EFFECT OF PLANT DENSITY AND TYPES OF SEEDBED ON THE GROWTH AND GRAIN YIELD OF BAMBARANUTS

(*Vigna subterranea* (L.) Verdc.)

BY

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ABSTRACT

A field experiment was laid out during the short (October to February) and long (March to June) rain seasons to evaluate the effects of population density and types of seedbed on the growth and grain yield of bambaranuts [*Vigna subterranea* (L.) Verdc.). The experimental design was a split-plot laid out in a randomized complete block with three replications. Types of seedbed (flat, ridge and furrow) were the main plot factors while population densities T_1 = (94 444), T_2 = (133 333), T_3 = (222 222) and T_4 = (666 666) plants ha^{-1} achieved by intra-row and inter-row spacings of 35 x 30, 25 x 30, 15 x 30 and 5 x 30 cm were sub plots, respectively.

During both seasons, bambaranuts planted on the ridge across all population densities were slowest to emerge. Generally, emergence rates decreased with increase in plant population densities.

During the short rain season, bambaranuts planted on the ridge were the tallest (38.2 cm) at 66 plants m^{-2}, had the highest leaf area $plant^{-1}$ (4460.6 cm^2), highest leaf area index and highest root: shoot ratio at 9 plants m^{-2}. Bambaranuts planted in the furrow had the highest number of flowers $plant^{-1}$ (26.0) at 9 plants m^{-2}, highest number of pegs $plant^{-1}$ (57.8) and highest number of pods $plant^{-1}$ (18.2 and 18.7) at 9 and 13 plants m^{-2}, respectively. The crop planted in the furrow or ridge resulted into higher values for root dry matter $plant^{-1}$ (6.7 g) at 13 plants m^{-2}, number of plants at harvest (63), highest grain yield (519.2 kg ha^{-1} at 13 plants m^{-2} and highest harvest index (62.5) at 13 plants m^{-2}. Bambaranuts recorded significantly ($P \leq 0.05$) higher values for shelling percentage at 13 plants m^{-2} across all types of seedbed.

During the long rain season, planting on the flat or in the furrow resulted into the tallest plants, highest leaf area $plant^{-1}$ (1343.69) at 13 plants m^{-2}, highest shoot dry matter $plant^{-1}$ (10.9 g and

10.1 g) at 13 and 22 plants m^{-2}, respectively. The crop planted in the furrow resulted into the highest number of plants (66) at harvest at 66 plants m^{-2} and highest above ground dry matter (1271.6 kg ha^{-1}) at 13 plants m^{-2}. Bambaranuts planted on the ridge or flat recorded significantly ($P \leq 0.05$) high values for shelling percentage (85.5 and 80.6) at 22 plants m^{-2}.

The crop planted on the flat resulted into the highest number of flowers (31.6) and pegs (72.9) $plant^{-1}$ at 22 plants m^{-2}, highest number of pods (14.4 and 14.7) at 13 and 22 plants m^{-2}, respectively, highest root dry matter (4.10) at 22 plants m^{-2}, highest root : shoot ratio (0.45) at 22 plants m^{-2}, highest pod yield (1065.3 kg ha^{-1}), highest grain yield (746.6 kg ha^{-1}) at 22 plants m^{-2}, highest 100-seed weight (36.6 g) at 9 plants m^{-2} and highest harvest index (95.8) at 22 plants m^{-2}.

Generally, leaf area $plant^{-1}$ for both seasons decreased with increase in population density while LAI increased. Flower, peg, pod, shoot and root dry matter decreased with increase in population density during the short rain season but were variable for the long rain season.

Bambaranut yield was positively correlated with the number of flowers, pegs, pods, pod dry matter and kernel dry matter during the short rain season. Positive correlations for the number of pods, leaves, pod dry matter, kernel dry matter, stem dry matter with grain yield were also observed during the long rain season. On the basis of coefficient of determination (R^2) values, pod dry matter, number of pods and kernel dry matter were the most important factors that determined yield.

DECLARATION

I, FRACKSON LAMECK MKANDAWIRE, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation has not been submitted for a degree award in any other university.

Signed: Mkandawire

Date: 30/09/96

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DEDICATION

1. To my dear wife Philles, daughters Christine and Lusungu and sons Gomezgeka and Otieno for whom I thank God.

2. To my late parents Lameck and Rhoda, brothers Mussa, Manuel, Bright and Vincent for their moral support.

3. To all the Jaranthowa family in Malawi.

"Then I will give you rain in due season,

And the land shall yield her increase,

And the trees of the field shall yield their fruit".

Leviticus 26:4. (King James Version).

"Thou waterest the ridges thereof abundantly;

Thou settlest the furrows thereof;

Thou makest it soft with showers;

Thou blessest the springing thereof".

Psalm 65:10 (King James Version).

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1.0 INTRODUCTION

Legumes are excellent sources of protein and contribute about 18.5% of the total protein requirements in the world (Rachie and Roberts, 1974). In terms of nutrition, legumes such as beans (*Phaseolus vulgaris* (L.); cowpeas (*Vigna unguiculata* (Walp)), groundnuts (*Arachis hypogaea* (L.)) field beans (*Vicia faba* (L.), soyabeans (*Glycine max* (L.) and bambaranuts (*Vigna subterranea* (L.) Verdc.) are highly complementary in the diets of people living in the tropics. Leguminous seed proteins are also the least expensive, easily stored and transported non-processed protein sources for both rural and urban utilization (Rachie and Roberts, 1974).

Bambaranuts contain about 6% oil, 60% carbohydrate and 18% protein (Duke et *al*., 1977). Bambaranuts also have an added advantage in that they have a higher lysine (6.9 mg) and methionine (1.9 mg) content per 100 gms of dry seed than are found in either groundnuts or cowpeas. Bambaranuts can, therefore, supplement the protein quality of cereal based diets of people in the tropics (Ezedinma and Maneke 1985). As a legume, bambaranuts fix atmospheric nitrogen which make them less dependant on mineral nitrogen of the soil, a quality of importance in intensively used infertile soils (Linnemann, 1994).

Bambaranuts are cultivated throughout most of tropical Africa by poor farmers, mostly women. In Tanzania bambaranuts are grown mainly in Bukoba, Mbeya, Musoma, Mwanza, Singida, Kondoa, Dodoma, Mtwara, some areas in Morogoro, Coastal areas, and Tabora regions. The crop is mainly grown for home consumption and production figures are difficult to find mainly because the surplus does not enter through the normal official government marketing system . The bulk of the crop is grown under monoculture but a limited amount is intercropped with maize, groundnuts, sorghum, cassava or finger millet (Ludwig, 1968; Rounce and Thornton, 1956). In fact, the seed sample contained traces of maize and groundnuts. There is a high degree of genetic variability in Tanzanian bambaranut landraces in terms of seed colour (Plate 1), yield and growth habit. Casual selection by farmers has been towards the bunch and semi-bunch types.

Initial interest in bambaranut research in Tanzania initiated at Ukiriguru around 1967/68 (Symth, 1968b) was curtailed during the 1970s and 1980s. During the same period, however, bambaranuts remained an important food crop for the rural poor especially in semi-arid areas. Against the background of bambaranuts being a high potential legume for the semi-arid areas where it is considered as a security food crop in case of drought and because of its role in crop diversification, a multi-country collaborative study was set up between Nottingham University in the United Kingdom and Sokoine University of Agriculture in Tanzania. The main objectives of the collaborative research are to evaluate and study the growth and development of local genotypes and to identify agronomic practices for the cultivation of bambaranuts in Tanzania.

Limited research indicates that bambaranuts have a high yield potential (Johnson, 1968; Rachie, 1979). However, available literature shows that yields per unit area in Tanzania are as low as 650 kg ha^{-1} (Symth, 1968b). Several factors account for this low yield. These include inconsistency in planting rates, low plant population and late planting,as well as variation in the type of seedbed used (Stanton *et al.*, 1966; Johnson, 1968).

Rachie (1979) expressed the need to improve the production of bambaranuts to match that of groundnuts because of the crop's importance amongst the rural poor. One method of achieving high yields in bambaranuts is to increase plant density up to a certain optimum (Doku, 1976). A lot of variation occurs in sowing densities. The average sowing rates for bambaranuts are 35 kg ha^{-1} (46 666 plants ha^{-1}) in Tanzania; 25-45 kg ha^{-1} (33 333 - 60 000 plants ha^{-1}) in Kenya; 50-60 kg ha^{-1} (66 666 - 80 000 plants ha^{-1}) in South Africa and 60-75 kg ha^{-1} (80 000 - 100 000 plants ha^{-1}) in Nigeria (Stanton *et al.* 1966). Similary, the number of plants per square metre can vary between 6.3 and 29 (Stanton *et al.*, 1966; Linnemann and Azam Ali 1993). Recent research indicates that denser plantings are required to maximise the amount of radiation intercepted by the crop and consequently produce more photosynthates necessary for seed dry matter (Karim, 1990), cited by Linnemann and Azam Ali (1993).

A lot of variation also occurs in the type of seedbed used. Some farmers plant on flat-beds while others plant on ridges and mounds (Johnson, 1968). Available literature shows that present knowledge on the effects of type of seedbed on the yield of bambaranuts in Tanzania is scarce. Scanty evidence indicates that there are no significant differences between ridge and flat bed planting (Tanzania: Ministry of Agriculture, 1970). However, low yields have also been reported on ridge planting especially on freely drained light textured soils (Stanton et *al.*, 1966). One aspect included by the researcher in the investigation is to plant in furrows.

There is need to establish the best treatment combination between type of seedbed and the optimum plant density in order to increase bambaranut yields. The purpose of this investigation, therefore, is to determine the effects of plant density and type of seedbed on the growth and grain yield of bambaranuts. This study is intended to achieve the following specific objectives:

a) Evaluate the effects of plant density on the growth and grain yield of bambaranuts and establish the optimum plant density for maximum grain yield.

b) Determine the effects of type of seedbed on growth and grain yield of bambaranuts.

2.0 LITERATURE REVIEW

2.1 Origins and spread of bambaranut

The name bambaranut traces its origins from Bambara district, near Timbuktu in Mali (Burkhil, 1906; Hepper, 1970). Bambaranut originated from Nigeria where wild forms are known to exist (Hepper, 1963; Ezedinma and Maneke 1985). Bambaranuts feature prominently in the traditional cropping system of the savanna marginal forest zones of Nigeria. From Nigeria, bambaranuts spread throughout West Africa and at present they are found throughout tropical Africa as well as Malagasy, India, Mauritius, Sri Lanka, Indonesia, the Phillipines, Malaysia, Iowa USA, New Caledonia, Northern Australia, Tropical Central America, Surinum and Brazil (Duke et *al.*, 1977).

The exact year when bambaranuts were introduced into East Africa is unknown but Sturdy (1939) and Lunan (1950) referred to bambaranut as a crop included in the rotation system and food among the Wasukuma and Afipa in Tanzania. Trade in bambaranuts was also reported in Zanzibar as early as 1892 (Burkhil, 1906). Symth (1968a) referred to bambaranuts as being part of the farming system in the Western Lake region of Tanzania on the highly infertile Rweya grassland soils.

2.2 Botany and morphology

Bambaranuts belong to the family Fabaceae, sub-family Papilionoideae. Bambaranut is very similar to groundnuts although botanically they are not closely related. Both have upright bushy and trailing forms and both are cultivated for subterranean pods. Bambaranut leaves are trifoliate, borne on an elongated petiole produced at the nodes of prostrate stems. Germination is hypogeal and takes 7-15 days. The bambaranut plant is indeterminate and grows up to 30 cm in height. Flowers are borne in pairs on peduncles which lengthen after fertilization bringing the ovary underground. Flowering starts 30-55 days after sowing (DAS) and may continue until the end of the life of the plant. Plants mature between 140-170 DAS depending on variety (Stanton *et al.*, 1966). The number of seeds per ovary is usually single although depending on fertility of the soil two seeds may be produced.

