Groundnut Varietal Response to Spacing in the Guinea Savannah and Forest Zones of Ghana

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IN

AGRONOMY

By:

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DECLARATION

I do hereby declare that this thesis entitled "*Groundnut Varietal Response to Spacing in the Guinea Savannah and Forest zones of Ghana*" was written by me and that it is the record of my own research work. It is neither in part nor in whole been presented for another degree elsewhere.

Works of other scientists cited and all assistance received are duly acknowledged.

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ABSTRACT

Field experiments were conducted at the KNUST Agricultural Research Station and Savannah Agricultural Research Institute (SARI) in 2006 and 2007 major seasons to assess the influence spacing on different groundnut varieties. The design was a factorial experiment laid out in randomized complete blocks with three replications. Two factors were tested; variety (6) and spacing (3).

Nkosuor and Kpanieli recorded high pod yields at KNUST, significantly improving pod yield by 18.18 and 15.63% over their respective treatment means in 2006 and 2007. Spacing1 and Spacing2 significantly increased pod yields by 36.85 and 6.99%, over their respective treatment means in 2006 and 2007. At Nyankpala, Adepa and Manipintar significantly increased pod yield by 9.19% and 40.25% over the mean of treatments, respectively in 2006 and 2007. SP1 improved pod yield in 2007 by 16.08% over the mean of treatments.

Jenkaar increased stover N by 4.08% whilst SP1 increased the stover N by 4.41 and 7.38% over treatment mean in 2006 and 2007, respectively. Jenkaar and Nkosuor recorded large stover N at Nyankpala, significantly increasing stover N by 40.83 and 31.86% over mean of treatments in 2006 and 2007, respectively. SP2 significantly increased stover N at over mean of treatments at Nyankpala by 24.76 and 4.66%, respectively in 2006 and 2007.

In 2006, Azivivi increased mean 100 seed weight over the mean of treatments by 19.03% at KNUST, whilst Manipintar improved mean 100 seed weight by 12.7% over treatments mean in 2007. SP3 increased mean 100 seed weight by 4.24 and 8.32% over mean of treatments in 2006 and 2007 respectively. At Nyankpala, Adepa and Kpanieli

significantly increased 100 seed weight by 0.54 and 9.98% over their respective treatment means in 2006 and 2007 respectively.

Although all treatments recorded benefit-cost ratio (BCR) of over 1.00 at KNUST, Nkosuor and Kpanieli had the highest BCR (4.48 and 7.49, respectively) in 2006 and 2007. SP1 recorded the highest benefit-cost ratio 2006 (5.13) and 2007 (6.79). At Nyankpala, Adepa and Manipintar recorded the highest benefit-cost ratios (8.76 and 4.90, respectively) in 2006 and 2007. SP1 again recorded the highest benefits-cost ratios (8.51 and 3.89, respectively) in 2006 and 2007. The economics of production among the different spacing were in decreasing order of spacing1>spacing2>spacing3.

Based on the results, the recommended groundnut variety for the Humid Forest was Nkosuor. For the Guinea Savannah, the recommended groundnut variety was Adepa. SP1 was however the recommended spacing for both the Humid Forest and Guinea Savanna agro-ecologies.

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DEDICATION

TO THE LIVING GOD, Dr JOSEPH SARKODIE-ADDO, MUM (YAYA), TAMPURI, KINANSUA, BINAMIN and BIRTEEB. AND THANKS TO ‘KID’ FOR BEING SO YOUNG ALL THE TIME.

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LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
BCR	Benefits-cost ratio
BNF	Biological nitrogen fixation
CIRAD-CORAF	Conference des Responsables de Reserche Agronomique en Afrique de lOuest et du Centre
CGR	Crop growth rate
CRSP	Collaborative Research Support Programme (Groundnut)
CIMMYT	International Wheat and Maize Improvement Centre
DM	Dry matter
ECEC	Effective cation exchange capacity
FAO	Food and Agriculture Organization of the United Nations
GR	Gross returns
GRV	Groundnut rosette virus
HI	Harvest index
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
KNUST	Kwame Nkrumah University of Science and Technology
LAI	Leaf area index
LEISA	Low external input sustainable agriculture
LSD	Least significant difference
MSW	Mean seed weight
NB	Net benefits
PBNV	Groundnut bud necrosis virus
PPMC	Pearson product moment correlation coefficient

RCBD	Randomized complete block design
SARI	Savanna Agricultural Research Institute
SAT	Semi-arid tropics
SHR	Seed-hull ratio
TDM	Total dry matter
TND	Total nitrogen difference
TFN	Total fixed nitrogen
TSWV	Tomato spotted wilt virus
TVC	Total variable cost
USA	United States of America
WAF	Weeks after flowering
WAP	Weeks after planting

CHAPTER ONE

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an annual soil enriching, self pollinated legume, cultivated widely in the arid and semi-arid regions of the world (40^o N and 40^o S), in temperature regimes ranging from warm temperate to equatorial. It is an important oilseed crop of the semi-arid tropics-SAT (Fletcher *et al.*, 1992; Tarimo, 1997; Anon, 2004; ICRISAT, 2008), and ranks thirteenth (13^{th}) in importance among world crops (Hatam and Abbasi, 1994).

Groundnuts are staple food in a number of developing countries. (Peanut CRSP, 1990). Groundnuts are protein rich fruits that grow well in semi-arid regions (Schilling and Gibbons, 2002). They are also grown as a protein source and source of income. It is a good source of edible oil for humans as well as a nutritive feed supplement (as protein cake) for livestock (Goldsworthy and Fisher, 1987).

In Ghana, groundnut is grown by smallholder farmers, on a small scale, both in pure stands and in crop mixtures, especially with cereals. Yields obtained from the crop are traditionally low due to a combination of factors including: unreliable rains, little technology available to small scale farmers, pest and disease occurrences, poor seed technology and agronomic practices as well as increased cultivation on marginal lands. Also, non-supportive small scale policies have negatively impacted on groundnut production in Ghana (Atuahene-Amankwa *et al*., 1990). Furthermore, cultivation of the crop is considered a woman's domain. Despite the numerous problems facing groundnut cultivation, it ranks as the number one grain legume grown, especially in the northern parts of Ghana by about 90% of farm families (Tsigbey *et al.*, 2003; Naab *et al.*, 2005).

Like other legumes, groundnut has the additional advantages of adding symbiotically (biologically) fixed nitrogen to the soil. In many parts of arid the climates, virtually every part of the crop is useful (from seed to vine and shell) after harvest. As far as nitrogen is concerned, cropping systems (rotations or mixtures) including a legume is reported to have shown in many cases, very significant benefits for the yields of accompanying (mixed cropping) or subsequent non-legume crops (Okito *et al.*, 2004; Schilling and Masari, 1992).

In most parts of Africa, to enable the farm family meet its household food and cash requirements, many subsistence farmers practice mixed or intercropping in which legumes form an important, and always an integral part of the system (Kafiriti, 1994, Abulu, 1978). In Ghana, groundnut is fairly intercropped, it is grown largely in pure stands from home compounds to large fields (Atuahene-Amankwa *et al.*, 1990).

Establishment of sole groundnut crop using unsuitable varieties in wide rows often lead to lower yields ha^{-1} as a result of sub-optimum plant densities, leading to poor utilization of crop growth resources and under-utilization of scarce land and/or soil in the face of pressing need for cash income by the farm family (Kafiriti, 1994; Schilling and Masari, 1992). There is therefore the need to come up with groundnut varieties and optimum spacing that will enable farmers in different agro-ecological zones to produce the crop without significant increase in production cost and land area. This is expected to increase groundnut production nationally without decreasing the annual production of cereal.

1.1 Objectives of the study

In an effort to select groundnut varieties in two agro-ecological zones of Ghana, and also to identify the optimum row spacing, this research work was initiated with the following objectives:

1. Determine the influence of spacing on growth and yield of the peanut varieties.
2. Determine the biological nitrogen fixing capacity of the different varieties and spacing.
3. Determine the effect of the different agro-ecological zones on Biological Nitrogen Fixation (BNF) and yield of the varieties and different spacing.
4. Measure the profitability of the different varieties and spacing in the two agro-ecologies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and Distribution of groundnuts

Groundnut (*Arachis hypogaea* L.), is a member of a small genus of about 69 species of tropical and sub-tropical herbs found in South America from River Amazon through Brazil, Bolivia, Uruguay and northern Argentina to about 35 ^{o}S. The cultigen (*Arachis hypogaea*) is not known in a wild state; the other species are wild, forming an important part of the herbage which is extremely grazed. All species are geocarpic, ripening their fruits underground (Bunting *et al*, 1985; Hammons, 1994).

Several sources testify to the South American origin of groundnuts. These include reports by explorers and naturalist of the sixteenth to nineteenth centuries, and archeological discoveries of seeds in Peruvian tombs dating back to 1500-1200 BC (Bunting 1955). The best evidence, however, is provided by plant explorers, who have collected around 70 wild species and identified seven (7) distinct zones of genetic differentiation in South America, whereas no wild species are found outside this region (Weiss 2000, Smith 2002). Smart (1992) indicated that the cultivated groundnut (*A. hypogaea* L.) was first domesticated in the Eastern foothills of the Bolivian Andes. Paraguay, eastern Bolivia, and central Bolivia show the greatest diversity of wild varieties of *Arachis* species. The plant is believed to have been originally domesticated by predecessors of the Arawak-speaking peoples who now live in its homeland (Isleib and Wynne, 1992; Hammons, 1994).

The Brazil coast was the point of departure for the Portuguese in the 16th century who transferred the crop to West Africa, and then on to East Africa. Spanish sailors took them across the Pacific to the Philippines from where they spread to China, Japan, Malaysia, India, and as far as Madagascar. The crop was introduced to the USA much later, via West Africa, through the slave trade (Bunting, 1955, 1958).

The first introduction into Europe was probably from Brazil to Portugal in 1784 (Smart, 1992). The first recorded commercial trade took place in 1835, from Gambia to Britain and the USA. Senegal began exporting to France in 1840-a trade that was to form the basis of Marseille's soap and oil manufacturing industry (Summerfield and Bunting, 1978).

Cultivated groundnut has spread throughout the tropics and sub-tropics from two secondary centers of diversification: West Africa and part of south East Asia (Philippines, Indonesia, and Malaysia). *A. hypogaea* is the only *Arachis* species to have become cultivated worldwide, but several other species have been grown by indigenous peoples of South America, while a few are known to have penetrated somewhat further. The species include *A. villosulicarpa* and *A. repens*, used as anti-erosion plants in the northern Matto Grosso of Brazil, and *A. glabrata* and *A. pintoi*, grown as forage crops in South America, Australia and the USA (Smart, 1992). The diffusion of the crop can be traced along the varietal lines (Krapovickas, 1969; Hammons, 1994).

Today groundnut is widely distributed and has adapted in various countries of the World. The most important producing countries are India, China, Brazil and USA. In Africa, major producers include Nigeria, Sudan, Senegal, Chad, Congo and Ghana (ICRISAT, 2008).

Table 2.1 Summary of groundnut cultivars

Subspecies	Cultivar	Primary Area of origin
hypogaea	Virginia	Southern Bolivia and Northern Argentina
hirsuta	Peruvian runner	Peru
fastigiata	Valencia	Peru, Brazil, Paraguay
vulgaris	Spanish	Paraguay, Uruguay, Brazil

Source: Kokalis-Burelle (1997)

The subspecies *hypogaea* and *hirsuta* share similar morphological features as they don't have floral axes on main axis (Weiss 2000, Bunting *et al* 1985). Pairs of vegetative branches and floral axes alternate along lateral branches. The Virginia type is less hairy and branches are short, whereas Peruvian is more hairy with long branches.

Similarly, the subspecies *fastigiata* and *vulgaris* share similar morphological features as floral axes are found on the main axis.

There are continuous runs of multi-floral axes along lateral branches. Valencia type is little branched whereas Spanish type is more branched. Although some authorities have established botanical varieties, *Arachis* is best regarded as a single variable species in distinct varieties. Bunting (1955, 1958), separates the varieties on clearly identifiable characters of agronomic significance, of which the most important are; i) Bunch form: alternate or sequential; ii) habit: erect bunch, spreading bunch or running; iii) size and shape of pod: beaked or keeled, constricted or not constricted; iv) number of seed per pod and testa colour after storage.

2.2 Botany and Morphology

The groundnut is an annual legume, unusual in its genus being allotetraploid (2n=4x=40) with a genome 1C=2891Mbp (ICRISAT, 2008). It can interbreed only with another species, *A. monticola*; the probable wild progenitor of the crop. *A. hypogaea* is an erect or trailing, sparsely hairy, annual herb, 15-75 cm tall and can spread up to 120 cm (Bunting, 1958). The aerial part of the plant consists of a main stem, which is always erect, and two primary branches, which may be erect or trailing and which determines the habit of the plant (Pattee and Young, 1982).

Many of the wild species have tuberous roots but not *A. hypogaea*, which has a well developed tap root with many lateral roots. The root system consists of a thick tap root and numerous fibrous side roots, which bear nodules that fix atmospheric nitrogen. Adventitious roots develop from the hypocotyls and aerial branches particularly in prostrate forms. There are no root hairs as there is no true epidermis. Absorption takes place 8-10 cm behind the root cap (Bunting, 1958; Bieberdorf, 1938).

The main stem or central axis develops from the terminal bud of the epicotyl. The first two lateral monopodial branches arise from buds in the axils of the cotyledons. A monopodial vegetative branch then develops at each node above on the main axis, usually for the first 3-5 nodes (Bunting, 1955). The lateral branches may also produce secondary monopodia. The arrangement of the monopodial vegetative branches and reduced reproductive branches are of two distinct types;

a) Alternate branched form which is the most primitive and occurs in the true runners (prostrate) and spreading bunch (upright) forms of the Virginia group.

b) Sequential branched forms which occur in the true erect bunch forms of the Spanish-Valencia group.

Spirally arranged with phyllotaxy of 2/5, pinnate with opposite pairs of aborate leaflets, micronate, 3-7 x 2-3 cm, entire; stipules prominent, linear-pointed, about 2.5-3.5 cm long, pulvini at point where stipules become free and at base of each leaflet. A unique characteristic of the peanut plant is the nyctinastic movements of the leaflets (Coffelt 1989). During dark periods and hot sunny days, the paired leaflets are close together in a vertical position, and on a normal day leaflets are separated from each other in a horizontal position. The leaf blade consists of four ovals to obvate leaflets attached to the midrib by small articulations which allow for movement.

Flowers are borne on inflorescence located in the axils of the leaves. Flowers are never at the same node as vegetative branches, although very short internodes on some plants may make it appear that they are (Coffelt 1989). Environmental conditions may cause the transformation of reproductive axes into vegetative axes, but not the reverse. The first flowers appear from 4 to 6 weeks after planting. Each flower is subtended by two bracts; the lower, on an axis of the inflorescence and the upper in the axil of the lower bract. The flower contains five petals: a standard, two wings, and two petals fused to form a keel. There are two calyx lobes, an awn-like one opposite the keel and a broad opposite the back of the standard.

The flower has 10 stamens, two of which are usually not fully developed. The pistil consists of an ovary, style, and stigma. Anthesis and pollination usually occur at sunrise with pollination taking place within the closed keel of the flower (Boote, 1982).

Immediately after fertilization, pods first appear at the end of pointed stalk-like structure (carpophore) known as the peg, which elongates by means of an intercalary meristerm at base of sessile ovary. Cells at tip of ovary become lignified and push base of stigma to one side, forming a protective cap as peg enters soil (Schilling and Gibbons, 2002).

The peg is positively geotropic but not negatively phototropic. The peg elongates and grows downwards, penetrating the soil to a depth of 2-7 cm, when it loses its geotropism and the tip turns to the horizontal position and the ovary swells rapidly. Young peg is conical in shape and the tip retains this shape until the maximum penetration of the soil is reached. The time taken for the peg to reach this depth depends on the initial distance from the soil but if this is more than 15 cm it usually fails to reach the ground and the tip dries (Schilling and Gibbons, 2002).

Pod enlargement begins at the base. If the apical seed aborts, the terminal section swells no further. Mature fruit is a structurally dehiscent, but functionally indehiscent legume, oblong, 1-8 x 0.5-2 cm, and may contain 1-6 seeds. The dry pericarp of the mature fruit is reticulate with 10 longitudinal ridges. The reticulations are due to mechanical tissue below the veins in the hardened mesocarp. Studies show that varieties differ significantly in pod length, diameter and number of pods plant^{-1} (Ahmad and Mohammad, 1997). This is attributed to both the genotype of the plant and environmental factors (Ogundele, 1988).

Mature seeds are elongated and cylindrical or ovoid, 1-2 x 0.5-1 cm. Varieties vary in seed size, shape and testa colour; colour ranging from white, pink, red, purple to shades of brown. Seeds have a thin testa and contain no endosperm. They have two massive cotyledons, an apicotyl with three buds of which the terminal bud has 4 foliage leaves and the two cotyledonary laterals have 1-2 leaves, hypocotyls, and the large radicle

The mature seed has a dormancy period of 30-60 days in the Virginia groups but no dormancy occurs in the Valencia or Spanish types, whose seeds can germinate immediately if conditions are wet. Dormancy can be broken in the laboratory by the presence of ethylene or by placing apple peel in the germination dish.

Ahmad and Mohammad (1997) reported non-significant differences in the number of seeds per pod. The variation in seed number per pod was found to be largely due to genetic characteristics of varieties. Ogundele (1988) confirmed that the number of seeds was a genetically heritable trait. Studies on mean seed weight also showed (Ahmad and Mohammad, 1997) significant differences. Heritable genetic characteristics was attributed to play a dominant role with regard to mean seed weight (Karkannavar *et al*, 1991)

2.3 Production and Uses

1.3.1 Production

The groundnut is one of the world's most popular and universal oilseed crop, cultivated in more than 100 countries in all six continents (Nwokolo, 1996). China and India are the largest producers. A substantial proportion of total production is consumed by growers, without ever being recorded (Weiss, 2000). Although USA had been third largest producer in the world until mid - 1990s, Nigeria is the third largest producer in the world today. Israel ranks the top in yield per unit area with an average yield of 5,401 Kg ha^{-1} in 2003. On the world production table, Ghana (185,000 ha) ranks 9th and occupies the 4th position on the African continent (FAO, 2003).

Although peanut is grown in all the agro-ecological zones of Ghana, about 85 % of the area under groundnut cultivation and the bulk of groundnut production take place in the Guinea savannah and Sudan savannah agro-ecological zones in the north (Atuahene-Amankwa *et al.*, 1990). The annual rainfall in these two production areas ranges from 800 mm to 1200 mm and the rains usually start in May and continue through October. Groundnut yield in Ghana is limited by variable rainfall, low soil fertility, pest and diseases and poor crop management (Tsigbey *et al.*, 2003).

Groundnut is produced mostly by subsistence farmers. Generally, it is intercropped with other crops such as sorghum, pearl millet, maize, and cassava. In the northeastern parts of Ghana, it is grown in pure stands on flats and ridges (Atuahene-Amankwa *et al*., 1990). Farmers do not stick to specific row spacing and only in the case of ridges is spatial arrangement considered in the establishment of the crop.

2.3.2 Uses

The early records on peanut suggest that it was a common food to the Indians of South America before the arrival of Columbus and other Spanish explorers. It was consumed raw or roasted. It was also considered as having soporific and anti-inflammatory effect (Smith, 2002). In Peru and Brazil, it was used to prepare groundnut milk and products similar to traditional almond confectionary. It was taken by the Portuguese to Africa where it became an important part of diet. The groundnut paste was used to thicken soups, stews and similar dishes, and the oil was used for culinary purposes. Early records of groundnut use in the US show that it was used as beverage, as a good substitute for chocolate (Weiss, 2000).

All parts of the groundnut plant can be easily utilized; the vines, with leaves make excellent high protein hay for horses and ruminant livestock. The shells or pods can be used as feed for livestock, burned for fuel, made into particle board, and many other uses (Tsigbey *et al.*, 2003). The groundnut is grown mainly for human consumption of the seed. The seed can be used directly for food and can be crushed to produce oil and a high protein meal. Nearly two thirds of all groundnuts produced are crushed for oil (Bunting *et al.*, 1985). Groundnut oil can be used in cooking, lighting, fuel and as a food constituent. The oil has a better keeping quality than soybean, corn, and safflower oils and is a good source of Vitamin E. Used directly as food; groundnut is a major crop for subsistence (Hammons, 1982; Pietrarelli, 1980). The multiple uses of the groundnut make it an excellent cash crop for domestic markets as well as foreign trade. In most parts of the world, the crop is utilized primarily as whole seed. The most common method of preparation for human consumption of whole seeds is dry roasting the seed (Coffelt, 1989; Pietrarelli, 1980).

The groundnut is a well-established snack food as fresh cooked and roasted groundnuts. In the USA, the major use of groundnut is for grinding into groundnut butter.

Groundnut is also used as ground flour, concentrates, and isolates. These serve as potential extenders in many meat formulations. Groundnut flour has been used to replace part or all of wheat flour or corn meal in making various types of bread and other bakery products. Groundnut protein isolates have for many years been used in the manufacture of imitation milk as an extender to cow or buffalo milk (Weiss, 2000). Groundnut protein isolate and groundnut oil have been used to make cheese analogs for the production of cream cheese and cheese spread products.

In Ghana, groundnut is an important oilseed. The bulk of the production is used for extracting oil. The cake is fried to make a local food called *kuli-kuli*. Groundnut paste from roasted kernel is used to thicken stews, soups and as bread spread. The stover is used as forage (Atuahene-Amankwa *et al* 1990).

2.4 Soil and climate requirements

2.4.1 Soil

Soil structure is an important factor affecting groundnut production. The soil must be soft enough to allow pegging and the lifting of ripe pods. In addition, groundnuts need well drained and well aerated soils, owing to high respiratory exchanges during pod formation. Sandy or fine textured friable soils with good infiltration are most suitable. Clays can produce high yields but are more difficult to work. Growing on clay soils will require the use of machinery to obtain good results (Piggott, 1960).

According to Tsigbey *et al*., (2003), groundnut showed high sensitivity to soil salinity, tolerating a wide range of pH values, but preferred neutral to slightly acidic soils. Highly acid soils ($pH<5$) or soils deficient in calcium oxide led to Manganese or Aluminium toxicity, which became severe if crops were grown continuously without soil amendments. Alkaline soils ($pH>8$) or soils subject to water logging induced iron deficiency.

2.4.2 Climate

ICRISAT (1994) identified heat as a major environmental factor limiting groundnut pod yield in the semi-arid tropics (SAT). The optimum daylight temperatures for vegetative and reproductive growth and development in peanut ranges from 25/25 °C (Wood, 1968) to 30/36 °C (Cox 1979) and from 25/25 °C (Wood, 1968) to 26/22 °C (Cox, 1979) and warm nights (>25 °C) are common in the SAT (Sivakumar *et al.*, 1993). Germination is inhibited if the temperature falls below 15 °C or rises above 45 °C. Daytime fluctuations of more than 20 °C, and nocturnal temperatures of less than 15 °C greatly slow down development, delaying completion of the plants life cycle. Very low temperatures early or late in the growing period can lead to immature pods at harvest. High temperatures retard growth and may lead to moisture stress. Pod growth is better when the temperature of the top 15 cm of the soil remains at 30 °C.

Studies in controlled environments have shown that both continuous hot days (35 °C) and short episodes of hot days (>38 °C for 6 days) reduce the number of pegs and pods in groundnuts (Ketring, 1984; Wheeler *et al*, 1997; Vara Prasad *et al.*, 1998). Vara Prasad *et al.*, ., (1998) reported that groundnut plants were sensitive to hot days from 6 days before until 15 days after coming into flower, with maximum effects occurring 9 days after flowering. Again, it was found that day temperatures above the optimum affected the number of flowers, pegs, fruits set and the number of pods plant^{-1}.

