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RESPONSE OF BAMBARA GROUNDNUT (*Vigna subterranea* (L) Verdc.) LANDRACES TO PLANT DENSITY AND PHOSPHORUS APPLICATION

BY

KINGSLEY OFORI GYIMAH

MARCH, 2013.

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THESIS SUBMITTED TO THE DEPARTMENT OF CROP AND SOIL SCIENCES, FACULTY OF AGRICULTURE OF THE COLLEGE OF AGRICULTURE AND NATURAL RESOURCES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN AGRONOMY.

BY

KINGSLEY OFORI GYIMAH

MARCH, 2013.

DECLARATION

I hereby declare that this thesis is original and is my own composition under supervision, and that it has neither been produced wholly nor partially for the award of any degree in this University or elsewhere.

Materials from other authors which have served as source of relevant information have been duly acknowledged.

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DEDICATION

This thesis is dedicated to the Almighty God for seeing me through this programme, my wife Esther Boakyewaa and my lovely sons Kofi Ofori-Antwi, Kwaku Ofori-Gyimah and Kwadwo Kwarteng Ofori-Gyimah.

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ABSTRACT

Field experiment was conducted at the Plantation section of the Department of Crop and Soil Sciences at the Kwame Nkrumah University of Science and Technology, Kumasi ($6^o 43^/$ N, $1^o 36^/$ W) in the forest zone of Ghana, during the major season (May – September), 2008 to study the response of two bambara groundnut (*Vigna subterranea* (L) verdc.) landraces to population density and phosphorus application.

The experimental design was a 2 x 3 x 3 Factorial in a randomized complete block design (RCBD). Two bambara groundnut landraces (Mottled cream and Nav 4), 3 fertilizer rates (0, 20 and 40 kg P_2O_5/ha) and 3 plant population densities (30cm x 30cm, 30cm x 40cm and 30cm x 50cm) were randomized in three blocks to give a total of fifty-four (54) plots.

The two varieties differed in their growth and yield components. Mottled Cream emerged earlier, flowered and reached maturity earlier than Nav 4. It also had greater 100-seed weight. NAV 4 recorded greater canopy spread and produced more shoot dry matter, pods per plant, greater pod dry weight and higher yield than mottled cream.

Population density had significant effect on some growth functions such as leaf area index, crop growth rate, relative growth rate, net assimilation rate and seed yield with the densest stand of 11 plants/m^2 (30cm x 30cm) producing the highest values.

The results showed that phosphorus application did not have any significant influence on growth and yield components of bambara groundnut probably due to initial medium P levels in the soil.

Following the responses of the landraces to the varying growth and yield components, it was observed that the performance of NAV 4 was significantly higher than Mottled Cream. It was also observed from the results that population of 11 plants m^{-2} is the best among the three population densities in both growth and yield characters.

It is therefore recommended that farmers cultivate NAV 4 using plant density of 11 plants/ m^2 in both subsistence and commercial farming in order to achieve maximum yield to contribute to food security in the country.

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LIST OF ABBREVIATIONS

CGR	Crop Growth Rate
CRI	Crop Research Institute
CSIR	Council for Scientific and Industrial Research
DAP	Days After Planting
DAS	Days After Sowing
FAO	Food and Agriculture Organization
IITA	International Institute of Tropical Agriculture
KNUST	Kwame Nkrumah University of Science and Technology
LAI	Leaf Area Index
LSD	Least Significant Difference
NAR	Net Assimilation Rate
NAS	National Academy of Sciences
NAV 4	Navrongo number 4
RCBD	Randomized Complete Block Design
RGR	Relative Growth Rate

CHAPTER ONE

1.0 INTRODUCTION

Owing to the poverty in Africa, most people are malnourished especially those in the sub-Saharan region. This is due to the fact that most people are not able to afford animal protein which is expensive. There is, therefore, the need to identify and make maximum use of crops that are able to supply protein and other nutrients at a very low or cheap cost. One of such crops which provide adequate amounts of protein and carbohydrate and also easy to cultivate but has been neglected is bambara groundnut (Azam-Ali, 2005). It can be a good substitute for animal protein. "Increasing the yields of Bambara groundnut is a very good solution to food security and sustainability since it can do well in hostile environment and also yield. This is the quality that can rarely be obtained in most major crops" (Azam-Ali, 2005).

Bambara groundnut (*Vigna subterranea* (L) verdc.) originated in the dry savannas in the North of Nigeria and Cameroon (Bandoin and Mergeai, 2001). It is a legume indigenous to tropical Africa and is mainly cultivated by subsistence farmers in semi-arid regions, mostly by women (Rachie, 1999).

It is the third crop after groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* (L) Walp) (Sellschop, 1962) in most of the semi-arid regions of Africa. In addition to sub-Sahara Africa, it is now found in many parts of South America, Asia and Oceania (Bandoin and Mergeai, 2001). It has an annual, bunchy or trailing habit. The leaf has three leaflets. It also has yellowish-white flowers which grow in pairs. The pods are round which usually have one seed and the seeds are round and of many colours (Williams *et al.*, 1980).

Bambara groundnut is a hardy crop particularly well suited to the growing conditions found in the savanna regions with a Sudanese and Sudano-Guinean climate (Bandoin and Mergeai, 2001). It does well in a hot climate and does better than most other bean crop in poor soils. It also grows best with moderate rainfall and sunshine (Williams *et al.*, 1980).

Bambara groundnut seeds are admired by peasant farmers in sub-Sahara Africa for its nutritional value. The ripe seeds contain on average 10% water, 15-20% protein, 4-9% fat 50-65% carbohydrates and 3-5% fibre (Bandoin and Mergeai, 2001; NAS, 1979). Although bambara groundnut seeds are not known on the world markets, they play an important role in the diet (nutrition) of people in most West African countries.

The immature seeds of bambara groundnut are eaten fresh or roasted. The mature seeds are usually boiled after soaking in water for some time. They can also be ground into flour for use in soups, purees, porridge and flats cakes (Bandoin and Mergeai, 2001). According to Doku (1996), bambara groundnut was canned in Ghana and competed very favourably with Heinz baked beans (Doku, 1996).

Although bambara groundnut is a favoured crop and mainly cultivated by peasant farmers in West Africa, there has not been enough information on the right planting distance or spacing which will help the farmer achieve the maximum yield of the crop. Studies from different parts of Africa report large variations in seeding rates (Linnemann, 1992). Optimum population density or spacing can lead to an increase in yield. Dunbar (1969) indicated that farmers sow bambara groundnut at an average spacing of 30cm x 30cm in north-western Tanzania.

Moreover, though, it has been reported that the crop in a hardy plant which is suited to the growing conditions in savanna regions and even in soils poor in plant nutrients, sufficient phosphorus availability is essential for root and pod formation and hence increase in yield (Wassermann *et al*., 1983).

However, reports on the response of bambara groundnut to phosphorus application are contradictory. Research conducted in some African countries has failed to show any response of bambara groundnut to phosphorus application at rates up to 336kg/ha and sometimes yields were depressed (Nnandi *et al.*, 1981; Goli and Ng, 1988; Musonda, 1988). There is little or no information on the responses of bambara groundnut to phosphorus application in Ghana, yet it is a popular crop especially in the Northern part of the country. It is even reported that P content in the soils of most West African countries and for that matter Ghana is considerably low (Doku, 1996).

Therefore, it is the objective of this study to:

i. determine the optimum population density for the growth and yield of bambara groundnut landraces.

ii. identify the phosphorus level for the optimum growth and yield of the landraces.

iii. determine the interactive effect of spacing and phosphorus on the growth and yield of bambara groundnut landraces.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Taxonomy and Origin of Bambara Groundnut

Bambara groundnut is of the family *Leguminosae*, and subfamily *Papilionoideae*. The crop is first mentioned in the 17^{th}–century literature (Marcgrav de Liebstad, 1648). In 1763, Linnaeus described it in species *Plantarum*, and named it *Glycine subterranea*, in accordance with his system of nomenclature. Du Petit-Thouars (1806) found the crop in Madagascar, under the vernacular name "Voanjo; subsequently written as Voandzou' in French. He then proposed the name *Voandzeia subterranea* (L) Thouars, which was widely used by subsequent researchers for over a century. Detailed botanical studies were undertaken by Marechal *et al.* (1978), who found great similarities between Bambara groundnut and plant species of the genus *Vigna*. This confirmed studies by Verdcourt (1980), who seized the opportunity in 1980 to propose the current name *Vigna subterranea* (L) Verdc. (Goli, 1997). The crop has many common names such as Congo groundnut, Congo gobber, Madagascar groundnut, earth pea, njugobean (South Africa), Voandzou, nzama (Malawi) and underground bean (Stephens, 2003).

Bambara groundnut originated in the dry savannas in the north of Nigeria and in Cameroon. It has been widely cultivated in tropical regions since the 17^{th} century. In addition to sub-Saharan Africa, it is now found in many parts of South America, Asia and Oceania (Bandoin and Mergeai, 2001).

Hepper's (1970) observations about wild bambara groundnut confirmed a view that was generally held that areas of North Yola in North east Nigeria and Garoua in Northern Cameroon are the centers of origin.

Also, according to Brink and Belay (2006), the centre of origin of bambara groundnut is probably North-eastern Nigeria and northern Cameroon. It is found in the wild from central Nigeria eastwards to southern Sudan, and is now cultivated throughout tropical Africa, and to a lesser extent in topical parts of the Americas, Asia and Australia.

2.2. Botany of Bambara groundnut

Bambara groundnut occurs in both erect and prostrate types. It flowers within 43 days with maximum yields of between 2080 kg/ha and 2400 kg/ha of pod (Marfo, 1992). It is an annual creeping or erect herb with branching stems growing to heights of 20-30cm. The leaves are pinnate trifoliate on long erect petioles (Marfo, 1992). Toungos *et al*. (2004) recorded a grain yield of 1024 kg/ha in their work at Adamawa in Nigeria.

Following self-fertilisation, the peduncle of the flower grows downward, and the developing pod is buried in the soil. The mature pods vary from 1 to 3cm in length containing one to two seeds, which may be spherical or elliptical 7-15cm in diameter (Yamaguchi, 1983). The crop matures 100-150 days after planting.