2.3 Ecology

Bambaranuts tolerate harsh conditions of moisture stress better than groundnuts (Karim, 1990), cited by Linnemann and Azam-Ali (1993). Bambaranuts have been known to produce a small crop in areas receiving 600-750 mm of rain annually (Stanton *et al.*, 1966; Vietmeyer, 1979; Wrigley, 1981; Linnemann, 1987). However, for optimum yield, bambaranuts require an annual rainfall of 900-1200 mm. The bambaranut is, therefore, a legume particularly suited for hot, dry regions (Vietmeyer, 1978). Experimental evidence has also shown that bambaranuts can tolerate heavy rainfall, except at maturity (Hepper, 1970; Duke *et al.*, 1977;). In a trial with four moisture stress treatment regimes: 30% available moisture (% AM), 40% AM, 50% AM and 75% AM with field capacity at 100%, Ameyaw and Doku (1983) found no significant differences, between treatments, on the number of flower buds and flowers. Significant differences were, however, found in terms of grain yield with 40% AM giving the highest and 75% AM the lowest.

Bambaranut is adapted to poor wornout soils (Hepper, 1963; Stanton *et al.*, 1966; Johnson, 1968; Rachie and Roberts, 1974).Bambaranuts grow on any free-draining soils but prefer soils which are predominately light sandy loams rich in organic matter with a pH range of between 5.0 and 6.5 (Johnson, 1968; Wrigley, 1981). Calcareous and soils high in nitrogen are unsuitable but those rich in phosphorus and potassium are often found beneficial (HeXpper, 1970).

The crop is usually cultivated at altitudes of up to 1600 m above sea level (Savile and Wright, 1958; Hepper, 1970; Duke *et al.*, 1977) and is more suited to day temperatures ranging from 20-28^{0}C (Doku, 1969; Duke *et al.*, 1977; Wrigley, 1981`). Bambaranut is typically a short day plant and requires a frost free period of $3^1/_2$ months (Johnson, 1968; Duke *et al.*, 1977; Linnemann, 1987).

2.4 Economic importance and uses of bambaranut

Bambaranut is regarded as an insurance or security crop in the semi-arid tropics (SAT). The crop is mainly planted on small farms in Africa and production is very low averaging 650-850 kg ha^{-1} (Stanton *et al.*, 1966). World production was estimated at 330 000 tons annually in 1982 with about half from West Africa (Linnemann, 1994). The crop ranks third among the pulses after groundnuts and cowpeas (Rachie and Roberts, 1974). According to a study carried out by the United Nations Centre for Trade and Development (UNCTAD/GATT) in 1982 demand for bambaranuts in West Africa exceeded supply (Linnemann, 1994).

The generic name *Voandzeia* was derived from a Malagasy term `voanjo' meaning seed which satisfies (Stanton *et al.*, 1966; Doku and Karikari, 1971). Ballard, a pharmacist of the French colonial armies referred to bambaranuts as one of the rare examples which nature gives as a complete food (Burkhil, 1906). Bambaranuts are, therefore, eaten in a variety of ways ranging from freshly cooked pods, cooked dry grain, "coffee" drink to bam corn, a mixture of bambaranut flour and corn (Lartey, 1976b). Large scale canning has been reported in Zimbabwe and Ghana (Johnson, 1968; Lartey, 1976a).

Duke *et al.* (1977) reported oil extraction by the Azande of Congo. The tops have been used as feed for livestock (Holm and Marloth, 1940 ; Duke *et al.*, 1977). Furthermore, bambaranuts have been used as a protein source in pig and poultry ration (Uwaegbute,1977).

2.5 Cultivars

Due to its wide geographic distribution in Africa, a wide genetic variability in cultivars (landraces) occurs. Most of the cultivars existing today have arisen by casual selection in the course of cultivation and people's migration and are very local in their distribution (Johnson, 1968; Hepper, 1970). Numerous cultivars have been identified in terms of the colour of the seed (Holm and Marloth, 1940; Johnson, 1968; Hepper, 1970), growth habit (early, medium and late maturing), colour of flowers (yellow, green or orange), pod size, pod thickness, pod surface, pod colour as well as number of seeds per pod. On the basis of seed colour alone, for instance, Holm and Marloth (1940) listed five cultivars grown in South Africa, while Johnson (1968) identified seven such cultivars grown in Zimbabwe.

In Tanzania initial selection of landraces was also based on colour of the testa, eye colour and place of origin (Symth, 1968b). Some of the landraces grown in Tanzania like the red coloured BA/48/1, the cream red-eyed Mwanza, the cream `none-eyed' BA/2 and the cream `black-eyed' Mpwapwa were identified at Ukiriguru in 1968/69 season (Tanzania: Ministry of Agriculture, 1970).

Although bambaranuts can be found in vastly different environments in Africa, there are indications that individual cultivars are not in themselves very adaptable (Rachie, 1979; Temu, 1994). High yielding types from one location may fail when grown elsewhere. For example, Tanzanian cultivars have yielded poorly in Zambia (Rachie, 1979). Some cultivars from North West Tanzania have proved unsatisfactory in the drier climate and different soils of Central Tanzania (Kinyawa, 1969; Rachie, 1979).

2.6 Agronomy of bambaranuts

Bambaranuts grow well where the soil is deep ploughed and the seedbed reduced to a fine, friable tilth which is conducive to plants burying the pods (Johnson, 1968). If ridging equipment is available (Johnson, 1968) recommended flat topped ridges especially where the soil is susceptible to water-logging or is shallow.

Planting on the ridge depends on the nature of the soil and the risk of erosion. Date of sowing is very critical for optimum yields. Under rainfed conditions, sowing with the first effective rains is recommended (Holm and Marloth, 1940). Sowing depth depends on the soil type. Sowing 2.5 cm deep on heavy soils and 5-7.5 cm on light soils enhances seed emergence (Stanton *et al.*, 1966; Johnson, 1968; Doku and Karikari, 1971). Under wet conditions shallow sowing has also been reported to enhance earlier seed emergence (Stanton *et al.*, 1966). Bambaranut is planted under different cultural systems. Bambaranuts have been reported to be planted in pure stand or as an intercrop with cereals, root crops and other legumes (Doku and Karikari, 1971). This practice, however, is not advised where rotation follows a nematode susceptible crop (Johnson, 1968).

Planting in the row at high population density facilitates weeding and is essential for high yields. It is important to begin controlling weeds when the crop is about 10 cm high (Holm and Marloth, 1940; Johnson, 1968). For successful podding, the crop is earthed-up or banked at first flowering so that the developing pods are covered. Ridging close to the plant is not recommended in order to prevent damaging the pegs. When pods are ready, timeliness in harvesting has been reported to be less important than in groundnuts, as bambaranut seed remain dormant for a long time and there is little risk for seeds germinating before harvesting except in areas of high rainfall (Chavula, 1991).

While bambaranuts may appear to give good yields on land too poor for most other crops, it should not be implied that this crop is best adapted to relatively infertile soils. This fact merely emphasizes the need for a careful programme of fertilization and management to maintain a high level of production of bambaranuts and other crops grown in rotation (Doku and Karikari, 1971).

Information on fertilizer application is sparse and where available it is inconsistent. According to Stanton *et al.*, (1966) the application of 60 kg ha^{-1} superphosphate followed by a top dressing of 40 kg ha^{-1} sulphate of ammonia was found beneficial. However, according to trials in Malawi, Nigeria and Swaziland, there appears to have been no beneficial responses to single superphosphate at rates of up to 336 kg ha^{-1} and in Malawi yields actually decreased. Potassium at the rate of 35 kg ha^{-1} has been reported to increase yields in Swaziland while liming increased yields in Zaire (Linnemann, 1987).

2.7 Bambaranut diseases and pests

The notion that bambaranuts are free from disease has no scientific explanation (Stanton *et al.*, 1966; Rachie, 1979). Research indicates that the crop is affected by a number of diseases and pests. According to Duke *et al.*, (1977) leaf diseases affecting bambaranuts include *Ascochyta phaseolorum* which causes leaf blight, *Cercospora canescens* and *C. voandzeia* which cause leaf spots and *Sphaerotheca voandzeia* (powdery mildew). Roots have been reported to be affected by *Rhizoctonia solani* (causes the destruction of above ground parts especially during the wet season), *Phaseolus manihotis* (infects the underground parts with its white mycelium). Bambaranuts are also prone to viral diseases like alfalfa mosaic (AM), alsike clover mosaic (ACM), bean chlorotic ring spot (BCRS), bean local chlorosis (BLC), bean mosaic (BM), bean necrosis (BN) and white clover mosaic (WCM). Although bambaranuts are infected by nematodes such as *Heterodera marioni* and *Meloidogyne javanica*, they are relatively free from storage pests (Duke *et al.*, (1977). However, shelled bambaranuts have been reported to be susceptible to attack by bruchids, *Callesobruchus maculatus* (F) and *C. subinotatus* (Pic) (Amuti and Larbi, 1981).

2.8 Crop productivity and plant density

Low grain yields in bambaranuts have been attributed to low plant density and late planting (Johnson, 1968). A lot of variation also exists in plant densities. Generally, seed rates vary from 25-

75 kg ha^{-1}, with interrow and intrarow spacing varying from 30-75 cm and 10-50 cm, respectively (Duke *et al.*, 1977). In South Africa, Holm and Marloth (1940) showed that high yields were obtained from rows 75 cm apart with seeds spaced 10-15 cm within the row. High yields were also realized from rows spaced 30 cm apart with an interrow spacing of 15 cm (Nabos, 1970). In Ghana narrower row spacings of 20 cm with plants spaced 4 cm apart within the row produced 2000 kg dry seed ha^{-1} (Doku, 1976).

Spacing in bambaranuts also varies with respect to the cropping system. Bambaranuts may be planted as a mixed crop with cereals at the spacing of 100 - 200 cm and as a sole crop at 15 x 30, 25 x 30, 20 x 50, and 40 x 40 cm (Rachie and Silvestre, 1977), cited by Linnemann (1992). In the highly leached soils of Bukoba in North western Tanzania, bambaranuts were reported to be sown at an average spacing of 30 x 30 cm (Dunbar,1969). Ameyaw and Doku (1983), while working on an experiment on moisture requirements, recommended a spacing of 30 cm between rows and 6 cm between plants on the row. In an experiment on the effect of fertilizer, seedrate and spacing of bambaranuts in Swaziland, Cumberland (1978), reported no significant differences in yield between seedrate of 50, 75 and 100 kg ha^{-1}. However, double rows spaced a metre apart resulted into significantly ($p < 0.01$) higher yields than rows at 50 cm apart. In Mokwa, Nigeria row spacing of 75 cm gave higher yields tha 37.5 cm and the increase in seed yield amounted to 93 % more than at 37.5 cm spacing (Goli and Ng, 1987), cited by Linnemann (1992).

There appears to be differences in the reaction of bambaranuts to population density from area to area. At Chitala in Malawi a density of 167 440 plants ha^{-1} gave the highest yields while in Thuchila (Malawi) this was reached by a lower density of 83 720 plants ha^{-1} (Malawi; Agriculture Research Council, 1972, 1975), cited by Linnemann (1992). Under conditions of moisture stress high plant population density has been reported to depress yields. In fertilizer versus plant population study in Zimbabwe overall yields were low (about 1 ton ha^{-1}) with plants frequently showing moisture stress symptoms. Under such conditions neither population density, which varied between 148 000 and 296 000 plants ha^{-1} nor fertilizer (single super phosphate) resulted in significance differences (Metelerkamp,1988). In another fertilizer, spacing and population trial in Swaziland unshelled yields of bambaranuts were lowest from single rows one metre apart (962 kg ha^{-1}) followed by double rows one metre apart (1113 kg ha^{-1}) and 50 cm rows (1316 kg ha^{-1}) gave the highest yield (Swaziland; Ministry of Agriculture, 1979). In an experiment on planting date and four intra-row spacings (5,10,15 and 20 cm), conducted in Nigeria (Tanimu and Yayock, 1989) the highest yields were obtained at 5 cm spacing at a density of 240 000 plants ha^{-1}. A cream selection of bambaranuts was planted in Zimbabwe at four inter-row spacings and five fertilizer levels. It was reported that population and fertilizer main effect were non significant on the number of pods and kernels per plant^{-1}, shelling percentage and yield (Zimbabwe Government, 1985). Elia (1985), working on an experiment on variability for yield reported that at a population density of 220 000 plants ha^{-1}, bambaranut yields varied from 3.1 to 8.5 g per plant^{-1}. On the other hand, Ezedinma and Maneke (1985), reported substantially higher bambaranut yields ranging from 5.3 to 40.7 g plant^{-1} for bambaranuts planted at a density of 40 000 plants ha^{-1}.