In Africa, altitude has a major effect on temperature and hence on time of maturity. For example, at 1,200 m above sea level in Zimbabwe, long-season Virginia varieties may require 150-160 days to mature, whereas 120-140 days may be needed at 400-500 m in the lowlands (ICRISAT, 1994). It is generally agreed that groundnuts are not affected by day length to any great extent. However, long days (>14 hrs) combined with high night temperatures (>30 °C) may lead to high haul production at the expense of seed.

Summerfield and Bunting (1985) reported that long days and high night temperatures were important where irrigation is used and in zones with bimodal rainfall. In these situations, 2 or 3 crops can be grown in a year in a cereal-groundnut rotation, but the cycle of each crop must be matched to the limitations imposed by the season and the cropping calendar. In both rain-fed and irrigated systems, early sowings were often associated with good yield (Piggott, 1960).

Although groundnut is generally tolerant to drought, its sensitivity varies at different growth stages. The seed needs large amounts of water, close to the soils retention capacity, in order to germinate. In contrast, as soon as germination begins, the embryo has a high requirement for oxygen. During the period up to flowering (0-30 days) the crop has good resistance to drought, but this is followed by a period of maximum sensitivity, during which there is considerable physiological activity-flowering and pod formation. Relatively dry conditions are again favourable in the period to maturity, and rain at this stage can have a highly negative effect on yields especially in non-dormant types, which tend to re-germinate in wet soils or even while drying after harvest (ICRISAT, 1992, Boote and Ketring, 1990). Rainfall of 500-1000mm per annum is normally enough for successful cash cropping. The distribution is important and if the rains are too early, mature pods may crack, allowing penetration by the fungal agent *Aspergillus flavus* (Gram, 1958). Because of its drought tolerance, peanut is often cultivated in areas that are virtually arid, where water is the main factor limiting yields. In the semi-arid topics (SAT), drought is found to be the most important environmental factor limiting pod yield (ICRISAT, 1994; Gram, 1958).

2.5 Management practices

In Ghana, groundnuts are grown in all the ten administrative regions, mostly during the major season and harvested by hand pulling towards the end of the season. About 185,000 ha of land is under groundnut cultivation with average yield of 0.85 t ha^{-1} (FAO, 2003). The crop is established either on ridges or on flats, with farmers in the northern parts planting on ridges while their counterparts in the south plant on flats. The predominant cropping pattern is a mixture of cereal-legume, with maize being the major cereal. Other cereals include sorghum and millet. In most instances, no forms of chemicals (fertilizer, weedicides, fungicides, insecticides) are used in groundnut production (Tsigbey *et al* 2003). Elsewhere, groundnut is often grown in rotation with cotton, tobacco, maize and other cereals and is usually grown late in the rotation (Gram, 1958).

Tarimo (1997) confirmed reports by Piggott (1960) and Patel (1988) that spacing and seed rate is related to growth habit and that the closer the spacing the higher the yield. This was also found to help prevent too much damage from groundnut rosette virus and suppressed weed growth and late flowering, or at least renders it ineffective, thus producing more compact and more even maturity. Tarimo (1997) further reported that factors promoting vegetative growth after anthesis in groundnut, such as low plant population greatly reduce pod yield at maturity.

On commercial fields, seeds are often treated with mercurial or Thiram dressing before sowing, especially machine shelled seeds which are often damaged. In the Sudan it was found that the addition of Dildrin reduced termite damage. Artificial inoculation with the right strain of *Rhizobium* has given inconsistent results but was rendered ineffective by chemical seed treatment (CIRAD-CORAF, 1988-95). Gram (1958) and Piggott (1960) both suggested the adoption of early sowing in order to obtain high yields

As a deep rooting legume enjoying symbiotic association with *rhizobia* and *mycorrhizae*, groundnut is able to explore large volume of soil for the nutrients it needs, often in poor soils under marginal conditions (Gibbons and Martin, 1980). This ability has earned it an unfair reputation for low responsiveness to fertilizers, to the extent that their use is often not considered and is even actively discouraged by researchers and extensionist (Peanut CRSP, 1997; Arrant, 1951; Piggott (1960). This is in spite of the fact that groundnuts are usually grown on sandy soils of poor fertility (Piggott, 1960). The crop is very unpredictable in the response to fertilizers. As such, fertilizers are usually best applied to other crops where it is grown in rotation or the intercrop partner.

Nitrogen is the most limiting nutrient for crop production in agro-ecosystems (Singh *et al*., 1990; Ssali and Keya, 1980). This is because atmospheric N and fertilizer N make up the main source of nitrogen in crop production, whilst N is lost through harvested produce, decaying materials, denitrification, leaching and volatilization (Singer and Munns, 1991; Loomis and Connor, 1992).

Nodulation and nitrogen fixation is only effective after three weeks and groundnut respond well to small doses of nitrogen fertilizers at the early stage of growth in some areas. The substantial nitrogen needs of groundnuts are partly satisfied by symbiotic fixation. However, numerous reports in the literature indicates positive responds to an application of N at sowing (starter nitrogen), reflecting the absence of biological nitrogen fixation at the early stages of growth (Piggott, 1960; Ssali and Keya, 1980).

Phosphorus is the major nutrient most needed by groundnuts. Groundnut can utilize phosphorus at lower levels than most crops and there is little response to phosphorus in many areas. However, high economic returns and long residual effects have been obtained from single super phosphate applied at the rate of 5.5 Kg P_2O_5 per acre in northern Nigeria (Peanut CRSP, 1997). In Sierra Leone, Piggott (1960) reported that the only fertilizers improving yield were calcium, Potassium and Magnesium, the last two elements having no effect alone, but only in the presence of calcium when a combination of all three gave the highest yields.

Calcium was found to be effective in improving the shelling percentage by reducing the number of "pops" or empty pods (CIRAD-CORAF, 1988-1995). Piggott (1960) indicated that Calcium was important in pod formation, particularly in large-seeded Virginia varieties and should be applied at the peak of the flowering stage, in the form of $CaSO_4$.

Groundnut also takes up large amounts of potassium, even absorbing more than it can use during the growth stages. It is however found not to show much responds to application of potassium fertilizers. Application of K in large quantities can upset the ratio of K: Ca, including uptake of calcium during pod formation (Schilling and Gibbons, 2002).

2.6 Cropping systems

2.6.1 Plant population and spatial arrangement in sole groundnut

For new crop varieties, different aspects of plant population and spatial arrangement need to be understood as well as their performance in different climatic zones. Plant population defines the number of plants per unit area and determines the area available to the individual plant. Spatial arrangement, on the other hand, defines the pattern of distribution of plants over the ground; which is the shape of the area available to the individual plant (Ntare, 1990).

For crops arranged in rows, spatial arrangement is defined by the ratio of the inter-row spacing and this impinges on individual plant performance and productivity, consequently affecting the total yield. Kang Young Kil *et al*., (1998) reported that vegetative and reproductive growth parameters were found to increase with increasing row spacing. Also, reproductive parameters increased with increasing row spacing, whereas crop growth rate increased with decreasing row spacing (Bullock *et al*., 1998)

2.6.2 Effects of spacing on weed control

According to Lee *et al.*, (1994), maintenance of a complete crop cover over the soil inhibits weed seed germination and reduces the need to carry out weeding. Early canopy closure likewise smothers weeds and reduces weed/crop competition, especially for soil nutrients and soil water (Werner, 1988, Coolman and Hoyt, 1993; Hildebrand, 1976; Thellen, 2006). Benefits of narrow-row spacing to farmers with regard to weed control were reported by Leihner (1979) and Thellen (2006) to be evident under low input conditions. Bradley (2006) reported a significant impact of narrow-row production system on the incidence of weeds within a given agro-ecosystem and on the approaches that producers might adopt for weed management.

Increases in yield under such narrow-row spacing have been attributed to improved weed control as observed in sole peanut and soybean based systems (Ahmad *et al*., 2007; Dubey, 1998; Duke and Alexander, 1964). From a weed management standpoint, perhaps the greatest influence that narrow-row spacing has on legume production is the reduction in the amount of light that reaches the soil surface and the reduction in the amount of time that it takes for the crop to reach full canopy closure (Norden and Lipscomb, 1974). Puricelli *et al*., (2003) and Steckeland and Prague (2004) have each detected significantly less radiation at the soil surface in narrow compared to wide-row soybean throughout most of the growing season. Similarly, Dalley *et al*., (2004) and Yelverton and Coble (1991) observed greater light interception in narrow-row compared to wide-row soybean throughout most of the growing season. Results from other studies involving soybean have also revealed that narrow-row soybeans reach complete canopy closure quicker than wide-row soybeans (Shibbles and Webber, 1965, 1966, Wax and Pendleton 1968). For example, in one of the earliest investigations conducted on the effects of row spacing on weed control, Burnside and Colville (1964) reported that soybeans grown in 25-inch rows provided complete shading of the ground 22 days earlier than soybeans grown in 75-inch rows.

These reductions in light penetration and time to canopy closure have a profound influence on the likelihood of weed emergence later in the growing season, a phenomenon which Yelverton and Coble (1991) first termed "weed resurgence." Yelverton and Coble (1991) determined that as row spacing increased, weed resurgence also increased in the majority of studies they carried out. Similar responses have been observed elsewhere. A review of row spacing experiments in which an initial weed management practice had been accomplished revealed that in 64% of the cases, less late-season weed density and/or biomass, or greater late-season weed control was achieved in narrow compared to wide-row soybean production systems (Bradley, 2006).

In addition to the effects on weed resurgence, row spacing has a profound impact on the critical period of weed control. Knezevic *et al*., (2003) found that earliest critical time of weed removal occurred in wide-row spacing while latest critical time of weed removal occurred in narrow-row crop. Similarly, Mulugeta and Boerboom (2000) found that the critical time of weed removal occurred much earlier in wide compared to narrow-row soybeans. Bradley (2006) confirmed that under most conditions narrow-row spacing will reduce the likelihood of weed resurgence in soybean. In many studies, this response has been directly correlated with the faster rate of canopy closure and reduction in light interception at the soil surface in narrow compared to wide-row systems. The available studies also indicate that the critical time of weed removal is most likely to occur later in narrow compared to wide-row crop. Also, peanuts grown in narrow rows lost less water to evapotranspiration than those grown in wide rows, enhancing yield among the narrow row crop (Chin *et al*., 1977).

Groundnut, as well as other legumes, has been used in crop mixtures to achieve early weed control. In groudnnut/cereal mixtures the ability of the groundnut to grow fast and form a closed canopy enables it to smother and suppress weed growth and competition. Venkateswarlu (1984a) reported reduction in nutrient drain by weeds in pigeon pea based intercropping system, and cowpea with a good canopy cover was found to be more efficient than sesame in weed control. In another study (Venkateswarlu, 1984b), he found that inclusion of green gram or cowpea as smother crops in sorghum/pigeon pea intercropping system suppressed the weed growth and proved effective as carrying out two hand weeding.

2.6.3 Effects of spacing on disease and pest occurrence

Production practices such as decreased row spacing were reported to significantly reduce the occurrence and spread of tomato spotted wilt virus (TSWV) in groundnut crop (Gorbet and Shokes, 1994, Wehtje *et al.*, 1994)). Gorbet and Shokes (1994) found that spotted wilt incidence decreased as row spacing decreased and plant density within rows increased. Branch *et al.*, (2004) confirmed that spotted wilt incidence was lowest among narrow-row and greatest among wide-row groundnut crop. Brown *et al*., (2005) and Jadhav (2006) then noted that decreasing row spacing increases the plant population density and this dilutes the thrips (*Scirtothrips spp,* *Frankliniella spp*) vector such that there is a lower probability of individual plant infection.

Gibbons and Martins (1980) and Mahmoud *et al*., (1992) also reported cultural control methods such as narrow-row crop that produced high plant densities to be highly effective in controlling the incidence and spread of groundnut rosette virus (GRV) since it slowed down the multiplication of the vector; *Aphis craccivora*. Schilling and Gibbons (2002) reported that wide spacing giving lower plant densities open groundnut crop up to infestation by aphids which prefer light and airy conditions. They recommended the adoption of narrow-rows at high densities, especially where new varieties are used.

2.6.4 Effects of spacing on yield

The advantages of planting groundnut in narrow-row spacing have been documented in studies largely conducted in other countries, especially in the Americas. The adoption of narrow-row spacing has primarily been driven by the potential for higher yields in narrow-row compared to wide-row production systems. Several workers have reported higher yields in narrow-row compared to wide-row systems in both corn and soybean (Lehman and Lambert, 1960; Lutz *et al*., 1971; Mickelson *et al*., 1997; Ottman and Welch, 1989). Higher yields in these systems are usually attributed to the more equidistant arrangement of crop plants that decreases the intraspecific competition for water, nutrients, and perhaps most importantly, light (Board *et al*., 1992; Olsen and Sander, 1988; Shibbles and Webber, 1966; Wells *et al*., 1993). Research has revealed that yield increases in these systems are closely linked to increased light interception that occurs in narrow versus wide-row spacing (Board *et al*., 1992; Dalley *et al*., 2004; Shibbles and Webber, 1966).

Groundnut research in Senegal revealed a continuous increase in groundnut yield with decreasing row spacing, which became multiples with the addition of chemical fertilizers (Schilling, 2002). Buchanan and Hauser (1980) reported higher yields (42 to 52 %) as rows were narrowed from 80 to 40 to 20 cm. In a study by Norden and Lipscomb (1974), pod yields obtained in narrow-row spacing were 16% higher compared to conventional row spacing. Duke and Alexander (1964) reported that yields from large seeded Virginia bunch types were higher in the 30 and 46 cm row spacing compared to the conventional row widths. Jaaffar and Gardner (1988) also found that narrow-row spacing had greater ground cover, leaf area indices, canopy light interception, crop growth rates and ultimately higher pod yields when compared to conventional row spacing. There were also increased light interception and leaf area indices with decreasing row spacing (Stewart *et al*., 1997). McGriff *et al*., (1999) consistently found that the tomato spotted wilt virus (TSWV) was reduced from 65 to 37% when groundnuts were planted in narrow-rows. Mozingo and Steele (1989) concluded that as row spacing decreased, pods plant^{-1} was significantly decreased.

Wright and Bell (1992) reported that a narrow-row groundnut crop extracted water from lower depths sooner than a wide-row crop and was not to be considered in drought prone areas where water stress becomes a major factor limiting yield. Reproductive development was found to be strongly influenced by row spacing with more pods m^{-2} in wide than narrow-row groundnut stands under such conditions. Mayeux and Maphanyane (1989) and Ahmad *et al*., (2007), both reported greater yields with narrow-row groundnut crop as against lower yields obtained from wide-row crop with lower plant population densities.

2.6.5. Groundnut use in crop mixtures

Intercropping involves growing two or more crops on the same land, and in the same season. Intercropping is a popular cropping system among small holder farmers in the tropics (Vandermeer 1992; Gomez and Gomez 1983c; Ruthenberg 1980; Mahmoud *et al.*, 1992; Willey, 1979b). The component crops are not necessarily sown at the same time and their harvest times may be quite different, but they are usually grown together for a significant part of the growing period (Willey, 1979a). The predominance of intercropping in poorly developed agriculture is as a result of its great stability of yield over different seasons (Ntare, 1990; Kafiriti and Chambi, 1989; Ramanaiah *et al.*, 1987). However, Nigam *et al*., (2006) reported that under situations of crop failure resulting from considerable intercrop competition, sole cropping gave greater yield stability.

In Ghana, groundnut is produced mostly by subsistence farmers. Generally, it is intercropped with other crops such as sorghum, pearl millet, maize and cassava. In the north eastern parts of the country, it is grown in pure stands on ridges (Atuahene-Amankwah *et al.*, 1990). In the cropping systems practiced by majority of farm families, the major staple intercropped with groundnut is maize (Tsigbey *et al.*, 2003). In other instances, yam and tobacco are used in a mixed cropping system with groundnut.

However, Kombiok (2005) indicated that sole cropping had become a common feature in the peri-urban areas, especially in Northern Ghana, characterized by limited degree of mechanization and external inputs. This he attributed to improved access to financial services; crops grown included cotton, groundnut, soybean, rice and maize.

Several workers have reported that maize/groundnut intercropping was not consistently advantageous to the soil as compared with rotation of the two partners (Ramanaiah *et al.*, 1987; Reddy *et al.*, 1989; Kafiriti and Chambi, 1989; Rwamugira and Massawe, 1990). However, a few maize/groundnut combinations showed positive intercropping effects. Reddy *et al.,* (1987) reported that maize at full sole crop density intercropped on the same ridges with groundnut at full density led to 22% intercropping advantage, in that maize yield was not reduced but the additional groundnut production amounted to 20% of a respective sole crop yield.

2.6.6 Groundnut use in crop rotations

In general, grain yield of succeeding crop increased markedly when legumes preceded than compared with that when cereals preceded. Different legumes have the capacity to leave behind different amounts of N for use by the succeeding crop. Yardav *et al.,* (2003) reported that yields of wheat following cowpea were significantly greater by 19-20%, compared with those following rice. Similarly, yields of wheat following soybean were significantly greater by 25% compared with those following sorghum (Ghosh *et al.*, 2004a).

Fodder legumes are also known to contribute N more than grain legumes for use by the succeeding crop. The carryover of N for use by the succeeding crop may be 60-120 Kg N in herseem, 75 Kg in Indian clover and cluster bean, 35-60 Kg in fodder cowpea, 68 Kg in gram, 55 Kg in black gram, 54-58 Kg in groundnut, 50-51 Kg in soybean, 50 Kg in lathyrus, and 36-42 Kg in pigeon pea (Singh *et al.*, 1988; Hedge and Dwivedi, 1993).

According to Das *et al.,* (1982), when groundnut was used as a preceding crop in the cropping system, subsequent sorghum crop responded to lower doses of N fertilizer

(20 Kg ha^{-1}). In the case where cowpea was used as the preceding crop, 60 Kg N ha^{-1} was needed to achieve the same crop response from the succeeding sorghum. Similarly, wheat which followed groundnut recorded higher grain yield than that following pearl millet. In another study, cowpea for grain and fodder contributed 24 and 30 Kg N equivalence ha^{-1} to the following wheat (Ghosh *et al.*, 2007). Giri and De (1980) had earlier reported benefits from grain legumes like groundnuts and cowpea grown for the full season to be equivalent to 60 Kg N ha^{-1} on the subsequent crop of pearl millet.

2.6.7 Green manure cropping system

Incorporation of whole plants of summer green gram into soil (after picking pods) before transplanting rice resulted in economizing 40-60 Kg N ha^{-1} in rice (Meelu and Rekhi, 1981). Ghosh and Sharma (1996) in Mollisols of Pantnagar, and Saraf and Patil (1995) in Inceptisols of Delhi reported that growing summer mung as a catch crop in rice-wheat rotation increased soil organic carbon and could substitute up to 50% NPK needs of rice, amounting to 60 Kg N, 30 Kg P_2O_5 and 15 Kg K_2O ha^{-1} in rice-wheat system without any adverse effects on total productivity.

Similarly, the practice of incorporating cowpea stover after picking the pods maintained higher soil organic carbon in rice-wheat systems than rice-wheat-jute and soybean-potato-wheat system after 25 years of cropping cycle (Nambiar, 1994).

2.6.8 BNF and nutrient uptake by succeeding and intercrops

Apart from nitrogen fixation, legumes included in the cropping system help in solubilising insoluble P in soil, improving the soil physical environment, increasing soil microbial activity, restoring organic matter and smothering weeds (Ghosh *et al.*, 2007).

The carryover of N derived from legumes grown in either crop sequence or in intercropping system for succeeding crops is also important. For example, sorghum yields increased when sown after groundnuts, cowpea and green gram (Ghosh *et al.*, 2007). Grain legumes like groundnut and cowpea provide an equivalent of 60 Kg N ha^{-1} to the subsequent non-legume crop or cereal. In legume/legume intercropping, pigeon pea/groundnut crop mixtures were found to be the most efficient in terms of resource use efficiency (Ghosh *et al.*, 2007)

In a country like Ghana, where most of the crop farming is carried out by subsistence farm families with little, if any resources and the average consumption of plant nutrients from chemical fertilizers on national basis are very low, the scope for exploiting direct and residual fertility due to legumes like groundnut obviously has a great potential.

Where maize is intercropped with leguminous cover crops, the leguminous crops contribute significantly to N nutrition of the maize crop. It was found by Rwamugira and Massawe (1990) that intercropped maize responded to fertilizer only up to 60 Kg N ha^{-1} while sole maize responded up to 120 Kg N ha^{-1}. In N-uptake study of intercropped maize and cowpea, it was observed that at low N level, the N content of intercropped maize was higher than that of sole maize (Francis, 1986), indicating some transfer of fixed N from cowpea to maize. Dusad and Morey (1979) reported a reduction in the N needs of sorghum intercropped with black gram by 9 Kg N ha^{-1}.

At ICRISAT, Hyderabad, however, there was no transfer of fixed N to maize when it was intercropped with peanuts (Nambiar *et al.*, 1983). Other experiences gained from ICRISAT on red and black soils revealed that there was non-significant transfer of N from legume to companion crop in sorghum pigeon pea systems (Kanwar and Rego, 1983). Venkateswarlu (1984a) then suggested the application of N and P to the cereal component only in cereal/legume systems under dry land conditions.

Nair *et al.,* (1979) observed that legumes namely soybean, cowpea, pigeon pea and groundnut grown as intercrop in maize had beneficial residual effect on the yield of succeeding wheat crop. Wheat yield and N-uptake increased when preceded by sorghum/legume systems. Intercropping of sorghum with groundnut, cowpea (both for grain and fodder) and green gram reduced the N fertilizer requirements of the succeeding wheat crop by 30-84 Kg N ha^{-1} over sole sorghum. In the case of Ghosh *et al.,* (2007), the N requirements of wheat for a target yield of 4.0 t ha^{-1} was 100.8 Kg ha^{-1} after sole sorghum, which was reduced to 87, 61, 83 and 38 Kg ha^{-1} after intercropping of sorghum with fodder or grain cowpea, groundnut and green gram respectively.

Atuahene-Amankwah (1990) reported the existence of a limited scale of legume/legume intercropping involving groundnuts (erect bunch types) and the runner varieties of cowpea in the north eastern parts of Ghana. The cowpea was planted wide apart (over 3 meters) after the peanut had established. In this type of intercropping system, the cowpea is seen as a “bonus crop”.

Elsewhere, for example in India, the predominant legume-legume intercropping system is pigeon pea/groundnut system, practiced in most of the dry land areas. This is because groundnut makes rapid canopy coverage of the ground and uses the resources more efficiently. For this system where the main crop as well as the intercrop was grain legume, Modak and Rai (1994) emphasized that both crops as sole and intercrops responded to 90 kg P_2O_5 ha^{-1}. In a study at IARI, Patel (1980) reported that where wheat was grown in rotation with sole pigeon pea, pigeon pea/green gram, pigeon pea/cowpea, pigeon pea/soybean intercropping, there was no indication of much residual fertility on the following wheat crop. However, when it was intercropped with black gram, groundnut and cowpea fodder, there was a gain of the order of 40-80 Kg N ha^{-1} for the following wheat crop (Ghosh *et al.*, 2007).

This study investigated the effects of groundnut genotypes and spacing in two agro-ecological zones of Ghana.

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Location/sites of Experiments

The experiments were conducted in 2006 and 2007 major seasons at two locations; SARI (Nyankpala) and Anwomaso (KNUST), respectively representing the Guinea Savannah and Humid Forest Agro-ecological zones of Ghana.

3.1.1 Savanna Agricultural Research Institute, Nyankpala

Nyankpala (9^o 25'N, 1^o 00'S) is located 16 km west of Tamale and is 183 metres above sea level. The land has a gentle slope of about 2% and it's strongly disturbed by sheet erosion. It is a well drained Voltaian sandstone soil unit locally referred to as *Tingoli* series, classified as ferric Luvisol (FAO/UNESCO, 1997). The field fallowed for three years after being cropped to cereal (maize) for several years.