The duration of the crop cycle of Bambara groundnut is between 100 and 180 days, unshelled pods may be used for seeding but as a rule only the seeds are used. The proper cultivation on the flats seems to give the best result, but the plant can also be grown on mounds, ridges and beds. The best yields are obtained when Bambara groundnut is grown in a pure stand, although it is often intercropped with cereals (millet, sorghum or maize), tuber crops (yam, sweet potato or cassava), traditional vegetables and other legumes (Bandoin and Mergeai, 2001).

Stem branching begins very early, about one week after germination, and as many as 20 branches may be produced and each branch is made up of internodes. The plant has a well developed tap root with profuse geotropic lateral roots. The roots form nodules for nitrogen fixation in association with appropriate Rhizobia. Leaf and flower buds arise alternately at each node (Doku and Karikari, 1971).

The flowers are usually yellowish-white or bluish and grow in pairs (William *et al.*, 1980). Matured pods are indehiscent, often wrinkled, ranging from a yellowish to a reddish dark brown colour. Seed colour also varies from white to creamy, yellow brown, purple, red or black. Various testa patterns are found including mottled, blotched or striped (Goli, 1997).

2.3 Uses of Bambara Groundnut

Bambara groundnut is grown mainly for its edible protein and not as an oil crop. When dried, the seeds are very hard and can only be eaten when ground into flour. Unripe seeds can be eaten fresh but matured seeds have to be soaked before eating (Gibbon and Pain, 1985). Bambara seeds play an important role in traditional festivities or ceremonies e.g. funeral rites. Mature dry seeds are boiled and eaten as pulse. They can also be ground into flour sometimes after roasting to prepare porridge (Brink and Belay, 2006). Immature seeds are boiled and eaten as snack. Seeds are also used as animal feed for pigs and poultry and stover used as fodder. As medicinal treatment, leaf preparations are applied on diseases and infected wounds in Senegal with the leaf sap applied to the eyes to treat epilepsy. The roots are also taken as aphrodisiac (Brink and Belay, 2006).

Bambara groundnuts are grown for their edible seeds which are used as a nutritious pulse and not as oil-seed. The fresh seeds are eaten in an unripe state or the pulse after soaking and boiling, as the dried seeds are very hard. The dried seeds are sometimes roasted and ground into flour (Purseglove, 1968).

Although Bambara seeds are not sold on world market, they play an important role in the diet of people in several West African countries (Nigeria, Ghana, Togo and Benin) where they are the second most important commodity after cowpea and groundnut in the national production and consumption statistics (Bandoin and Mergeai, 2001). Adu –Dapaah *et al.* (2006) observed that colour and grain size were major preference by Bambara groundnut consumers with white or cream colour and big size being preferred in the transition and Guinea Savanna agro-ecological zones.

Bambara groundnut is eaten in various ways, depending on the region. Before maturity, the seeds are eaten fresh or roasted. At maturity, they are usually boiled after soaking in water. They can also be processed into flour for the use in soups, purees and flat cakes. The canning of Bambara seeds in sauce has been reported in Ghana (Bandoin and Mergeai, 2001).

The crop has been described by Azam-Ali *et al*. (2001) as an underutilized crop. They reported that despite the several years of cultivation of the crop, Bambara groundnut is still cultivated from landraces rather than varieties bred specifically for particular agro-ecological condition or production systems. The crop has been described as a 'poor man's' crop which is cultivated mainly for subsistence (Azam-Ali *et al*., 2001).

The performance of any crop is dependent on its genetical attributes, environment and the interaction between the two. In view of this, it is important that the crop makes efficient use of all the production factors such as nutrients, light, water and carbon dioxide under conditions of optimum ambient temperatures in order to achieve maximum yield (Arnon, 1972).

2.4 Nutritional Composition of Bambara groundnut

Nutrition is one of the basis upon which a crop is valued. Bambara groundnut is a leguminous crop which is rich in protein and other nutrients. According to Bandoin and Mergeai (2001), the ripe seeds of Bambara contain on average 10% water, 15-20% protein, 4-9% fat, 50-65% carbohydrate and 3-20% fibre. Linnemann (1992) reported that, works on the chemical composition and nutrition of bambara groundnut indicated that lysine is relatively high while methionine and calcium are low. Brink and Belay (2006), indicated that the raw immature Bambara groundnut seeds contain per 100 g edible portion : water 57.3 g, energy 152 kcal, protein 7.8 g, fat 3.1 g, carbohydrate 30.0 g, fibre 3.0 g, ash 1.8 g, calcium 14 mg, phosphorus 258 mg and iron 1.2 mg . They again stated that, the matured dry seeds per 100 g contains; 10.3 g water, energy 367 kcal, protein 18.8, fat 6.2 g, carbohydrate 61.3 g, fibre 4.8 g, ash 3.4 g, Ca 62 mg, P 276, and Fe 12.2 mg.

Bambara groundnut seeds are favoured for their nutritional value and versatility. The mature kernels are rich in protein (16-22% DM) and carbohydrate (42-60% DM) but are low in lipid

(5-6% DM) (Poulter and Caygill, 1980; Aykroyd and Doughty, 1982; Deshpande and Damodaran, 1990; Brough and Azam-Ali, 1992).

The composition of mature dry seeds per 100 g edible portion is: water 10.3 g, energy 1537 KJ (367 kcal), protein 18.8 g, fat 6.2 g, carbohydrate 61.3 g, fiber 4.8 g, ash 3.4 g, Ca 62mg, P 276 mg, Fe 12.2 mg, B-carotene 10 ug, thiamin 0.47 mg, riboflavin 0.14 mg, niacin 1.8 mg and ascorbic acid traces (Leong and Ong, 1983). The content of essential amino acids per 100g food is : tryptophan 192 mg, lysine 1141 mg, methionine 312 mg, phenylalanine 991 mg, threonine 617 mg, valine 937 mg, leucine 1385 mg, and isoleucine 776 mg (FAO, 1970). Dried leaves for fodder contain crude protein 15.9%, crude fiber 31.7%, ash 7.5% and fat 1.8%.

Gibbons (1994) also made similar analysis of the chemical composition of some landraces of bambara groundnut as follows: protein content varied from 8.2 to 16.6%; carbohydrate from 51.2to 57.0%; fat from 5.5 to 6.8%; fibre from 5.5 to 6.4% and ash from 3.2 to 4.0%. He also observed that different landraces were high in mineral content (mg/100g), with the following ranges: Ca 95.8-99; K 1144.7-1435.5 and Na 2.9-10.6. The dark seeded landraces (red and black) tended to have higher nutrient and mineral contents than the light seeded ones (cream and white). The ratio of saturated: unsaturated fatty acid is 1:2 (Brink and Belay, 2006).

Ijarotumi and Esho (2009) in their study on nutritional and mineral composition of bambara groundnut also reported that processed Bambara groundnut contains: fat 6.02-6.57g/100g; protein 20.00-20.49g/100g; ash 1.17-3.46g/100g; carbohydrate 65.82-68.74g/100g and energy 400.2-412.18 kcal. Calcium ranged between 14.12-18.26 mg/100g, potassium 57.61-80.62 mg/100g, magnesium 50.47-69.34mg/100g and phosphorus 164.73-187.13mg/100g.

2.5. Soil and Climatic Requirements of Bambara groundnut

The crop does well on soil in hot, dry regions that are marginal for groundnuts and other pulses, for example the savanna ochrosols of Africa. Production can occur under rainfall of 600-700mm per annum but optimum growth occurs with 900-1200mm per annum (Gibbon and Pain, 1985).

According to Bandoin and Mergeai (2001), average daily temperatures between 20^0C and 28^0C are best suited for the crop. In its production regions, the rainfall amount varies between 600 and 1500mm. The plant is said to be less susceptible than groundnut to water stress and mineral deficiency in the soil. While it can adapt readily to a wide range of soils, it prefers sandy, well drained soils (Bandoin and Mergeai, 2001). Bambara groundnut is a typical short day plant which thrives under hot climate conditions. It is very drought resistant but for good yields it requires moderate rainfall of 750-1000mm during the rainy season (Tweneboah, 2000). The crop is also adapted to a wide range of soils especially light loams and sandy loams, and because it is native to Africa, it can grow in a hot climate. It does better than most other bean crops in poor soils and grows best with moderate rainfall and sunshine.

Ocran *et al.* (1998) reported that bambara groundnut is adapted to warm conditions (20-28^{o}C) with abundant sunshine, that is climate suitable for growing groundnut or sorghum. It is the most drought resistant of all the grain legumes and may be found growing successfully where annual rainfall is 500mm. Optimum rainfall is 900-1000mm/year. It also tolerates very poor soils, thriving on sands too exhausted to groundnut. Brink and Belay (2006) observed that bambara groundnut is cultivated in the tropics at altitudes up to 2000 m. A frost free period of at least 3 months is necessary. Average temperatures of 20-28^{o}C and full sun are preferred. The crop tolerates drought and is cultivated successfully in areas with an average annual rainfall of 600-750 mm.

It is reported that optimum yields are obtained when rainfall is higher (900-1200 mm/year). It is also grown in humid conditions, for example in northern Sierra Leone, where the annual rainfall exceeds 2000 mm. Podding may also be delayed by drought (Brink and Belay, 2006). Brink and Belay (2006) confirmed that bambara groundnut can be grown on any well drained soil but light sandy loams with a pH of 5.0-6.5 are most suitable. Soil rich in P and K are suitable, but calcareous soils are not. N-rich soils promote vegetative growth at the expense of seed yield. Sandy soils enhance pod penetration into the soil but nematode incidence is generally higher on sandy than on loamy soils. Subsistence farmers claim that in years when groundnut fails due to low rainfall, bambara groundnut produces good returns (Linnemann, 1990). When bambara groundnut was under drought for over 100 days it was still able to produce at least some pod yield (Collinson *et al.*, 1999). In relative terms, bambara groundnut appears to maintain a greater supply of water to root which is a strategy that has clear advantages when water is scarce (Nyamudeza, 1989). Its tolerance of drought and ability to provide at least some yield on the poorest of soil makes it ideal for marginal areas where low input agriculture is the norm.

2.6 General effects of spacing on crops

An essential aspect of crop production is spacing (population density) and its effects on growth and yield. The reason being that in any environment there is an optimum density for crop yield beyond which no significant increase would occur with further increases in density.Several researchers have attempted to establish quantitative relationships between plant population density and crop yield. Holiday (1960) studied the relationship between crop density and yield of soybean and observed two relationships:

a) an asymptotic relationship, where yield rises to a maximum and then remains constant with further increases in density, and

b) a parabolic relationship, where yield rises to a maximum and then declines with increase in density.