In other crops, Shear and Miller (1960) observed that jumbo runner groundnuts planted at variable spacings as close as 15.24 cm resulted into higher yields as the space between plants decreased while fruit development was reduced. In a study on the effect of plant density on the yield of four Malawian groundnut varieties, pod number per plant was inversely proportional to plant density while kernel weight and shelling percentage were lower at reduced plant densities and kernel size declined at very high plant densities (Lawrence, 1974). He concluded that in general, higher densities were superior in terms of shelling quality than lower densities. Increases in pod yield, haulm production and shelling percentage with increase in plant density up to 17 200 plants ha^{-1} have also been reported (Tanimu and Yayock, 1990). Lawrence (1983) showed that as groundnut plant density increased from 0.06 to 12 plants m^{-2}, pod and kernel yield rose from 2.1 to 5 tons ha^{-1}

while the mean kernel weight decreased. Tolerance to spacing is dependant on the type of the variety. Generally, long season varieties of groundnuts have been found to be more tolerant to spacing than short season upright bunch varieties (Preston *et al.*, 1986).

Sibuga *et al.* (1992) reported that high population densities are not required for spreading varieties of groundnuts, while upright bunch varieties need higher plant densities. This is in agreement with Nyirenda *et al.* (1992) who reported no significant differences in yield for the Malawian spreading variety `Chalimbana' using one or two seeds per hill. Although yield increases of 14-26% were obtained through closer ridge spacing and increase in plant density (Maliro, 1988), groundnuts tend to produce fewer pods per plant as plant density increases (Eliesen and Freira, 1992).

2.9 Crop productivity and type of seedbed

Seedbed refers to a piece of land which has been tilled for sowing. Tillage is a physical, chemical or biological soil manipulation so as to provide favourable conditions for sowing, seed emergence and crop establishment (Lal, 1973). Short term objectives of tillage and hence types of seedbed are the optimization of soil temperature and moisture conditions, to minimise weed competition and to stimulate root system proliferation. Seedbed types commonly used in Africa are flat, ridges, furrows and mounds (Lunan, 1950; Lal, 1973; Lawrence, 1974; Nangju, 1979). The type of seedbed used is largely influenced by the type of soil and method of lifting. Planting groundnuts on the ridge is recommended on clay soil to facilitate lifting (Weiss, 1983). Nangju (1979) reported that ridges of various shapes and sizes are commonly used in Africa. Furrow seedbed is accomplished by raising the soil into ridges and the crops are planted in the furrow between the two adjacent ridges (Lal, 1973).

A piece of land which has been ploughed, harrowed and ready for planting is referred to as flat seedbed or conventional tillage (Nangju, 1979). Flat seedbed has been reported to be susceptible to crusting after the rains (Taylor, 1974). Crusting often leads to crop lodging, water runoff and soil erosion. Flat seedbed has, however, been reported to be less susceptible to fluctuations in soil temperature than ridges (Lal, 1974).

Information on types of seedbed on bambaranuts is scanty. In a field study report in Nigeria and Zambia, it was reported that most of bambaranut sowing was done on the flat (Linnemann, 1988, 1990).In an experiment on the effect of planting on the ridge or flat on the yield of bambaranut at Ukiriguru it was reported that, although yields were very poor in the first year (132 kg ha^{-1}) due to late planting, there were no significant differences between any of the treatment combinations (Tanzania: Ministry of Agriculture, 1970). In a similar trial conducted in Zambia to compare planting on the flat versus planting on the ridge, planting on the flat (30 x 30 cm) yielded 299 kg ha^{-1} while planting on ridges (60 x 15 cm) yielded 120 kg ha^{-1} (Kannaiyan, 1988, cited by Linnemann (1992)). In the same trial planting on the flat (30 x 30 cm) without earthing up compared with planting on the flat in pairs of rows without earthing up and planting on raised beds in pairs of rows without earthing up resulted in no significance differences in yields.

In a groundnut experiment planted on the flat, ridge, and furrow over a period of two years Rweyemamu and Boma (1990) reported that seedbed types influenced yield component. Under conditions of moisture stress the number of pods and grain yield $plant^{-1}$ were highest in either furrow or flat. During the season when rainfall was not limiting, furrows recorded the lowest seed yield ha^{-1} because of low plant density caused by heavy rains during seedling emergence. The number of pods and seed yield $plant^{-1}$ were lowest for groundnuts planted on the ridge.

In another experiment, Nangju (1979) showed that yield of cowpeas and soyabeans grown on the ridge or flat fluctuated from year to year depending on moisture pattern during planting, seedling emergence and crop growth. Generally, ridges had higher temperature and lower soil moisture than the flat seedbed. These factors caused a large reduction in seedling emergence, above ground dry matter and grain yield in seasons of low or irregular rainfall.

In a soyabean and cowpea experiment, Lal (1979) showed that leaf area index, plant height and grain yield were affected by different methods of mulching and seedbed preparation. Leaf number, leaf area, leaf area index and plant height was higher for the crop planted on the ridge than on the flat. Grain yield was, however, lowest for the crop planted on the ridge. Tully et al. (1986) reported reduced grain yield plant^{-1} for soyabeans planted on the ridge. He attributed this to desiccation which lead to a rapid temperature increase and a decrease in soil moisture. Planting bambaranuts on ridges has been reported to enhance kernel yield but causes a reduction in population density (Bond, 1966; Purseglove, 1974).

Planting in furrows is rarely practiced but the method is useful under conditions of extreme moisture stress. The method has, however, been used in groundnuts (Singh and Oswalt, 1991) and the main purpose is to enable plants tap and utilize infiltrated water harvested from the sides of the ridges and from the lower horizons along furrows. Furrows have been reported to serve as micro-watershed (Weiss, 1983). In Nigeria, planting maize (*Zea mays* (L).) in the furrow under conditions of moisture stress enhanced crop yield (Lal, 1973). Maize planted in the furrow outyielded the crop grown on the ridge, flat and mound. Furrow method is adaptable to both traditional and mechanised farming. Rawitz *et al.* (1983), reported that furrow seedbed ensures success in most crops where rainfall is erratic. In Tanzania groundnuts have been reported to be grown in the furrow when intercropped with maize or sorghum *Sorghum bicolor* (L).) Moench) in the drier central region. This is a common practice in Dodoma, Tabora and Singida (Sibuga, K.P. personal communication, 1995).

3.0 MATERIALS AND METHODS

3.1 Location and layout of the experiment

Field experiments were conducted at Sokoine University of Agriculture Crop Museum situated at latitude 6^0 45" South and longitude 37^0 40" East in Morogoro region (525 m.a.s.l.), Tanzania. Sokoine University of Agriculture (SUA) is situated on the leeward side of Uruguru Mountains (2653 m.a.s.l.). Sokoine University of Agriculture is in a typical rainshadow area and receives mean annual rainfall of between 600 and 800 mm per year (Masseri and Jana, 1979).

Morogoro experiences bimodal rainfall with short intermittent rains falling between October and January (R_S) and long rains between March and May (R_L). The experiment first conducted during the 1994-95 short rain season was repeated in the following long rain season(February to June,1995). Due to the irregular nature of the short rains supplemental irrigation was used to sustain crop growth during this season. A summary of climatic data collected during the study period is given in Appendix I.

The experiment was laid out in a reverted piece of land which had not been used since 1991. Itchgrass (*Rottboellia cochinchinensis* (Lour) (Clayton), sensitive plant (*Mimosa pudica*), wild sorghum (*Sorghum halepense*) and mixed sedges (*Cyperus spp*) were the predominant weeds at the time of land clearing and continued throughout the growing season. Land was disc - ploughed and harrowed. Thirty six soil samples were collected, one from each plot from 0-20 cm depth . The samples were mixed and a single composite sample (FLM_S) obtained for analysis of the physical and chemical characteristics as summarized in Table 1 . The same procedure was followed in the second experiment during the long rain season to produce composite sample (FLM_L) .

Table 1. Soil Analysis

Sample	Available P Mg P/kg PPM	pH H_2O 1:2.5	Total N %	Organic carbon %	Organic matter %	C:N Ratio	TEXTURE			Class	Me/100g Soil	
							Sand %	Silt %	Clay		K^+	Ca^{++}
FLM_S	7.72	6.70	0.15	1.69	2.61	11.51	70.40	6.40	23.20	Sand clay loam	0.974	3.78
FLM_L	4.91	5.30	0.14	1.92	3.29	14.21	32.00	17.20	50.80	Clay loam	1.64	2.26

FLM_S : Short rain season

FLM_L : Long rain season

• Analysis was done in the laboratories of the Department of Soil Science, Sokoine University of Agriculture.

The experimental design was a split-plot in a randomized complete block design with three replications. The main plot (factor A) was made up of three types of seedbed (S_1 - flat as presented in Fig. 1A, S_2 - ridge as presented in Fig. 1B, S_3 - furrow as presented in Fig. 1C). The sub-plot factor B was achieved by maintaining a constant inter-row spacing of 30 cm and varying the intra-row spacing by 10 cm from 35, 25, 15 and 5 cm designated as T_1, T_2, T_3, and T_4 to give plant populations of 94 444, 133 333, 222 222 and 666 666 ha^{-1}, respectively. Plots were 3x3 metres consisting of 10 rows labelled 1-10 (Table 3).

Seeds were bought from an open market at Dodoma in Central Tanzania. The seed was a mixture of different types of landraces as summarized on bambaranut germplasm collection data sheet Appendix II and on Plate 1. Cream landrace was selected for planting because it formed about half of the total germplasm. Plots were sown on 8 November, 1994 (R_S) and 3 March, 1995 (R_L). Two seeds were planted per station at a depth of 4-5 cm. Emergence counts started 5 days after sowing (DAS) and continued until 16 DAS. A seed was considered to have emerged if the plumule broke through the surface of the soil (Temu, 1994). Bambaranuts display hypogeal germination with cotyledons remaining under-ground. Seedlings were thinned to one seed per station at 27 DAS for both R_S and R_L sowings. Thinning was delayed for 9 days after the last emergence count because of weeding following a high emergence rate of sedges. During this operation some plants were accidentally lost. After the weeding operation, bambaranuts were given sufficient time to re-establish in order to determine te weak plants which were later thinned out. Prior to sowing, triple superphosphate was broadcast over each treatment at the rate of 220 kg P_2O_5 ha^{-1} and then incorporated into the soil by a hoe.