The climate of the Nyankpala is warm, semi-arid with mono-modal annual rainfall of 1200 mm which falls mostly between May and October. This is then followed by six months of dry season, which is characterized by the dry Hamattan winds with high risk of uncontrolled bushfires resulting in the loss of vegetative cover of the soil. The average monthly atmospheric temperatures range from a minimum of 26 °C to a maximum of 39 °C with an annual mean of 32 °C.

The summary of the rainfall data during the period of the experiment at Nyankpala in 2006 and 2007 are presented in Table 3.1. Detailed climatological data in separate years are also presented in Figure 4.2 and Table 4.3.

Table. 3.1 Summary of rainfall data at Nyankpala during the period of crop growth.

	Rainfall (mm)	
Month	2006	2007
May	106.0	136.8
June	105.9	68.0
July	142.7	124.1
August	107.5	310.9
September	147.1	184.4
October	131.2	49.3

The vegetation of the site is made up of short widely spaced deciduous fire resistant/tolerant economic trees such as the Shea (*Butyrospermum parkii*) and the Dawa dawa (*Parkia biglobosa*) which do not form closed canopy. The ground flora is made up of different species of shrubs and grasses of varying heights but which are generally classified as short.

3.1.2 KNUST Agricultural Research Station, Anwomaso

Anwomaso (6° 41.850' N, 1° 31.545' W) located near KNUST is the humid forest and 292 m above sea level. The land is greatly undulating with signs of strong disturbance, especially in the cultivated areas where sheet and gulley erosion are prominent. The soil is well drained. The experimental field fallowed for 3 years after being cropped to forage crops for two years.

The climate of Anwomaso site is warm, moist with bimodal annual rainfall. The site experiences the major season from March-Aug, and the minor season from August-November. The total annual rainfall is about 2,056.3 mm. The bulk of it however, is received during the major season. The minor season receives less rain comparatively but is often enough for the cultivation of short season crops. Following the minor season is a short dry season from late November to Early March.

Average monthly atmospheric temperatures range from a minimum of 16.3 ^oC to a maximum of 35.0 ^oC with an annual mean temperature of 26.8 ^oC. The summary of rainfall data at Anwomaso during the experimental periods in 2006 and 2007 are presented in Table 3.2. Detailed climatological data in separate years are also presented in Figure 4.1 and Table. 4.2.

Table. 3.2 Summary of rainfall data at KNUST during the period of crop growth.

	Rainfall (mm)	
Month	2006	2007
May	143.0	84.3
June	113.9	244.2
July	68.0	374.0
August	75.8	127.3
September	96.8	539.8
October	117.9	237.6

The vegetation at Anwomaso is typically a rainforest. It is made up of closely spaced; mostly non-decidious tree species such as the oil palm (*Elaeis guneensis*). Most trees form close canopies. The ground flora is made up of relatively taller shrubs and very tall grass species such as the elephant grass (P*ennnisetum spp*) and Spear grass (*Impirata spp*).

3.2 Experimental design and treatments

The factorial experiments in both years were laid out as 6x3 factorial Randomized Complete Block (RCB) design with three replications per trial at each location. The treatments were six groundnut varieties and three spacing. Plots were 6m long and 4m wide. The groundnut varieties evaluated were Adepa, Azivivi, Jenkaar and, Nkosuor from Crop Research Institute (CRI) in 2006. Two more varieties; Manipintar and Kpanieli obtained from the Savanna Agricultural Research Institute (SARI) were added in 2007. With the exception of Manipintar which was indeterminate, the rest of the varieties were determinate in their growth habit. The different spacing included;

(i) SP1 = 30cm x 15cm giving a population of 222,222 plants ha^{-1},

(ii) SP2 = 40cm x 10cm giving a population of 250,000 plants ha^{-1} and

(iii) SP3 = 50cm x 10cm giving a population of 200,000 plants ha^{-1}.

Maize crop variety, Dorke SR, planted at 75cm x 40cm was used as the reference crop.

3.3 Management practices.

Land clearing was done manually with a cutlass. A single tractor ploughing and harrowing operation was then carried before sowing. Both sites were fumigated two weeks prior to establishment of the crop. Two manual weeding operations were carried out at each site using the hand-hoe. The first weeding was two weeks after planting. The second weeding operation was carried out at the onset of flowering. Subsequent weed growth was easily controlled by hand pulling. No fertilizer application took place throughout the conduct of the experiment. Harvesting was done by hand-pulling at maturity.

In both 2006 and 2007, seeds were sown on flats in both locations after a single ploughing and harrowing operation. Establishment of crops however differed with regard to the planting date due to the differences in the start of the cropping seasons between KNUST and Nyankpala. KNUST trial started earlier in both years. In 2006, plants were sown on May 18 and harvested on September 10 at KNUST. The Nyankpala trial was sown on July 4 and harvested on October 15. In 2007, the KNUST trial was planted on May 17 and harvested on the August 28, whilst the Nyankpala crop was sown on June 4 and harvested on September 20.

3.4 Data collected

3.4.1 Initial soil status determination

Six representative samples were taken from each block to the depth of 0-15cm using a soil auger. The samples were taken in a Zigzag (W pattern) across each replication (Smith and Atkinson, 1975). The samples were bulked together, mixed thoroughly and a sub-sample taken and prepared for analyses.

The soil samples were first air dried, crushed and passed through a 2 mm sieve. Portions such as undecomposed plant parts, stones and gravel were discarded. The samples were placed in black polythene and stored in the laboratory for physical and chemical analyses. The results of the analyses represented the initial soil status at the start of the experiment in 2006. These are shown in Table 3.3.

3.4.1.1 Soil total nitrogen

Soil total nitrogen was determined by the micro-kjeldahl procedure involving digestion, distillation and titration. 1g of soil sample was digested in 5ml of concentrated sulphuric acid (H_2SO_4). Few drops of 30 % hydrogen peroxide (H_2O_2)

were then added to the solution with Selenium as catalyst. This procedure ensured the conversion of organic nitrogen to ammonium sulphate. The resultant solution was then made alkaline by the addition of 5ml of 40 % sodium hydroxide (NaOH). Ammonia was distilled into 2 % boric acid and titrated against standard hydrochloric acid (HCl).

3.4.1.2 Available phosphorus

The determination of available soil phosphorus was done calorimetrically using a Pye Unicam spectrophotometer at 880 mm wavelength in absorbance after extraction with Bray P-1 extractant composed of 0.03M NH_4F and 0.025M HCl - Bray and Kurtz (1945), and the Molybdate/ascorbic acid reduction.

3.4.1.3 Exchangeable basic cations

The exchangeable basic cations were extracted using neutral 1.0M NH_4OAc. EDTA complexometric titration method was used to determine calcium and magnesium in the extract while sodium and potassium were determined by flame photometry.

3.4.1.5 Exchangeable acidity

Exchangeable acidity (Al & H) was determined by the titration method after extraction with 1.0M KCl (Thomas, 1982)

3.4.1.6 Effective cation exchange capacity

Effective cation exchange capacity was determined through calculation. ECEC was calculated by the summation of the exchangeable basic cations and exchangeable acidity.

3.4.1.7 Soil pH

The soil pH was determined in 0.01M $CaCl_2$ solution using an 8120 Weichman, Germany pH meter and a soil to solution ratio of 1:2.5

3.4.1.8 Soil organic Carbon and organic matter

The Walkley and Black (1934) method was employed in the determination of soil organic carbon. The percent organic matter was then calculated by multiplying the percent organic carbon by 1.724 (van Bemmelen factor).

3.4.1.9 Particle size analysis

The distribution of particle size in the soil sample was determined by the modified Bouyoucos hydrometer method using sodium hexametaphosphate as the dispersing agent. Wet sieving was employed to separate the mineral part of the soil sample into various fractions and their proportions determined. The samples were pretreated with hydrogen peroxide to remove organic matter before shaking with the dispersing agent. Sand fraction was separated from silt and clay with a 50µm sieve while clay and silt fractions were determined using a hydrometer

3.4.2 Measurement of crop variables

3.4.2.1 Days to 50% emergence

This measured the number of days taken by the germinated seeds to emerge out of the soil.

3.4.2.2 Plant stand

This was taken two weeks after planting (WAP), after seedlings would have completely emerged from the soil. The two central rows were used in the determination of plant stand at 2WAP.

3.4.2.3 Plant height

Five plants of each treatment/plot were randomly selected and identified with a tag. Heights of these selected plants were monitored at two weeks interval throughout the growing period of each experiment. The height of each plant was measured using a measuring tape. Measurement was done from the ground level to the last terminal leaf of peanut plants at 4, 6 and 8WAP.

3.4.2.4 Canopy width

The canopy spread of five plants selectively tagged for height measurement was also monitored. The spread was measured from the last leaf on one side to the last leaf on the other side using a measuring tape. This was done 4, 6, and 8, WAP and the average canopy width per plant calculated.

3.4.2.5 Number of branches

The number of branches of the five randomly selected/tagged plants from each plot was determined by counting. This was done at maturity.

3.4.2.6 Leaf Area Index

Five plants were randomly chosen in each treatment from the two border rows and cut to the ground level and all the leaves stripped. The fresh leaves were weighed

(W_f) and the weights recorded. Fifty leaf discs of the fresh leaves were made using a 1.0cm diameter cork borer. These were also weighed (W_b). Since the diameter of the cork borer was known, the area of each leaf disc was estimated using πr^2 (formula for estimating the area of a circle). Total area of 50 leaf discs was then determined to be the product of the area of one disc and the number of discs in cm^2. By relating the area of 50 discs to the weight, it was possible to calculate the leaf area as W_f / W_b x area of leaf discs (f / b x area of leaf discs). The LAI of groundnuts was then calculated as the ratio of the total leaf area to the area of ground space covered by each plant, described by Watson (1952).

3.4.2.7 Shoot dry matter

From the two border rows on each side of each treatment plot, five plants were randomly chosen and cut to the ground level for shoot dry matter determination 4, 6 and 8 WAP. Total fresh shoot weight was taken using an electronic balance in the laboratories of KNUST and SARI in 2006 and 2007. Plant materials were then put in large brown envelopes and oven dried at 80 °C for 72 hours. The dry materials were weighed and shoot dry weight recorded.

3.4.2.8 Relative growth rate

Five whole plants were cut to the ground level from the two border rows in each treatment at 4, 6 and 8 WAP. The plant materials were weighed fresh before oven drying at 80 °C for 72 hours. Samples were then weighed and the dry weights recorded. These were used to determine relative growth rates for the treatments at two stages (4-6WAP and 6-8WAP) as;

$RGR = (InW_2\text{-}InW_1) / (T_2\text{-}T_1)$ (g m^{-2} wk^{-1})

Where;

RGR = relative growth rate (g m^{-2} wk^{-1})

W_1 & $W_{2=}$ dry weight at first and second sampling (in grams)

T_1 &T_2 = Time of first and second sampling (in weeks) respectively.

3.4.2.9 Nodule number per plant

Five plants from the two border rows were randomly selected and gently dug out. The plants were then washed through a fine sieve in water to remove soil particles. The number of nodules on each plant was then determined and the average nodules per plant calculated. This was done 6WAP.

3.4.2.10 Estimation of N_2-fixed

The technique used to estimate N_2-fixed was the Total Nitrogen Difference (TND) method. This method is based on the total nitrogen difference between nitrogen fixing crop and non-nitrogen fixing crop (maize) grown on the same soil (Hanssen, 1994). The groundnut varietal trial was compared to a single treatment of maize per replication, grown as the reference crop. The difference between the two crops on per plant basis was regarded as the quantity of N provided by biological nitrogen fixation (BNF).

Thus N_2 fixed = $Nyield_{fix} – Nyield_{ref}$

$\%Ndfa = 100(Nyield_{fix} – Nyield_{ref}) / Nyield_{fix}$

Where:

%Ndfa — percentage of plant nitrogen derived from atmosphere

$Nyield_{fix}$ — nitrogen yield by N_2-fixing system (peanut)

$Nyield_{ref}$ — nitrogen yield by reference crop (maize)

Nitrogen yield or nitrogen uptake is estimated as the plant total dry matter yield and nitrogen concentrations. This method is based on the assumption that the N_2-fixing crop and the non N_2-fixing crop assimilate identical amounts of soil and fertilizer nitrogen.

3.4.2.11 Number of pods plant^{-1}

Pod harvest from five consecutive peanut plants were counted and the average of this taken as the number of pods plant^{-1}.

3.4.1.12 Number of seeds pod^{-1}

The pods harvested from five consecutive plants from each treatment were then shelled and the seeds counted. The number of seeds for each treatment was divided by the number of respective pods to obtain the number of seeds pod^{-1}.

3.4.2.13 Mean (100) seed weight

Hundred seeds from each treatment were randomly picked and weighed. This was replicated five times and the average seed weight determined. The average weight of five counts was then taken as the weight of hundred seeds for each treatment.

3.4.2.14 Shelling percentage

The pods and ears from the net plots of peanuts were each put in open bags and air dried thoroughly to a moisture level of 10% before shelling. Harvest from five randomly selected groundnut plants were weighed before shelling (Me & Pp respectively). After shelling, the shelled nuts were weighed and recorded. The shelling percentage was determined as the weight of groundnut seed divided by weight of pods as shown below.

.i.e.: shelling percentage = Ps / Pp x 100% where;

Ps weight of peanut seed

Pp weight of peanut pods

3.4.2.15 Seed-Hull ratio (SHR)

This is the ratio of the seed/kernel to the hull after shelling. SHR was determined using the shelling percentage as described by Pattee *et al.*, (2006) as;

SHR = Shelling percentage/100 – Shelling percentage.

Seed-hull ratio has been reported by Abdel (1994) and Pattee *et al.*, (2006) to be an accurate indicator of maturity among peanut varieties.

3.4.2.16 Dry pod yield and seed yield

The total weight of peanut and maize from the respective net plots were recorded before shelling and further drying to a moisture content of 13 % using a moisture meter. The weights of peanuts harvest from each net plot were then extrapolated to total pod yield per hectare basis.

3.4.2.17 Stover yield

Groundnut haulms after harvest were dried and weighed. This was then added to the weight of the empty shells after shelling to obtain the total stover weight from each net plot. The values were then converted to stover yield ha^{-1} for each treatment.

3.4.2.18 Total plant biomass

The vines or stover of groundnuts from the net plots were dried and weighed. This was added to the total weight of pods harvested from the net plots to give the total plant biomass of groundnut produced from each net plot. These values were then converted to biomass yield ha^{-1}.

3.4.2.19 Harvest Index (HI).

This is the ratio of total economic yield to the total plant dry matter or biomass produced by the system at harvest. HI for was determined using the relationship expressed below;

HI = Seed weight/ Total dry matter at harvest.

3.5 Correlation analysis

Correlation between yield and yield components were determined using Microsoft Excel and the results interpreted by the Pearson product moment correlation (PPMC) coefficient method (Allan, 2001; Pelosi and Sandifer, 2003,). This method recognizes negative one (-1) as perfect negative correlation, positive one (+1) as perfect positive correlation and zero (0) as no correlation.

3.6 Economic analysis

Partial budgeting was used to organize experimental data and information relating to costs and benefits of treatments (CIMMYT, 1988). It deals with the variable cost of production of crops under the different treatments and the net benefits derived from these operations after harvesting the crops.

The crop enterprise budget technique developed by Wesley *et al.,* (1993) was used to assess the economic returns to management under each treatment. The cost of all recommended variable inputs used on all the treatments in the study were considered. Prices of crops and the operational cost used in the study were seasonal averages prevailing in the study areas during the cropping seasons.

The values of the crop treatments were determined at harvest, removing cost components attributable to storage. Prices of produce on the local markets were considered, also removing cost attributable to transport and handling. Crop values were calculated manually as the product of treatment harvest (yield) and average market prices at the time. Variable cost was the actual price paid by the farmers each year which include the cost of land preparation, seed, planting, weed control, insecticide, fertilizer and harvesting.

Net returns per hectare were then calculated as the difference between the gross income and total variable cost. Average net returns were calculated as the mean of the annual net returns over the study period of 2 years. No capital cost such as charges for land, depreciation of machinery, interest on operating capital and other overheads were considered.

The benefits cost ratio (BCR) which is the net benefit divided by the operational cost were used to compare plant population (varietal trial) and cropping systems (CIMMYT, 1988; Wesley *et al.*, 1993). The populations and cropping systems that produced the highest among the treatments would be considered as being the most profitable under the circumstances. Thus;

NB= GR - TVC

BCR = NB / TVC

Where;

NB = Net Benefit

GR = Gross Returns

TVC = Total Variable Cost of production

BCR = Benefit-Cost Ration

The partial budgeting and prices of inputs such as agro-chemicals and services such as land preparation for both years and locations are presented in Appendix 1.

3.5 Data analysis

All data collected were subjected to statistical analysis using Genstat Discovery Edition3 (2007). The analysis of variance procedure for multifactor experiments was followed to determine whether differences existed among treatments (Table 3.4). All treatment means were compared using the Least Significant Difference (LSD) at 5% level of significance. A correlation analysis between yield and yield components was also carried out.

Table 3.3 Skeleton of Analysis of Variance for factorial experiments in randomized complete block design (RCBD).

Source of Variation	Degree of Freedom
Replication	r-1 =2
Variety (var)	a-1 =5
Spacing (sp)	b-1 =2
Var x Sp	(a-1) (b-1) = 10
Error	(rab-1) - [(r-1)+(a-1)+(b-1)+(a-1)(b-1)] = 34
Total	rab-1 = 53

CHAPTER FOUR

RESULTS

4.1 Climate and soil analysis

4.1.1 Soil analysis

The results of initial soil analysis at both locations in 2006 are presented in Table 4.1. The results show that Total N (%), pH, effective cation exchange capacity (ECEC), potassium, organic carbon and available P were all higher at KNUST compared to their respective values at Nyankpala. Calcium and bulk density were however higher at Nyankpala than at KNUST.

Table. 4.1 Initial soil status of the KNUST and Nyankpala sites at the start of the experiment in 2006.

Parameter	Description (0-15 cm)	
	KNUST	Nyankpala
Mineralogical		
Sand (%)	68.5	73.6
Silt (%)	15.9	15.8
Clay (%)	15.6	12.2
Ca + Mg Carbonate (%)	33.7	35.2
Available P (mg/Kg)	13.2	10.5
Base Saturation (%)	72.3	74.1
Bulk Density (g/cm^3)	1.43	1.46
Exchangeable Cations		
K	0.31	0.21
Ca	2.10	2.33
Mg	0.72	0.48
Na	0.23	0.18
(Al + H)	1.31	1.12
ECEC (c mol/Kg)	5.34	4.33
Organic Carbon	1.32	0.37
pH 1:2 ($CaCl_2$)	7.80	6.50
Total N)%)	0.073	0.044

4.1.2. Rainfall

The results of rainfall data in 2006, 2007 and mean monthly rainfall from 1953 to 2007 are presented in Figure. 4.1. The mean monthly rainfall in April, then from June to October were all higher than both their respective mean values in 2007, as well as the national mean monthly values from 1953 to 2007. The total annual rainfall (2,114.3 mm) and mean monthly rainfall (178.69 mm) in 2006 were also higher than the 2007 values (1,998.3 mm and 166.5 mm respectively).

At Nyankpala, (Figure 4.2), mean monthly rainfall in March, May, August and September in 2007 were all higher than both their respective 2006 mean values and the national mean values from 1960 to 2007. The total annual (814.4 mm) and mean monthly rainfall (91.6 mm) in 2007 were also higher than that received in 2006. Also, the total annual and mean monthly rainfalls received at Nyankpala were lower than that received at KNUST in both years.

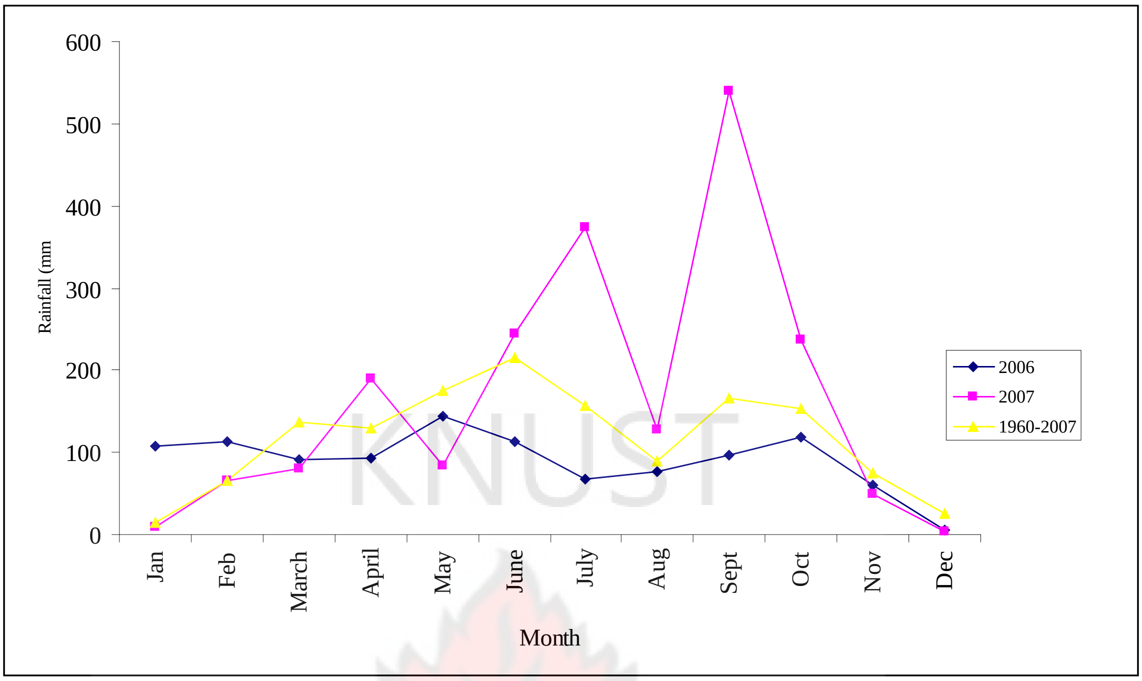

Figure 4.1 Mean monthly rainfall at KNUST in 2006 and 2007 compared to national mean monthly rainfall from 1953-2007.

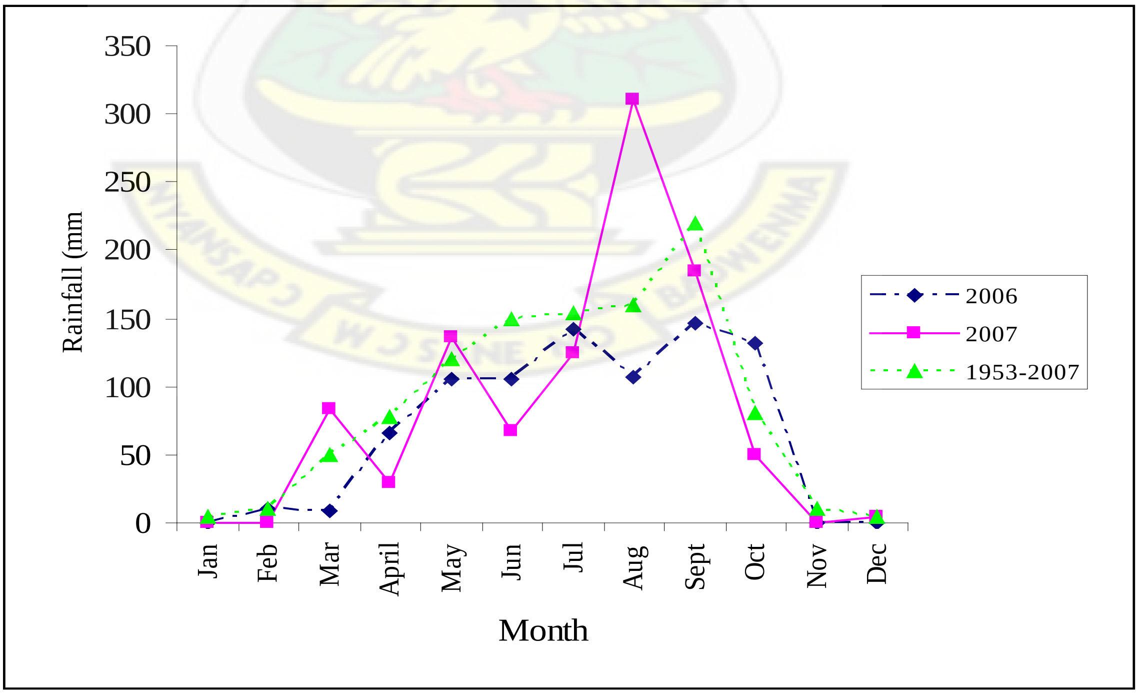

Figure. 4.2 Mean monthly rainfall at Nyankpala in 2006 and 2007 compared to national mean monthly rainfall from 1960-2007

4.1.3 Temperature

Data on temperature at KNUST are presented in Table. 4.2. The data show that there were no wide fluctuations in mean (Tmean), minimum (Tmin) and maximum (Tmax) temperatures in both years. Also, the Tmean (26.7 ^{o}C and 26.8 ^{o}C) in 2006 and 2007 respectively did not show wide fluctuations.