Crops are spaced to obtain maximum yields of suitable quality. A moderate amount of competition between plants is not detrimental on an area basis. Competition increases with the density of the plant population. Excessive populations often reduce the yield of seeds, while stimulating vegetative growth (Raemaekers, 2001).

Raemaekers (2001) reported that sugar beet may respond to additional space from a missing plant, increasing in weight enough to compensate for 96 percent of the loss. He again observed that close spacing in flax reduces the growth of plants significantly. As the space between plants increases, there is an increase in number of bolls, yield per plant, weight per plant and stem per plant. Raemaekers (2001) further observed that, in sorghum within certain limits, medium-thick planting makes the plants taller because of greater competition for light. Thick stands make the plants shorter because of adequate moisture or nutrients to support a good growth in so many plants. In terms of seeding rate, Raemaekers (2001) observed that, the goal of seeding rate is to match leaf area to an expected water supply. Seeding rate is usually higher in narrow row spacing than in wider (Raemaekers, 2001).

If plant population is too low, there are fewer plants to contribute to yield and weeds will be a greater risk, grain quality is only slightly affected by usual variations in seeding rate. Within normal populations, fewer plants will result in more production per plant, and more plants will result in less production per plant (Raemaekers, 2001).

At higher populations, corn will produce fewer kernels per ear, soybean will produce fewer pods and seeds per pod, smalls grains will tiller less and cotton will produce fewer bolls. In flax, differences in plant spacing show no consistent influence on the oil content of the seed. In cotton, higher population may contribute to decrease size of boll (Raemaekers, 2001).

2.6.1 Effects of spacing (population density) on the yield of Bambara groundnut

Willey and Heath (1969) established that total dry matter yield conforms to the asymptotic relationships, while the economic yield, that is grain or seed yield conforms to the parabolic relationship. Crop yield increases in direct proportion to increase in plant density when there is hardly any interplant competition owing to wider spacing, but at high densities which exacerbate interplant competition, yield decreases with increasing density (Funnah and Matsebula, 1985; Egli, 1988). Dunbar (1969), reported a reduction in the number of pods at high densities, and attributed it to a reduction in the number of nodes on both the main stem and the branches as plant density increased.

Bambara groundnut response to population density also varies with location and cropping systems. At Chitala in Malawi, a population density of 167,400 plants/ha gave the highest yield while in Thuchila, also in Malawi high yields were obtained at a lower population density of 83,720 plants/ha (Malawi Agriculture Research Council, 1975, cited by Linnemann, 1992). Matelerkamp (1988) also reported that under conditions of moisture, high population density can depress yield.

Funnah and Matsebella's (1985) work showed that grain yield depended on both the plant density and the planting pattern. They observed that 60 cm x 15 cm spacing gave a significantly higher grain yield than 30 cm x 30 cm even though they had the same plant density. Willey and Heath (1969) have reported that crops generally give the highest yields at equidistant spacing. According to Willey and Heath (1969), square planting, which ensures equal distances from neighbours in both directions, give higher yields at any given plant density than rectangular planting. Willey and Heath (1969) further emphasized that at high densities cultivars with narrow leaves respond better to square planting because of their efficiency in light interception.

According to Brink and Belay (2006) dry matter production of bambara groundnut is low, so high plant densities are recommended. However, high densities are only possible where rainfall and soil fertility are adequate. Bandoin and Mergeai (2001) also observed that the best yield is obtained when bamabara groundnut is grown in a pure stand with row spacing of 10-45 cm with an inter row spacing of 15-75 cm. The normal planting distance is 30-60 cm between ridges or rows and 30 cm or less within the rows (Tweneboah, 2000). Some few researchers have also quoted different planting distances which have not been able to maximize yield, for instance Bandoin and Mergeai (2001) observed that recommended row spacing is usually 10-45 cm, with an inter row spacing of 15-75 cm. Ameyaw and Doku (1983) recommended a spacing of 60 cm x30 cm in West Africa. Dunbar (1969) indicated that farmers sow bambara groundnuts at an average spacing of 30 cm x 30 cm in Tanzania. The cumulative number of flowers produced per plant was affected by plant population with the number decreasing with increase in population. Tanimu (1988) reported that intra row spacing affected grain yield and that a 5cm intra-row spacing resulted in the best grain yield in his research.

2.6.2 Effects of spacing on Leaf area

Mkandawire and Sibuga (2002) observed highest leaf area index values at a population density of 66 plants/m^2. Leaf area index was also found to increase with population density. The increase in LAI with increase in plant density, however, did not necessarily result in high yields. However, according to Rassel (1960) planting density is usually low in farmers' fields, especially when crops are not in rows. In experimental plots, recommended plant density ranged from 6 to 29 plants/m^2. Crops with larger plants are planted at lower rates than smaller plants. Varieties and hybrids that tiller or branch more are planted at lower rates than ones that tiller or branch little (Martin *et al*., 2006).

If plant population is too high, plants will be tall, spindly, and more susceptible to lodging. Yields may decrease because not only does lodging make harvest difficult resulting in greater harvest loss, but it also disrupts the leaf canopy, often limiting grain development and yield (Martin *et al*., 2006).

2.6.3 Effect of population density on pod yield

Mkandawire and Sibuga (2002) reported that increasing the plant population density reflected negatively on pod yields. They observed that during the short rains, 9 plants/m^2 produced the highest pod yields, while at 66 plants/m^2 pod production was generally lowest regardless of type of seedbed. However, during the long rains the optimum population density for pod yield was 22 plants/m^2 on the flat seedbed with no apparent yield advantage due to increase in plants density to 66 plants/m^2. Grain yield followed a similar trend for the long rain season crop, but in the short rains, grain yields were significantly higher for 9 or 13 plants/m^2. Similar pod yield decreases have been reported in other studies. For instance, Cumberland (1978) reported high pod yield of Bambara groundnut at population densities of 7 and 14 plants/m^2. Eliesen and Freira (1992) working with groundnuts and Edje *et al.* (1971) with beans reported a decrease in number of pod plants^{-1} with increase in plants population.

Usually, with increase in plant density, the combined demand for nutrients and light results into competition for these resources unless the supply is either unlimited or has been somehow supplemented. As plant population is increased interplant competition comes into effect and probably causes decline in pod yields.

The higher grain yields for the long rain season crop compared to the short rains season crop is attributed to increased pod production and enhanced grain filling for the long rain season (Mkandawire and Sibuga, 2002). Sessey and Yarmah (1996) observed that high plant population sometimes leads to a decrease in pod production, when they reported that high plant population of 33 plants m^{-2} resulted in poor reproductive yield. The number of pods and shoot dry matter production expressed on a per plant basis, generally declined with increase in plant population for certain landraces. Also on a unit area basis, dry matter production and yield increased with an increase in plant population (Sessey and Yarmah, 1996). They reported that sowing at populations higher that 25 plants m^{-2} may be detrimental to productivity per unit area.

2.6.4. Effect of Spacing (population density) on harvest index

According to Mkandawire and Sibuga (2002) on the basis of harvest index (HI) value, the plant density of 22 plants m^{-2} was most productive for seed especially on the flat seedbed. They observed that in the short rain season, lowest plant densities of 9 and 13 plants m^{-2} recorded seed harvest index (HI) values of 59.9 and 62.5 respectively, and these were significantly the highest. Mkandawire and Sibuga (2002) observed that a sparse stand will use the store of water in the soil more rapidly than a dense stand and will therefore have a greater partition factor for grain. Thus under dry conditions, the HI usually increases as the plant population density decreases. According to Mkandawire and Sibuga (2002), plant densities of 9 and 13 plants m^{-2} were significantly more productive than at higher densities during the short rains, and also the intermediate density of 22 plants m^{-2} was significantly more productive than plant densities below or above this level in the long rains.

Mkandawire and Sibuga (2002) observed that during the short rains when total precipitation was low, sowing at not more than 13 plants m^{-2} was recommended for the long rain season crop.

2.7 Effect of phosphorus on the growth and yield of bambara groundnut

Phosphorus has many roles in plant growth and metabolism. It helps in energy transfer, essential for photosynthesis, formation of nodules, synthesis of enzymes, protein and carbohydrates. It is also important for the formation of seeds and tubers and also necessary for root development. It speeds up plant maturity and helps to resist stress (Borget, 1997). The removal of phosphorus is low but the response to phosphate application is practically always positive. On groundnut, 20 to 60kg/ha P_20_5 is recommended as it is also on asparagus bean and cowpea (Borget, 1997).

Brady and Weil (1996) emphasized on the importance of phosphorus. They stated that neither plants nor animals can grow without phosphorus. It is an essential component of the organic compound often called the energy currency of the living cell, ATP. For most plant species the total phosphorus content of healthy leaf tissue is usually between 0.2% and 0.4% of the dry matter.

It has also been observed that adequate phosphorus nutrition enhances many aspects of plant physiology, including the fundamental processes of photosynthesis, nitrogen fixation, flowering, fruiting and maturation (Brady and Weil, 1996). Root growth, particularly development of lateral root and fibrous rootlets is encouraged by phosphorus. In cereal crops, good phosphorus nutrition strengthens structural tissues such as those found in straw or stalks, thus helping to prevent lodging.

Improvement of crop quality especially in forages and vegetables is another benefit attributed to phosphorus (Brady and Weil, 1996). Phosphorous is needed in cell division, in the formation of fat, in the transformation of starch to sugar, in seed germination, fruiting and flowering and in- fact in every phase of plants vital processes (Sauchelli, 1965).

Bell *et al.* (1987) reported that sandy soils are liable to be low in phosphorus, but as phosphate fixation and crop removal on such soils are generally low, only low rates of phosphorus application are required. Because of higher rates of fixation, Oxisols and oxidic ultisols require higher rates of phosphorus application. Mycorrhizal fungi can improve the uptake of phosphorus and other elements, for example zinc even at a higher levels of applied phosphorus. In terms of yield, Linnemann (1992) observed that in the majority of cases, yields were depressed after fertilizer application, or there was no response and in very few cases, yields improved after K application. The natural supply of phosphors in most soils is small, and the availability of that which is present is very low (Brady and Weil, 1996).