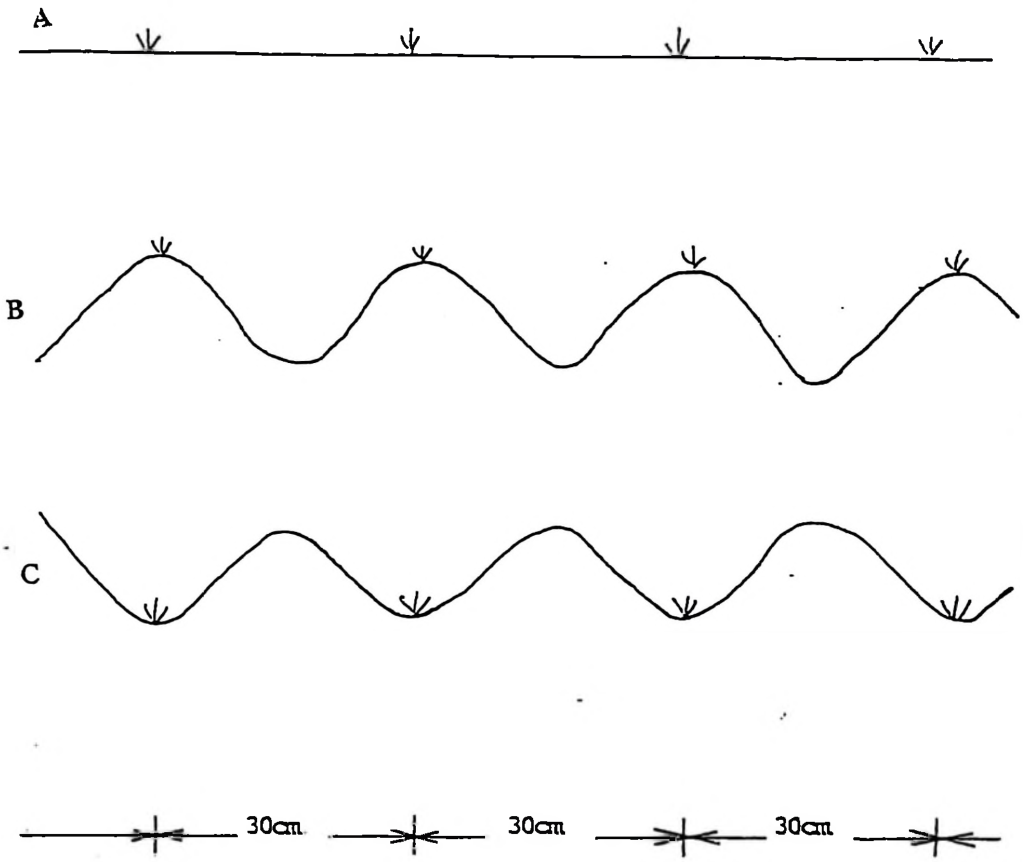

Fig. 1: Diagramatic representation of types of seedbed

A = Bambaranuts planted on the flat

B = Bambaranuts planted on the ridge

C = Bambaranuts planted in the furrow

Plate 1: Variability in seed colour of the seed sample

Table 2.Details of population density and types of seedbed treatments.

Treatment	Description
Main plots	
S_1	Flat bed
S_2	Ridge
S_3	Furrow

Sub plots	Plants ha^{-1}	Number of plants M^{-2}
T_1 = (35x30 cm)	94 444	9
T_2 = (25x30 cm)	133 333	13
T_3 = (15x30 cm)	222 222	22
T_4 = (5x30 cm)	666 666	66

Plots were maintained weedfree by periodic hand weeding at two week intervals. The two-week weeding interval was necessary because of the rate at which weeds were growing. This frequency may not, however, be practical for a farmer who has a large acreage of the crop due to priorities in labour allocation. Plots were earthed-up 57 DAS, 10 days after the first flowers were noticed.

Each sub plot had 10 rows; 2 border rows, 4 rows used for destructive growth measurements while the two centre rows were used for final harvest (Table 3). Twenty four plants were randomly marked in each subplot and used for growth analysis. Three plants in each plot were uprooted every 14 days from 21 to 119 DAS and the following measurements were taken: plant height, number of leaves, number of flowers, number of pegs, number of pods per plant, presence or absence of nodules, leaf area, leaf dry matter, pod dry matter, stem and root dry matter.

Ten plants from the harvest area were also randomly marked 1-10. At harvest the following measurements were taken from the 10 plants: number of leaves, plant height, number of pegs, number of pods, weight of leaf, dry weight of stem, oven dry weight of pods, kernel dry weight.

3.2 Sequential growth measurements

During the period of growth the following agronomic yield components were measured from 3 uprooted plants from each subplot at 21, 35, 49, 63, 77, 91, 105 and 119 DAS.

3.2.1 Plant height

This was measured by a ruler from the crown to the tip of the longest leaf and recorded in cm.

3.2.2 Number of leaves per plant

Obtained by counting the number of fully opened trifoliate leaves.

Table 3. Details of individual treatment layout

	1 - outer border row
	2 - Plants used for destructive measurements
	3 - Plants used for destructive measurements
	4 - Inner border row
	5 - Final harvest area
	6 - Final harvest area
	7 - Inner border row
	8 - Plants used for destructive measurements
	9 - Plants used for destructive measurements
	10- Outer border row

3.2.3 Presence or absence of nodules

Determined by the presence or absence of small round regular swellings on roots and root hairs.

3.2.4 Number of days to beginning of flowering

These were the number of days the plants took to the appearance of the first flowers. This was determined by observation.

3.2.5 Number of flowers

Flowers were removed from the peduncles of plants used for growth analysis and were counted. Flower counts started 49 DAS.

3.2.6 Number of days to 50% flowering

This was the number of days from one DAS to the time when half the total number of plants in each plot had flowered. This was determined by observation.

3.2.7 Number of pegs and pods

Pegs were identified as lengthened peduncles at the base of petioles. Peduncles lengthen after pollination and fertilization to drive the ovaries (pods) under ground. Pegs and pods were removed from the uprooted plants and counted.

3.2.8 Leaf area

Leaf area was estimated by using a graph paper. A sample of 18 plants was randomly selected from among the plants uprooted for growth analysis from randomly chosen plots in each treatment (1, 12, 21, 22, 30 and 35) at 21, 35, 49, 63, 77, 91, 105 and 119 DAS. A sub-sample of 6 plants was then selected from the 18 plants. Each fully opened trifoliate leaf from the sub-sample was traced on graph paper and the area determined as per leaf weighing method (Rhoads and Bloodworth, 1964) outlined in Appendix III. Leaf area was recorded as cm^2/plant.

3.2.9 Leaf dry matter

All leaf blades were removed from the uprooted plants from each treatment at 21, 35, 49, 63, 77, 91, 105 and 119 DAS. The leaves were oven dried to constant weight at 60^0C. Leaves were then weighed and recorded as g/plant.

3.2.10 Stem dry matter

Petioles, prostrate stems, and the crown were all considered part of the stem. These were removed from the plants at 21, 35, 49, 63, 77, 91, 105 and 119 DAS. They were then oven dried to constant weight at 60^0C and then weighed and recorded as g/plant.

3.2.11 Root dry matter

This was determined from parts of the plant below the crown. The parts were cut from the stem at 21, 35, 49, 63, 77, 91, 105 and 119 DAS and oven dried to constant weight at 60^0C and recorded as g/plant.

3.3 Final harvest

At harvest a sample of 10 plants from each sub plot were harvested from the harvest area and the following measurements were taken.

3.3.1 Number of leaves and leaf dry matter (DM)

Living leaves were removed, counted, oven dried and weighed to constant weight at 60^0C and recorded as g/plant.

3.3.2 Number of pegs and pods

Pegs and pods were removed from the plants and counted.

3.3.3 Dry weight of stems

Dry weight of stems was made of petioles, prostrate stems and the crown. These were oven dried to constant weight at 60^0C and recorded as g/plant.

3.3.4 Dry weight of pods

Pods were removed and oven dried to constant weight at 60^0C and recorded as g/plant.

3.3.5 Kernel dry weight

Pods were shelled and kernels were oven dried to constant weight at 60^0C and recorded as g/plant.

3.3.6 Shelling percentage

Shelling percentage was calculated as kernel weight divided by total weight of pods multiplied by 100.

$$\text{Shelling \%} = \frac{\text{Kernel weight} \times 100}{\text{pod weight}}$$

3.3.7 Harvest index

Harvest index (HI), was computed by dividing the grain yield by biological yield for the respective treatment combinations.

$$\text{HI} = \frac{\text{Economic yield (grain yield)}}{\text{Total biological yield}}$$

Biological yield was made of all above ground parts and converted into kg ha^{-1} while grains were for economic yield.

3.4 Data analysis

Data was analysed using the MSTAT-C computer programme (Michigan State University, 1990). The data was also subjected to linear regression analysis as described by Gomez and Gomez (1984) to estimate linear correlation for the various parameters. Mean separation was performed using Duncan's Multiple Range Test (DMRT) to detect differences between treatment means. Graphs were drawn using Quartro Programme.

4.0 RESULTS

4.1 Plant development

4.1.1 Climatic information

During the short rain season the trial received intermittent rain (Appendix I) in the months of November and December, 1994. The moisture supplied by the rains was not sufficient to support the crop and supplemental irrigation was used when plants showed signs of wilting at noon to bring the soil moisture to field capacity. On average, there was one such watering for every seven days. Total pan evaporation, sunshine hours, temperature and mean radiation were high between the months of November, 1994 to January, 1995. Mean RH values for the same period were lower compared to the long rain season crop - March to June, 1995.

During the long rain season, rainfall amounts were fairly adequate. The rate of pan evaporation was highest in April followed by March. The months of May and June experienced fairly low pan evaporation values. Temperatures were 2^0C to 3^0C lower than those experienced by the short rain season crop. Sunshine hours were lower than for the short season crop with the month of May experiencing the lowest number of sunshine hours. Generally, RH values were lower than for the short rain season crop with June recording the lowest value. Mean radiation (MJ M^{-2}) was generally, lower for the long rain than for the short rain season crop.

The soil at the site of the experiment was an oxisol. Soil characteristics at planting are shown in Table 1.

4.1.2 Seedling emergence

Emergence percentage for the short rain season is summarized in Fig. 2. Differences in emergence percentage were significant ($P \leq 0.05$) for seed-bed type from 6-10 DAS. Bambaranuts planted on ridges were the slowest, to emerge. Bambaranuts planted on the flat had the highest emergence percentage between 8-10 DAS. Thereafter, emergence levels for all seedbed types were similar.

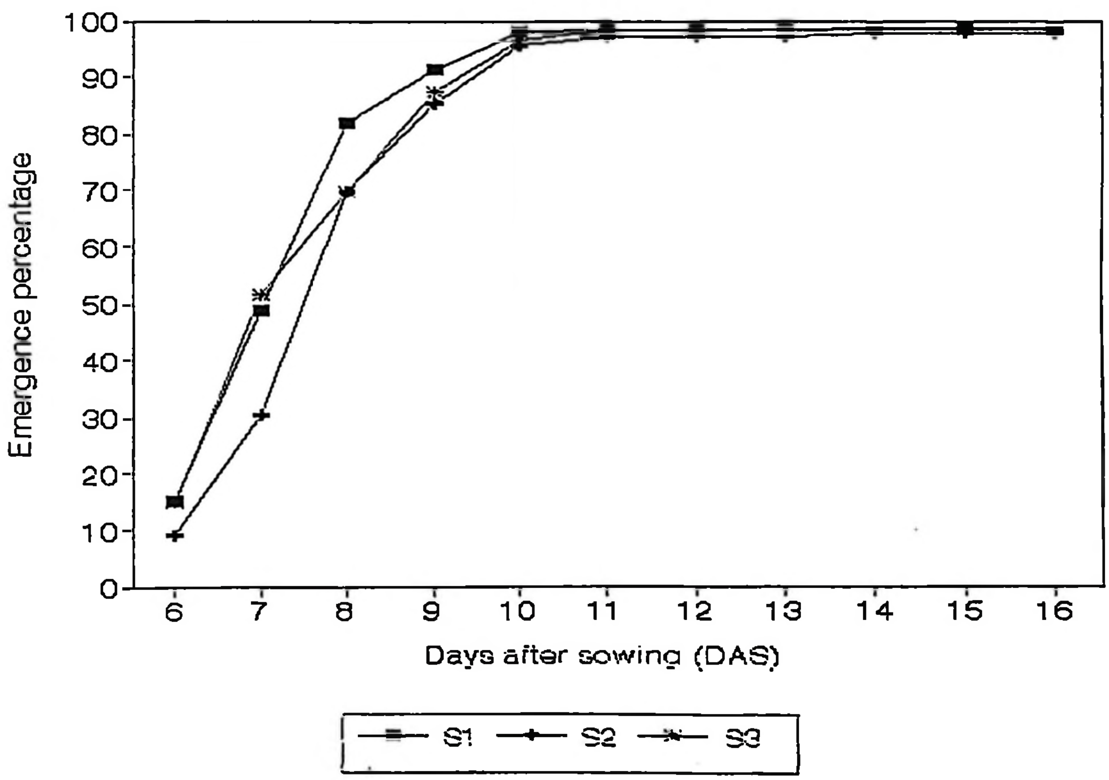

Fig.2 Seed emergence for different types of seedbed during the short rain season: S_1 = Flat, S_2 = Ridge, S_3 = Furrow.