At Nyankpala (Table. 4.3) no wide fluctuations in Tmin, Tmean and Tmax were also recorded in both years. However, Tmin and Tmean were inversely related to rainfall. The reduced rainfall (8.7 mm) received in March lead to the highest Tmin (35.9 ^{o}C). This resulted in the highest Tmean (33.6 ^{o}C) at Nynkpala in 2006. Again, the very high rainfall (301.9 mm) received in 2007 in August lead to the lowest Tmin and Tmean in that year.

In both years, the Tmin, Tmean and Tmax (Table. 4.2 and Table. 4.3) values at KNUST were generally lower than their respective corresponding values at Nyankpala. The differences in temperatures recorded between the locations were largely due to the differences in rainfall amount received at each location during the period.

Table. 4.2 Minimum, mean and maximum monthly temperatures at KNUST in 2006 and 2007.

	2006 (^oC)			2007 (^oC)		
Month	T min	T mean	T max	T min	T mean	T max
January	21.2	26.9	32.6	16.5	25.3	34
February	22.5	28.8	35	22.4	28.5	34.5
March	21.8	27.4	32.9	22.6	28.9	35.2
April	22.5	28.4	34.2	21.8	27.9	34
May	22	27.1	32.2	22.2	27.6	32.9
June	20.6	26	31.4	22.6	27.1	31.6
July	20.8	25.6	30.3	22.9	26.3	29.6
August	20.5	24.9	29.2	22.1	26	29.9
September	21.1	25.6	30.1	22	26.1	30.2
October	21.7	26.6	31.5	21.9	26.4	30.9
November	21.8	27.1	32.3	22.1	26.8	31.4
December	21.4	27.1	32.7	19.9	26	32.1
Mean	21.4	26.7	32	21.5	26.8	32.1

Table. 4.3 Minimum, mean and maximum monthly temperatures at Nyankpala in 2006 and 2007.

	2006 (^oC)			2007 (^oC)		
Month	T min	T mean	T max	T min	T mean	T max
January	21.7	29.7	37.6	18.8	26.6	34.3
February	22.8	30.6	38.4	23.1	30.6	38.1
March	25.9	33.6	37.7	24.4	32.2	39.9
April	24.7	30.7	36.7	25	31	37
May	23.7	28.3	32.9	24.4	28.8	33.1
June	23.4	27.6	31.7	24.1	28.1	32
July	23.5	27.2	30.9	23.7	27.4	31
August	22	26	29.9	23.1	26	28.9
September	22.5	26.3	30	22.7	26.5	30.3
October	23	27.3	31.5	23.1	28.2	33.3
November	18.8	25.9	32.9	24.4	29.6	34.7
December	17.9	26.6	35.3	20.3	27	33.7
Mean	22.6	28.2	33.8	23.1	28.5	33.9

4.2 KNUST Results

4.2.1 Growth and yield

4.2.1.1 Plant stand

Results of plant stand 2WAP at KNUST in 2006 and 2007 are shown in Table. 4.4. Crop variety significantly affected plant stand at 2WAP in both years. The results show that plant stand in 2006 ranged between a low of 16.44 recorded by Jenkaar and a high of 19.11 plants m^{-2} recorded by Adepa. Plant stand of Adepa was significantly greater ($P<0.05$) than that of Jenkaar. All other treatment differences were not significant. In 2007 cropping season, plant stand ranged between 16.50 (Azivivi) and 18.56 (Manipintar) plants m^{-2}. Manipintar which recorded the highest plants stand had its effect significantly higher ($P<0.05$) than those of Azivivi, Jenkaar and Kpanieli. Also, Adepa which recorded 18.29 plants m^{-2} was significantly higher ($P<0.05$) than Azivivi. Spacing did not significantly affect plant stand in both cropping seasons.

4.2.1.2 Number of branches

Results of number of branches $plant^{-1}$ in both years are presented in Table. 4.4. In 2006, Jenkaar recorded the greatest number of branches which was significantly higher ($P<0.05$) than the effect of Azivivi variety only. Other treatment differences were not significant.

In 2007, number of branches $plant^{-1}$ recorded in the Kpanieli variety was significantly higher ($P<0.05$) than in all other varieties, except Manipintar. Also, Manipintar which produced 12.50 branches $plant^{-1}$ had its effects being significantly higher ($P<0.05$) than those of Adepa and Azivivi varieties. Effects of Azivivi, Nkosuor and Jenkaar were however not statistically different from one another. Spacing significantly affected number of branches plant^{-1} with SP1 recording 12.60 branches plant^{-1} which was significantly higher ($P<0.05$) than the effects of SP2 and SP3 treatments. In 2007, spacing effects were not significant.

Table. 4.4 Plant stand at 2 WAP and number of branches at maturity as affected by variety and spacing in 2006 and 2007.

Treatment	Plant Stand (m^{-2})			Number of Branches plant^{-1}		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	19.11	18.29	18.70	11.73	11.13	11.43
Azivivi	18.33	16.50	17.42	11.44	11.04	11.24
Jenkaar	16.44	16.88	16.66	12.58	11.69	12.14
Kpanieli	*	16.83	16.83	*	12.83	12.83
Nkosuor	17.22	18.04	17.63	11.56	11.66	11.61
Manipintar	*	18.56	18.56	*	12.50	12.50
Lsd (5%)	2.58	1.61		1.13	1.07	
SPACING						
SP1	16.67	17.79	17.23	12.60	11.91	12.26
SP2	18.33	17.92	18.13	11.42	11.80	11.61
SP3	17.83	16.85	17.34	11.47	11.72	11.60
Lsd (5%)	NS	NS		0.98	NS	
CV (%)	9.0	3.8		11.4	6.1	

4.2.1.3 Plant height

Table. 4.5 show results of plant height at 4, 6 and 8WAP in 2006 and 2007. Plant height for all treatments increased from 4 through 6 to 8WAP in both cropping seasons. Adepa consistently recorded greater effects at all sampling times in 2006 but its effects were statistically similar to other varietal effects. Spacing did not significantly affect plant height in 2006 growing season. In 2007, Manipintar consistently recorded the tallest plants (19.83cm, 33.36cm and 39.30cm) at 4, 6 and 8WAP respectively. These were significantly higher than effects of all other varieties at the respective sampling stages. Also, Kpanieli recorded plant height of 16.3cm at 4WAP and this was significantly higher (P<0.05) than that of Adepa and Nkosuor. At 6WAP, plant height of the Kpanieli was significantly higher (P<0.05) than that of the Adepa variety only. No such effects were observed at 8WAP. Spacing effects were significant on all sampling days in 2007. On all sampling occasions, plant height from the SP1 treatment was the highest, and this was significantly higher (P<0.05) than that of the SP3 treatment only. Differences between the effects of SP2 and SP3 were not significant on all sampling occasions.

Table. 4.5 Plant height at 4, 6 and 8 WAP as affected by variety and spacing in 2006 and 2007.

Treatment	2006 (cm)			2007 (cm)		
	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP
VARIETY						
Adepa	15.57	24.89	34.50	14.21	19.94	29.89
Azivivi	14.61	23.56	33.30	15.38	22.29	30.89
Jenkaar	14.00	24.78	33.90	15.69	23.11	33.26
Kpanieli	*	*	*	16.30	23.80	31.56
Nkosuor	15.49	23.11	32.60	15.33	22.27	30.91
Manipintar	*	*	*	19.83	33.36	39.90
Lsd (5%)	2.518	4.308	6.180	0.675	2.820	3.345
SPACING						
SP1	15.06	23.83	32.90	16.66	25.64	34.11
SP2	15.12	24.53	34.40	16.02	23.87	32.60
SP3	14.57	23.89	33.40	15.69	22.87	31.13
Lsd (5%)	NS	NS	NS	0.675	1.994	2.365
CV (%)	2.50	5.40	6.00	3.10	9.90	7.10

4.2.1.4 Canopy width

Results of plant canopy spread in 2006 and 2007 cropping seasons are presented in Table. 4.6. The results show that canopy widths of all peanut varieties continued to increase from 4 through 6 to 8WAP in both cropping seasons. In 2006, Nkosuor recorded the widest canopy of 19.69 cm 4WAP. The least spread of 17.34 cm was recorded by Jenkaar. The difference between the two varieties was significant ($P<0.05$). Canopy spread of Azivivi was also significantly higher ($P<0.05$) than that of Jenkaar on this occasion. At 6 and 8WAP, varietal differences were not significant at 5% level of probability.

In 2007, canopy width ranged between 15.62 and 19.33 cm (4WAP), 20.87 cm and 27.42 cm (6WAP) and 41.58 and 47.81 cm (8WAP). The widest canopy spread at 4WAP (19.23) was measured in Manipintar whose effect was significantly higher ($P<0.05$) than all other treatment effects. Effect of Jenkaar was also significantly higher ($P<0.05$) than those of Adepa and Azivivi. Other treatment effects were not significant. Manipintar recorded the greatest canopy spread also at 6WAP and this was significantly higher ($P<0.05$) than all other treatment effects. The Adepa variety also had significantly larger canopy width than Nkosuor. All other treatment effects were statistically similar.

At 8WAP, the greatest effect was produced by the Jenkaar variety which was significantly higher ($P<0.05$) than the effects of Kpanieli, Manipintar and Nkosuor. All other treatment differences were not significant.

Spacing significantly affected canopy width of peanut varieties in both seasons. In 2006, SP3 treatment recorded the widest canopy spread on all sampling occasions.

At both 4 and 6WAP, canopy spread of this treatment was significantly higher ($P<0.05$) than those of SP1 and SP2 treatments, which produced similar effects. However at 8WAP, the effect of the SP2 treatment was also significantly higher ($P<0.05$) than that of the SP1 treatment. In 2007, canopy spread of the SP3 treatment was significantly higher on all sampling occasions. Additionally, on all sampling occasions, treatment effect of SP2 was also significantly higher ($P<0.05$) than that of the SP1 treatment at 5% level of probability.

Table. 4.6 Plant canopy widths 4, 6 and 8WAP as affected by peanut variety and spacing in 2006 and 2007.

Treatment	2006 (cm)			2007 (cm)		
	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP
VARIETY						
Adepa	18.92	35.09	45.89	15.69	23.39	44.02
Azivivi	19.39	34.64	48.08	15.62	21.23	44.09
Jenkaar	17.34	36.11	49.52	17.52	21.87	47.81
Kpanieli	*	*	*	16.87	22.56	41.58
Nkosuor	19.69	33.98	45.16	16.71	20.87	43.44
Manipintar	*	*	*	19.23	27.42	42.97
Lsd (5%)	1.75	NS	NS	1.45	2.38	4.06
SPACING						
SP1	17.59	31.38	38.53	15.40	20.30	36.74
SP2	18.16	34.20	48.48	16.78	22.34	45.93
SP3	20.76	39.28	54.53	18.69	26.03	49.29
Lsd (5%)	1.51	3.45	4.20	1.02	1.68	2.87
CV (%)	5.30	3.80	4.70	3.20	4.30	8.90

4.2.1.5 Shoot dry matter

Results of above ground plant biomass are presented in Table. 4.5. Shoot DM for all treatments increased from 4 to 8WAP during cropping seasons, reflecting crop growth and development. At 4WAP in 2006, DM $plant^{-1}$ ranged between 13.22 and

14.79 g. No significant differences (P<0.05) were however observed among varieties. At 6WAP, Azivivi recorded shoot dry matter of 28.10 g, which was significantly higher (P<0.05) than that recorded by Adepa and Nkosuor (20.33 and 23.72 g respectively). Also, Jenkaar recorded 27.26 g which was significantly higher (P<0.05) than that of Adepa. At 8WAP, effect of Jenkaar (50.30 g) was significantly higher (P<0.05) than Adepa which recorded the least DM (37.60 g) per plant. All other treatment differences were not significant.

In 2007, Manipintar recorded the largest shoot DM (16.06 g) at 4WAP and this was significantly higher (P<0.05) than effects of Adepa and Azivivi. Effects of Jenkaar and Kpanieli were also significantly higher (P<0.05) than those of Adepa and Azivivi. At 6WAP, Manipintar produced the largest plant dry matter but this was significantly higher (P<0.05) than that of Adepa only. All other treatment differences were not significant. At 8WAP, Kpanieli recorded the largest shoot DM (49,46g) and this was higher (P<0.05) than the effects of Nkosuor, Jenkaar and Adepa varieties. Effects of Manipintar was also significantly higher (P<0.05) than those of Nkosuor, Adepa and Azivivi.

Spacing significantly affected shoot DM at all three sampling stages in 2006. Effect of SP3 was significantly larger (P<0.05) than only SP1 at 4WAP. Effects of the SP1 treatment were significantly higher (P<0.05) than that of the SP2 at 6WAP. At 8WAP, the greatest effect was measured in the SP3 treatment. At 4WAP in 2007, shoot dry matter of the SP3 treatment was significantly higher (P<0.05) than that of SP1 treatment only. No significant differences in shoot dry matter were observed among treatments 6 and 8WAP in 2007.

Table. 4.7 Shoot DM 4, 6 and 8WAP as affected by variety and spacing at KNUST in 2006 and 2007.

Treatment	2006 (g plant^{-1})			2007 (g plant^{-1})		
	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP
VARIETY						
Adepa	13.22	20.23	37.60	12.30	19.19	32.41
Azivivi	13.78	28.10	44.30	13.53	26.11	36.46
Jenkaar	14.62	27.26	50.30	15.06	25.67	42.87
Kpanieli	*	*	*	15.00	26.80	49.46
Nkosuor	14.79	23.72	43.10	15.17	23.68	37.97
Manipintar	*	*	*	16.06	27.33	47.37
Lsd (5%)	NS	3.96	7.64	1.15	3.78	6.65
SPACING						
SP1	13.12	27.18	41.40	13.92	25.59	41.52
SP2	13.84	22.06	40.40	14.33	23.56	39.42
SP3	15.35	25.34	49.60	15.31	25.23	41.93
Lsd (5%)	1.91	3.43	6.62	0.81	2.67	NS
CV (%)	12.8	25.0	13.0	0.90	24.8	8.90

4.2.1.6 Relative growth rate

Table. 4.8 shows results of relative growth rate in both cropping seasons. Growth rates between 4-6WAP were generally higher than between 6-8WAP. From 4-6WAP in 2006, Jenkaar recorded the largest growth rate of 0.622 g wk^{-1} which was significantly higher ($P<0.05$) than that of Nkosuor only. All other treatment differences were not significant. Between 6-8WAP, Jenkaar still recorded the greatest crop growth rate, and this was significantly higher ($P<0.05$) than that of Azivivi only which recorded the lowest crop growth rate. In 2007 peanut varieties did not show significant differences in growth rates 4-6WAP. From 6-8WAP however, Kpanieli recorded the greatest crop growth rate of 0.426 g wk^{-1} which was significantly higher (P<0.05) than that of Azivivi with the least growth rate of 0.193 g wk^{-1}.

Spacing did not show significant variation in growth rates in 2007 and also between 4-6WAP in 2006. However, between 6-8WAP in 2006, crop growth rate by the SP1 was significantly lower (P<0.05) than those of the SP2 and SP3 treatments. Difference between the SP2 and SP3 treatments effects were not significant.

Table. 4.8 Relative growth rates as affected by variety and spacing in 2006 and 2007.

Treatment	4-6 WAP (g $m^{-2}wk^{-1}$)			6-8 WAP (g m^{-2} wk^{-1})		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	0.522	0.222	0.372	0.314	0.256	0.285
Azivivi	0.573	0.297	0.453	0.238	0.193	0.216
Jenkaar	0.622	0.257	0.440	0.337	0.259	0.298
Kpanieli	*	0.272	0.272	*	0.426	0.426
Nkosuor	0.517	0.218	0.368	0.310	0.242	0.276
Manipintar	*	0.259	0.259	*	0.284	0.284
Lsd (5%)	0.057	NS		0.096	0.105	
SPACING						
SP1	0.576	0.291	0.434	0.228	0.225	0.227
SP2	0.537	0.236	0.387	0.314	0.267	0.291
SP3	0.562	0.236	0.399	0.358	0.258	0.308
Lsd (5%)	NS	NS		0.083	0.074	
CV (%)	3.30	23.70		50.7	38.2	

4.2.1.7 Number of nodules plant^{-1}

Table. 4.9 show the results of number of nodules plant^{-1}. In the 2006 cropping season, nodule numbers ranged between 89 and 125. No significant differences were observed among varieties in 2006. In 2007, number of nodules plant^{-1} ranged between a low of 99.3 recorded by Jenkaar and a high of 127.2 recorded by Manipintar. Manipintar which recorded the most nodules plant^{-1} had its effect significantly higher ($P<0.05$) than the effects of Adepa and Jenkaar varieties. Spacing did not significantly affect nodule numbers.

4.2.1.8 Stover yield

Results of crop stover yield at KNUST in both years are presented in Table. 4.9. Varieties showed significant differences with respect to stover yield. In 2006, the Jenkaar variety recorded the largest stover yield and this was significantly higher ($P<0.05$) than that of the Adepa variety. All other treatment differences were not significant. No significant differences were observed among varieties in 2007.

In 2006, plant spacing did not significantly affect stover yield. However, in 2007, the SP1 treatment recorded the largest stover yield (4.11 t ha^{-1}) and this was significantly higher ($P<0.05$) than those of the SP2 and SP3 treatments. All other treatment differences were not significant.

Table. 4.9 Number of nodules plant^{-1} and stover yield as affected by variety and spacing in 2006 and 2007.

Treatment	Number of Nodules Plant^{-1}			Stover Yield (t ha^{-1})		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	89.0	100.5	94.75	4.08	2.85	3.47
Azivivi	125.0	109.5	117.25	4.91	3.77	4.34
Jenkaar	118.0	99.3	108.65	5.51	3.54	4.53
Kpanieli	*	112.8	112.80	*	2.73	2.73
Nkosuor	110.0	114.7	224.70	4.79	2.86	3.83
Manipintar	*	127.2	127.20	*	3.18	3.18
Lsd (5%)	NS	19.63		0.85	NS	
SPACING						
SP1	100.0	113.2	106.60	4.52	4.11	4.32
SP2	114.0	109.8	111.90	5.05	2.60	3.83
SP3	116.0	109.0	125.50	4.96	2.74	3.85
Lsd (5%)	NS	NS		NS	0.80	
CV (%)	46.7	12.5		26.8	26.8	

4.2.2 Yield and Yield Components

4.2.2.1 Number of pods plant^{-1}

Results of number of pods plant^{-1} at KNUST in 2006 and 2007 seasons are presented in Table. 4.10. Number of pods plant^{-1} ranged between 12.96 and 15.23 in 2006. No significant differences were observed among varieties. In 2007, number of pods plant^{-1} ranged between 10.82 and 34.77. Kpanieli recorded the highest number (34.77) pods plant^{-1} which was significantly higher ($P<0.05$) than those produced in all other varieties. Effects of the Manipintar variety were also significantly higher than those of the remaining varieties. Treatment differences among the rest were not significant. No significant differences in pods plant^{-1} were observed in both seasons from the different spacing treatments.

4.2.2.2 Number of seeds pod^{-1}

Table. 4.10 show results of the number of seeds pod^{-1} in 2006 and 2007. Varietal differences in both years were not significant (P<0.05). Spacing did not affect number of seeds in 2007. However in 2006, the SP3 treatment supported seed production which was significantly higher (P<0.05) than that of the SP2 treatment.

Table. 4.10 Number of pods plant^{-1} and seeds pod^{-1} as affected by variety and spacing in 2006 and 2007.

Treatment	Pods Plant^{-1}			Seeds Pod^{-1}		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	12.96	10.82	11.89	1.58	1.46	1.52
Azivivi	15.23	11.48	13.36	1.47	1.60	1.54
Jenkaar	13.97	13.46	13.72	1.53	1.52	1.53
Kpanieli	*	34.77	34.77	*	1.56	1.56
Nkosuor	14.00	11.10	12.55	1.65	1.55	1.60
Manipintar	*	21.30	21.30	*	1.52	1.52
Lsd (5%)	NS	3.61		NS	NS	
SPACING						
SP1	15.23	16.85	16.04	1.55	1.57	1.56
SP2	11.76	17.07	14.42	1.47	1.52	1.50
SP3	15.12	17.73	16.43	1.65	1.52	1.59
Lsd (5%)	NS	NS		0.16	NS	
CV (%)	23.4	13.1		5.30	3.20	

4.2.2.3 Shelling percentage

Results of shelling percentage in both years are presented in Table. 4.11. In 2006, shelling percentage ranged between 59.23 % recorded by Azivivi and 60.39 % recorded by Nkosuor. No significant differences (P<0.05) were observed among varieties. In 2007, peanut varieties showed significant effects on shelling percentage. Manipintar recorded the highest shelling percentage which was significantly higher (P<0.05) than the rest of the varieties except Kpanieli which also recorded a high shelling percentage of 64.56 %. The effect of Kpanieli was also significantly higher (P<0.05) than all the other varietal effects except that of Adepa variety.

Spacing also had significant effects on shelling percentage in 2006. The SP3 treatment recorded 62.02 % which was significantly higher (P<0.05) than the effect of the SP1 treatment. No significant treatment differences were observed in 2007.

4.2.2.4 Mean 100 seed weight

Results of 100 seed weight for both cropping seasons are presented in Table. 4.11. Treatments differences in 2006 were not significant. In 2007, Jenkaar recorded 100 seed weight of 50.49 g which was significantly higher (P<0.05) than all other treatment effects. The effect of the Manipintar variety was also significantly higher (P<0.05) than the effects of the remaining varieties. All other treatment effects were statistically similar.

In both years, plant spacing significantly affected 100 seed weight. SP1 and SP3 treatments recorded 100 seed weight values of 39.97 and 40.84 g respectively in 2006 and were both significantly higher (P<0.05) than the effects of the SP1 treatment. In 2007, the treatment effect of SP3 was significantly higher (P<0.05) than that of the SP2 treatment only.

Table. 4.11 Shelling percentage and 100 Seed Weight as affected by variety and spacing in 2006 and 2007.

Treatment	Shelling Percentage (%)			Mean 100 Seed Weight (g)		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	59.97	61.30	60.64	38.32	36.13	37.23
Azivivi	59.23	60.33	59.77	40.24	38.41	39.33
Jenkaar	59.31	59.23	59.27	38.51	35.91	37.21
Kpanieli	*	64.56	64.56	*	50.49	50.49
Nkosuor	60.39	58.61	59.50	39.66	38.25	38.96
Manipintar	*	64.99	64.99	*	46.07	47.07
Lsd (5%)	NS	3.26		NS	3.00	
SPACING						
SP1	56.55	60.39	58.47	39.97	41.08	40.53
SP2	60.61	61.71	61.16	36.74	39.12	37.93
SP3	60.02	62.41	62.22	40.84	42.44	41.64
Lsd (5%)	2.36	NS		2.87	2.12	
CV (%)	1.60	1.40		7.50	6.30	

4.2.2.5 Pod yield

Results of pod yield in both years are presented in Table 4.12. Peanut varieties significantly affected pod yield in both cropping seasons. In the 2006, Nkosuor produced the largest yield of 1.19 t ha^{-1} which was significantly higher (P<0.05) than the effects of Azivivi and Jenkaar varieties. During the 2007 cropping season, Kpanieli recorded the largest pod yield (4.01 t ha^{-1}) and this was significantly higher (P<0.05) than that recorded by Azivivi and Nkosuor (2.918 and 3.156 t ha^{-1} respectively). Also, Adepa, Jenkaar and Manipintar varieties produced significantly higher (P<0.05) effects than that of Azivivi. In both cropping seasons, spacing significantly affected pod yield. The SP1 treatment recorded the largest pod yield (1.38 t ha^{-1}) in 2006 and was significantly higher (P<0.05) than that of the SP3 treatment. Treatment differences between SP2 and SP3 were not significant. In 2007, the SP2 treatment supported the greatest pod yield which was significantly higher (P<0.05) than those of P1 and SP3 treatments. The latter two treatments supported similar effects.