However, phosphorus plays very important role as far as the growth of the plant is concerned. It enhances flowering, fruiting including seed production and maturation. It also helps in root growth, particularly development of lateral roots and fibrous rootlets (Brady and Weil, 1996). Different researches have come out with different observations on the application of P and the response of bambara groundnut to phosphorus. Tanimu and Yayock (1990) observed that application of 11-22kg P/ha was found to significantly increase the grain yield and the yield characters of the crop. Johnson (1968), also recommended the use of 112-170kg P_20_5/ha.

Tanimu and Yayock (1990) observed that, the bambara groundnut yield response to phosphorus observed at Samaru may have been a result of the low available phosphorus in the soil or the high phosphorus required for the various physiological processes in the crop.

2.7.1 Effect of phosphorus on shoot, root and nodule growth

According to Ramolemana *et al.* (1997) there was no significant phosphorus and phosphorus X moisture interaction effect on shoot growth of bambara groundnut. This was observed in their work on the response of bambara groundnut to phosphorus with or without irrigation.

They also reported that phosphorus application did not affect bamabara shoot growth in their experiment.

Wassermann *et al*. (1983) in South Africa reported an increase in shoot dry matter with a phosphorus rate of $30kgha^{-1}$ from a field and a pot experiment.

Ramolemana *et al.* (1997), however, observed that there were significant phosphorus x moisture interaction effects at 28 DAS and a significant phosphorus effect at 49 DAS on root growth. There was no significant phosphorus effect at 78 DAS. Phosphorus application was reported to increase root and shoot growth of other leguminous crops such as cowpea (Othman *et al.* 1991), Soybean (Israel, 1987) and Centrosema species (Cadisch *et al.,* 1992).

On nodule growth, Ramolemana *et al.* (1997) observed no significant phosphorus effect on nodulation at 28 DAS and there was no phosphorus x irrigation effect at any growth stage. But at 49 DAS an increase in phosphorus rate significantly increased nodule weight. From the above observation, there seemed to be a high demand for phosphorus by the plant between 28 and 49 DAS which resulted in increased nodulation. The effect of phosphorus application on nodulation was not observed at 28 DAS, despite increased root growth. Probably the increased availability of phosphorus to roots at early stages of growth may have resulted in increased nodule growth by 49 DAS. Alternatively, this could be the important stage of nodule growth when phosphorus demand is high. Israel (1987) reported that the phosphorus requirement for nodulation was high compared to that for plant growth.

2.7.2 Effect of phosphorus on pod yield and grain yield

Work on the response of bambara groundnut to phosphorus with or without irrigation, showed no significant phospohorus or phosphorus X moisture interaction effects on pod dry weight (Ramolemana *et al.,* 1997). They established further that there were no significant phosphorus and phosphorus X irrigation interaction effects for total seed yield and average weight per seed.

Ramolemana *et al.* (1997) concluded that their results have not shown a phosphorus requirement for shoot growth and yield. However, there seemed to be a phosphorus requirement for root and nodule growth, which did not translate into increased plant growth and yield. Probably the low soil pH of 4.6 limited the availability of the applied phosphorus, and organs such as root and nodules with high phosphorus demand perhaps were given priority.

Tanimu (1988) reported that application of 11 kg P/ha gave significantly higher yields than 33 kg P/ha, but was at par with 22 kg P/ha and the control. In a separate experiment, the application of 22kg P/ha resulted in higher grain yield than the other phosphorus levels, which were at par. They established that the application of 11-22 kg P/ha was found to significantly increase yield of grains and the yield components of bambara groundnut during their study. This corroborates the findings of Johnson (1968) who recommended the use of 112-170 kg P_2O_5/ha on bambara groundnut.

Cumberland (1978) and Nnandi *et al.* (1981) registered no response with application of up to 33kg P_2O_5/ha. In some cases, phosphorus application even decreased yield (Anonymous, 1998). In a greenhouse trial, Tanimu (1988) observed that rates and sources of phosphorus did not significantly affect the phosphorus content and phosphorus uptake of bambara groundnut. Tanimu (1988) discovered that in 1986, 1987 and 1990 phosphorus application did not cause significant differences in the 100-grain weight of the crop. The expected grain yield response to phosphorus levels showed that all the years, a quadratic response gave the best fit.

2.7.3 Organic and inorganic fertilizer requirement

Nitrogen needs of Bambara groundnut may be met by symbiotic nitrogen fixation. Nitrogen-fixation rates of up to 100kg/ha has been reported, but sufficient phosphorus availability is essential for nodulation. The use of animal manure or chemical fertilizers is not common. Research in Botswana has shown that under the prevailing conditions nitrogen fertilization is not advisable, whereas phosphorus application is only beneficial when it is done close to the seedlings within 2weeks of sowing and when the soil during this period is moist. Soils rich in phosphorus and potassium are suitable but calcareous soils are not (Brink and Belay, 2006). According to Tweneboah (2000) the crop is able to meet its nitrogen requirements but it is known to respond favorably to application of about 250kg/ha of single super phosphate applied before planting, although the economics of fertilizing the crop, in view of its subsistence level, needs to be worked out.

Response to K is generally positive, but variable according to soil type. The recommended application for groundnut and cowpea is from 30 to 50kg, K_2O/ha. Potassium aids grain formation and increases yield in soya (Borget, 1997). Magnesium, which is usually applied in the form of dolomite or as Kiesertite (Magnesium sulphate), has given results on Soya in Cameroon when used in association with organic matter. In soils rich in calcium, 400kg/ha of magnesium sulphate is recommended (Borget, 1997). Calcium has given some positive results on groundnuts with an application of 100kg/ha of calcium sulphate. Calcium is an important element for the production of groundnut with large nuts. Absence of calcium lowers the level of formation of the flowers, and renders the shell more fragile (Borget, 1997).

Organic manure has only a limited application in the tropics. However, every time it has been possible to practice this application, poor responses have been recorded even with very small doses of pen manure which does not have the fertilizing value of farm manure, since it has not been degraded by the sun and inclement weather. In India on pigeon pea, 15 t/ha of farm manure increases the yield by 55 percent in comparison with a control, 30 t/ha by 80 percent, 45 t/ha by 110 percent. Doses of 25 t/ha are recommended on common beans (Borget, 1997).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

The experiment was carried out at the Plantation Section of the Department of Crop and Soil Sciences of the Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi ($6^0$43'N, $1^0$36'W) in the forest zone of Ghana, during the major season between May and September, 2008.

The soil belongs to the Kumasi series which is locally classified as Ochrosols or Ferric Acrisol developed over deeply weathered granite. Soil samples from the experimental site were taken from 0-15cm and 15-30cm depth and analyzed for pH and other chemical properties.

Mean monthly rainfall, mean monthly maximum and minimum temperatures, and mean number of hours of sunshine per day during the period of the experiment, are presented in Appendix II.

3.2 Experimental Design and Treatments

The experimental design used was 2 x 3 x 3 factorial in a Randomized Complete Block Design (RCBD) with three replications. In all, there were 18 treatment combinations consisting of the following factors: Two bambara groundnut landraces, three fertilizer rates and three population densities which were randomized in three blocks giving a total of 54 plots. Each of the plots measured 3m X 4m. A distance of 1meter was left between the blocks while a distance of ½ a meter was left between the plots.

The factors:

Bambara Landraces:

(i) Mottled cream –V1

(ii) NAV 4 –V2

Phosphorus rates:

(i) 0 kg/ha – P0

(ii) 20 kg/ha – P1

(iii) 40 kg/ha – P2

Population densities:

(i) S1 = 30cm x 30cm = 11 plants/m^2= 111,100 plants/ha

(ii) S2= 30cm x 40cm = 8 plants/m^2= 83, 300 plants/ha

(iii) S3 =30cm x 50cm = 7 plants/m^2 = 66,600 plants/ha

3.3 Land preparation and Agronomic Practices

The field was cleared, ploughed and harrowed, lined and pegged before planting. Planting was done on 26th May, 2008. Two seeds were planted per hill at a depth of 4cm. The seedlings were thinned to one seedling per hill 20 days after planting (DAP). The seeds of NAV 4 were obtained from the Crops Research Institute at Fumesua, Kumasi while the seeds of Mottled Cream were obtained from the open market at Navrongo. The first weeding was done 14 days after germination and the subsequent ones were done whenever the need arose. Normal husbandry practices were undertaken.

3.4 Soil Sampling and Analysis

Soil sample was taken randomly from the experimental site from the depths of 0-15cm and 15-30cm using a soil auger. The soil was air dried for 48 hours and then oven dried, sieved between 2mm mesh before the analysis was done to determine the following parameters.

A. pH

Soil pH was determined in 1:2:5 suspensions of soil and water using a pH meter. Twenty grams soil sample was weighed into 100ml polythene bottles. To this, 50ml distilled water was added and the bottle shaken for two hours. After calibrating the pH meter with buffer solution of pH 4.0 and 7.0, the pH was read by immersing the glass electrode into the upper part of the suspension.

B. Organic Carbon

Organic carbon was determined by Walkley Black wet oxidation method (Olsen and Sommers, 1982). One gram of soil sample was weighed into a 400ml flask and 10ml of 1*N* potassium dichromate ($K_2Cr_2O_7$) added. This was swirled to ensure contact with all the soil particles. The flask was made to stand on an asbestos sheet for 30 minutes to cool. Ten (10) ml of 85% orthophosphoric acid (H_3PO_4) and 2ml of barium diphenylsulphate indicator were added. The solution was titrated with 1.0N ferrous sulphate for a colour change from blue to bright green end point. A blank titration was carried out without soil. Per cent carbon was calculated as:

$$\%C = \frac{\text{INFeSO}_4 \text{ x } (V1 - V2) \text{ x } 0.39}{W}$$

Where

I*N*$FeSO_4$ is normally of FeSO4 used for titration

V1 = ml for blank titration

V2 = ml for sample titration

W = weight of soil sample used.

0.39 = 3 x 0.001 x 100% x 1.3 (3 = equivalent weight of C)

1.3 = a composition factor for the incomplete combustion of the organic matter.

Per cent organic matter was obtained by multiplying the per cent organic carbon by the Van Bemmelen factor of 1.724.