For the long rain season (Fig. 3) differences in emergence percentage from 6-13 DAS were significant ($P \leq 0.05$) for seedbed types. Emergence rates for bambaranuts planted on the ridges were slower than those on furrow or flat. This trend continued up to 13 DAS. Bambaranuts planted in the furrow recorded the highest emergence percentage overall from 10 to 16 DAS.

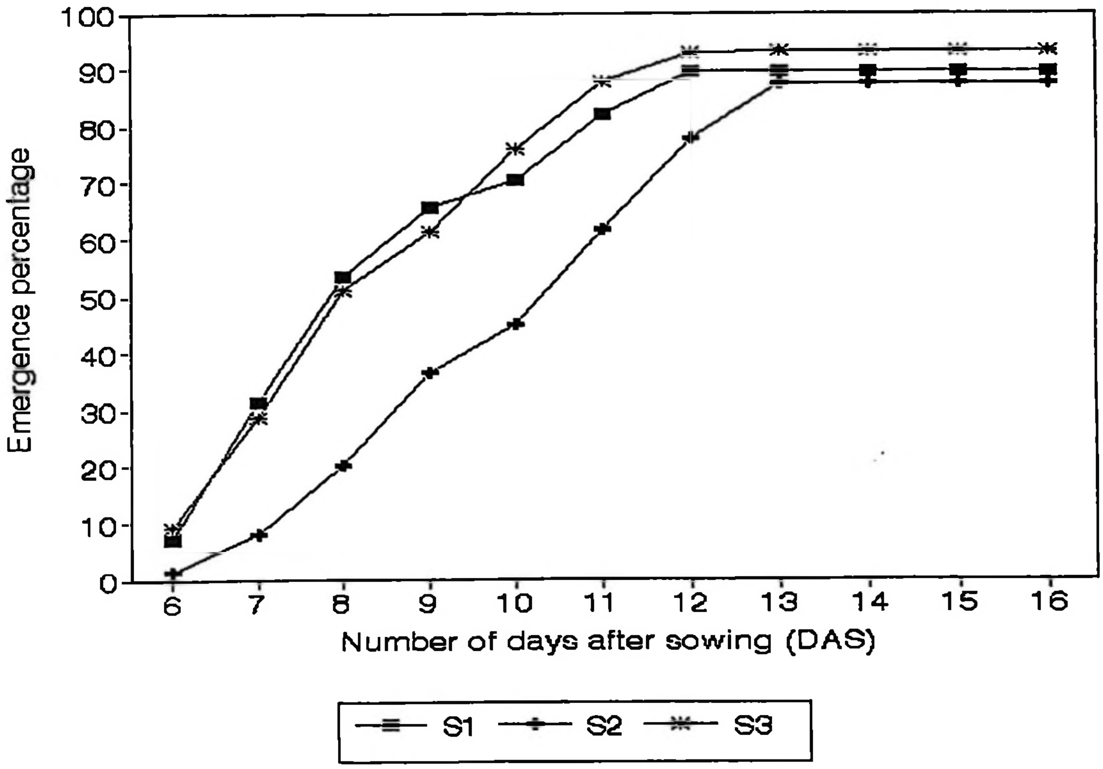

Fig.3 Seed emergence for different types of seedbed during the long rain season: S_1 = Flat, S_2 = Ridge, S_3 = Furrow.

Emergence percentage was also significantly ($P \leq 0.05$) affected by population density (Figs 4 and 5). In both seasons the emergence rates decreased with increase in population density. Emergence rates for the short rain season (Fig. 4) were variable and less even. The highest emergence percentage for the long rain season for each of the population densities was 80% for T_4, 88% for T_3 90% for T_2 and 100% for T_1 at 12 DAS (Fig. 5)

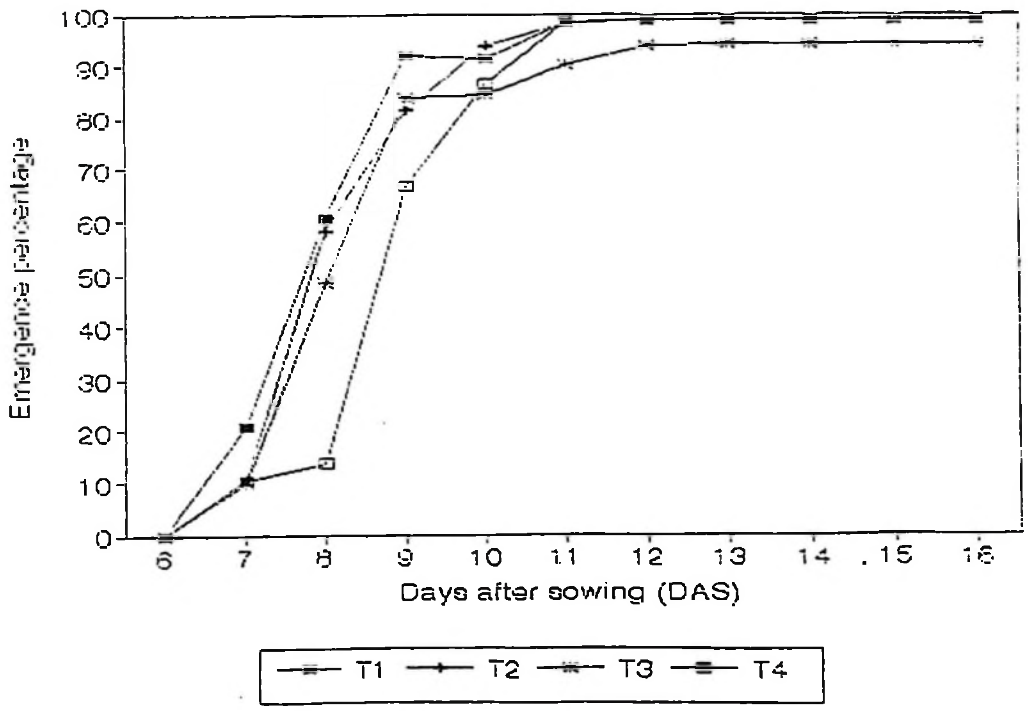

Fig.4 Seed emergence for different population densities during the short rain season: T_1 = 35x30 cm, T_2 = 25x30cm, T_3 = 15x30 cm, T_4 =5x30 cm.

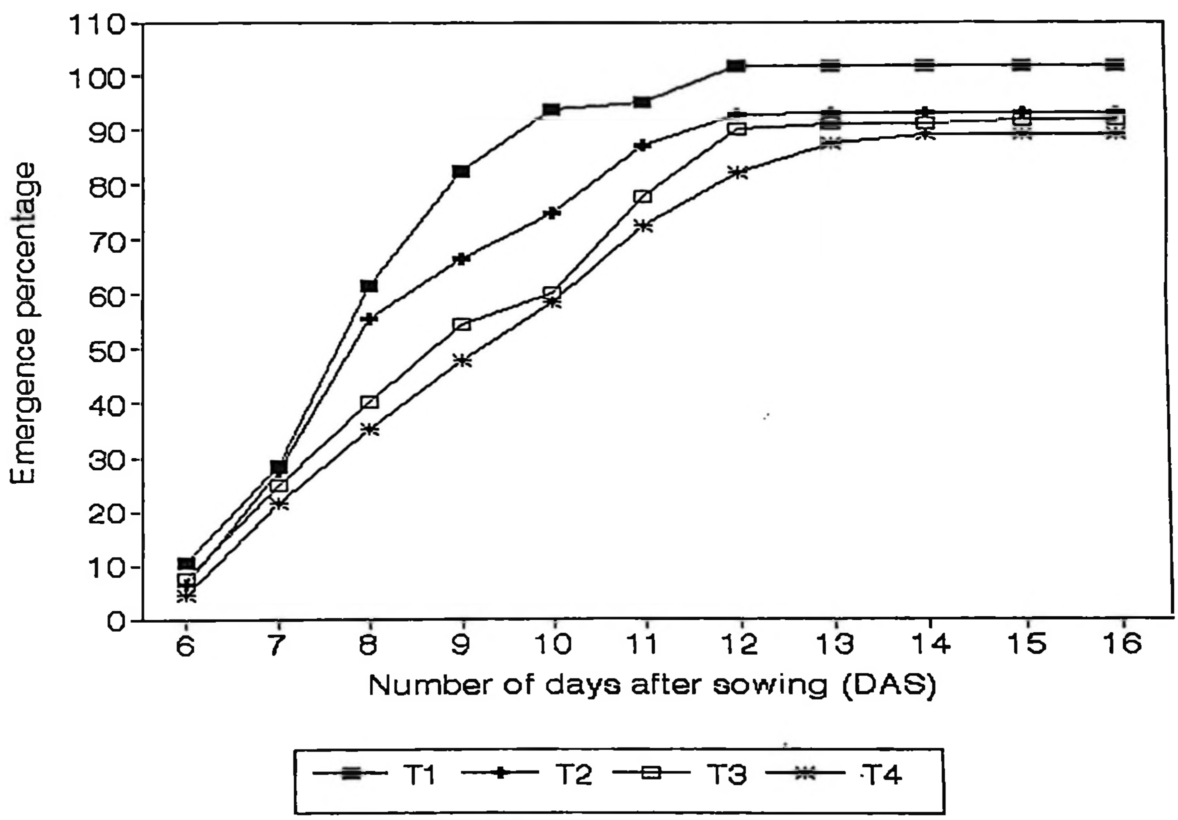

Fig.5 Seed emergence for different population densities during the long rain season: T_1 = 35x30 cm, T_2 = 25x30 cm, T_3 = 15x30 cm, T_4 =5x30 cm.

4.1.3 Plant height

Seedbed type did not affect plant height significantly ($P \leq 0.05$) in either season at 35 and 91 DAS (Tables 4 and 6) although for both periods plants were taller in the short rains than in the long rains. Differences in plant height were however, significant ($P \leq 0.05$) at 63 DAS. Bambaranuts planted on the ridge were taller than those planted on the flat or in the furrow for the short rain season crop. During the long rain season (63 DAS) bambaranuts planted on the flat were taller than either those planted on the ridge or flat (Table 5). The effect of plant density on plant height was not significant ($P \leq 0.05$) for both seasons at 63 and 91 DAS (Tables 5 and 6). Differences were, however, significant ($P \leq 0.05$) at 35 DAS (Table 4) for both seasons. Population density at 66 plants m^{-2} for the short rain season and at 9 plants m^{-2} for the long rain season recorded the tallest plants at 35 DAS (Table 4). The trend was towards taller plants with reduced population density for all types of seedbed x population density combinations for bambaranuts planted on the ridge and furrow during the long rain season with planting in the furrow at 9 plants m^{-2} recording the highest significant interactions.

At 63 DAS (Table 5) planting on the ridge for the short rain season and flat or furrow for the long rain season produced the tallest plants. Planting on the flat (91 DAS) (Table 6) at 13 plants m^{-2} and furrow at 66 plants m^{-2} produced the tallest plants during the long rain season. In general, the short rain season crop was taller than the long rain season crop (Tables 4, 5, 6).

Table 4. Height plant^{-1} (cm) at 35 DAS.

