO, Rome. Reprinted with updates as Technical Paper 20, ISRIC, Wagenigen, pp: 140.

FAO, 2010. Crop production statistics. Food and Agriculture Organization of United Nations, Rome, Italy.

Kang, Y.K., M.R. Ko, N.K. Cho and Y.M. Park, 1998. Effect of planting date and planting density on growth and yield of soybean in Cheju island. Korean J. Crop Sci., 43: 44-48.

Lanier, J.E., D.L. Jordan, J.F. Spears, R. Wells and P.D. Johnson *et al*., 2004. Peanut response to planting pattern, row spacing and irrigation. Agron. J., 96: 1066-1072.

Leong, S.K. and C.K. Ong, 1983. The influence of temperature and soil water deficit on the development and morphology of groundnut (*Arachis hypogaea* L.). J. Exp. Bot., 34: 1551-1561.

Mayeux, A. and G.S. Maphanyane, 1989. Groundnut cultivation under low rainfall condition in Botswana. Proceedings of the 3rd Regional Groundnut Workshop for Southern Africa, March 13-18, 1988, Pantancheru, India, pp: 149-155.

McKenzie, B.A. and G.D. Hill, 1989. Environmental control of lentil (*Lens culinaris*) crop development. J. Agric. Sci., 113: 67-72.

Mercer-Quarshie, H., 1972. Effect of inter-ridge and within-ridge plant spacing performance of groundnuts (*Arachis hypogaea* L.) in North Ghana. Ghana J. Agric. Sci., 5: 103-109.

Naab, J.B., F.K. Tsigbey, P.V.V. Prasad, K.J. Boote, J.E. Bailey and R.L. Brandenburg, 2005. Effects of sowing date and fungicide application on yield of early and late maturing peanut cultivars grown under rainfed conditions in Ghana. Crop Prot., 24: 325-332.

Naab, J.B., K.J. Boote, P.V.V. Prasad, S.S. Seini and J.W. Jones, 2009. Influence of fungicide and sowing density on the growth and yield of two groundnut cultivars. J. Agric. Sci., 147: 179-191.

Ong, C.K. 1986. Agroclimatological factors affecting phenology of groundnut. Proceedings of the International Symposium on Agrometeorology of groundnut, August 21-26, 1985, Niamey, Niger, pp: 115-125.

Reddy, T.Y., V.R. Reddy and V. Anbumozhi, 2003. Physiological responses of groundnut (*Arachis hypogea* L.) to drought stress and its amelioration: A critical review. Plant Growth egul., 41: 75-88.

Roy, R.C., J.W. Tanner, O.E. Hatley and J.M. Elliot, 1980. Agronomic aspects of peanuts (*Arachis hypogaea* L.) production in Ontario. Can. J. Plant Sci., 60: 679-686.

SAS, 2010. SAS/STATS User's Guide. Statistical Analysis System Institute, Cary, NC., USA.

Schilling, R. and R. Gibbon, 2002. Groundnut. Macmillan Education Ltd., London, UK.

Squire, G.R., 1990. The Physiology of Tropical Crop Production. CAB International, Wallingford, UK., Pages: 236.

Summerfield, R.J., E.H. Roberts, R.H. Ellis and R.J. Lawn, 1991. Towards the reliable prediction of time to flowering in six annual crops. I. The development of simple model for fluctuating field environments. Exp. Agric., 27: 11-31.

Wallace, D.H., K.S. Yourstone, J.P. Baudoin, J. Beaver, D.P. Coyne, J.W. White and R.W. Zobel, 1995. Photoperiod and temperature interaction effects on the days to flowering of beans (*Phaseolus vulgaris* L.). In: Handbook of Plant and Crop Physiology, Mohammad, P. (Ed.). Marcel Dekker, New York, USA., pp: 863-891.

Weiss, E.A., 2000. Oilseed Crops. Blackwell Science, London, Pages: 364.

Wilson, D.R. and M. Robson, 1996. Pea phenology responses to temperature and photoperiod. Proceedings of the 8th Australian Agronomy Conference, 30 January-2 February, 1996, The University of Southern Queensland, Toowoomba, Queensland, pp: 590-593.

Wright, G.C. and M.J. Bell, 1992. Plant population studies on peanut (*Arachis hypogaea* L.) in subtropical Australia. 3. Growth and water use during a terminal drought stress. Aust. J. Exp. Agric., 32: 197-203.

Zeyong, X., 1992. Groundnut production and research in East Asia in the 1980s. Proceedings of International Workshop on Groundnut-A Global Perspective, November 25-29, 1991, Patancheru andra Pradesh, India, pp: 157-165.