4.2.2.6 Seed yield

There were no significant differences among varieties in 2006 (Table. 4.12). However, in 2007 the effects of the Adepa, Kpanieli and Manipintar varieties were significantly higher than the effects of the Azivivi, Jenkaar and Nkosuor varieties.

The SP1 plant spacing recorded the largest seed yield in 2006 and its effect significantly different (P<0.05) from the effects of the SP2 and SP3 plant spacing. In 2007, the effect of the SP2 plant spacing on seed yield was similar to the effect of the SP3 plant spacing but was significantly higher (P<0.05) than the effect of the SP1 plant spacing.

Table. 4.12 Pod and seed yields as affected by variety and spacing in 2006 and 2007.

Treatment	Pod Yield (t ha^{-1})			Seed Yield (t ha^{-1})		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	1.02	3.65	2.34	0.522	1.898	1.210
Azivivi	0.92	2.91	1.92	0.451	1.467	0.959
Jenkaar	0.90	3.51	2.21	0.438	1.730	1.084
Kpanieli	*	4.01	4.01	*	2.127	2.127
Nkosuor	1.19	3.15	2.17	0.593	1.537	1.065
Manipintar	*	3.58	3.58	*	1.916	1.916
Lsd (5%)	0.19	0.53		NS	0.282	
SPACING						
SP1	1.38	3.29	2.34	0.673	1.661	1.167
SP2	0.90	3.71	2.31	0.447	1.899	1.173
SP3	0.74	3.40	2.07	0.384	1.777	1.081
Lsd (5%)	NS	0.37		0.069	0.199	
CV (%)	4.10	3.50		4.20	4.90	

4.2.2.7 Harvest index

The results of harvest index (HI) in both years are shown in Table 4.13. HI in the 2007 cropping season was generally higher than in 2006. The effect of the Azivivi variety was significantly lower ($P<0.05$) than those of the Jenkaar and Kpanieli varieties in 2007. Spacing effects were significant only in 2007 when the effects of the SP2 spacing on harvest index were significantly higher than that of the SP1 spacing.

4.2.2.8 Seed-Hull ratio

Data on seed-hull ratio (SHR) are presented in Table 4.13. Varietal effects in 2006 were statistically similar. In 2007, the greatest effect was produced in the Manipintar variety which was significantly higher ($P<0.05$) than effects of Azivivi, Jenkaar and Nkosuor. Spacing significantly affected SHR in 2006 only. Treatment differences between SP2 and SP3 were not significant but either treatment effect was significantly higher ($P<0.05$) than that of the SP1 treatment.

Table. 4.13 Harvest index and seed-hull ratio as affected by variety and spacing in 2006 and 2007.

Treatment	Harvest Index			Seed-Hull Ratio		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	0.26	0.34	0.30	1.51	1.59	1.55
Azivivi	0.25	0.29	0.27	1.47	1.54	1.51
Jenkaar	0.24	0.37	0.31	1.46	1.52	1.49
Kpanieli	*	0.37	0.37	*	1.72	1.72
Nkosuor	0.25	0.34	0.30	1.53	1.42	1.48
Manipintar	*	0.33	0.33	*	1.81	1.81
Lsd (5%)	NS	0.08		NS	0.22	
SPACING						
SP1	0.25	0.29	0.27	1.31	1.56	1.44
SP2	0.25	0.39	0.32	1.54	1.61	1.58
SP3	0.26	0.35	0.31	1.63	1.62	1.63
Lsd (5%)	0.03	0.06		0.13	NS	
CV (%)	NS	4.60		3.20	2.30	

4.2.3 Estimation of N-fixed

4.2.3.1 Percent residue nitrogen

Results of percent residue nitrogen are presented in Table. 4.14. Varietal and spacing effects did not significantly affect percent residue N in both years.

4.2.3.2 Percent seed nitrogen

Results of percent N in peanut seed are presented in Table. 4.14. Varietal and spacing differences did not significantly affect percent seed N in both years.

4.2.3.3 Percent total fixed nitrogen

Results of total fixed nitrogen (TFN) by treatments are shown in Table. 4.14. Treatment differences were not statistically significant in both years.

Table. 4.14 Percent residue, seed and total fixed N as affected by variety and spacing in 2006 and 2007.

Treatment	Residue N (%)			Seed N (%)			Total Fixed N (%)		
	2006	2007	Mean	2006	2007	Mean	2006	2007	Mean
VARIETY									
Adepa	1.45	1.73	1.59	4.05	4.00	4.03	5.50	5.73	5.62
Azivivi	1.72	1.88	1.80	3.77	3.26	3.52	5.49	5.14	5.32
Jenkaar	2.09	2.15	2.12	3.47	3.97	3.72	5.56	6.12	5.84
Kpanieli	*	1.85	1.85	*	2.97	2.97	*	4.87	4.87
Nkosuor	2.43	1.97	2.20	3.48	3.11	3.30	5.91	4.08	5.00
Manipintar	*	2.13	2.13	*	3.66	3.66	*	5.79	5.79
Lsd (5%)	NS	NS		NS	NS		NS	NS	
SPACING									
SP1	2.14	1.89	2.02	3.59	3.53	3.56	5.73	5.32	5.53
SP2	1.84	2.17	2.01	4.02	3.64	3.83	5.84	5.81	5.83
SP3	1.78	1.79	1.79	3.46	3.32	3.39	5.44	5.11	5.28
Lsd (5%)	NS	NS		NS	NS		NS	NS	
CV (%)	8.10	13.70		8.80	2.00		7.50	5.00	

4.2.3.4 Total plant dry matter

Results of total plant dry matter are presented in Table. 4.15. The effect of the Jenkaar variety which recorded the largest total plant dry matter in 2006 was significantly different ($P<0.05$) from the effects of the remaining varieties. No significant differences in total dry matter were observed among varieties in 2007.

The SP1 plant spacing recorded the largest total dry matter in 2007, and its effect on total dry matter was significantly different ($P<0.05$) from the effects of SP2 and SP3 spacing, which recorded similar effects.

4.2.3.5 Stover N

Table. 4.15 shows results of stover N (Kg N ha^{-1}) at KNUST. The results show that peanut varieties did not record significant differences in stover N in both cropping seasons. Spacing did not give significant differences in 2006. In 2007 however, the SP1 treatment recorded stover N which was significantly higher ($P<0.05$) than the effect of the SP3 treatment only.

Table. 4.15 Total plant dry matter and stover yield as affected by variety and spacing in 2006 and 2007.

Treatment	Total Plant DM (t ha^{-1})			Stover N (Kg N ha^{-1})		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	5.10	6.50	5.80	55.70	53.80	54.75
Azivivi	5.00	6.68	5.84	58.90	57.99	58.45
Jenkaar	6.41	7.05	6.73	61.20	55.10	58.15
Kpanieli	*	6.74	6.74	*	55.76	55.76
Nkosuor	4.98	6.01	5.50	59.40	56.76	58.08
Manipintar	*	6.76	6.76	*	60.22	60.22
Lsd (5%)	1.27	NS		NS	NS	
SPACING						
SP1	5.90	7.40	6.65	61.40	60.81	61.11
SP2	5.95	6.31	6.13	60.10	55.84	57.97
SP3	5.70	6.14	5.92	54.90	53.23	54.07
Lsd (5%)	NS	1.21		NS	4.82	
CV (%)	5.70	8.70		9.70	1.70	

4.3 Nyankpala Results

4.3.1 Growth and Development

4.3.1.1 Plant Stand

Results of plant stand for the two seasons are shown in Table. 4.16. Germination and plant stand 2WAP was generally higher and fairly stable across treatments in 2007 than in 2006 which recorded wide fluctuations. Plant stand 2WAP in 2006 cropping season ranged between 12.93 and 19.10 plants m^{-2}. Plant stand of Nkosuor and Adepa was similar but either effect was higher than those of Azivivi and Jenkaar. In 2007, Manipintar recorded highest plant concentration (20.06 plants m^{-2}) and this was significantly higher ($P<0.05$) than those of Nkosuor and Kpanieli. Also, plant stand of the Jenkaar variety was significantly higher ($P<0.05$) than that of the Kpanieli variety.

In both cropping seasons, row spacing significantly affected plant stand. The SP1 and SP2 treatment effects were significantly higher ($P<0.05$) than that of the SP3 treatment. In 2007, treatment effects of SP1 and SP3 were similar but either effect was significantly lower ($P<0.05$) than the effect of the SP2 treatment.

4.3.1.2 Number of branches

Table. 4.16 shows number of branches for the two years. Peanut variety did not significantly affect number of branches $plant^{-1}$ in 2006. In 2007, Azivivi recorded the greatest number of branches and this was significantly higher ($P<0.05$) than the effect of only the Kpanieli variety. Spacing on the other hand affected number of branches in both years. In 2006, the SP1 treatment supported significantly lower effects than the SP2 and SP3 treatments which recorded similar effects. In 2007, the

SP1 treatment recorded the greatest effect which was significantly higher (P<0.05) than that of the SP3 treatment only.

Table 4.16 Plant stand and number of branches at Nyankpala as affected by variety and spacing in 2006 and 2007.

Treatment	Plant Stand (m^{-2})			Number of Branches $Plant^{-1}$		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	19.06	19.49	19.27	13.16	11.22	12.19
Azivivi	12.93	13.31	13.12	13.31	11.96	12.64
Jenkaar	13.87	19.73	16.80	12.99	11.76	12.38
Kpanieli	*	18.52	18.52	*	10.54	10.54
Nkosuor	19.10	18.69	18.90	13.74	11.82	12.78
Manipintar	*	20.06	20.06	*	11.38	11.38
Lsd (5%)	1.50	1.09		NS	1.39	
SPACING						
SP1	17.16	18.91	18.04	11.94	11.97	11.96
SP2	17.07	20.69	18.88	13.40	11.50	12.45
SP3	14.51	18.22	16.37	14.56	10.87	12.72
Lsd (5%)	1.30	0.77		1.28	0.98	
CV (%)	2.60	5.70		1.40	6.10	

4.3.1.3 Plant Height

Results of plant height are presented in Table. 4.17. Plant height of all treatments increased from 4 through 6 to 8WAP in both cropping seasons. At 4WAP in 2006, plant height ranged between 12.63 and 14.16 cm. Plants of the Nkosuor variety were significantly taller (P<0.05) than those of Azivivi variety only. At 6 and 8WAP, peanut varieties did not show significant effect on plant height. In 2007, plant height showed significance at all three sampling occasions. Manipintar recorded significantly taller (P<0.05) plants than all other varieties at 4WAP. Other treatment effects were not statistically different. At 6 and 8WAP, the Manipintar variety produced plants that were significantly taller (P<0.05) than those of other varieties.

Additionally, plants of the Kpanieli were also significantly taller (P<0.05) than those of the remaining varieties whose heights were similar on both sampling occasions. Spacing significantly affected plant height only at 4WAP in both seasons. In 2006, on this sampling occasion, treatment effect of SP2 was significantly greater (P<0.05) than that of the SP1 treatment only, whilst in 2007, effects of the SP2 treatment was significantly greater (P<0.05) than that of the SP3 treatment only.

Table. 4.17 Plant heights at 4, 6 and 8 WAP as affected by variety and spacing in 2006 and 2007.

Treatment	2006 (cm)			2007 (cm)		
	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP
VARIETY						
Adepa	13.73	20.93	30.52	15.02	17.32	30.62
Azivivi	12.63	20.96	29.79	13.28	19.87	32.67
Jenkaar	13.20	20.59	31.16	13.83	18.56	31.24
Kpanieli	*	*	*	15.53	25.13	40.00
Nkosuor	14.16	20.71	28.44	14.38	18.71	31.82
Manipintar	*	*	*	20.80	34.96	46.40
Lsd (5%)	1.52	NS	NS	2.66	4.78	3.86
SPACING						
SP1	12.56	20.18	30.87	14.93	23.69	36.72
SP2	13.92	21.25	30.89	16.84	21.89	35.49
SP3	13.81	20.96	28.18	14.65	21.69	34.17
Lsd (5%)	1.32	NS	NS	1.96	NS	NS
CV (%)	5.70	5.10	4.48	0.70	1.70	3.30

4.3.1.4 Canopy width

Plant canopy results at 4, 6 and 8 WAP are presented in Table. 4.18. Canopy width increased throughout the sampling period in both seasons. Adepa recorded the widest canopy spread of 18.88 cm in 2006 which effect was significantly higher (P<0.05) than that of Jenkaar variety only. All other treatment differences were not significant. At 8 WAP, treatment effect of the Nkosuor variety was significantly lower (P<0.05) than those of Adepa and Jenkaar varieties. In 2007, varietal differences at 4 WAP were not significant. At 6 WAP, treatment effect of Jenkaar variety which recorded the greatest width was significantly higher (P<0.05) than that of the Manipintar and Kpanieli varieties only. Other treatment effects were statistically similar. At 8 WAP, treatment effect of the Nkosuor variety was significantly higher (P<0.05) than all other treatment effects. Also, treatment effect of Kpanieli which recorded the smallest canopy width was significantly lower (P<0.05) than all the other treatment effects.

Spacing significantly affected canopy width on all sampling occasions in 2006. Effect of the SP3 treatment was significantly higher (P<0.05) than that of both SP1 and SP2 treatments which recorded similar effects on the three sampling occasions. In 2007, treatment effects were significant only during sampling at 6 WAP. On this occasion, the effect of the SP3 treatment was significantly higher (P<0.05) than that of the SP1 treatment only.

Table. 4.18 Plant canopy width at 4, 6 and 8 WAP as affected by variety and spacing in 2006 and 2007.

Treatment	2006 (cm)			2007 (cm)		
	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP
VARIETY						
Adepa	28.88	32.83	47.60	23.82	44.29	59.33
Azivivi	17.24	29.18	45.60	22.09	40.41	61.98
Jenkaar	16.20	31.41	47.30	25.02	46.00	59.22
Kpanieli	*	*	*	23.11	39.29	57.71
Nkosuor	17.47	29.53	42.90	23.02	43.16	63.58
Manipintar	*	*	*	22.17	39.56	61.18
Lsd (5%)	1.56	NS	3.12	NS	5.30	NS
SPACING						
SP1	16.21	27.22	41.60	22.51	39.94	59.16
SP2	15.67	28.70	43.70	22.97	42.17	61.23
SP3	20.47	36.30	52.10	24.15	44.24	61.46
Lsd (5%)	1.35	4.48	2.70	NS	3.74	NS
CV (%)	5.10	5.50	3.10	10.90	2.70	0.90

4.3.1.5 Shoot dry matter

Shoot dry matter results at 4, 6 and 8WAP in 2006 and 2007 are presented in Table. 4.19. In 2006, Azivivi and Jenkaar varieties recorded similar shoot dry matter at 4 and 6 WAP, and either effect was significantly higher (P<0.05) than that of Nkosuor only. Difference between the effects of Adepa and Nkosuor was not significant. At 8 WAP, treatments effects of Azivivi and Jenkaar were similar but the effects of each treatment was significantly higher (P<0.05) than that of Nkosuor varietal effect. Treatment differences between Adepa and Azivivi were also not significant. In 2007, at 4WAP, shoot dry matter of the Manipintar variety was significantly higher (P<0.05) than those of Nkosuor and Azivivi varieties only. All other treatment differences were not significant. Treatment differences at 6 and 8WAP in 2007 were not significant. Spacing did not significantly affect shoot dry matter in both years.

Table 4.19 Shoot dry matter at 4, 6 and 8 WAP as affected by variety and spacing in 2006 and 2007.

Treatment	2006 (g plant^{-1})			2007 (g plant^{-1})		
	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP
VARIETY						
Adepa	10.83	21.20	34.00	13.92	25.04	36.60
Azivivi	15.54	29.80	45.50	12.06	23.70	33.31
Jenkaar	15.29	29.20	48.80	14.16	25.81	34.83
Kpanieli	*	*	*	14.41	22.90	31.13
Nkosuor	9.27	18.00	28.70	12.56	22.04	31.59
Manipintar	*	*	*	16.66	23.53	35.02
Lsd (5%)	4.77	7.89	12.11	3.01	NS	NS
SPACING						
SP1	13.85	25.80	33.50	14.24	24.36	35.21
SP2	13.70	26.10	42.90	13.49	23.39	33.08
SP3	10.72	21.90	41.40	14.14	23.76	32.96
Lsd (5%)	NS	NS	NS	NS	NS	NS
CV (%)	17.3	15.9	13.1	1.00	6.40	5.10

4.3.1.6 Relative growth rate

Results of relative growth rates (R) for the two seasons are presented in Table. 4.20. Growth between 4-6 weeks was generally higher than between 6-8 weeks after planting. Varietal differences for the two periods in 2006 were not significant. Between 4-6week in 2007, the R of the Manipintar variety was significantly lower (P<0.05) than for all other varieties, except Kpanieli. All other treatment effects were similar.

Effects of spacing on R were not significant between 4-6 WAP in 2006 and at both periods in 2007. During the 6-8 WAP sampling occasion in 2006, R of the SP3 spacing was significantly higher (P<0.05) than that of the SP1 treatment only.

Table. 4.20 Relative growth rate at Nyankpala as affected by variety and spacing in 2006 and 2007.

Treatment	RGR 4-6WAP ($g\ m^{-2}\ wk^{-1}$)			RGR 6-8WAP ($g\ m^{-2}\ wk^{-1}$)		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	0.35	0.30	0.33	0.27	0.19	0.23
Azivivi	0.34	0.31	0.33	0.22	0.19	0.21
Jenkaar	0.37	0.30	0.34	0.26	0.15	0.21
Kpanieli	*	0.24	0.24	*	0.15	0.15
Nkosuor	0.34	0.29	0.32	0.28	0.17	0.23
Manipintar	*	0.17	0.17	*	0.19	0.19
Lsd (5%)	NS	0.08		NS	NS	
SPACING						
SP1	0.33	0.27	0.30	0.19	0.18	0.19
SP2	0.36	0.27	0.32	0.26	0.18	0.22
SP3	0.37	0.26	0.32	0.32	0.16	0.24
Lsd (5%)	NS	NS				
CV (%)	19.7	15.2		8.50	15.1	

4.3.1.7 Number of nodules

Results of number of nodules plant^{-1} are presented in Table 4.21. There were no significant varietal differences in the number of nodules plant^{-1} in 2006. In 2007, nodules plant^{-1} ranged between 107.4 and 201.2. Manipintar supported the largest number of nodules plant^{-1} and was significantly higher (P<0.05) than all other varieties. Treatment effect of the Kpanieli variety was significantly higher (P<0.05) than that of Adepa and Azivivi varieties. Effect of the Adepa variety was also significantly lower (P<0.05) than that of the Azivivi variety.

There were no significant effects of spacing on nodule number plant^{-1} in both years.

4.3.1.8 Stover yield

Results of stover yield are presented in Table. 4.21. The results showed that peanut variety significantly affected stover yield in both cropping seasons. In 2006, Jenkaar produced the largest stover yield and was significantly higher (P<0.05) than all other treatment effects. Azivivi also supported greater stover yield than that of the Nkosuor variety. Difference between Adepa and Nkosuor varietal effects were not significant. In 2007, Nkosuor recorded the largest stover yield (2.84 t ha^{-1}) and this was significantly higher (P<0.05) than the effects of Adepa, Kpanieli and Jenkaar varieties. Treatment effects of the Manipintar variety was also significantly higher (P<0.05) than that of Adepa and Kpanieli varieties. All other treatment differences were not significant.

Spacing significantly affected stover yields in both cropping seasons. In 2006, the effects of the SP1 and SP2 treatments were similar but either effect was significantly higher (P<0.05) than that of the SP3 treatment. In 2007, the effect of the SP1 treatment was significantly higher (P<0.05) than those of SP2 and SP3 treatments. Also, the effect of the SP2 treatment was significantly higher (P<0.05) than that of the SP3 treatment.

Table. 4.21 Number of nodules and stover yield as affected by variety and spacing in 2006 and 2007.

Treatment	Number of Nodules			Stover Yield (t ha^{-1})		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	199.8	107.4	153.6	1.64	2.15	1.90
Azivivi	214.7	139.4	177.1	1.87	2.49	2.18
Jenkaar	206.1	154.6	180.4	2.41	2.41	2.41
Kpanieli	*	174.9	174.9	*	2.05	2.05
Nkosuor	216.7	163.9	190.3	1.32	2.84	2.08
Manipintar	*	201.2	201.2	*	2.66	2.66
Lsd (5%)	NS	26.25		0.41	0.39	
SPACING						
SP1	209.4	156.4	182.9	2.01	2.87	2.44
SP2	209.0	159.4	184.2	2.19	2.45	2.32
SP3	209.6	154.9	182.3	1.23	1.95	1.59
Lsd (5%)	NS	NS		0.35	0.27	
CV (%)	4.80	8.40		10.5	16.4	

4.3.2 Yield and Yield Components

4.3.2.1 Number of pods $plant^{-1}$

Table. 4.22 show the results of number of pods $plant^{-1}$ sampled in the two cropping seasons. In both cropping seasons, variety significantly affected number of pods $plant^{-1}$. In 2006, Jenkaar recorded the greatest (18.12) number of pods $plant^{-1}$ which was significantly higher ($P<0.05$) than the effects of Adepa and Nkosuor varieties only. The effect of the Azivivi variety was also significantly higher than those of Adepa and Nkosuor varieties. In 2007, Azivivi and Kpanieli (17.29 and 17.33, respectively) recorded significantly higher ($P<0.05$) pods than Adepa and Manipintar (13.84 and 14.26 respectively). Spacing significantly affected the number of pods

$plant^{-1}$ in 2007 when the effect of the SP1 treatment was significantly higher (P<0.05) than that of the SP3 treatment only.

4.3.2.2 Number of seeds pod^{-1}

Number of seeds pod^{-1} is presented in Table. 4.22. Peanut variety significantly affected the number of seeds pod^{-1} in both cropping seasons. In 2006, Nkosuor recorded the highest number of seeds pod^{-1} and this was significantly higher (P<0.05) than that of Adepa variety only. Other treatment differences were not significant. In 2007, Manipintar recorded the greatest number of seeds pod^{-1} which was significantly higher (P<0.05) than that recorded by Jenkaar variety. All other treatment differences were not significant.

Spacing effect was significant on seed number in 2007 where the effect of the SP3 was significantly higher (P<0.05) than that of SP1 and SP2 treatments. Also, seed number of SP2 treatments was significantly higher (P<0.05) than that of the SP1 treatment.

Table. 4.22 Numbers of pods plant^{-1} and seeds pod^{-1} as affected by variety and spacing in 2006 and 2007.