	Plants m^{-2}	Height plant^{-1} (cm) (R_s)					Height plant^{-1} (cm) (R_l)			
		Type of Seedbed					Type of Seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean		Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 = (35x30) cm	(9)	23.2	24.9	22.5	23.6 b[2]		23.3 bc[1]	23.2 bc[1]	26.2 a[1]	24.3 a[2]
T_2 = (25x30) cm	(13)	26.2	25.7	24.7	25.5 ab		22.4 bc	19.7 d	23.5 bc	21.9 b
T_3 = (15x30) cm	(22)	20.9	22.6	26.7	23.4 b		24.8 ab	19.6 d	15.9 e	20.1 c
T_4 = (5x30) cm	(66)	25.5	29.4	26.2	27.0 a		19.5 d	22.6 bc	21.7 cd	21.2 bc
Mean		23.9	25.7	25.0		Mean	22.5	21.3	21.8	

SE: Subplots(S)	= 0.94	SE: Subplots(S)	= 0.49
SE: Mainplots(M)	= 1.10	SE: Mainplots(M)	= 0.80
SE: (MxS)	= 1.62	SE: MxS	= 0.84
CV:	= 11.30%	CV:	= 0.69%

[1,2] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 5. Plant height (cm) at 63 DAS

Plants m^{-2}	Height $plant^{-1}$ (cm)					Height $plant^{-1}$(cm) (R_L)			
	Type of Seedbed					Type of Seedbed			
	Flat S_1	Ridge S_2	Furrow S_3	Mean		Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 = (35x30) cm (9)	32.7	37.1	30.9	33.5		29.1	20.9	26.1	25.4
T_2 = (25x30) cm (13)	32.7	33.5	33.3	33.2		26.0	24.6	27.9	26.2
T_3 = (15x30) cm (22)	31.9	35.7	32.2	33.3		28.1	21.9	26.4	25.5
T_4 = (5x30) cm (66)	32.6	38.2	33.9	34.9		27.4	25.1	26.8	26.5
Mean	32.5 b[3]	36.1 a	32.6 b		Mean	26.7 a[3]	23.1 b	26.8 a	

SE: Subplots(S)	= 0.67	SE: Subplots(S)	= 1.31
SE: Mainplots(M)	= 0.27	SE: Mainplots(M)	= 0.59
SE: (MxS)	= 1.17	SE: MxS	= 2.27
CV:	= 6%	CV:	= 15.19%

[3] Values in the marginal means, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT)

Table 6. Height plant^{-1} (cm) at 91 DAS

	Plants m^{-2}	Height plant^{-1} (cm) (R_5)				Plant height cm (R_1)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 = (35x30) cm	(9)	31.6	31.5	30.5	31.2	27.2 ab[1]	25.9 ab[1]	19.9 c[1]	24.3
T_2 = (25x30) cm	(13)	29.6	30.8	31.7	30.7	28.6 a	23.0 bc	26.0 ab	25.9
T_3 = (15x30) cm	(22)	31.9	30.3	33.2	31.8	26.2 ab	23.8 bc	26.4 ab	25.5
T_4 = (5x30) cm	(66)	30.9	33.2	32.5	32.2	23.3 bc	20.6 c	29.4 a	24.5
Mean		31.0	31.4	32.0		26.3	23.3	25.4	

SE: Subplots (S) = 0.49	SE: Subplots (S) = 0.78
SE: Mainplots (M) = 0.32	SE: Mainplots(M) = 0.75
SE: (MxS) = 0.85	SE: (MxS) = 1.28
CV: = 4.65	CV: = 8.85%

[1] Values in the main table followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.1.4 Leaf area plant^{-1}

In both seasons differences in leaf area plant^{-1} measured at 35 DAS (Table 7) and 63 DAS (Table 8) were significant ($P \leq 0.05$) for seedbed types (except at 35 DAS during the short rain season), plant population and the interaction of the two factors. Except for bambaranuts planted on the ridge in both seasons, leaf area values at 35 DAS were generally higher for the long rain season than the short rain season crop while at 63 DAS the reverse was true.

In the short rain season at both 35 and 63 DAS bambaranuts planted on the ridge (Tables 7 and 8) recorded the highest leaf area plant^{-1} followed by bambaranuts planted on the flat. Population density at 13 plants m^{-2} at 35 DAS and at 9 plants m^{-2} at 63 DAS produced significantly ($P \leq 0.05$) higher leaf area plant^{-1}.

Significant ($P \leq 0.05$) interactions between type of seedbed and population density were also observed. In the short rain season bambaranuts planted on the ridge at the density of 13 plants m^{-2} (Table 7) and at 9 plants m^{-2} (Table 8) gave the highest leaf area plant^{-1}. Leaf area plant^{-1} was significantly ($P \leq 0.05$) reduced to the lowest value (134.2 cm^2) at 9 plants m^{-2} for bambaranuts planted in the furrow. At 63 DAS (Table 8) leaf area was highest for bambaranuts planted on the ridge at 9 plants m^{-2} (4460.6 cm^2 plant^{-1}) and lowest for plantings in the furrow at 66 plants m^{-2} (2016.2 cm^2 plant^{-2}) with the other treatment combinations falling in between.

In the long rain season bambaranuts planted on the ridge resulted in significantly ($P \leq 0.05$) lower leaf area plant^{-1} overall both at 35 DAS (Table 7) and at 63 DAS (Table 8) while plant populations at 13 plants m^{-2} or 22 plants m^{-2} enhanced leaf area. At 35 DAS, highest leaf area plant^{-1} were recorded for plantings on the flat at 22 plants m^{-2} (408 cm^2 plant^{-1}) and plantings in the furrow at 13 plants m^{-2} (434.5 cm^2 plant^{-1}). The latter also maintained superiority (1343.7 cm^2 plant^{-1}) at 63 DAS (Table 8). The most unfavourable combinations for leaf area were plantings on the ridge at 22 plants m^{-2} (205.5 cm^2 plant^{-1}) at 35 DAS and at 13 plants m^{-2} (438.2 cm^2 plant^{-1}) at 63 DAS.

Table 7. Leaf area plant^{-1} cm^2 at 35 DAS

	Plants m^{-2}	Leaf area plant^{-1} (cm^2) (R_S)				Leaf area plant^{-1} (cm^2) (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 = (35x30) cm	(9)	261.9bcd[1]	334.9ab[1]	134.2e[1]	243.7b[2]	282.1cd[1]	235.8ef[1]	320.6bc[1]	279.5bc[2]
T_2 = (25x30) cm	(13)	296.9bc	399.4a	283.7bc	326.7a	343.7b	237.7ef	434.5a	338.7a
T_3 = (15x30) cm	(22)	164.6bc	242.3bcd	336.5ab	247.8b	408.0a	205.5f	266.6de	293.4b
T_4 = (5x30) cm	(66)	270.1bc	281.4bc	226.7cde	259.4b	306.0bcd	203.9f	276.0de	262.6c
Mean		248.4	214.5	245.3		335.28a[3]	220.7b	324.2a	

SE: Subplots (S) = 17.87	SE: Subplots (S) = 7.83
SE: Mainplots (M) = 40.70	SE: Mainplots(M) = 10.14
SE: (MxS) = 30.95	SE: (MxS) = 13.55
CV: = 19.90%	CV: = 8.00%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 8. Leaf area $plant^{-1}$ cm^2 at 63 DAS.

	Plants m^{-2}	Leaf area $plant^{-1}$(cm^2) (R_S)				Leaf area $plant^{-1}$ (cm^2) (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 - (35x30) cm	(9)	2718.1c[1]	4460.6a[1]	2278.2c[1]	3322.3a[2]	864.12e[1]	893.66e[1]	1056.99cd[1]	938.26[2]
T_2 - (25x30) cm	(13)	2159.8e	2937.7b	1816.3f	2304.6c	840.03e	438.20i	1343.69a	883.97c
T_3 - (15x30) cm	(22)	2290.7d	3028.2b	2197.8de	2505.6b	1175.40b	1108.27c	634.85h	972.84a
T_4 - (5x30) cm	(66)	1367.7h	1704.8g	1262.5i	1445.0d	782.34f	706.23g	1030.76d	839.78d
Mean		2134.1b[3]	3032.9a	2016.2c		922.97b[3]	786.59c	1016.57a	
SE: Subplots (S) - 18.21						SE: Subplots (S) - 10.28			
SE: Mainplots (M) - 13.50						SE: Mainplots(M) - 10.14			
SE: (MxS)	- 31.53					SE: (MxS)	- 7.05		
CV:	- 2.28%					CV:	- 17.8%		

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.1.5 Leaf area index (LAI)

Differences in LAI due to type of seedbed during the short rain season were not significant from 21 DAS to 35 DAS (Fig. 6). Significant ($P \leq 0.05$) differences were, however, apparent between 49 to 119 DAS. Bambaranuts planted on the ridge attained the highest LAI (8.5) between 63 and 77 DAS. The crop planted on the flat or furrow had a lower LAI. There was a marked decline in LAI from 77 DAS to 119 DAS due to senescence, powdery mildew (*Sphaerotheca voandzeiae* (Bour) and (*Cercospora* leaf spot (*Cercospora voandzeiae* Bour.) which attacked the plants.

Significant ($P \leq 0.05$) differences in LAI in response to changes in population density were recorded (Fig. 7). Population density at 66 plants m^{-2} had the highest LAI (9.5) at 63 DAS after which it declined but remained highest throughout. Population densities at 13 plants m^{-2} and at 9 plants m^{-2} recorded the lowest LAI at 63 DAS. In general LAI increased with increase in population density.

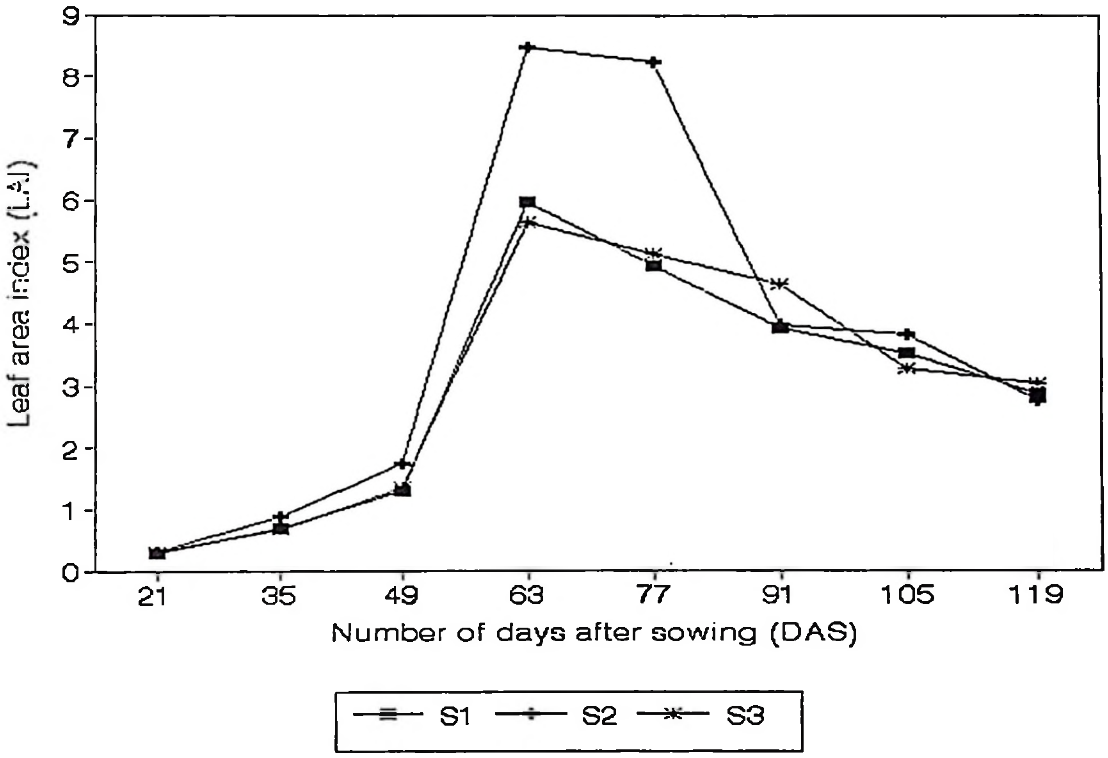

Fig.6 Leaf area index for different seedbed types during the short rain season: S_1 = Flat, S_2 = Ridge, S_3 = Furrow.