C. Total Nitrogen

Total Nitrogen was determined by the modified Kjeldahl digestion method. In this method , 10g of soil was digested with 30ml concentrated sulphuric acid, using a catalyst tablet of sodium sulphate (2), copper sulphate (1) and selenium (1). Digestion was followed by the Kjeldahl distillation process, using 40% caustic soda solution (NaOH) to distil ammonia which was received into 4% boric acid. Titration was done using 0.1 N HCl (Okalebo *et al*. 1993).

Calculation:

$$\%N = \frac{N \times (a - b) \times 1.4 \text{ mcf}}{S}$$

Where:

N= Normality of the HCl used in the

a = ml HCl used in sample titration

b = ml HCl used in blank titration

S = weight of dry sample (g)

Mcf = moisture correction factor (100+%moisture)/100

1.4 = 14 x 0.001 x 100% (14 = atomic weight of nitrogen)

D. Available Phosphorus.

The readily acid-soluble forms of P were extracted with HCl: NH_4F mixture. The Bray PI method was used (Bray and Kurtz, 1945; Olsen and Sommers, 1982). Phosphorus in the extract was determined by the blue ammonium molybdate method with ascorbic acid as the reducing agent.

Two grams soil sample was weighed into shaking bottle (50ml) and 20ml of extracting solution of Bray-1(0.03M NH_4F and 0.025M HCl) was added. The sample was shaken for one minute by hand and immediately filtered through Whatman No. 42 filter. 1 ml of the standard series, the blank and extract, 2ml boric acid and 3ml of the colouring reagent (ammonium molybdate and antimony titrate solution) were pipetted into a test tube and homogenized. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21D spectrometer at 660nm wavelength.

A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6 mgP/l were prepared from a 12 mgP/l stock solution by diluting 0. 10, 20, 30, 40 and 50 ml of the stock solution in 100 ml volumetric flask and made to volume with distilled water. Aliquots of 0, 1,2,4,5 and 6 ml of the 100 mgP/l of the standard solution were put in 100 ml volumetric flask and made to 100ml mark with distilled water.

Calculation: $$P\ (mg/kg) = \frac{(a - b) \times 20 \times 6 \times mcj}{S}$$

Where:

a = mg/lP in sample extract

b = mg/l P in blank

s = sample weight (g)

mcf = moisture correcting factor

20= ml extracting solution

6 = ml final sample solution

E. Exchangeable cations (K, Na, Ca and Mg)

Exchangeable bases (potassium, sodium, calcium and magnesium) in the soil were determined in 1.0M ammonium acetate (NH_4OAc) solution at pH 7 and the exchangeable acidity was determined in 1.0M KCl extract (Okalebo *et al*, 1993).

Ten grams sample was transferred into a leading tube and leached with 250ml of buffered 1.0M ammonium acetate (NH_4OAc) solution at pH 7.

Determination of calcium and magnesium

For the determination of calcium and magnesium, a 25 ml portion of the extract was transferred into an Erlenmeyer flask and the volume made to 50 ml with distilled water. A 10ml portion of hydroxylamine hydrochloride, 1 ml of 2.0 per cent potassium cyanide (from a burette), 1.0 ml of 2.0 per cent ferrocyanide, 10.0M EDTA (ethylenediaminetetraacetic acid) to a pure turquoise blue colour. A 20 ml of 1.0M magnesium chloride solution was also titrated with 0.01M EDTA in the presence of 25 ml of 1.0M ammonium acetate solution to provide a standard blue colour for the titration

Exchangeable potassium and sodium determination

Potassium and sodium in the percolate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting 1000 mg/l of potassium and sodium solutions to 100 mg/l. This was done by taking a 25 ml portion of each into one 250 ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15 and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flask respectively. One hundred millilitres of 1.0M NH_4OAc solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 mg/l for potassium and sodium. Potassium and sodium were measured directly in the percolate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively.

Calculations:

$$\text{Exchangeable K(cmol/kgsoil)} = \frac{(a - b) \times 250 \times mcf}{10 \times 39.1 \times S}$$

$$\text{Exchangeable Na(cmol/kgsoil)} = \frac{(a - b) \times 250 \times mcf}{10 \times 23 \times S}$$

Where:

a = mg/l of K or Na in the diluted sample percolate

b= mg/l of K or Na in the diluted blank percolate

S = air-dried sample weight of the soil in gram

mcf = moisture correcting factor

39.1 = molar mass of potassium

23 = molar mass of sodium

3.5 Growth Parameters

3.5.1. Plant Height

Using a 30cm ruler, the heights of four plants selected randomly from each plot were taken from the ground level to beneath the leaf blade at 30, 50, 70 and 90 days after planting (DAP). The mean plant height was then recorded.

3.5.2. Number of leaves

Four plants were uprooted randomly from each plot and the leaves were counted. Sampling was done at 30, 60 and 90 DAP. The mean number of leaves was then recorded.

3.5.3 Leaf Area Index

Leaves from four plants randomly selected from each plot were passed through the leaf area meter machine. The leaf area figures recorded were used to calculate the leaf area index by dividing the leaf area by the area covered by the plant.

3.5.4 Canopy spread

Four sticks were put at the four crossed sides of each of the four plants selected to measure the canopy spread. Tape measure was used to measure across to obtain the average length of the canopy.

3.5.5. Dry Matter Yields

Sampling started at thirty (30) days after planting (DAP) and continued at regular intervals of 20 days. Four plants were randomly selected from each plot.

The fresh shoot weights of the plants were taken and then dried in the oven at a temperature of 70^0C for 48 hours. The shoot dry weights were calculated, and used to determine the following growth components:

a. **Crop growth rate (C G R)**

   This was calculated by using the formula

$$CGR = \frac{W_2 - W_1}{T_2 - T_1}$$

Where W_1 and W_2 are dry weights at sampling periods T_1 and T_2, respectively (Gardner *et al.*, 1985).

b. Relative growth rate (R G R)

This was also determined by the formula

$$RGR = \frac{Log_e W_2 - Log_e W_1}{T_2 - T_1}$$

Where W_1 and W_2 are dry weights at sampling periods T_1 and T_2, respectively (Gardner *et al*, 1985).

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c. Net assimilation rate (N A R)

The net assimilation rate was determined by using the formula.

$$NAR = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{logeLA_2 - logeLA_1}{LA_2 - LA_1}$$

Where W_1 and W_2 are dry weights at sampling periods T_1 and T_2, respectively.

LA is the leaf area index (Gardner *et al*., 1985).

3.6. Yield Parameters

At the final harvest (110 DAP), eleven, eight and seven plants were harvested from all the plots for spacing S1, S2 and S3 respectively and the following yield components were determined:

i number of pods per plant

ii fresh pod weight

iii dry pod weight

iv number of seeds per pod

v 100-seed weight

vi seed yield

After uprooting, the pods were counted, air dried before drying them in an oven at 70^{o}C for 48 hours. The dry pods were weighed and recorded. The pods were then dehusked (shelled) by hand and the seeds were weighed. Hundred (100) seeds were randomly selected from each sample and their weights were determined. Number of seeds per pod was determined for each sample. Shelling percentage was also determined by dividing the weight of the extracted seed by the pod dry weight.

3.7 Statistical Analysis

All data were analyzed with the Analysis of Variance (ANOVA) using the Genstat 5 statistical package. The Least Significant Difference (Lsd) was used to determine treatment differences. The significant differences between the treatments were compared at 5% level of probability.

CHAPTER FOUR

4.0 RESULTS

4.1 Soil Analysis

Results of initial soil analysis are presented in Table 1. The available P in the soil of the experimental site was in the medium range (Rhoodes, 1982 and Okalebo *et.al*., 1993).

Table 1: Results of initial soil analysis

SAMPLE IDENTIFICATION	% ORGANIC CARBON (O.C)	% ORGANIC MATTER (O.M)	% TOTAL NITRO-GEN (N)	EXCHANGEABLE CATION- Cmol./Kg/Me/100g				AVAI-LABLE PHOS-PHORUS mg/kg or ppm	pH
				POTA-SSIUM (K)	SO-DIUM (Na)	CAL-CIUM (Ca)	MAGNE - SIUM (Mg)		
0 – 15cm	0.6185	1.066	0.182	0.146	0.248	2.5	0.9	17.74	6.24
15 – 30cm	0.3990	0.6879	0.168	0.103	0.232	2.1	0.8	14.22	6.16

4.2 Days to emergence and 50% flowering

There was variation with respect to seedling emergence. Mottled Cream emerged seven days after planting while NAV 4 took ten days to emerge (Table 2). Number of days to 50% flowering followed the trend of emergence. Mottled cream and NAV 4 recorded 50% flowering at 34 and 40 DAP respectively (Table 2).

Table 2: Days to emergence and 50% flowering

Landrace	Emergence	50% flowering
Mottled Cream	**7**	**34**
NAV 4	**10**	**40**

4.3 Plant height

The result of plant height is presented in Table 3. Plant height increased with time. Results showed no significant difference (p>0.05) with respect to P application and plant density at any of the sampling periods. The landraces varied in plant height with NAV 4 registering significantly (p< 0.05) higher values from 30 to 90 DAP.

Table 3: Effect of phosphorus application and plant density on plant height of two bambara groundnut landraces.

Treatment	**Plant height (cm) at**			
Phosphorus application	30 DAP	50 DAP	70 DAP	90 DAP
P0 (0kg/ha)	14.1	17.8	19.9	20.4
P1 (20kg/ha)	14.2	18.0	19.8	20.6
P2 (40kg/ha)	13.8	17.8	19.7	20.5
lsd (5%)	NS	NS	NS	NS
Spacing				
S1 (30 x 30cm)	14.2	18.2	19.9	20.8
S2 (30 x 40cm)	13.9	17.5	19.6	20.3
S3 (30 x 50cm)	13.9	17.9	19.8	20.5
lsd (5%)	NS	NS	NS	NS
Landrace				
Mottled cream	13.2	16.2	17.4	18.1
NAV 4	14.8	19.6	22.2	22.9
Mean	14.0	17.9	19.8	20.5
lsd (5%)	0.46	0.92	0.65	0.63
CV %	5.9	9.3	5.9	5.5

4.4 Number of leaves per plant

Number of leaves per plant followed similar trend as plant height and increased with time. Phosphorus application and density of planting showed no significant differences ($p>0.05$) at any of the sampling periods (Table 4). NAV4 registered significantly ($p< 0.05$) higher values of 114.9, 281.3 and 280.6 at 60 DAP, 90 DAP and 110 DAP respectively than those of mottled cream.