Treatment	Pods Plant^{-1}			Seeds Pod^{-1}		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	11.22	13.84	12.53	1.58	1.72	1.65
Azivivi	17.91	17.29	17.60	1.65	1.71	1.68
Jenkaar	18.12	15.97	17.05	1.63	1.70	1.67
Kpanieli	*	17.33	17.33	*	1.74	1.74
Nkosuor	11.77	14.83	13.30	1.75	1.75	1.75
Manipintar	*	14.26	14.26	*	1.76	1.76
Lsd (5%)	3.57	2.81		0.14	0.05	
SPACING						
SP1	13.31	16.68	15.00	1.64	1.68	1.66
SP2	14.77	15.66	15.22	1.65	1.72	1.69
SP3	16.19	14.42	15.31	1.68	1.79	1.74
Lsd (5%)	NS	1.99		NS	0.03	
CV (%)	14.6	1.30		5.60	0.30	

4.3.2.3 Shelling percentage

Results of shelling percentage at Nyankpala are shown in Table. 4.23. The results show that all the treatments gave higher values for shelling percentage in 2006 than in 2007. Peanut variety significantly affected shelling percentage in both years. In 2006, Nkosuor recorded the least shelling percentage and was significantly lower ($P<0.05$) than the effect of Adepa variety only. All other treatment differences were not significant in 2006. The effect of the SP2 treatment recorded significantly higher ($P<0.05$) shelling percentage (60.57 %) than that of SP3 (57.89 %) treatment.

4.3.2.4 Mean 100 seed weight

Results of 100 seed weight at Nyankpala in 2006 and 2007 cropping seasons are shown in Tables. 4.23. 100 seed weight values in 2006 cropping season were generally higher than in 2007 cropping season. Peanut varieties did not give significant mean seed weights in 2006 cropping season. In 2007, Kpanieli recorded the heaviest 100 seed weight which was significantly higher (P<0.05) than that of the Adepa only. All other general effects were not significant. Spacing did not show significant effect on 100 seed weight in both cropping seasons.

Table. 4.23 Shelling percentage and Mean seed weight as affected by variety and spacing in 2006 and 2007.

Treatment	Shelling Percentage (%)			Mean 100 Seed Weight (g)		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	62.93	45.20	54.07	44.28	34.62	39.45
Azivivi	58.78	46.10	52.44	43.90	36.26	40.08
Jenkaar	58.48	44.90	51.69	44.14	35.13	39.64
Kpanieli	*	48.40	48.40	*	39.69	39.69
Nkosuor	57.50	37.90	47.70	44.43	35.13	39.78
Manipintar	*	46.60	46.60	*	35.70	35.70
Lsd (5%)	2.79	7.51		NS	3.96	
SPACING						
SP1	59.81	45.10	52.46	44.78	35.60	40.19
SP2	60.57	46.60	53.59	45.25	36.63	40.94
SP3	57.89	42.70	50.30	42.54	36.04	39.29
Lsd (5%)	2.41	NS		NS	NS	
CV (%)	6.60	8.90		1.80	1.00	

4.3.2.5 Pod yield

Results of dry pod yield (t ha^{-1}) are presented in Table. 4.24. The results show that peanut variety significantly affected dry pod yield in both years. Treatment effect of the Adepa variety was significantly higher (P<0.05) than that of Azivivi variety only in 2006. All other treatment effects were significantly similar. In 2007, the largest pod yield was produced by the Manipintar variety and this was significantly higher (P<0.05) than all other treatments effects. All other treatment differences were not significant. In 2006, spacing effect was not significant. In 2007, treatment effects of SP1 and SP2 were statistically similar, but either effect was significantly higher (P<0.05) than that of the SP3 treatment.

4.3.2.6 Seed yield

Results of seed yield are presented in Table. 4.24. The effect of the Adepa variety on seed yield was significantly higher (P<0.05) than the effects of the Azivivi and Nkosuor varieties in 2006. In 2007, the effect of the Manipintar variety on seed yield was significantly higher (P<0.05) that the effects of the remaining varieties. The SP1 plant spacing recorded the largest seed yield in 2006 (Table.4.21) and its effect was significantly different (P<0.05) from the SP2 and SP3 plant spacing which recorded similar effects. No significant effects on seed yield were recorded between any two plant spacing in 2007.

Table. 4.24 Pod yield and seed yield as affected by variety and spacing in 2006 and 2007.

Treatment	Pod Yield (t ha^{-1})			Seed Yield (t ha^{-1})		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	1.77	0.76	1.27	0.933	0.591	0.762
Azivivi	1.49	0.78	1.14	0.736	0.412	0.574
Jenkaar	1.63	0.78	1.21	0.799	0.405	0.602
Kpanieli	*	0.78	0.78	*	0.429	0.429
Nkosuor	1.58	0.94	1.26	0.749	0.564	0.657
Manipintar	*	1.23	1.23	*	0.753	0.753
Lsd (5%)	0.27	0.20		0.157	0.189	
SPACING						
SP1	1.72	1.01	1.37	0.866	0.607	0.737
SP2	1.62	0.89	1.26	0.820	0.575	0.698
SP3	1.51	0.72	1.12	0.727	0.491	0.609
Lsd (5%)	NS	0.14		0.136	NS	
CV (%)	2.00	14.1		8.70	12.90	

4.3.2.7 Harvest index

The results of harvest index in 2006 and 2007 are presented in Table. 4.25. In 2006, The Adepa variety recorded the highest HI (0.27) and this was significantly higher ($P<0.05$) than the effects of Azivivi and Jenkaar Nkosuor varieties. The Jenkaar variety recorded the highest (0.32) harvest index in 2007 which was significantly higher ($P<0.05$) than the treatment effects of the Kpanieli variety.

Spacing did not affect harvest index values in 2007. However, in 2006, treatment effect of SP3 treatment was significantly higher ($P<0.05$) than that of SP2 spacing.

4.3.2.8 Seed-Hull ratio

The results of seed-hull ratio (SHR) are shown in Table. 4.25. All the varieties in 2006 recorded SHR of more than 1.00, however, no significant differences were recorded among varieties. In the 2007 Kpanieli recorded the highest SHR but this was significantly higher (P<0.05) than that of Nkosuor variety only. SHR of other varieties were also higher than that of the Nkosuor variety.

No significant effects of spacing were observed in both cropping seasons.

Table 4.25 Harvest index and Seed-hull ratio as affected by variety and spacing in 2006 and 2007.

Treatment	Harvest Index			Seed-Hull Ratio		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	0.27	0.28	0.28	1.65	0.87	1.26
Azivivi	0.22	0.29	0.26	1.46	0.89	1.18
Jenkaar	0.32	0.21	0.27	1.46	0.83	1.15
Kpanieli	*	0.25	0.25	*	1.08	1.08
Nkosuor	0.26	0.23	0.25	1.44	0.26	0.85
Manipintar	*	0.26	0.25	*	0.88	0.88
Lsd (5%)	0.04	0.07		NS	0.33	
SPACING						
SP1	0.24	0.27	0.23	1.58	0.87	1.23
SP2	0.22	0.29	0.26	1.58	0.94	1.26
SP3	0.26	0.28	0.27	1.34	0.78	1.06
Lsd (5%)	NS	0.05		NS	NS	
CV (%)	16.5	10.0		17.3	20.1	

4.3.3 Estimation of N-fixed

4.3.3.1 Percent residue nitrogen

Results of residue N at Nyankpala are presented in Table. 4.26. In both cropping seasons, peanut variety significantly affected residue N. In 2006, residue N ranged between 1.49 and 1.86 %, and Adepa variety supported the greatest residue N which was significantly higher (P<0.05) than that of Nkosuor variety only. All other treatment effects were statistically similar. In 2007, residue N of Manipintar and Nkosuor varieties were similar but either effect was significantly higher than each of the remaining varieties whose effects were similar. Spacing did not significantly affect residue N in both seasons.

4.3.3.2 Percent seed nitrogen

Table. 4.26 shows the results of seed N in 2006 and 2007 cropping seasons. The effects of peanut varieties on the amount of N accumulated in the seed in 2006 were not significant. In 2007, seed N ranged between 2.63 % supported by Azivivi and 3.46 % supported by Nkosuor. The N in the Azivivi seed was significantly lower ($P<0.05$) than that accumulated by the other varieties, all of which had similar effects.

Spacing did not significantly affect seed N in both cropping seasons.

4.3.3.3 Total Fixed Nitrogen

Results of total fixed nitrogen (TFN) are presented in Table. 4.26. The results show that peanut variety did not significantly affect TFN in 2006. In 2007, treatment effects of Nkosuor and Manipintar varieties were not significantly different. However, the effect of the Nkosuor treatment was significantly higher ($P<0.05$) than all other treatment effects. Treatment effect of the Manipintar variety was also significantly higher ($P<0.05$) than that of Adepa, Azivivi and Jenkaar varieties, all of which recorded similar total plant N.

There were no significant effects of spacing on total plant N in both years.

Table 4.26 Percent residue, Seed and total fixed N as affected by variety and spacing in 2006 and 2007.

Treatment	Residue N (%)			Seed N (%)			Total Fixed N (%)		
	2006	2007	Mean	2006	2007	Mean	2006	2007	Mean
VARIETY									
Adepa	1.82	1.67	1.75	3.18	3.16	3.17	5.00	4.83	4.92
Azivivi	1.60	1.41	1.51	2.86	2.63	2.75	4.46	4.04	4.25
Jenkaar	1.75	1.55	1.65	2.91	3.14	3.03	4.66	4.69	4.68
Kpanieli	*	1.48	1.48	*	3.44	3.44	*	4.92	4.92
Nkosuor	1.49	1.96	1.73	3.40	3.37	3.39	4.89	5.33	5.11
Manipintar	*	1.96	1.96	*	3.46	3.46	*	5.42	5.42
Lsd (5%)	0.36	0.27		NS	0.44		NS	0.49	
SPACING									
SP1	1.74	1.74	1.74	3.19	3.93	3.56	4.93	5.67	5.30
SP2	1.74	1.74	1.74	2.71	3.04	2.88	4.45	4.78	4.62
SP3	1.54	1.65	1.60	3.43	3.32	3.38	4.97	4.97	4.97
Lsd (5%)	NS	NS		NS	NS		NS	NS	
CV (%)	2.70	4.50		16.90	3.60		11.30	0.90	

4.3.3.4 Total plant dry matter

The results of total plant dry matter (Table. 4.27) show that the effect of the Jenkaar variety, which recorded the largest total dry matter (TDM) in 2006 was significantly different ($P<0.05$) from the effect of the Nkosuor variety only, which recorded the least TDM. In 2007, the largest TDM was recorded by the Manipintar variety and this effect was significantly different ($P<0.05$) from the effects of the Adepa, Kpanieli and Nkosuor varieties.

The SP1 plant spacing recorded the largest effect on TDM in 2007. The differences between the effects of the SP1, and the effects of the SP2 and SP3 spacing was significant ($P<0.05$).

4.3.3.5 Stover N

Results of stover N (Kg N ha^{-1}) are presented in Table. 4.27. Peanut variety significantly affected stover N in both cropping seasons. Stover N in 2006 was greatest in the Jenkaar variety, and this effect was significantly higher (P<0.05) in the Nkosuor variety only. All other treatment effects were not significant. In 2007 the Nkosuor and Manipintar varieties recorded similar stover N. Treatment effects of Nkosuor however was significantly higher (P<0.05) than all other varieties. All other treatment differences were not significant.

Spacing significantly affected stover N only in 2007. Effect of the SP1 treatment was significantly higher (P<0.05) than that of the SP3 treatment only. Also, the effect of the SP2 treatment was significantly higher (P<0.05) than that of the SP3 treatment.

Table. 4.27 Total plant dry matter and Stover N as affected by variety and spacing in 2006 and 2007.

Treatment	Total Plant DM (t ha^{-1})			Stover N (Kg N ha^{-1})		
	2006	2007	Mean	2006	2007	Mean
VARIETY						
Adepa	3.41	2.91	3.16	31.1	35.2	33.2
Azivivi	3.36	3.27	3.32	29.3	35.3	32.3
Jenkaar	4.04	3.19	3.62	43.8	37.3	40.6
Kpanieli	*	2.83	2.83	*	39.4	39.4
Nkosuor	2.90	2.73	2.82	20.1	53.8	37.0
Manipintar	*	3.89	3.89	*	43.9	43.9
Lsd (5%)	1.07	0.97		21.8	10.0	
SPACING						
SP1	3.73	3.88	3.81	36.6	46.6	41.6
SP2	3.81	3.34	3.58	38.0	42.6	40.3
SP3	2.74	2.67	2.71	18.7	32.2	25.5
Lsd (5%)	NS	0.77		NS	7.10	
CV (%)	5.60	9.80		7.70	20.5	

4.3.4 Correlation analysis among groundnut growth and yield parameters

4.3.4.1 Correlations at KNUST in 2006

The correlation coefficients of growth and yield parameters of groundnuts in 2006 at KNUST are presented in Table. 4.28. Plant canopy width was positively and highly correlated with pod yield (r = 0.75, P<0.01) and shelling percentage (r = 0.70, P<0.05) in 2006. Pod yield was also positively and highly correlated with harvest index (r = 0.91, P<0.01) but negatively and highly correlated with shelling percentage (r = 0.62, P<0.05). Also, plant canopy width was negatively and highly correlated with harvest index (r = -0.810, P<0.01).

Table. 4.28 Correlation matrix between growth and yield parameters at KNUST in 2006.

	Cnpy	Pdplt	Pdyld	Msw	Rsdn	Sdn	Strvn	Sdpd	Shlng	HI
Hght	0.02	-0.10	-0.18	-0.17	-0.68*	0.30	-0.04	0.24	0.26	-0.39
Cnpy		0.37	0.75**	-0.10	-0.24	-0.23	-0.30	0.14	0.70*	-0.81**
Pdplt			-0.42	-0.28	-0.03	0.34	-0.40	-0.26	0.55	-0.36
Pdyld				0.33	0.41	-0.14	0.15	0.08	-0.62*	0.91**
Msw					0.09	-0.21	-0.28	0.57	-0.08	0.27
Rsdn						-0.11	0.40	-0.38	-0.28	0.43
Sdn							-0.09	-0.25	0.11	-0.06
Stvrn								-0.48	-0.62*	0.34
Sdpd									0.32	-0.12
Shlg										-0.73*

*P < 0.05 **P < 0.01

Legend:
Hght = plant height
Cnpy = canopy width
Pdplt = number of pods plant^{-1}
Pdyld = pod yield
Msw = mean seed weight
Rsdn = residue N (%)
Sdn = Seed N (%)
Stvrn = stover N (Kg N ha^{-1})
Sdpd = number of seeds/pod
HI = harvest Index

4.3.4.2 Correlation at Nyankpala in 2006.

Table. 4.29 show the correlation coefficients of growth and yield parameters groundnut at Nyankpala in 2006. Correlation coefficients of residue N and pod yield (r = 0.62, P<0.05), residue N and stover N (r = 0.63, P<0.05), plant height and stover N (r = 0.64, P<0.05) were positively and highly correlated. However, the correlation coefficients between stover N and seed N (r = -0.63, P<0.05), stover N and Harvest index (r = -0.59, P<0.05), number of seed pod^{-1} and shelling percentage (r = -0.68, P<0.05) were negatively and highly correlated.

Table 4.29 Correlation matrix of growth and yield parameters at Nyankpala in 2006.

	Cnpy	Pdplt	Pdyld	Msw	Rsdn	Sdn	Strn	Sdpd	Shlng	HI
Hght	0.01	-0.10	0.55	0.32	0.23	-0.15	0.64*	-0.55	0.45	-0.67
Cnpy		0.37	-0.07	-0.60	0.10	0.12	-0.25	-0.24	0.09	0.28
Pdplt			-0.39	-0.39	0.07	-0.48	0.27	-0.15	-0.24	-0.30
Pdyld				0.31	0.62*	-0.08	0.54	-0.31	0.35	0.02
Msw					-0.12	-0.04	0.19	0.06	0.25	-0.42
Rsdn						-0.31	0.63*	-0.37	0.38	0.14
Sdn							-0.63*	0.48	-0.34	0.49
Stvrn								-0.48	0.30	-0.59*
Sdpd									-0.68*	0.30
Shlng										-0.23

*P < 0.05 **P < 0.01

Legend:
Hght = plant height
Cnpy = canopy width
Pdplt = number of pods plant^{-1}
Pdyld = pod yield
Msw = mean seed weight
Rsdn = residue N (%)
Sdn = Seed N (%)
Stvrn = stover N (Kg N ha^{-1})
Sdpd = number of seeds/pod
HI = harvest Index

4.3.4 .3 Correlation at KNUST in 2007

The correlation coefficients of growth and yield parameters of groundnuts in 2007 at KNUST are presented in Table 4.30. Pod yield was positive and significantly correlated with stover N (r = 0.46, P<0.05) and harvest index (r = 0.50, P<0.05). However, pod yield was negatively and highly correlated with canopy width (r = 0.67, P<0.05).

Table. 4.30 Correlation coefficients of yield and components of yield at KNUST in 2007.

	Cnpy	Pdplt	Pdyld	Msw	Rsdn	Pltdm	Stvrn	brnch	Shlng	HI
Hght	-0.29	0.23	0.24	0.26	0.34	0.09	0.52*	0.50*	0.34	0.04
Cnpy		-0.16	-0.67*	-0.18	0.10	0.65*	-0.75*	-0.28	0.11	-0.08
Pdplt			0.04	0.86**	-0.09	-0.17	0.04	0.78**	0.69**	0.29
Pdyld				0.01	0.43	0.45	0.46*	0.12	-0.09	0.50*
Msw					-0.02	-0.18	0.13	0.64**	0.72**	0.26
Rsdn						0.03	0.01	-0.00	0.06	0.34
Pltdm							0.65**	0.17	-0.35	-0.48*
Stvrn								0.25	-0.18	-0.05
Brnch									0.50*	0.32
Shlng										0.27

*P < 0.05. **P < 0.01.

Legend:
Brnch = number of branches plant^{-1}
Cnpy = canopy width
Hght = plant height
HI = harvest Index
Msw = mean seed weight
Pdplt = number of pods plant^{-1}
Pdyld = pod yield
Pltdm = total plant dry matter
Rsdn = residue N (%)
Stvrn = stover N (Kg N ha^{-1})

4.3.4.4 Correlation at Nyankpala in 2007

The correlation coefficients of growth and yield parameters of groundnut in 2007 at Nyankpala are presented in Table 4.31. Pod yield gave highly significant positive correlations with plant height (r = 0.61, P<0.01), residue N (r = 0.60, P<0.01), plant dry matter (r = 0.86, P<0.01) and Stover N (r = 0.63, P<0.01). Also, mean seed weight was positively and highly Correlated with plant canopy width (r = 0.47, P<0.05) and shelling percentage (r = 0.50, P<0.05). Total dry matter was also positively and significantly correlated with stover N (r = 0.78, P<0.01).

Table 4.31 Correlation coefficients of yield and components of yield at Nyankpala in 2007.

	Cnpy	Pdplt	Pdyld	Msw	Rsdn	Pltdm	Stvrn	Brnch	Shlng	HI
Hght	0.39	0.09	0.61**	0.27	0.16	0.36	0.18	-0.10	0.26	0.60**
Cnpy		0.15	0.10	0.47*	-0.13	-0.15	-0.48*	0.02	0.44	0.37
Pdplt			-0.01	0.44	-0.59*	0.21	0.16	0.40	0.23	-0.30
Pdyld				-0.12	0.60**	0.86**	0.63**	0.26	0.12	0.44
Msw					-0.33	-0.27	-0.20	-0.15	0.50*	0.39
Rsdn						0.43	0.53*	-0.08	-0.35	0.40
Pltdm							0.78**	0.50*	-0.03	-0.06
Stvrn								0.25	-0.26	-0.04
Brnch									-0.13	-0.41
Shlng										0.37

*P < 0.05. **P < 0.01.

Legend:
Brnch = number of branches plant^{-1}
Cnpy = canopy width
Hght = plant height
HI = harvest Index
Msw = mean seed weight
Pdplt = number of pods plant^{-1}
Pdyld = pod yield
Pltdm = total plant dry matter
Rsdn = residue N (%)
Stvrn = stover N (Kg N ha^{-1})

4.3.5 Economic Returns

4.3.5..1 Net benefits

Table. 4.32 show results of analysis of net benefits (NB) at KNUST and Nyankpala for the 2006 and 2007 cropping seasons. The net benefits obtained differed significantly among the groundnut varieties in both years and locations. Groundnut variety significantly affected NB in both years and locations. The highest NB (GH¢ 323.85) at KNUST in 2006 was recorded by Adepa, while the least was recorded by Jenkaar (GH¢ 272.50). In 2007, Kpanieli recorded the highest NB (GH¢ 794.50), followed by Adepa GH¢654.77. The least NB (GH¢ 310.10) in 2007 at KNUST was recorded by Manipintar. The SP1 recorded the highest NB in both 2006 and 2007. The corresponding low NB were recorded by SP2 and SP3 respectively in both years (Table. 4.32).

At Nyankpala in 2006, Adepa recorded the highest NB (GH¢ 635.47). The least NB (GH¢ 527.07) was recorded by Azivivi. In 2007 cropping season, Manipintar gave the highest NB (GH¢ 408.57). Adepa recorded the lowest NB (GH¢ 222.17) in 2007. SP1 recorded the highest NBs in both cropping seasons.

Table. 4.32 Net Benefits at KNUST and Nyankpala as affected by variety and spacing in 2006 and 2007.

	Net Benefits (¢)		Net Benefits (¢)	
	KNUST		Nyankpala	
Treatment	2006	2007	2006	2007
VARIETY				
Adepa	323.85	654.77	635.47	222.17
Azivivi	281.85	471.17	527.07	228.97
Jenkaar	272.50	599.57	581.87	231.77
Kpanieli	*	794.50	*	230.57
Nkosuor	291.05	556.10	559.87	292.57
Manipintar	*	310.00	*	408.57
SPACING (cm)				
SP1	463.63	612.60	616.00	323.90
SP2	272.73	576.90	575.00	271.00
SP3	219.20	560.40	536.60	207.20

4.3.5.2 Benefits-Cost Ratio (BCR)

Benefit-cost ratio (BCR) for varieties and spacing in 2006 and 2007 at KNUST and Nyankpala are presented in Table 4.33. Groundnut variety significantly affected BCR at both locations and in both cropping seasons. In both cropping seasons and locations, all varieties recorded BCR values of more than 1.00. Nkosuor recorded the highest BCR (4.48:1) at KNUST in 2006. Jenkaar recorded the least BCR (3.12:1). In 2007, Kpanieli recorded the highest BCR (7.49:1) followed by Adepa (6.18:1) and Jenkaar (5.65:1). The least BCR (2.92:1) at KNUST in 2007 was recorded by Manipintar. SP1 and SP2 recorded the highest BCR (5.13:1 and 6.79:1 respectively) in 2006 and 2007.

At Nyankpala in 2006, Adepa gave the highest BCR (8.76:1) followed by Jenkaar (8.01:1). The least BCR (7.27:1) in 2006 was recorded by Azivivi. In 2007, Manipintar recorded the highest BCR (4.90:1). The least BCR (2.66:1) in 2007 was recorded by Adepa. SP1 recorded the highest BCR in both seasons.

Table. 4.33 Benefits-cost ratio as affected by variety and spacing at KNUST and Nyankpala in 2006 and 2007.

	Benefits-Cost Ratio		Benefits-Cost Ratio	
	KNUST		Nyankpala	
Treatment	2006	2007	2006	2007
VARIETY				
Adepa	3.71	6.18	8.76	2.66
Azivivi	3.23	4.44	7.27	2.74
Jenkaar	3.12	5.65	8.01	2.78
Kpanieli	*	7.49	*	2.76
Nkosuor	4.48	5.24	7.72	3.51
Manipintar	*	2.92	*	4.90
SPACING (cm)				
SP1	5.13	6.79	8.51	3.89
SP2	3.00	6.27	7.75	3.17
SP3	2.71	6.45	7.56	2.54

CHAPTER FIVE

DISCUSSION

5.1 Growth and development parameters

5.1.1 Plant stand

Plant stand m^{-2} indicates the germination ability and seedling survival of the treatments. Varieties recorded significant differences in plant stand 2WAP in both cropping seasons and locations. Row spacing also significantly affected plant stand 2WAP in both years and locations. At KNUST, Adepa and Manipintar recorded the highest plant stand in 2006 and 2007 respectively, whilst at Nyankpala, Adepa and Nkosuor respectively recorded highest plant stand in the two years. Differences in plant stand could be attributed to genetic (Ahmad and Mohammad, 1997) and environmental factors such as amount of soil moisture and temperature (ICRISAT, 1992), as well as soil and disease factors affecting seedling emergence and survival. Very high or low temperatures have also been reported to inhibit germination (Cox, 1979; Wood, 1968). ICRISAT (1994) reported that the effect of drought as a major environmental factor limiting groundnut yield is cumulative and starts from germination. The differences in plant stand observed among the varieties in the same season and location could be attributed to genetic factors since the varieties experienced similar environmental conditions. Between locations, plant stand at Nyankpala was generally higher than that at KNUST in 2007. The differences between locations were probably due to the different ways in which the varieties interacted with the environment.