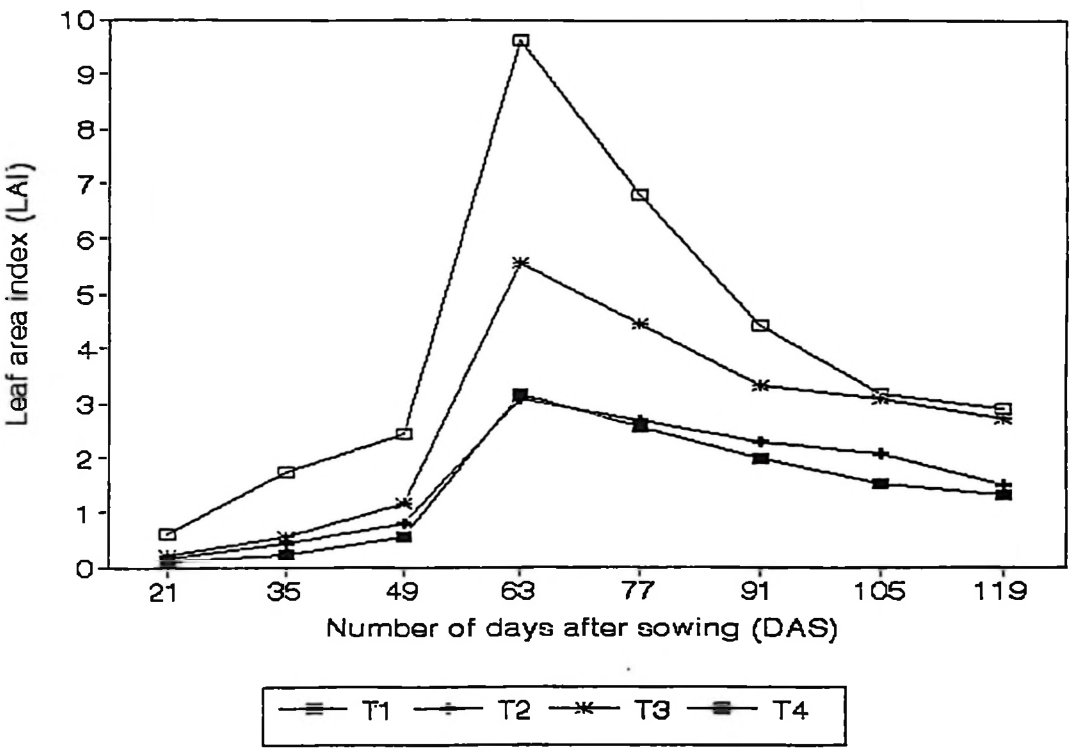

Fig.7 Leaf area index for different population densities during the short rain season: T_1 = 35x30 cm, T_2 = 25x30 cm, T_3 = 15x30 cm, T_4 = 5x30 cm.

Leaf area index for the long rain season is presented in Figs. 8 and 9. In general LAI for the different types of seedbed rose gently from 21 DAS and attained maximum values at 63 DAS and declined drastically before levelling off at 91 DAS. Bambaranuts planted in the furrow attained the highest LAI (2.9) followed by those on the flat (2.5) and ridge (2.1). Planting on the ridge also resulted in the lowest LAI throughout the season (Fig. 8).

Changes in population density significantly ($P \leq 0.05$) affected LAI from 35 to 119 DAS (Fig. 9). In general LAI rose gently from 21 to 49 DAS with the maximum attained at 63 DAS and declined by 77 DAS before gradually falling off at 105 DAS. A rise in leaf area index by 119 DAS at a density of 66 plants m^{-2} was possibly due to calculation error.

Plant density at 66 plants m^{-2} had the highest value for LAI throughout the growing season. On the other hand the lowest population density at 9 plants m^2 maintained lowest LAI values throughout the growing season reaching the maximum of only 1.8 at 63 DAS. The other two population densities at 22 plants m^{-2} and 13 plants m^{-2} were in between these extremes.

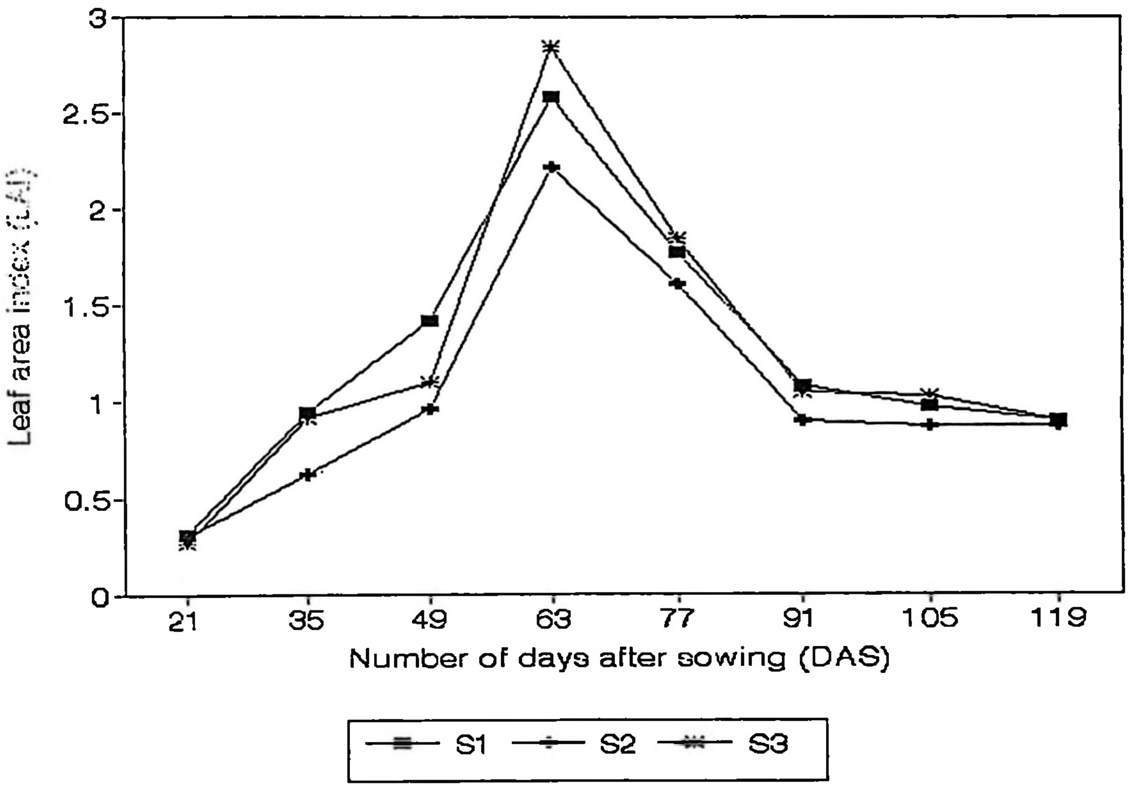

Fig.8 Leaf area index for different seedbed types during the long rain season: S_1 = Flat, S_2 = Ridge, S_3 = Furrow.

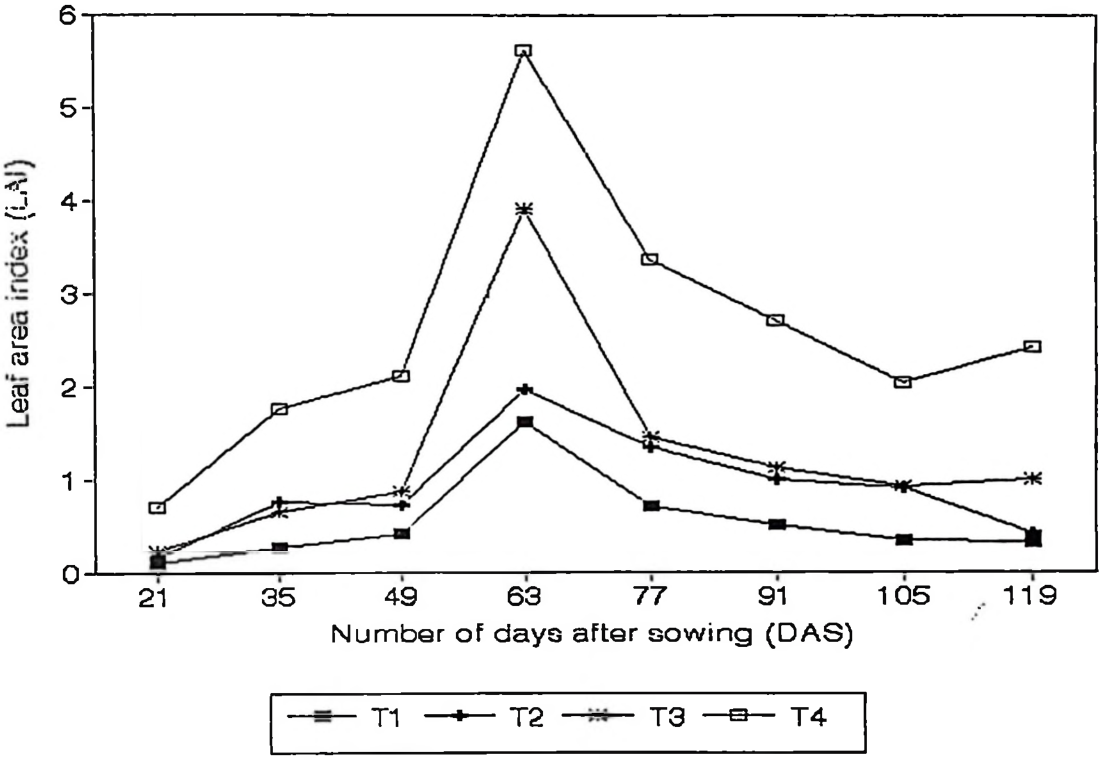

Fig.9 Leaf area index for different population densities during the long rain season: T_1 = 35x30 cm, T_2 = 25x30cm, T_3 = 15x30 cm, T_4 = x30 cm.

4.1.6 Number of flowers plant^{-1}

The onset of flowering for both seasons was at 39 DAS, but actual counting started at 49 DAS. Types of seedbed, plant population density and the interaction of the two factors significantly ($P \leq 0.05$) affected the number of flowers plant^{-1} for both seasons (Tables 9 and 10). Generally, the short rain season crop produced fewer flowers plant^{-1} at 63 DAS while at 91 DAS the trend was reversed.

At 63 DAS bambaranuts planted on the ridge and furrow during the short rain season produced the highest number of flowers plant^{-1} (Table 9). Bambaranuts planted on the flat recorded the highest number of flowers plant^{-1} (25.2) during the long rain season.

Bambaranuts planted in the furrow recorded a higher number of flowers plant^{-1} (16.2) in the short rain season while those on the flat and ridge produced more flowers plant^{-1} (15.9, 14.4), respectively during the long rain season. Bambaranuts planted on the ridge during the short rain season recorded the lowest number of flowers plant^{-1} (9.4) (Table 10).

Population densities at 13 and at 22 plants m^{-2} for the short and long rain season, respectively recorded the highest number of flowers plant^{-1} at 63 DAS (Table 9). At 91 DAS, however, plant density at 9 plants m^{-2} for the short rain season and at 13 plants m^{-2} for the long rain season recorded significantly ($P \leq 0.05$) higher numbers of flowers plant^{-1} (Table 10).

Generally, flower production tended to increase with increase in population density at 63 DAS for the short rain season crop up to 13 plants m^{-2} for bambaranuts planted on the ridge and in furrows (Table 9). The long rain season crop tended to result into an increase in the number of flowers plant^{-1} for bambaranuts planted on the flat up to 22 plants m^{-2} while the number of flowers plant^{-1}

decreased with increase in population density for bambaranuts planted on the ridge or in the furrow (Table 9).

Bambaranuts planted on the ridge at 13 plants m^{-2} in the short rain season and those planted on the flat at 22 plants m^{-2} in the long rain season produced the highest number of flowers $plant^{-1}$ (Table 9). Although the short rain season crop produced more flowers $plant^{-1}$ when planted on the ridge, the number of flowers for this type of seedbed declined more drastically with increase in plant density compared to the other seedbed types (Table 10). This was not the case for the long rain season crop.

Table 9. Number of flowers $plant^{-1}$ at 63 DAS.