Table 4: Effect of P application and plant density on mean number of leaves per plant of two bambara groundnut landraces.

Treatment	Number of leaves at			
Phosphorus application	30 DAP	60 DAP	90 DAP	110 DAP
P0 (0kg/ha)	47.4	93.3	207.3	206.8
P1 (20kg/ha)	48.8	94.4	221.1	220.5
P2 (40kg/ha)	48.1	90.4	205.1	203.9
lsd (5%)	NS	NS	NS	NS
Spacing				
S1 (30 x 30cm)	51.4	91.6	216.4	215.6
S2 (30 x 40cm)	47.7	92.7	210.8	210.3
S3 (30 x 50cm)	45.3	93.8	206.3	205.4
lsd (5%)	NS	NS	NS	NS
Landrace				
Mottled cream	47.9	70.5	141.1	140.2
NAV 4	48.3	114.9	281.3	280.6
Mean	48.1	92.7	211.2	210.4
lsd (5%)	NS	7.64	23.83	23.54
CV %	18.5	14.9	18.6	18.5

4.5 Canopy spread

The results of canopy spread for the varieties response to phosphorus application and population density are presented in Table 5. Canopy spread increased with time. There were significant difference between the two landraces at the sampling periods with NAV 4 recording the higher values in all the sampling occasions ($P<0.05$). No significant difference ($p> 0.05$) was recorded with P application and plant density.

Table 5: Effect of P application and plant density on canopy spread of two bambara groundnut landraces.

Treatment	Canopy spread (cm) at			
Phosphorus application	30 DAP	60 DAP	90 DAP	110 DAP
P0 (0kg/ha)	39.9	51.4	61.6	62.7
P1 (20kg/ha)	40.2	51.3	61.6	62.0
P2 (40kg/ha)	38.9	52.1	64.0	64.5
lsd (5%)	NS	NS	NS	NS
Spacing				
S1 (30 x 30cm)	39.7	51.2	62.6	63.5
S2 (30 x 40cm)	39.2	51.2	63.2	63.6
S3 (30 x 50cm)	40.1	52.5	61.4	62.2
lsd (5%)	NS	NS	NS	NS
Landrace				
Mottled cream	37.1	42.0	46.9	47.4
NAV 4	42.2	61.2	77.9	78.8
Mean	39.7	51.6	62.4	63.1
lsd (5%)	1.97	1.98	2.8	2.9
CV %	9.0	6.9	8.2	8.5

4.6 Leaf Area index

Table 6 shows the results of leaf area index. Significant difference was observed between the two landraces ($P<0.05$) in all the sampling periods with NAV 4 registering higher values at 50, 70, 90 and 110 DAP. There were also significant difference among the population densities ($p<0.05$) with 30cm x 30cm treatment being greatest at all sampling periods. There was no significant difference ($p>0.05$) with respect to phosphorus application in leaf area index.

Table 6: Effect of P application and plant density on leaf area index of two bambara groundnut landraces.

Treatment	Leaf area index at				
Phosphorus Application	30 DAP	50 DAP	70 DAP	90 DAP	110 DAP
P0 (0kg/ha)	0.83	1.92	3.71	3.52	3.22
P1 (20kg/ha)	0.78	1.90	3.65	3.50	3.15
P2 (40kg/ha)	0.78	1.71	3.50	3.31	3.1
lsd (5%)	NS	NS	NS	NS	NS
Spacing					
S1 (30x30cm)	0.94	2.50	4.28	4.10	3.8
S2 (30x40cm)	0.80	1.80	3.61	3.4	3.1
S3 (30x50cm)	0.65	1.20	2.99	2.85	2.5
lsd (5%)	0.11	0.24	0.31	0.27	0.24
Landrace					
Mottled cream	0.87	1.52	3.31	3.12	2.82
NAV 4	0.72	2.14	3.90	3.75	3.43
Mean	0.79	1.83	3.62	3.43	3.12
lsd(5%)	0.09	0.19	0.25	0.23	0.20
CV%	20.3	19.7	9.9	10.5	11.4

4.7 Leaf dry weight/plant

Leaf dry weight increased with time (Table 7). The results showed no significant difference with respect to plant density and phosphorus application (p>0.05). However, phosphorus application at 20kg/ha and plant density of 30cm X 50cm recorded the highest values at most of the sampling periods. The landraces varied in leaf dry weight with NAV 4 recording significantly higher values from 50 to 110 DAP (Table 7).

Table 7: Effect of P application and plant density on leaf dry weight/plant of two bambara groundnut landraces.

Treatment	**Leaf dry weight plant^{-1} (g) at**				
Phosphorus application	30 DAP	50 DAP	70 DAP	90 DAP	110 DAP
P0 (0kg/ha)	7.3	19.5	37.8	58.7	66.1
P1 (20kg/ha)	6.8	20.2	39.5	61.4	69.8
P2 (40kg/ha)	6.7	18.8	38.2	60.2	68.7
lsd (5%)	NS	NS	NS	NS	NS
Spacing					
S1(30 x 30cm)	7.0	19.3	37.4	58.0	65.2
S2(30 x 40cm)	6.5	18.7	38.3	60.5	69.3
S3(30 x 50cm)	7.3	20.5	39.8	61.7	70.1
lsd (5%)	NS	NS	NS	NS	NS
Landrace					
Mottled Cream	7.1	14.4	24.9	38.5	48.2
NAV 4	6.7	24.5	52.1	81.6	88.1
Mean	6.9	19.5	38.5	60.1	68.2
lsd (5%)	NS	2.53	3.61	5.74	8.12
CV %	18.0	23.5	17.0	17.3	18.9

4.8 Total Dry Weight per plant

The results for total dry weight for the various sampling periods are presented in Table 8. No significant difference was recorded with plant density and phosphorus application (p> 0.05). The landraces showed significant difference in total dry weight (p< 0.05) with NAV 4 recording significantly higher values from 50 to 110 DAP (Table 8).

Table 8: Effect of P application and plant density on total dry weight/plant of two bambara groundnut landraces

Treatment	**Total dry weight plant^{-1}(g) at**				
Phosphorus application	30 DAP	50 DAP	70 DAP	90 DAP	110 DAP
P0 (0kg/ha)	17.3	31.5	52.8	74.7	81.1
P1 (20kg/ha)	16.8	32.2	54.5	77.4	84.8
P2 (40kg/ha)	16.7	30.8	53.2	76.2	83.7
Lsd (5%)	NS	NS	NS	NS	NS
Spacing					
S1 (30 x 30cm)	17.1	31.3	52.4	74.0	80.2
S2 (30 x 40cm)	16.4	30.7	53.3	76.5	84.3
S3 (30 x 50cm)	17.3	32.5	54.8	77.7	85.1
lsd (5%)	NS	NS	NS	NS	NS
Landrace					
Mottled Cream	17.0	26.4	39.9	54.5	63.2
NAV 4	16.8	36.5	67.1	97.6	103.1
Mean	16.9	31.5	53.5	76.1	83.2
lsd (5%)	NS	2.75	3.83	5.96	8.34
CV %	19.0	23.6	17.5	18.3	18.9

4.9 Crop growth rate(C)

Significant difference was recorded by crop growth rate with respect to population density and landrace (p <0.05). Significant difference between the two landraces was observed with NAV 4 registering higher values at all the sampling periods (Table 9). Plant spacing of 30cm x 30cm recorded highest values at all the sampling occasions. There was no significant difference with respect to phosphorus application (p>0.05).

Table 9: Effect of P application and plant density on crop growth rate of two bambara groundnut landraces

Treatment	Crop growth rate (gm^{-2} day^{-1}) at			
Phosphorus application	H2- H1 50-30 DAP	H3-H2 70-50 DAP	H4-H3 90-70 DAP	H5-H4 110-90 DAP
P0 (0kg/ha)	5.2	7.8	8.9	7.2
P1 (20kg/ha)	5.8	8.3	9.4	7.7
P2 (40kg/ha)	5.3	8.5	9.6	7.9
lsd (5%)	NS	NS	NS	NS
Spacing				
S1 (30 x 30cm)	6.8	9.9	11.4	9.2
S2 (30 x 40cm)	4.9	7.9	8.9	7.3
S3 (30 x 50cm)	4.6	6.8	7.7	6.3
lsd (5%)	1.28	1.31	1.35	1.26
Landrace				
Mottled cream	4.3	6.6	7.9	6.1
NAV 4	6.5	9.8	10.7	9.1
Mean	5.4	8.2	9.3	7.6
lsd (5%)	1.05	1.11	1.21	1.07
CV %	22.8	20.7	18.8	21.6

4.10 Net assimilation rate

Net assimilation rate decreased with time. No significant difference was recorded with respect to phosphorus application ($p>0.05$). However, significant difference ($p<0.05$) was observed with the landraces (Table 10), with NAV 4 registering the higher values at all the harvesting periods. Population density effect was significant in the last two sampling periods. On each occasion, the 30 x 30cm treatment effect was significantly higher than all other treatment means.

Table 10: Effect of P application and plant density on Net Assimilation Rate of two bambara groundnut landraces.

Treatment	Net assimilation rate (gm^{-2} day^{-1}) at			
Phosphorus application	H2 – H1 50-30 DAP	H3 – H2 70-50 DAP	H4 – H3 90-70 DAP	H5 – H4 110-90 DAP
P0 (0kg/ha)	2.7	1.7	1.5	1.4
P1 (20kg/ha)	2.9	2.1	1.6	1.5
P2 (40kg/ha)	2.8	2.1	1.7	1.3
lsd (5%)	NS	NS	NS	NS
Spacing				
S1 (30 x 30cm)	3.5	2.1	2.1	1.9
S2 (30 x 40cm)	2.1	2.0	1.4	1.1
S3 (30 x 50cm)	2.8	1.6	1.4	1.1
lsd (5%)	NS	NS	0.35	0.28
Landrace				
Mottled Cream	2.0	1.3	1.1	0.9
NAV 4	3.6	2.7	2.1	1.9
Mean	2.8	2.0	1.6	1.4
lsd (5%)	1.4	0.7	0.28	0.21
CV%	22.2	20.3	19.9	21.2

4.11 Relative growth rate

The results of relative growth rate are presented in Table 11. The results follow similar trend as net assimilation rate. Phosphorus application did not register any significant difference between the treatments ($p>0.05$). The landraces recorded significant difference ($p <0.05$), with NAV 4 recording the higher values in all the sampling periods. Population density effect was also significant in all the sampling periods. The 30cm x 30cm treatment effect was significantly higher than the other treatments.