5.1.2 Number of branches

Groundnut variety significantly influenced the number of branches plant^{-1} at KNUST and Nyankpala in both years. Number of branches plant^{-1} in both years and locations increased with an increase in plant spacing. However, in 2007, the mean of treatments at Nyankpala was reduced by 13.9% probably due to drought experienced in June of that year.

Wide-row treatments resulted in several bigger size branches while narrow-row treatments resulted in the development of fewer branches. This agrees with the findings of Kang Young Kil *et al.*, (1998) that vegetative parameters increased with increasing row spacing that reduced plant population density. This finding however contradicts the findings of other researchers; the production of small size numerous branches by high density treatments in response to increased competition for light resource have been observed by several researchers. Andrade *et al* (2002) reported profuse branching in narrow-row groundnut crop compared to wide-row groundnuts.

Branches are important as they hold leaves in position for the absorption of light energy. Treatments that encourage more branching and large LAI were found to support photosynthesis and therefore DM accumulation and high crop yields. This supports the findings of Widdicombe and Thellen (2002**)** who reported direct and positive correlation between number of groundnut branches and pod yield. Yield increase observed from crops grown in narrow-rows has been attributed to an increased branching and higher LAI, resulting in more efficient interception of solar radiation and increased rates of photosynthesis (Shibles and Weber, 1966). In the present study, the negative significant correlation between canopy size and pod yield ($r = -0.75$, $P<0.0$) contradicts the observation of these workers.

5.1.3 Plant height

Plant height is influenced by both genetic and environmental factors. Plants compete with other plants and weeds for light and other growth resources. To out-compete weeds, plants need to outgrow and shade the weeds rapidly. Plant height therefore is an important plant genetic attribute although unfavorable environmental factors affect it. There were no significant influences of both variety and spacing on plant height at KNUST and Nyankpala in 2006. At both KNUST and Nyankpala in 2007, Manipintar recorded significantly taller plants 4, 6 and 8WAP which may be due to genetic factors. At Nyankpala plant height was significantly influenced by plant spacing at the early stages (4WAP) when seedlings, using available growth resources achieved rapid growth. A narrow-row treatment (SP2) produced the tallest (16.84cm) plants at this stage. At the later stages, no differences were recorded as growth rates among narrow-row treatments reduced. This may have been caused by depletion of soil nutrient as well as other negative effects associated with narrow-row cropping. In both locations, narrow-row treatments significantly supported taller plants than wide-row treatments.

Research indicated that there is intense competition for light by closely spaced crop compared to widely spaced crop, and the subsequent rapid depletion of growth resources by closely spaced crop results in decreased growth at the later stages of crop growth (Farnham, 2001). Porter *et al.,* (1997) also reported early rapid growth among corn grown in narrow-rows compared to corn grown in wide rows and the subsequent reduction in growth rate due to depletion of soil nutrients and adverse effects of intra-specific plant competition among narrow-row crop.

5.1.4 Canopy width

The rate at which plant canopy forms and closes is of agronomic importance to the plant. Closed plant canopy intercepts more solar radiation, reduces loss of nutrients through soil erosion, smothers young weeds and prevents weed seeds from germinating. Plants have a potential to achieve a certain height and canopy width but the actual size of the canopy usually depend on factors such as variety, plant spacing, competition, as well as pest, diseases and availability of growth resources. Canopies of all treatments continued to spread from 4 to 8WAP, indicating crop growth and development. However, narrow-row treatments significantly reduced canopy width in both cropping seasons and locations. At both locations in 2006 and 2007, wide-row spacing, SP3, giving low crop density produced wider canopies compared to narrow-row spacing with high crop density. However, narrow-row treatments resulted in completely closed canopies. This was found to be effective in controlling weed growth and agrees with the findings of several other researchers (Tillman *et al*, 2006; Baldwin *et al*, 1998; 2001; Brown *et al*, 2003; Gorbet and Shokes, 1994, Naab *et al*, 2005; Norden and Lipscomb, 1974) who concluded that closely planted groundnut crop was effective in controlling weeds and groundnut diseases such as Tomato spotted wilt virus (TSWV) and groundnut rosette virus (GRV).

Agronomic research among other legumes indicates that soybean produced in high narrow-row plant stands reduced weed competition (Yelverton and Coble, 1991), thereby reducing the amount of herbicide needed to control weed growth. Mickelson and Renner (1997) found that planting soybean in high density stands reduced the frequency of herbicide applications and increased crop profitability. They concluded that soybean planted in narrow-row stands out-competed weeds for space and light. Nelson and Renner (1998, 1999) provided evidence that, in some situations, soybean produced in narrow-row stands decreased the amount of herbicide needed, thereby increasing economic returns to narrow-row crop compared to wide-row crop.

5.1.5 Shoot dry matter

Shoot DM (g $plant^{-1}$) of all treatments increased from 4-8WAP which is consistent with crop growth and development at both KNUST and Nyankpala. Groundnut varieties significantly influenced shoot DM in both years and locations. The differences in shoot DM among varieties could be attributed to the ability of some of the varieties to achieve higher photosynthetic rates, thereby accumulating higher amount of DM under the same conditions. This agrees with the findings of Gouri *et al*., (2005), Patel *et al*., (2005), and Bharud and Pawar, (2005) who suggested physiological differences as the basis for the variation in shoot DM among groundnut varieties. These differences according to Patel *et al*., (2005) are influenced more by genetic factors than by the environment since the varieties were grown in the same environment.

Wide-row treatments recorded relatively larger shoot DM later in the season probably because of lesser competition for growth resources compared to narrow-row treatments. This was because early competition for resources and subsequent depletion of growth resources, coupled with the effects of mutual shading among narrow-row treatments reduced photosynthetic rates, resulting in lower shoot DM.

However, the low shoot DM recorded by some narrow-row treatments was more than compensated for by the additional plants m^{-2}, resulting in significantly large stover yield (t ha^{-1}) compared to wider-row treatments. This agrees with the findings of Bulson *et al*., (1987) that shoot DM declines with further increases in row spacing after the optimum spacing has been achieved, and that the reduction in shoot DM plant^{-1} is compensated for by the additional plants up to the optimum spacing after which DM (t ha^{-1}) declines rapidly. Hauggaard-Nielsen *et al* (2001) however reported that competition among closely spaced crops resulted in increases in shoot DM even at very high plant densities due to a reduction in weed competition and efficient interception and utilization of solar radiation. They however concluded that this was only possible if growth resources are not exhausted and adverse effects of intra-specific competition does not set in.

5.1.6 Relative growth rate

Relative growth rate (R) was determined at two weeks interval two times in both cropping seasons for each location. This was from 4-6, and 6-8 WAP. Plant spacing significantly influenced R at the early stages in both seasons and locations. Relative growth rate was greater at early growth stages among narrow-row treatments compared to wider-row treatments. At later stages, competition for growth resources among narrow-row treatments and negative effects mutual shading may have caused the decrease in R whilst wide-row treatments with access to solar radiation continued to grow. At KNUST, both variety and plant spacing influenced R from 4-8WAP in both years.

The general reduction in R from 4-8 WAP with decreasing row spacing agrees with the findings of Kang Young kil *et al.,* (1998) who reported that vegetative growth parameters decreased with a decrease in plant spacing.

Relative growth rate is important as it determines the time from emergence to maturity. Average maturity days for groundnuts are 100 days for the short maturity cultivars and between 120-140 days for long maturity cultivars (ICRISAT, 1994; Weiss, 2000). Rapid early growth rate enables crops to overcome early weed competition, and vigorous growing seedlings have been shown to offer more resistance to pest and diseases (Lee, 2006; Norsworthy and Oliveira 2004). Crops achieving rapid growth rates have also been shown to develop good plant structure and accumulate enough DM in preparation for the reproductive phase of growth (Shibles and Weber; 1966, Ahmed *et al.*, 2007; Norden and Lipscomb, 1974).

5.1.7 Number of nodules plant^{-1}

Apart from pod production and the use of the vines as animal feed, groundnuts have the additional benefit of symbiotically fixing nitrogen which can be potentially made available to the succeeding crop. The process of nitrogen fixation often involves the formation of nodules which serve as 'mini factories' for BNF. The ability to nodulate and fix nitrogen is a genetic factor affected by environmental conditions.

Nodulation and nitrogen fixation require large amounts of the plants DM (Bieberdorf, 1938; Dakora *et al*, 1987; Giller and Wilson, 1991; Nambiar and Dart, 1980). Therefore, differences in the number of nodules plant^{-1} recorded could be attributed to both plant factors affecting DM production and partitioning, and environmental factors affecting crop growth and development, as well as soil factors affecting the process of nodulation and nitrogen fixation (Pulver *et al.*, 1982; Banerjee *et al.*, 2005; Ahmad *et al.*, 2007). In the present study, number of nodules at KNUST was higher than at Nyankpala in 2007. This is attributable to the relatively higher and well distributed rainfall at KNUST in both years compared to Nyankpala which recorded low and erratic rainfall; receiving the least (68.0 mm) in June 2007 and high rainfall afterwards. Varieties and row spacing giving higher number of nodules in both locations and seasons could therefore be said to be potentially able to make N available to the subsequent non-legume crop.

5.1.8 Stover yield

Treatments with narrow-rows supported smaller shoot DM (g $plant^{-1}$). However, the reduced shoot DM (g $plant^{-1}$) was more than compensated for by the additional plants m^{-2}, resulting in higher stover yield among narrow-row treatments compared to wide-row treatments. Stover yield is important because it is this component of the crop yield that is incorporated into the soil to make nutrients (N) available to the subsequent non-legume crop(s). The amount of nitrogen made available to the succeeding crop not only depends on nitrogen concentration in the crop residue but also on the amount of crop stover. Excess supply of moisture and nutrients, especially N has been reported to encourage vegetative growth, leading to high stover yield and reduced pod yield (Schilling and Gibbons, 2002). Moisture stress and nutrient deficit therefore resulted in decreased photosynthesis, reduced growth rates and lowered stover yield in the groundnut varieties. This agrees with the findings of Banerjee *et al*., (2005) who reported significant reduction in stover yield among drought stressed groundnut. Stover yield of all treatments in 2006 at KNUST and Nyankpala were larger than in 2007, attributable to the adverse effects of the erratic rainfall pattern during the 2007 cropping season.

5.1.9 Total plant dry matter

Total dry matter yield (TDM) reflects the amount of dry matter accumulated by varieties throughout the growing period. Total dry matter is a function of the genetic potential of varieties and environmental factors. Adverse factors such as drought, water stress and nutrient deficiencies are known to adversely affect groundnut growth rate and dry matter accumulated at the close of the season (Abdullah *et al*., 2007; Ali and Malik, 1992). Total dry matters accumulated by all treatments in 2006 were higher than in 2007, following the pattern of stover yield. In 2006, SP1 spacing probably accumulated the largest dry matter in both locations not only because of high plant population density but also because its canopy structure was well developed and able to capture the incident solar radiation. Much of this dry matter was diverted into the pod as SP1 produced the largest dry pod yields at both locations in 2006 and at Nyankpala in 2007 only.

At KNUST in 2006, the significant and large total dry matter supported by the Nkosuor variety was probably due its genotype since all varieties were grown under the same field conditions. Environmental effects were however significant as the SP1 spacing supported the largest dry matter. Both the Nkosuor variety and the SP1 spacing were found to also support the largest pod yield indicating diversion of sufficient photosynthates to the pod. In 2007, the Jenkaar variety and the SP1 spacing supported the largest dry matter and pod yield in 2007. At Nyankpala in 2006 and 2007, SP2 also recorded large and significant dry matter and supported the largest dry pod yield. The Adepa and Manipintar varieties which produced the largest dry matter in 2006 and 2007, respectively supported the largest dry pod yield in both years. There was therefore a strong and positive relationship between total dry matter accumulated and pod production ($r = 0.85$, $P<0.01$; Table 4.28 and $r = 0.45$, $P<0.05$; Table 4.27) in both years. Treatments accumulating larger TDM could therefore potentially support high pod yields.

5.2 Yield and Yield Components

5.2.1 Number of pods plant^{-1}

Variation in number of pods plant^{-1} is a genetic trait influenced by the environment and has been reported by other researchers. Number of pods recorded differed between varieties and spacing. The number of pods plant^{-1} recorded by this study was 10.8-34.7 (KNUST) and 11.2-18.1 (Nyankpala). The variations recorded however, support the findings of Ahmad and Mohammad (1997) and Virk *et al*., (2005) who indicated that groundnut varieties differ significantly in the number of pods plant^{-1}. Abdullah *et al*., (2007) reported between 18-24 pods plant^{-1}, and Virender and Kandhola (2007) reported 24.1-28.7 pods plant^{-1}. The general variation in number of pods plant^{-1} within the locations was probably due largely to the genotypes of the varieties. However, between locations, the variations in pod number could be attributed to both genetic and environmental effects, as well as interactions between the two, especially the weather, and availability of growth resources (Ogundele, 1988; Wright and Bell, 1992).

Two Varieties; Azivivi and Kpanieli recorded significantly larger pods plant^{-1} in both cropping seasons and locations, indicating their genetic stability where number of pods is concern. Ogundele (1988) attributed the number of pods plant^{-1} of groundnut to both the genotype of the plant and effects of the environment. However, these two varieties maintained the trait across two different agro-climatic zones and differing seasons.

Moisture stress and adverse temperatures have also been shown to significantly reduce number of pods plant^{-1} in groundnut crop (Cox, 1979; Wood, 1968; Sivakumar *et al*., 1993; Piggot, 1960). Several research reports (ICRISAT, 1994; Ketring, 1984; Wheeler *et al*., 1997; Vara Prasad *et al*., 1998) suggest that heat is a major environmental factor limiting pod yield in groundnuts. Also, the higher number of pods plant^{-1} recorded by wide row treatments could be attributed to less competition for scarce growth resources among wide-row crop. This agrees with the findings of Mozingo and Steele (1989) who reported an increase in pods plant^{-1} with increasing row width as a result of more availability of growth resources in wide-row compared to narrow-row groundnut crop.

5.2.2 Number of seeds pod^{-1}

At KNUST in 2006, Nkosuor increased number of seeds pod^{-1} by 9.25% while Adepa and increased seeds pod^{-1} by 9.17% over their respective treatment means in 2007. At Nyankpala, Nkosuor increased number of seeds pod^{-1} by 9.05% in 2006 whilst Nkosuor and Manipintar increased seeds pod^{-1} by 9.70 and 9.68% respectively in 2007.

Number of seeds pod^{-1} is a varietal characteristic, controlled largely by plant genetic factors (Ahmad and Mohammed, 1997; Ogundele, 1988). Generally, variations in number of seeds pod^{-1} were observed both among the varieties and spacing as well, showing that the trait was subject to influence by the environment. Studies (Groundnut CRSP, 1997; CIRAD-CORAF, 1988-1995) have shown that adverse conditions such as drought, heat stress and insufficient nutrients during crop growth and pod filling periods can significantly affect seeds pod^{-1}. This explains why SP3, a wide spacing treatment giving low plant density, characterized by the availability of more growth resources plant^{-1} and reduced intra-specific competition, recorded significantly higher number of seeds pod^{-1} at both locations in 2006 compared to SP1 and SP2 treatments.

5.2.3 Mean 100 seed weight

Mean seed weights of all treatments at KNUST and Nyankpala in both cropping seasons were lower than reported by other research works. Padi *et al*., (2006) reported between 67 and 70g. Virender and Kandhola (2007) reported between 61.6 and 67.8g. The significance recorded by the SP1 treatment in 2006, as well as the SP3 treatment in both years at KNUST supports the research findings of Sumarnno and Adie (1995) that narrow plant spacing giving high plant densities significantly reduced MSW.

Mean seed weight is an indication of the amount of DM allocated to seed development by treatments. This has been attributed to plant or varietal factors (Karkannavar, *et al*., 1991). Other researchers (Ahmad and Mohammad, 1997; Ogundele, 1988) have reported that environmental factors significantly influence MSW. The relatively lower MSW values recorded in 2007 for all treatments at both locations compared to 2006 were probably as a result of the drought experienced at the experimental sites in that year. ICRISAT (1994) and Vara Prasad *et al.*, (1998) have shown that drought or water stress significantly reduced yield indices in groundnut crop. Inadequate photosynthates and low levels of soil nutrients especially calcium were also reported to result in partially filled or 'pops', leading to low MSW values (CIRAD-CORAF, 1988-1995; Piggot, 1960).

5.2.4 Pod yield

Pod yield at both locations in 2006 were generally higher than in 2007. The lower pod yields in 2007, especially at Nyankpala were as a result of severe drought experienced during the growing period especially in June. Other researchers have reported pod yield of 1.076-1.149 t ha^{-1} (Shambharkar *et al*, 2006), 1.64-2.99 t ha^{-1}

(Abdullah *et al*., 2007), 0.55-1.15 t ha^{-1} (Mayeux and Maphanyane, 1989) and 2.26-2.86 t ha^{-1} (Virender and Kandhola, 2007). Decrease in plant spacing reduced yield components but the additional plant m^{-2} more than compensated for the reduction, resulting in higher pod yield. Thus narrow spacing treatments giving high density crop were more efficient in the use of solar energy and other growth resources. Similar results have been obtained by Virk *et al*., (2005). Also, water stress at the early growth stages might have resulted in the allocation of more DM to the roots for water and nutrient uptake (Ali and Malik, 1992; Bailey and Biosvert, 1991, Banerjee *et al*., 2005). Subsequent excessive rains in the season probably promoted vegetative development at the expense of pod formation and pod filling (Schilling and Gibbons, 2002), resulting in high stover yield and low pod production by all treatments in 2007 compared to 2006 cropping season at Nyankpala.

The SP3 groundnut crop gave the highest pod $plant^{-1}$. However, narrow-row treatments recorded the greatest pod yields. This was probably because the additional plants in narrow-row treatments more than compensated for the reduced number of pods, giving higher pod yields. This confirms research reports by Ahmad *et al*., (2007) who found out that pod yield was 16% higher in narrow-row plantings compared with traditional wide-row crop. Norden and Lipscomb (1974) and, Duke and Alexander (1964) had earlier reported pod yield among narrow-row groundnut to be 14% higher than wide-row groundnuts.

5.2.5 Seed yield

Following the pattern of pod yield, seed yield of all treatments in both years and locations were higher in 2007 than in 2006. The higher and significant seed yield obtained from the Kpanieli variety at KNUST and Nyankpala in 2007 was probably due to the genotype of the variety since differences in seed yield among varieties grown under the same conditions have been reported to result largely from genotypic effects (Ahmad *et al*., 2007). The ability of the Kpanieli variety to out yield the other varieties in two different environments show that the plant factors controlling yield in the variety is genetically stable. In both locations in 2006, the SP1 spacing with intermediate plant population density supported higher seed yields. However, in 2007, the SP2 spacing with the highest plant density supported the highest seed yield probably because of the higher number of plants m^{-2}.

5.2.6 Shelling percentage

Shelling percentage, as an index of crop yield indicates the proportion of the total DM synthesized that has been allocated to the seed. It is affected by varietal factors, as well as environmental factors affecting photosynthesis, DM partitioning and accumulation. Shelling percentages of varieties at KNUST in 2006 did not show significance. The highest shelling percentage in 2006 was recorded by Nkosuor (60.39%). In 2007, Kpanieli and Manipintar recorded significantly high shelling percentage (64.56 and 64.99% respectively), increasing shelling percentage by 8.26 and 8.86% over the mean. SP3 recorded significance (62.02%) in 2006 whilst no significance was recorded in 2007 although SP3 again recorded the highest shelling percentage (62.41%).

At Nyankpala, both varieties row spacing recorded significant variations in both cropping seasons. Adepa, Azivivi and Jenkaar recorded high and statistically significant shelling percentages in 2006. Shelling percentage of 66-70% (Padi *et al*., 2006), 48-61% (Abdullah *et al*., 2007), 53.6-65.6% (Virender and Kandhola, 2007) have been reported by other researchers. The SP2 treatment registered the highest shelling percentage among the other spacing treatments. Whereas there were no significant variations among spacing treatments in 2006, effects of spacing was significant in 2007. The large variation in shelling percentage among varieties in 2007 was probably as a result of the drought experienced in that year. On that account, varieties or treatments giving statistically significant shelling percentages could be classified as performing well under conditions of water stress. Factors affecting seed size and MSW have also been shown to reduce shelling percentage (Abdullah *et al*, 2007; Ogundele, 1988; Piggot, 1960).

5.2.7 Harvest Index

Harvest Index is an indicator of how much of the total DM accumulated by the treatments is partitioned into the economic part (pod). There was significant influence of groundnut variety and spacing on HI in both years and locations. Pod filling in groundnut is very sensitive to moisture stress. Water stress as well as soil fertility factors have been reported to adversely affect DM production and partitioning among plant parts in groundnuts (ICRISAT, 1994). Differences in HI could probably have been as a result of differences in the way the treatments respond to moisture and heat stress in both years.

5.2.8 Seed-hull ratio

Seed-hull ratio (SHR) is a further breakdown of how the DM allocated to the pod is partitioned between the seed and hull (Cummins and Jackson, 1982; Abulu, 1978). It is used as index of groundnut maturity (Pattee *et al*, 2006; Abdel, 1994). SHR at KNUST increased with an increase in row spacing in both seasons. However, at Nyankpala, SHR decreased in both seasons with increased row spacing confirming the research findings of Abdel (1994) and Pattee *et al*., (2006) who reported delayed maturity among wide-row groundnuts compared to narrow-row groundnut crop. This is probably because relative availability of more growth resources encouraged continuous vegetative growth among the wide-row groundnut crop at the expense of reproductive growth compared to narrow-row groundnut crop. Such conditions that encourage vegetative growth have been reported to delay maturity and cause a reduction in mean seed weight and shelling percentage as well (Abdel and El Ahmadi, 1994; Schilling and Gibbons, 2002).

5.3 Estimation of nitrogen fixed

5.3.1 Percent residue and seed N

Residue and seed N are attributes of the crop variety influenced by the environment. The ability of a variety to nodulate and fix nitrogen, and how it allocates the fixed nitrogen among various plant parts determine the percentage of N accumulated in the residue and seed. Under conditions favouring growth such as sufficient supply of soil moisture and excess supply of soil N, groundnut is known to allocate more DM to vegetative growth (residue) at the expense of reproductive growth (seed), thus accumulating more N in the residue than in the seed (Schilling and Gibbons, 2002). Competition among narrow spacing treatments produced taller plants at the early stages in both locations in 2006 and 2007. This resulted in high residue N among the narrow spacing treatments compared to the wider spacing treatments that did not need to produce taller plants to overcome the effects of mutual shading. The distribution of N into residue and seed is important as it determines not only how the legume is utilized (Bunting, 1955, Coffelt, 1989) but also how much nitrogen is made available to the subsequent crop if the residue is incorporated into the soil

(Giller, 2001). Legumes accumulating more fixed N in the residue are ideally used as forages or green manure crops, whilst those accumulating more N in the seed produce economic yield (seed) and are cultivated for the grain (Summerfield and Roberts, 1985). Ghosh *et al.*, (2007) indicated that an ideal legume is one that efficiently allocates N to both residue and seed as it could play an important role in sustainable subsistence farming systems. At KNUST, both variety and plant spacing produced similar effects on residue and seed N.