Table 11: Effect of P application and plant density on Relative growth rate of two bambara groundnut landraces.

Treatment	Relative growth rate (g g^{-1} day^{-1}) at			
Phosphorus application	H2 – H1 50-30 DAP	H3 – H2 70-50 DAP	H4 – H3 90-70 DAP	H5 – H4 110-90 DAP
P0 (0kg/ha)	0.40	0.28	0.19	0.11
P1 (20kg/ha)	0.45	0.29	0.20	0.11
P2 (40kg/ha)	0.42	0.31	0.20	0.11
lsd (5%)	NS	NS	NS	NS
Spacing				
S1 (30 x 30cm)	0.53	0.35	0.25	0.14
S2 (30 x 40cm)	0.41	0.29	0.18	0.10
S3 (30 x 50cm)	0.34	0.23	0.16	0.09
lsd (5%)	0.07	0.05	0.01	0.01
Landrace				
Mottled Cream	0.33	0.24	0.19	0.10
NAV 4	0.51	0.35	0.20	0.12
Mean	0.42	0.29	0.20	0.11
lsd (5%)	0.06	0.04	NS	0.008
CV %	22.3	23.1	9.4	12.7

4.12 Seed Yield (kg/ha)

No significant difference was recorded by P application ($p > 0.05$) in seed yield (Table 12). Population density and the landraces, however, had significant effect ($p < 0.05$) on seed yield. NAV 4 registered a yield of 2119.4 which was significantly higher than that of mottled cream. Yield from the highest density (30 x 30cm) was significantly higher than that of the other treatments.

Table 12: Effect of P application and population density on seed yield of two bambara groundnut landraces.

Treatment	Seed yield (kg/ha)
Phosphorus application	
P0 (0kg/ha)	1800.4
P1 (20kg/ha)	1926.4
P2 (40kg/ha)	1944.2
lsd (5%)	NS
Spacing	
S1 (30 x 30cm)	2316.3
S2 (30 x 40cm)	1801.4
S3 (30 x 50cm)	1553.3
lsd (5%)	263.2
Landrace	
Mottled cream	1661.5
NAV 4	2119.4
Mean	1890.4
lsd (5%)	214.4
CV%	20.5

4.13 100 seed weight

Results showed that 100 seed weight registered significant difference with respect to the landraces ($p<0.05$), with mottled cream registering the higher value of 47.6g (Table 13). There was no significant difference with respect to phosphorus application and population density.

Table 13: Effect of P application and population density on 100 Seed weight of two bambara groundnut landraces.

Treatment	Mean seed weight (g)
Phosphorus application	
P0 (0kg/ha)	43.8
P1 (20kg/ha)	45.4
P2 (40kg/ha)	47.1
lsd (5%)	NS
Spacing	
S1 (30 x 30cm)	46.9
S2 (30 x 40cm)	44.2
S3 (30 x 50cm)	45.1
lsd (5%)	NS
Landrace	
Mottled Cream	47.6
NAV 4	43.2
Mean	45.4
lsd (5%)	2.2
CV%	6.2

4.14 Number of pods per plant

The landraces differed significantly from each other in the number of pods per plant ($p<0.05$), with NAV 4 registering higher mean value of 71.4 pods (Table 14). No significant difference was observed with phosphorus application and population density ($p>0.05$).

Table 14: Effect of P application and population density on number of pods per plant of two bambara groundnut landraces.

Treatment	Number of pods plant $^{-1}$
Phosphorus application	
P0 (0kg/ha)	56.3
P1 (20kg/ha)	60.7
P2 (40kg/ha)	60.9
lsd (5%)	NS
Spacing	
S1 (30 x 30cm)	55.1
S2 (30 x 40cm)	62.6
S3 (30 x 50cm)	60.3
lsd (5%)	NS
Landrace	
Mottled cream	47.2
NAV 4	71.4
Mean	59.3
lsd (5%)	6.88
CV %	21.0

4.15 Pod dry weight

The landraces registered significant difference in pod dry weight ($p<0.05$) with NAV 4 recording the higher mean value of 49.1g (Table 15). Phosphorus application and population density did not show any significant difference ($p>0.05$).

Table 15: Effect of P application and population density on pod dry weight of two bambara groundnut landraces.

Treatment	Pod dry weight (g)
Phosphorus application	
P0 (0kg/ha)	41.6
P1 (20kg/ha)	44.7
P2 (40kg/ha)	45.2
lsd (5%)	NS
Spacing	
S1 (30 x 30cm)	42.1
S2 (30 x 40cm)	45.0
S3 (30 x 50cm)	44.4
lsd (5%)	NS
Landrace	
Mottled cream	38.5
NAV 4	49.1
Mean	43.8
lsd (5%)	5.01
CV %	20.7

CHAPTER FIVE

5.0 DISCUSSION

5.1 Emergence and Flowering

While Mottled Cream took seven (7) day to emerge after planting, NAV 4 emerged ten (10) days after planting. The variation in the emergence of seedlings for the two landraces may be due to the differences in the thickness of the seed coat. Mottled Cream which has light seed coat emerged earlier (Table 2). Early emergence of seedlings helps the roots to develop fast, hence an advantage for the seedling to survive during adverse weather conditions such as drought. Rapid emergence reduces the period over which seedlings are susceptible to stress.

Flowering and fifty per cent (50%) flowering generally occurred between twenty-seven and thirty-four days after planting for Mottled Cream which was found to be an early maturing variety. For NAV 4 which is a late maturing variety, flowering occurred between thirty-eight and forty days after planting (Table 2). Kumaga *et al.* (2002) observed that the number of days to first flower opening varied between thirty-four and thirty-eight days after planting. Mottled Cream showed determinacy in its flowering while NAV 4 produced flowers throughout the growing season. The spreading types usually produce flowers throughout the growing season (Ofori, 1996). Photoperiod is said to influence flowering date in bambara groundnut. During the period of the experiment, photoperiod did not change but there was a reduction in temperature and sunshine hours (Appendix II). This might have influenced the flowering date. The two landraces used in the experiment are mostly adapted to the savannah and the drier zones of West Africa. Therefore, the high rainfall and the reduced temperature in the experimental zone might have also influenced the flowering date. Kumaga *et al*. (2002) observed that rainfall and temperature are the two most prominent climatic factors that influence vegetative growth, flowering and yield of bambara groundnut in Ghana. Sessay (2005) also attributed the longer period from sowing to flowering to delay in seedling emergence caused by the late arrival of rains. This is contrary to what was observed in this work. Since the rains came early, the days to 50% emergence and 50% flowering were not delayed.

5.2 Growth Components

In terms of canopy spread, there was significant difference between the landraces. The population density and the phosphorus application did not have any effect on canopy. NAV 4 had the wider canopy spread of about 78 cm (Table 5), while the Mottled Cream had the canopy spread of about 47 cm (Table 5). From this observation it could be deduced that NAV 4 is a spreading type while Mottled Cream is a bunched type. This is in agreement with the classification made by Doku and Karikari (1971), that bambara groundnut has both the spreading and the bunched types. The wider canopy spread of NAV 4 could also be attributed to the fact that it had longer internodes than the mottled cream.

With respect to the number of leaves per plant, the two (2) landraces were significantly different in the number of leaves produced. Mottled Cream produced the least number of leaves while NAV 4 produced the higher number of leaves. Mottled Cream showed determinate leaf production and so leaf development came to a stop during pod production. Therefore, though it produced fewer numbers of pods, its 100-seed weight was significant and its yield was relatively good. NAV 4 on the other hand showed indeterminate leaf production and so there was development of leaves during pod production. This may have accounted for the higher yield of NAV 4 in this experiment as compared to Mottled Cream.

Climatic conditions such as rainfall and temperature also influenced leaf development in bambara groundnut. This work was done during major farming season when rainfall was high with reduced temperature. Kumaga *et al*. (2002), and Elia and Mwandemele (1986) showed that in high rainfall bambara groundnut branches more profusely and produces more leaves than in low rainfall. Population density did not have any impact on leaf production. The highest population density had the highest number of leaves and this could be attributed to the high number of plants. This agrees with the observation made by Raemaekers (2001), that excessive population often reduces the yield of seeds, while stimulating vegetative growth.

5.3 Effect of population density and phosphorus on dry matter production.

From the results, leaf area index (LAI) increased with population density. The highest LAI was recorded at a population density of 11 plants m^{-2} (Table 6). This agrees with the observation of Mkandawire and Sibuga (2002) that the greatest LAI was registered at a population density of 66 plants / m^2. The high leaf area index may have accounted for the high yield recorded by the population density of 11 plants m^{-2}.

The phosphorus application did not have any effect on LAI (Table 6). The high LAI resulted in high yield. This is contrary to the observations of Mkandawire and Sibuga (2002) on bambara groundnut and Weber *et al.* (1966) on soybean that conditions that maximize LAI did not necessarily result in high yields. The high LAI may have resulted in more intercepted light to cause greater growth. This could probably be that the closest-spaced plants were able to intercept light and absorb nutrients and water available to the individual plants (Mkandawire and Sibuga, 2002).

There could have been some wastage of incident solar radiation on bare land at the early stages of growth in the lower population densities. This affected dry matter accumulation. This outcome is in line with the observations of Egli (1988), Funnah and Matsebella (1985) and Nakagawa *et al*. (1988), who observed that soybean yield increased with density up to 20 plants/m^2, beyond which the reduction in individual plant yield could not be adequately compensated for by increase in number of plants per unit area.

Between the two landraces, NAV 4 registered the highest LAI and this translated into high yield. This indicates that more solar radiation was intercepted for the production of more assimilates (Table 12). This is because NAV 4 developed a larger photosynthetic surface. The result is in line with the observation of Squire (1990) that at LAI of 6.5, groundnut was able to intercept over 90% of solar radiation. Chavula (1991) also stated that there is evidence that dry matter accumulation is directly related to the amount of solar radiation intercepted.

Though, Mottled Cream recorded the least LAI value (Table 6), it had the higher value for 100 seed weight (Table 13) and the number of seeds per pod. This shows that it was able to partition greater part of it assimilates into the sink.

Population density and phosphorus did not affect bambara groundnut shoot growth in the experiment. Wassermann *et al.* (1983) reported an increase in shoot dry matter with a P rate of 30 kg/ha from a field and pot experiment. The lack of effect by phosphorus on shoot growth may be due to the fact that the level of P in the soil used was in the medium range (17.52 mg / kg) and the pH was also optimum (6.24) for phosphorus availability. Brady (1974) reported that the optimal pH for phosphorus availability is between 6.0 and 7.0.

Varietal effects were registered with NAV 4 producing the highest dry shoot weight (Table 8). This could be due to the fact that NAV 4 showed indeterminate leaf production. This suggests that NAV 4 produced more photosynthates which could be partitioned to sinks for pod filling.

5.4 Effects of population density, phosphorus application and landrace on growth functions (CGR, NAR and RGR).

Crop growth rate, net assimilation rate and the relative growth rate increased with increasing plant population. Population density of 11 plants/m² recorded the highest values for CGR, NAR and RGR (Tables 9-11), followed by 8 plants/m², while 7 plants/m² produced the lowest values. Mkandawire and Sibuga (2002) observed that plant density of 66 plants/m² of bambara groundnut had significantly higher leaf area index while plant density of 9 plants/m² had the lowest. This indicates that the higher the population density, the higher the production of assimilates and hence growth rate. This was reflected in the 100-seed weight and yield. Here there was no interplant competition for resources.

There was also varietal effect on these three growth functions. NAV 4 had higher values than the Mottled Cream (Tables 9-11). Since NAV 4 is a spreading type with indeterminate growth habit, it was able to use the available resources for the production of photosynthates. There were no effects of phosphorus application on CGR, NAR and RGR of bambara groundnut. The lack of effect by phosphorus on the growth habits probably suggests that the landraces used are adapted to the medium level of P conditions, a similar situation was observed by Ramolemana *et al.* (1997), or the available P in the soil was readily released to the plants due to suitable moisture content and pH of the soil since the work was done in the major season.

5.5 Effect of phosphorus and population density on the yield and yield components of Bambara groundnut.

The availability of phosphorus applied and phosphorus in the soil to the plant may be influenced by the soil pH and moisture level. The optimal pH for phosphorus availability is reported to be between 6.0 and 7.0 (Brady, 1984). Ramolemana *et al*. (1997) observed that in semi - arid Botswana, soil phosphorus is generally low and low moisture supply may limit availability of P and plant growth. In this experiment there was no significant difference of P on yield and yield components (pod dry weight, number of pods per plant, number of seeds per pod and 100 seed weight). This could be attributed to the fact that the medium level of P in the soil was enough for the crop. However, among the rates of P applied, P2 (40kg / ha) had the highest values in all the yield components. This is in line with Ramolemena *et al.* (1997) who observed no significant phosphorus effects on pod yield and yield components at the rates of 0, 10, 20, 40 and 80kg / ha. There have been contradictory reports on the response of bambara groundnut to phosphorus application. Research conducted in Malawi, Nigeria and Zambia failed to show any response of bambara groundnut to phosphorus application at the rates of up to 33 kg / ha and sometimes yields were depressed (Malawi Government, 1980; Nnadi *et al.* 1981; Goli and Ng, 1987; Musonda, 1988). However, Tanimu and Yayock (1990) in Nigeria, reported a significantly higher yield from an application of 22 kg/ha. Wassermann *et al.* (1983) in South Africa reported an increase in total DM at 30 kg / ha, but seed yield was not increased.

The bambara groundnut yield response to phosphorus observed in this experiment may have been a result of the medium range of available phosphorus in the soil or the high phosphorus required by the plant for the various physiological processes. In some cases phosphorus application even decreased yield (Anonymous 1998). While Tanimu and Yayock (1990) and

Johnson (1968) observed significant increase in the yield of grains and yield components of bambara, Cumberland (1978) reported no response with the rate of up to 33 kg $P_2 0_5$ / ha.

With respect to population density, there was no significant effect on the number of pods per plant, pod dry weight and the number of seeds per pod. However, the population density of 8 plants/m² had the highest values. This indicates that the low values recorded by 11 plants/m² may be due to competition for interplant resources during pod production. This agrees with the observation of Sesay and Yarmah (1996) that the number of pods and shoot dry matter production, expressed on a per plant basis, generally declined with increase in plant population. However, there was a significant effect of population density on seed yield in this experiment. Seed yield increased with increasing population density. Plant density of 11 plants/m² recorded the highest values in both 100 seed weight and yield. Mkandawire and Sibuga (2002) recorded higher pod yield at population density of 22 plants/m². Similarly, Cumberland (1978) reported high pod yield of bambara groundnut at densities of 14 plants/m² than 7 plants/m². On the other hand, Eliesen and Freira (1992) working with groundnuts and Edje *et al.* (1971) with beans reported a decrease in number of pods per plants with increase in plant population.

Varietal effects showed that NAV 4 produced significantly higher seed yield than Mottled Cream. The yield of NAV 4 was 2119.4kg/ha while that of Mottled Cream was 1661.5kg/ha. The greater yield of NAV 4 may be due to the greater number of pods it produced. It could also be attributed to the larger leaf area index and also the wider canopy spread. These two factors may have been advantageous to NAV 4 in terms of interception of solar radiation. This indicates that NAV 4 was able to intercept more solar radiation for the production of photosynthates. It was also able to partition more of the photosynthates to the sink (pod) resulting in the higher pod yield.

Mottled Cream showed determinate growth habit but NAV 4 showed indeterminate growth habit during the growing period. Linnermann (1991) observed that fruit development may be influenced by length of photoperiod. However, there was no change in photoperiod during the growing period (Appendix II). Therefore, photoperiod did not influence podding and yield in this work. Linneman and Azam-Ali (1993); and Doku and Karikari (1970), observed that most cultivars of Bambara groundnut require 40 days period for pod and seed development. This indicates that the indeterminate flowering may not have had any significant influence on the higher yield recorded by NAV 4 in this study since all flowers produced 40 days before harvesting will not produce mature seeds.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

The two landraces of bambara groundnut used in the experiment showed some differences in their growth and yield components. The seed yield of NAV 4 was greater than that of Mottled Cream. NAV 4 produced greater number of pods per plant than Mottled Cream. Also the weight of 100 seeds of Mottled Cream was significantly higher than that of NAV 4. Mottled Cream emerged earlier, flowered and reached maturity earlier than NAV 4, but NAV 4 recorded higher dry matter and higher leaf area indices. NAV 4 is therefore recommended for both subsistence and commercial farming where higher yield is required in order to achieve food security in the country.

It was also observed from the experiment that Mottled Cream is a bunched type while NAV 4 is a spreading type. Mottled Cream could therefore be best recommended for mechanized farming while NAV 4 is best recommended for intercropping farming system with crops such as maize and cassava where it could serve as a cover crop to control weeds. This could reduce the cost of weed control for farmers.

The experiment also showed that the three rates of phosphorus applied did not show any significant difference among them on both growth and yield components. This could be attributed to the fact that the level of available phosphorus in the soil at the experimental site was medium as observed in the initial soil analysis performed. It is therefore recommended that no P should be applied in soils with medium level of P for bambara groundnut cultivation. Also the experiment should be carried out in an area where the available phosphorus in the soil is low or very low so that the optimum rate of phosphorus for maximum yield of bambara groundnut could be determined.

The experiment showed that, population density of 11 plants/m^2 (30cm x 30cm) recorded the highest canopy spread, leaf area index, dry matter and seed yield than the other two population densities. It could therefore be deduced that the population of 11 plant/m^2 (30cm x 30cm) is the optimum population density for the production of bambara groundnut.

Moreover, since Mottled Cream is early maturing it is recommended that Agricultural Extension Officers should encourage farmers to cultivate that landrace so that they could harvest it early and use the land to cultivate other crops during the farming season.

It was observed that Nav 4 is the commonest landrace on the market but mottled cream is good and has some potential as shown by the results.

The results showed that NAV 4 was the best landrace for both growth and yield components. It therefore recommended that to achieve maximum yield farmers should cultivate NAV 4 using the population of 11 plants m^{-2}.

Finally, it is recommended that the experiment should be repeated at different locations to validate the results.

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APPENDICES

APPENDIX I

SOIL SAMPLE ANALYSIS

SAMPLE IDENTIFICATION	% ORGANIC CARBON (O.C)	% ORGANIC MATTER (O.M)	% TOTAL NITROGEN (N)	EXCHANGEABLE CATION- Cmol./Kg/Me/100g				AV. PHOS-PHOR-US mg/kg or ppm	pH
				POTA-SSIUM (K)	SO-DIUM (Na)	CAL-CIUM (Ca)	MAGNE-SIUM (Mg)		
0 – 15cm	0.6185	1.066	0.182	0.146	0.248	2.5	0.9	17.74	6.24
15 – 30cm	0.3990	0.6879	0.168	0.103	0.232	2.1	0.8	14.22	6.16

APPENDIX II

Mean Monthly Weather Report

A. Major Season - 2008

Month	Temperature(^{o}C)				Rainfall (mm)	Relative Humidity (%)	Sunshine Duration (hrs)	Pressure (mb)
	Max	Min	Dry	Wet				
March	34.2	22.6	26.1	23.1	134.1	81	6.1	27.5
April	33.3	22.9	26.4	24.2	117.1	83	5.5	28.6
May	33.0	22.8	26.1	23.8	185.8	82	5.3	27.8
June	31.4	22.5	25.1	23.3	279.8	85	4.6	27.2
July	29.8	22.3	24.1	22.7	145.0	88	3.3	26.5

B. Minor season - 2008

Month	Temperature(^{o}C)				Rainfall (mm)	Relative Humidity (%)	Sunshine Duration (hrs)	Pressure (mb)
	Max	Min	Dry	Wet				
August	29.5	20.8	23.8	22.4	164.5	88	3.4	26.0
September	30.0	21.3	24.5	22.9	148.9	87	3.3	26.5
October	31.3	21.6	25.3	23.4	95.8	85	5.7	27.3
November	32.7	22.2	25.9	23.9	30.7	84.2	4.8	28.0

Source: KNUST Meteorological Station