5.3.2 Total fixed nitrogen

Groundnut variety did not significantly influence total fixed N (TFN) at KNUST in both years. Pate *et a*l., (1969) reported that moisture was a requirement for nitrogen fixation. Prolonged moisture restriction was found to inhibit nitrogen fixation (Alexander, 1985). In both years and locations, treatments giving higher TFN did not result in significantly higher pod yield (t ha^{-1}). This indicates that such treatments were not very efficient in partitioning DM into the pod. Insufficient availability of DM could also have caused reduced activity by treatments recording higher nodule numbers since nitrogen fixation is known to use up large amount of the plants DM reserves (Giller, 2001). Also, the periods of drought could have encouraged root development for moisture acquisition at the expense of nodule activity (Schilling and Gibbons, 2002,). This is in line with the findings of Banerjee *et al*., (2005) who reported significant nodulation among groundnut varieties but reduced nodule activity and N_2-fixation among drought stressed crop.

5.3.3 Stover N

Stover N reflects the amount of N that will be made available to the succeeding crop if the residue is incorporated into the soil. Stover N is influenced by the amount of crop residue as well as N concentration in the residue. Variations in stover N of varieties at KNUST in both years were not significant. The SP1 treatment supported the largest stover N in both years. Effects of intra-specific competition among the SP2 treatments probably resulted in a significant reduction in plant size. Wide-row treatments produced bigger plants but the overall TDM and N concentration was as low as to affect stover N significantly. SP1 was the optimum plant spacing for the purposes of stover N and efficiently utilized growth resources to achieve significant stover N in both years at KNUST. Varieties supporting large Plant TDM did not support the largest stover N in both years. However, narrow-row treatment, SP1, which supported the largest plant stover, also supported the largest stover N in both years.

At Nyankpala, consistent performances by Jenkaar and Nkosuor in the two seasons suggest a genetic stability across seasons. Plant spacing demonstrated a strong influence on stover N as its effects were significant in both locations and seasons. SP1 and SP2 treatments that registered significant amounts of plant DM in 2006 and 2007 also recorded the largest stover N in both years.

Stover N obtained from this research is similar to the findings of several other workers. Stover N of 60 Kg N ha^{-1} (Ghosh *et al*., 2007), 54-58 K g ha^{-1} (Singh *et al*., 1988; Hedge and Dwivedi, 1993) have been reported. Stover N of some treatments however were well below that reported by other researchers. This can be attributed to both plant and environmental factors controlling N concentration in the residue, and plant size that determines the overall stover yield ha^{-1}.

5.4 Correlation coefficients of pod yield and components of yield

At KNUST in 2006, increases in canopy width significantly increased pod yield, whilst increases in pod yield led to increases in harvest index. Also, increasing stover N led to decreases in shelling percentage. In both years, increases in canopy width led to decreases in harvest index. In 2007, increasing the number of branches significantly increased shelling percentage. At Nyankpala, increases in plant height, number of pods plant^{-1} and canopy size all brought about increases in pod yield. Increases in residue N strongly increased stover N. Also, increases in pod yield significantly improved harvest index. Increases in mean seed weight strongly increased shelling percentage, whilst increases in the number of branches lead to increases in stover yield. Boote *et al*., (1992) and Lapang *et al*., (1980) observed that mean seed weight was positively correlated to number of branches and plant dry matter in groundnuts, and an increase in number of branches resulted in corresponding increase in mean seed weight and hence shelling percentage. Also the very strong ($P<0.01$) and positive correlation coefficient between plant dry matter and stover N confirm other research findings of Bell *et al*., (1993) and Boote *et al*., (1992), who indicated that groundnut plant dry matter (t ha^{-1}) was positively and strongly correlated with stover N.

5.5 Economic returns

All treatments (variety and spacing) at KNUST and Nyankpala in 2006 and 2007 were subjected to economic analysis to determine its profitability or otherwise. The economic analysis method used was the benefit-cost ratio (BCR) of treatments. This involved the determination of variable costs, gross returns and net benefits for all treatments.

5.5.1 Net benefits

The high net benefits recorded by Nkosuor (GH¢ 391.05) in 2006 was as a result of the large pod yield (1.196 t ha^{-1}). In 2007, Kpanieli which produced the largest pod yield (4.017tah^{-1}) also recorded the highest NB (GH¢ 794.50). Differences in NB among varieties were as a result of differences in pod yields obtained in both seasons. The SP1 treatment recorded the highest NB (GH¢ 463.63 and GH¢ 612.60) respectively in 2006 and 2007.

At Nyankpala, Adepa which recorded 2.009 t ha^{-1} of dry pods ranked first (GH¢635.47) in 2006 whilst Manipintar (1.358 t ha^{-1}) ranked first (GH¢ 222.17) in 2007. The SP1 treatment which supported greatest dry pod yields (1.721 and 1.018 t ha^{-1} respectively) in 2006 and 2007 ranked highest (GH¢ 616.00 and GH¢ 323.90 respectively) in both years. The SP3 treatment ranked last (GH¢ 78.5). The SP1 treatment was therefore economically profitable as it reduced the cost of production compared to SP2 treatment, whilst at the same time producing the largest pod yield, resulting in the highest NB for both locations in 2006 and 2007 cropping seasons.

5.5.2 Benefits-Cost Ratio

The high benefits-cost ratio (BCR) obtained from Nkosuor (4.48:1) at KNUST was due to the large pod yield (1.196 t ha^{-1}) supported by the treatment in 2006. In 2007, Kpanieli supported the largest pod yields (4.017 t ha^{-1}), consequently recording the highest BCR (7.49:1). The lowest BCR at KNUST (3.12:1 and 2.92:1) were recorded by the Jenkaar and Manipintar varieties in 2006 and 2007 respectively.

At Nyankpala, the highest BCR (8.76:1) in 2006 was obtained from the Adepa variety which gave the largest dry pod yield (1.77 t ha^{-1}). In 2007, the Manipintar variety which produced 1.32 t ha^{-1} of dry pods recorded the highest BCR (4.90:1). In both years, the SP1 spacing produced the largest pod yields (1.721 and 1.018tha^{-1} respectively) and recorded the highest BCR (8.51:1 and 3.89:1 respectively).

Both variety and plant spacing significantly added to BCR in both years and locations up to an optimum (SP1), after which further increases in plant population density (SP2) added more to cost than to NB, resulting in a reduction in BCR. However, the additional cost of production did not reduce BCR as much as additional pod yield increased BCR. As a result, all the treatments were economically beneficial although some were more beneficial than others under the conditions of the experiment. Differences in BCR among treatments were basically as a result of differences in pod yield obtained from the different groundnut varieties and plant spacing.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The current shift in agricultural production strategies towards low external input sustainable agricultural (LEISA) practices has further emphasized the importance of selecting and promoting crop varieties that will fit into the subsistence farmers' practice of exploitative agriculture. Such varieties should be able to meet the immediate needs of the farmer in terms of food and/or income while at the same time conserving the soils' productive capacity for tomorrow's use.

To meet this two-pronged farmer need, studies were carried out at the KNUST agricultural research station, Anwomaso in the Ashanti region and the Savannah Agricultural Research Institute (SARI), Nyankpala 2006 and 2007. The field experiments involved two agro-climatic zones (Humid Forest and Guinea savannah), six groundnut varieties (Adepa, Azivivi, Jenkaar, Manipintar, Nkosuor and Kpanieli) and three plant spacing (30 cm x 15 cm, 40 cm x 10 cm and 50 cm x 10 cm).

The objective was to assess the influence of groundnut variety and row spacing on:

(i) Growth parameters

(ii) Yield parameters

(iii) Nitrogen fixation, and

(iv) Economic returns

6.2 Summary of KNUST results

6.2.1 Growth Parameters

Results show that the variety Adepa recorded the highest plant stand in 2006 followed by the Azivivi variety. In 2007, the Manipintar variety recorded the highest plant stand followed by the Adepa variety. Plant spacing did not show significant effects on plant stand in both years.

Plant canopy width was also significantly influenced by variety in both years. The Nkosuor variety produced the widest canopy at 4 WAP only in 2006, while the Manipintar variety recorded significantly wide canopy at 4, 6 and 8 WAP in 2007. The SP3 spacing recorded significant effects on canopy width on all sampling occasions in both years. Between 6-8 WAP in 2006, relative growth rate by the SP1 spacing was the highest and significant. Differences in the effects of varieties on plant height were significant in both years. Adepa consistently recorded the greatest effects on all sampling occasions in 2006 although its effects were similar to the other varieties. In 2007, effects of the Manipintar variety were larger and significant on all three sampling occasions.

Groundnut varieties recorded significant difference in shoot dry matter among themselves. In 2006, the Azivivi variety recorded the largest and significant shoot dry matter at 6 WAP, while the Jenkaar variety recorded the largest and significant shoot dry matter at 8 WAP. In 2007, the Manipintar variety recorded the largest and significant shoot dry matter at 4, 6 and 8 WAP. The SP3 spacing recorded significance at 4 and 8 WAP while the SP1 spacing recorded largest and significant shoot dry matter at 6 WAP in 2006. In 2007, the SP3 was significant only at 4 WAP. Like shoot dry matter, stover yield was significantly affected by groundnut variety in both years. The Jenkaar variety recorded the largest and significantly different stover yield in 2006. The largest and significant stover yield was recorded by the SP1 plant spacing.

6.2.2 Yield parameters

No significant differences in the effects of varieties on number of pods were recorded in 2006. However, in 2007, the Kpanieli variety recorded the highest and significant number of pods. No significant effects were observed in both years among the different plant spacing.

The largest pod yield in 2006 was obtained from the Nkosuor variety. In 2007, the Kpanieli variety recorded the largest and significant pod yield. Plant spacing also significantly influenced pod yield only in 2007. The SP1 spacing recorded the largest and significant pod yield in 2006 while the SP2 spacing recorded the largest and significant pod yield in 2007.

Varietal effects did not result into significant differences in the number of seeds in both years. The SP3 plant spacing supported the highest and significant number of seeds only in 2006.

Low plant densities also influenced mean seed weight shelling percentage and seed-hull ratio among treatments in 2006 and 2007. The Azivivi and Kpanieli varieties recorded the largest mean seed weight in 2006 and 2007 respectively. This was followed by the Nkosuor variety in 2006 and Manipintar variety in 2007. The SP3 plant spacing recorded the largest mean seed weight in both years. The highest shelling percentage was recorded by the Nkosuor variety in 2006. In 2007, the Manipintar variety recorded the highest shelling percentage. The SP3 spacing recorded the highest shelling percentage in 2006 only. The Nkosuor variety recorded the highest seed-hull ratio in 2006 while the highest in 2007 was recorded by the

Manipintar variety. SP3 plant spacing recorded the highest seed-hull ratio in both years.

6.2.3 Biological nitrogen fixation

Varietal and spacing effects did not result into differences in residue, seed and total fixed nitrogen in both years. Also, effects of varieties on stover N were not significant in both years. However, plant spacing significantly influenced stover N in 2007 only when The SP1 spacing, due to its high plant density and large stover yield recorded the largest and significant stover N.

6.2.4 Correlations

Pod yield was negatively and highly correlated with canopy width in 2006. Canopy width was positively and highly correlated with shelling percentage in 2006. Pod yield was also positively and highly correlated with harvest index but negatively and highly correlated with shelling percentage in 2006. In 2007, pod yield was again negatively and highly correlated with canopy width, stover N and harvest index.

6.2.5 Economic returns

Generally, cost of production decreased with decreasing plant population density in both years. The highest production cost was incurred by the SP2 spacing which resulted into the highest plant density, while the least cost was incurred by the SP3 with the lowest plant density. The SP1 spacing gave intermediate plant density and its cost of production was somewhere in-between the SP2 and SP3.

Gross returns (GR) to treatments were basically dependant on pod yield. The Nkosuor variety recorded the highest GR in 2006 followed by the Azivivi variety. In

2007, the Adepa variety produced the highest GR followed by the Manipintar variety. The SP1 plant spacing recorded the largest pod yield, resulting in highest GR in both years. Net benefits (NB) in both years followed the pattern of GR, favoured by large pod yields. The Nkosuor variety recorded the highest NB in 2006 followed by the Azivivi and Adepa varieties. In 2007, the Kpanieli variety recorded the highest NB followed by the Adepa, Manipintar and Azivivi varieties. Also, the SP1 plant spacing recorded the highest NB in both years.

The Nkosuor and Kpanieli varieties recorded the highest benefits-cost ratio in 2006 and 2007 respectively followed by the Jenkaar variety in 2006 and the Adepa variety in 2007. Highest benefit-cost ratios were also favoured by the SP1 plant spacing in both years.

6.3 Summary of Nyankpala results

6.3.1 Growth parameters

The Adepa and Nkosuor varieties recorded similar but significant number of plants m^{-2} in 2006. In 2007 the Manipintar variety recorded the highest plant stand followed by the Adepa variety. In both years, plant spacing showed significant effects on plant stand. The SP2 spacing because of its high seeding rate recorded the highest plant stand in both years. This was followed by the SP1 Plant spacing in both years. The SP3 with the least seeding rate recorded the least plant stand in both years.

The Jenkaar variety recorded the tallest plants at 4 and 6 WAP, while the Adepa variety produced the tallest plants at 8 WAP in 2006. In 2007, the Manipintar variety recorded the tallest plants throughout the growing period. The SP3 spacing recorded the tallest plants 4 WAP, while the SP2 spacing recorded the tallest plants 6 and 8

WAP in 2006. In 2007, the SP2 spacing recorded the tallest plants at 4 and 6 WAP, while the SP1 spacing recorded the tallest plants at 8 WAP.

Canopy width in 2006 and 2007 were also significantly influenced by groundnut variety. The Nkosuor variety recorded widest canopy at 4 and 6 WAP, while the Jenkaar variety recorded the widest canopy at 8 WAP in 2006. The Jenkaar variety recorded the widest canopy at 4 WAP, while the Kpanieli variety recorded the widest canopies at 6 and 8 WAP 2007. The widest and significant canopy was recorded by the SP3 spacing throughout the growth of the varieties in 2006. In 2007, no significance was recorded at 4 and 8 WAP, but at 6 WAP, the SP3 spacing again recorded the widest and significant canopy with.

Relative growth rate in both years did not follow a specific pattern. The Jenkaar variety recorded the highest relative growth rate 4-6 WAP, while the Adepa variety recorded the highest relative growth rate 6-8 WAP in 2006. In 2007, the Azivivi recorded the highest relative growth rate 4-6 WAP. At 6-8 WAP in 2006, relative growth rate of the SP3 spacing was the highest and also significant. The largest shoot dry matter in 2006 was recorded by Azivivi at 4 and 6 WAP, while Jenkaar recorded the largest shoot dry matter at 8 WAP. In 2007, the Manipintar, Jenkaar and Adepa varieties recorded the largest shoot dry matter at 4, 6 and 8 WAP respectively. The SP1 spacing recorded the largest shoot dry matter 4 WAP in 2006 and 2007 and at 8 WAP in 2007. The SP3 spacing recorded the largest at 6 WAP in 2007.

The Jenkaar and Nkosuor varieties recorded the largest stover yield in 2006 and 2007 respectively. Stover yield, like shoot dry matter was also significantly influenced by plant spacing in both years. The SP2 and SP1 spacing recorded the largest and significant stover yield in 2006 and 2007 respectively.

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6.3.2 Yield parameters

The Jenkaar and Kpanieli varieties recorded the highest number of pods plant^{-1} in 2006 and 2007 respectively. SP1 was the spacing that recorded the highest and significant number of pods in 2007 only. Differences in varietal effects on pod yield were significant in both years. The Adepa and Manipintar varieties recorded the largest and significant pod yields in 2006 and 2007 respectively. Effect of spacing was only significant in 2007 when the SP1 recorded the significantly large pod yield.

The largest mean seed weight in 2006 was recorded by the Nkosuor variety followed by the Adepa variety. In 2007, the Kpanieli variety recorded the highest mean seed weight. The SP2 spacing recorded the largest mean seed weight in both years although this was not significant.

The highest shelling percentage in 2006 was recorded by the Adepa variety followed by the Azivivi variety. In 2007, the Kpanieli variety recorded the highest shelling percentage and this was followed by the Manipintar variety. The SP2 spacing recorded the highest and significant shelling percentage in 2006 only. The highest seed-hull ratio was recorded by the Adepa and Kpanieli varieties in 2006 and 2007 respectively. Spacing did not significantly affect seed-hull ratio in both years.

6.3.3 Biological Nitrogen Fixation

Groundnut varieties showed significant effects on residue N concentration in both years. The highest and significant residue N was fixed by the Adepa and Nkosuor varieties in 2006 and 2007 respectively. In 2007, the Nkosuor variety fixed the highest and significant seed N.

The highest total plant N in 2006 and 2007 was fixed by the Adepa variety, however, this was only significant in 2007. Stover N, like residue N was significantly influenced by groundnut varieties in both years. The largest and significant stover N was supported by the Nkosuor and Jenkaar varieties in 2006 and 2007 respectively. The SP1 spacing, because of its large crop stover yield recorded the largest stover N in both years.

6.3.4 Correlations

In both years, pod yield was positively and highly correlated with residue N. Residue N was also positively and highly correlated with stover N in both years. Stover N was negatively and highly correlated with seed N and harvest index in 2006. In 2007, pod yield was positively and highly correlated with harvest index. However, pod yield was negatively and highly correlated with residue N, plant dry matter and stover N.

6.3.5 Economic returns

The highest cost of production was recorded by the SP2 spacing, while the least cost was incurred by the SP3 spacing. The SP1 spacing was in-between with regard to cost of production. Gross returns (GR) in both years depended much on the total dry pod yield. Treatments with high pod yields gave high GR. The Adepa variety gave the highest GR in 2006. In 2007, the Manipintar variety produced the highest GR. The SP1 spacing recorded the largest GR in both years.

Net benefits in both years followed the pattern of gross returns. The Adepa and Manipintar varieties gave the highest NB in 2006 and 2007 respectively. The SP1 again was the plant spacing that recorded the highest net benefits in both years. Benefit-cost ratio (BCR) also followed the pattern of NB in both years. The Adepa and Manipintar varieties recorded the highest BCR in 2006 and 2007 respectively. SP1 spacing again recorded the highest BCR in both years.

6.4 Conclusions

The findings of this research work indicates that the groundnut varieties performed differently in different environments, and also that optimum plant spacing is required to maximize return to inputs and labour in groundnut production. The selection of the right varieties and achievement of this optimum spacing is essential in reducing weed competition and maximizing the use of soil, light and farm inputs.

Costs of seed for the groundnut varieties were the same. The varieties and spacing however performed different under the same conditions. Under such conditions, varieties that showed significance would be considered as having the potential to improve groundnut production in the environment under consideration. Nkosuor supported the largest pod yield and also recorded the highest BCR in 2006 at KNUST. In 2007 Kpanieli produced the highest pod yield and BCR. At Nyankpala in 2006, Adepa recorded the highest pod yield and BCR whilst Manipintar recorded the highest pod yield and BCR in 2007. In 2006, Jenkaar supported the greatest stover N in both locations whilst in 2007 Manipintar supported the greatest stover yield in 2007. Spacing treatment, SP1 supported the greatest stover N at both locations in both years.

The cost of production of the SP1 treatment was lower than that of the SP2 treatment. Also, yields obtained from the SP1 treatment was higher and net benefits and BCR was the highest in both locations and seasons. In addition, SP1 treatment resulted in the production of large crop stover in both locations and years. Farmers therefore can potentially benefit more from the stover N that would be made available to the succeeding crop if the stover is incorporated into the soil. Based on the findings of this research work, it can be concluded that;

(i) The Nkosuor variety was the ideal groundnut variety for the Forest zone while the Adepa variety was the ideal groundnut variety for production of the crop in the Guinea savannah agro-climate.

(ii) The SP1 groundnut spacing would lead to higher pod yields in both the Guinea savannah and Forest agro-climates, on relatively the same land size with the potential to generate more income for the farm family.

(iii) The SP1 groundnut spacing produced very large stover N in both Guinea and Forest agro-climates, potentially making more nitrogen available to the succeeding non-legume crop.

6.5 Recommendations and future research directions

6.5.1 Recommendations

The following recommendations have been made after a careful consideration of the research findings:

(i) Considering the findings of this research, further research could be carried out on Nkosuor in the Forest zone and Adepa in the Guinea savannah zone. This should target the susceptibility of these varieties to disease and pest problems, and their response to Phosphorus fertilizers.

(ii) In the light of the current practice of carting away and/or burning of crop residue, leading to very low soil fertility, coupled with high cost of fertilizer N, production targets of major staples have fallen over the years. Poor farmers without access to fertilizer N, and who need to improve their cash income should therefore be encouraged to adopt the SP1 plant spacing the incorporation of residue into the soil after harvest because of the high stover N.

(iii) In the establishment of groundnut crop, irrespective of the reason given above, some farmers may prefer closer plant spacing due to limited land holdings. In situations where this is the case, the use of recommended soil amendments at the recommended rates should be adhered to in order to maximize crop yields and economic returns.

6.5.2 Future research direction

Future groundnut research in Ghana should focus on:

(i) Groundnut-cereals intercropping systems. The development of the right arrangement of groundnut with several major cereal staples in crop mixtures would play an important role in giving the farmer both cash income from groundnut harvest and food from the cereals. The added benefits of nitrogen fixation would also be exploited.

(ii) The influence of sowing time on quantity and quality of yield in the different agro-ecological zones giving the current climate change.

(iii) Influence of time of harvest on groundnut pod yield and seed quality.

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APPENDIX

Appendix.1 Variable cost of operations in 2006 and 2007 at KNUST and Nyankpala.

	KNUST (GH¢)		Nyankpala (GH¢)	
Input	2006	2007	2006	2007
(i) Land Preparation				
-Tractor plough & harrow	10.0	12.0	13.0	15.0
(ii) Planting material (ha^{-1})				
30cm x 15cm	20.9	23.8	11.4	13.3
40cm x 10cm	20.4	27.5	13.2	15.4
50cm x 10cm	10.83	20.8	10.0	11.6
(iii) Cost of inputs & Weeding (manual)	35.0	40.0	25.0	30.0
(iv) Harvesting (ha^{-1})	25.0	30.0	20.0	25.0
(v) Sub-totals				
30cm x 15cm	90.87	105.8	72.4	83.3
40cm x 10cm	90.37	109.5	74.2	85.4
50cm x 10cm	80.80	102.8	71.0	81.6

Appendix. 2 Total variable cost and gross returns in 2006 and 2007 at KNUST.

	Total Variable Cost (Cedis)		Gross Returns (Cedis)	
Treatment	2006	2007	2006	2007
VARIETY				
Adepa	87.35	106.3	411.20	760.80
Azivivi	87.35	106.4	369.20	577.20
Jenkaar	87.35	106.5	360.00	705.60
Kpanieli	*	106.6	*	900.80
Nkosuor	87.35	106.7	478.40	662.40
Manipintar	87.35	106.8	*	417.00
SPACING				
SP1 (30cm X 15cm)	90.37	105.8	544.00	718.40
SP2 (40cm x 10cm)	90.87	109.5	363.60	686.80
SP3 (50cm x 10cm)	80.80	102.8	296.40	663.20

Appendix.3 Total variable cost and gross returns at Nyankpala in 1006 and 2007.

	Total Variable Cost (Cedis)		Gross Returns (Cedis)	
Treatment	2006	2007	2006	2007
VARIETY				
Adepa	72.53	83.45	708.00	305.60
Azivivi	72.53	83.46	599.60	312.40
Jenkaar	72.53	83.47	654.40	315.20
Kpanieli	*	83.48	*	414.00
Nkosuor	72.53	83.49	632.40	376.00
Manipintar	*	83.50	*	492.00
SPACING				
SP1 (30cm X 15cm)	72.40	83.30	688.40	407.20
SP2 (40cm x 10cm)	74.20	85.40	649.20	356.40
SP3 (50cm x 10cm)	71.10	81.60	607.60	288.80