	Plants m^{-2}	Number of flowers $plant^{-1}$ (R_S)				Number of flowers $plant^{-1}$ (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 = (35x30) cm	(9)	2.9 cd[1]	4.6 bc[1]	4.6 bc[1]	4.0 b[2]	20.1 c[1]	15.0 de[1]	22.9 cd[1]	19.3 ab[2]
T_2 = (25x30) cm	(13)	2.1 d	7.8 a	5.4 b	5.1 a	28.2 b	14.6 de	15.6 d	19.5 ab
T_3 = (15x30) cm	(22)	4.4 bc	3.2 cd	3.6 cd	3.7 bc	31.6 a	14.6 de	15.6 d	19.5 ab
T_4 = (5x30) cm	(66)	3.6 cd	2.4 d	2.6 d	2.9 c	20.9 c	11.7 e	19.9 c	17.2 b
Mean		3.3 b[3]	4.5 a	4.0 ab		25.2 a[3]	14.0 c	17.9 b	

SE: Subplots (S) = 0.32	SE: Subplots (S) = 0.63
SE: Mainplots (M) = 0.27	SE: Mainplots(M) = 0.50
SE: (MxS) = 0.56	SE: (MxS) = 1.09
CV: = 24.63%	CV: = 9.97%

Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 10. Number of flowers plant^{-1} at 91 DAS.

	Plants m^{-2}	Number of flowers plant^{-1} (R_S)				Number of flowers plant^{-1} (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 = (35x30) cm	(9)	11.2 de[1]	15.8 cd[1]	26.0 a[1]	17.6 a[2]	18.0 b[1]	17.8 b[1]	7.6 f[1]	14.4 b[2]
T_2 = (25x30) cm	(13)	16.8 c	8.4 fg	18.0 b	14.4 b	21.3 a	15.6 c	11.3 d	16.1 a
T_3 = (15x30) cm	(22)	10.2 e	8.9 fg	15.2 cd	11.4 c	17.2 b	14.3 c	9.6 e	13.7 b
T_4 = (5x30) cm	(66)	4.2 g	4.4 g	5.8 g	4.8 d	7.2 f	10.1 de	17.5 b	11.6 c
Mean		10.6 b[3]	9.4 b	16.2 a		15.9 a[3]	14.4 a	11.5 b	

SE: Subplots (S)	= 0.86	SE: Subplots (S)	= 0.26
SE: Mainplots (M)	= 0.38	SE: Mainplots(M)	= 1.57
SE: (MxS)	= 1.49	SE: (MxS)	= 0.45
CV:	= 17.72%	CV:	= 5.64%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.1.7 Number of pegs plant^{-1}

For both seasons the number of pegs plant^{-1} was significantly ($P \leq 0.05$) affected by seedbed types (except at 91 DAS for the short rain season crop) (Tables 11 and 12).

Generally, the long rain season crop produced significantly ($P \leq 0.05$) more pegs plant^{-1} at 63 DAS than the short rain season crop (Table 11). Bambaranuts planted on the flat during the long rain or on the ridge during the short rain season, produced more pegs plant^{-1} at 63 DAS (Table 11). Bambaranuts planted on the flat during the long rain season produced more pegs plant^{-1} with increasing population density from 9 plants m^{-2} to 13 plants m^{-2} thereafter, the number of pegs plant^{-1} dropped though insignificantly (Table 11).

Significant ($P \leq 0.05$) interaction were observed during the short rain season for bambaranuts planted on the ridge at 9 plants m^{-2} (Table 11). During the long rain season bambaranuts planted on the flat at 13 plants m^{-2} produced significantly ($P \leq 0.05$) higher number of pegs plant^{-1}. Planting on the ridge resulted into higher number of pegs at 22 plants m^{-2} while bambaranuts planted in the furrow produced more pegs at 9 and 66 plants m^{-2}. In general, the highest plant density depressed peg production for bambaranuts planted on the flat or ridge (Table 11).

There was a marked improvement in the number of pegs plant^{-1} for the short rain season crop at 91 DAS (Table 12). Bambaranuts planted in the furrow resulted into the highest number of pegs plant^{-1} (37.1). This was followed by bambaranuts planted on the ridge (36.0) (Table 12). Plant population at 9 plants m^{-2} produced the highest number of pegs plant^{-1} (52.9).

Significant ($P \leq 0.05$) interactions were observed during both seasons. Planting bambaranuts in the furrow at 9 plants m^{-2} produced the highest number of pegs plant^{-1} during the short rain season (Table 12). Bambaranuts planted on the ridge resulted into higher number of pegs palnt^{-1} at 22 plants m^{-2} and 9 plants m^{-2} while planting on the flat produced significantly ($P \leq 0.05$) higher number of pegs plant^{-1} at 9 plants m^{-2}. In general, peg production was depressed with increase in population density for all plant population x type of seedbed interaction (Table 12).

During the long rain season, planting on the flat recorded the highest number of pegs plant^{-1} at 22 plants m^{-2}. For bambaranuts planted on the ridge and flat significantly ($P \leq 0.05$) higher number of pegs plant^{-1} were recorded at 9 plants m^{-2} and 13 plants m^{-2}, respectively. In general, the number of pegs plant^{-1} decreased with increase in population density for bambaranuts planted on the ridge. There was no specific trend for plantings on the flat and furrow x population density interactions.

Table 11. Number of pegs plant^{-1} at 63 DAS.

	Plants m^{-2}	Number of pegs plant^{-1} (R_5)				Number of pegs plant^{-1} (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 - (35x30) cm	(9)	0.6 bc[1]	1.3 a[1]	0.5 bc[1]	0.8 a[2]	50.2 b[1]	40.2 de[1]	35.9 ef[1]	42.1 a[2]
T_2 - (25x30) cm	(13)	0.6 bc	0.2 c	0.4 bc	0.4 b	58.5 a	39.0 de	29.0 g	42.2 a
T_3 - (15x30) cm	(22)	0.6 bc	0.9 ab	0.2 c	0.6 ab	46.0 bc	43.3 cd	20.1 h	36.5 b
T_4 - (5x30) cm	(66)	0.4 bc	0.7 bc	0.3 c	0.5 b	31.8 fg	29.8 g	36.2 ef	32.4 c
Mean		0.5 b[3]	0.8 a	0.4 b		46.5 a[3]	38.1 b	30.3 c	

SE: Subplots (S) - 0.09	SE: Subplots (S) - 1.06
SE: Mainplots (M) - 0.05	SE: Mainplots(M) - 1.31
SE: (MxS) - 0.16	SE: (MxS) - 1.84
CV: - 49.95%	CV: - 8.34%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 12. Number of pegs $plant^{-1}$ at 91 DAS.

	Plants m^{-2}	Number of pegs $plant^{-1}$ (R_5)				Number of pegs $plant^{-1}$ (R_t)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 - (35x30) cm	(9)	47.4 bc[1]	53.7 ab[1]	57.8 a[1]	52.9 a[2]	42.3de[1]	51.2bc[1]	29.1gh[1]	40.9bc[2]
T_2 - (25x30) cm	(13)	40.6 c	23.9 de	44.3 c	36.3 b	34.3fg	45.0d	53.0b	44.1ab
T_3 - (15x30) cm	(22)	30.7 d	55.1 ab	29.3 d	39.4 b	72.9a	34.7fg	27.7h	45.1a
T_4 - (5x30) cm	(66)	14.0 f	11.4 f	17.1 ef	14.2 c	36.6ef	37.0ef	46.0cd	39.9c
Mean		33.2 b[3]	36.0 ab	37.1 a		46.5a[3]	42.0b	38.9b	

SE: Subplots (S)	- 1.66	SE: Subplots (S)	- 1.12
SE: Mainplots (M)	- 0.83	SE: Mainplots(M)	- 0.91
SE: (MxS)	- 2.90	SE: (MxS)	- 1.93
CV:	- 14.04%	CV:	- 7.87%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.1.8 Number of pods plant^{-1}

In the short rain season differences in the number of pods plants^{-1} at 63 DAS were not significant ($P \leq 0.05$) for types of seedbed, plant population and the interaction of the two factors (Table 13). Generally, the short rain season crop produced less pods plant^{-1} across all types of seedbed than the long season crop.

Differences in the number of pods plant^{-1} were significant ($P \leq 0.05$) for seedbed types, plant population and the interaction of the two factors at 63 DAS for the long rain season (Table 13) and at 91 DAS for both seasons (Table 14) but podding was generally low at 63 DAS. For the long rain season, bambaranuts planted on the flat at 13 plants m^{-2} or 22 plants m^{-2} yielded the highest number of pods plant^{-1} at 63 DAS. A similar trend was followed at 91 DAS (Table 14).

In the short rain season, at 91 DAS (Table 14) podding was most favourable for bambaranuts planted in the furrow at 9 and 13 plants m^{-2} or on the flat at 22 plants m^{-2} (Table 14). Podding for plants on the ridge was generally poor. Planting in the furrow especially at the lower plant populations generally enhanced podding for the short rain season. This trend was not maintained during the long rain season.

Table 13. Number of pods plant^{-1} at 63 DAS.

	Plants m^{-2}	Number of pods plant^{-1} (R_S)				Number of pods plant^{-1} (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	0.5 abc[1]	0.6 ab[1]	0.0 bc[1]	0.3 a[2]	0.6 e[1]	0.6 e[1]	1.3 d[1]	0.8 c[2]
T_2 – (25x30) cm	(13)	0.3 abc	0.0 c	0.3 abc	0.2 ab	5.5 a	0.0 e	2.1 c	2.5 b
T_3 – (15x30) cm	(22)	0.1 bc	0.0 c	0.0 c	0.04 b	5.9 a	3.0 b	0.3 e	3.1 a
T_4 – (5x30) cm	(66)	0.7 a	0.2 abc	0.0 c	0.3 ab	0.0 e	1.8 cd	0.2 e	0.7 c
Mean		0.4	0.2	0.1		3.0 a[3]	1.3 b	1.0 b	

SE: Subplots (S)	= 0.09	SE: Subplots (S)	= 0.14
SE: Mainplots (M)	= 0.10	SE: Mainplots(M)	= 0.16
SE: (MxS)	= 0.16	SE: (MxS)	= 0.25
CV:	= 120.37%	CV:	= 24.06%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 14. Number of pods $plant^{-1}$ at 91 DAS.

	Plants m^{-2}	Number of pods $plant^{-1}$ (R_S)				Number of pods $plant^{-1}$ (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	6.3 cd[1]	4.5 de[1]	18.2 a[1]	9.7 b[2]	9.1 c[1]	8.8 c[1]	2.6 f[1]	6.8 c[2]
T_2 – (25x30) cm	(13)	4.2 de	2.5 e	18.7 a	8.5 b	14.4 a	3.8 ef	12.7 b	10.3 a
T_3 – (15x30) cm	(22)	16.1 a	9.2 b	8.7 bc	11.3 a	14.7 a	4.9 de	4.7 de	8.1 b
T_4 – (5x30) cm	(66)	4.4 de	3.4 e	2.2 e	3.4 c	3.8 ef	4.2 e	6.2 d	4.7 d
Mean		7.8 b[3]	4.9 c	11.9 a		10.5 a[3]	5.4 c	6.5 b	
SE: Subplots (S) – 0.49						SE: Subplots (S) – 0.29			
SE: Mainplots (M) – 0.36						SE: Mainplots(M) – 0.26			
SE: (MxS) – 0.85						SE: (MxS) – 0.50			
CV: – 17.87%						CV: – 11.69%			

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.1.9 Shoot dry matter (g) plant^{-1}

Shoot dry matter plant^{-1} is summarized in Tables 15, 16 and 17. Types of seedbed significantly ($P \leq 0.05$) affected shoot dry matter plant^{-1} for the long rain season crop at 35 and 91 DAS (Tables 15, 17) and at 63 DAS (Table 16) for the short and long rain season crop. Changes in population density significantly ($P \leq 0.05$) affected shoot dry matter at 35 and 91 DAS (Tables 15 and 17) for both seasons and at 63 DAS for the short rain season (Table 16). Significant ($P \leq 0.05$) interactions between types of seed-bed and population density were apparent for both seasons at 35 and 91 DAS (Tables 15 and 17) and at 63 DAS (Table 16) for the long rain season crop.

Generally, bambaranuts planted on the flat and in the furrow recorded higher values for shoot dry matter for the long rain season at 35, 63 and 91 DAS (Tables, 16, 17). In addition population densities at 13 plants m^{-2} at 35 and 91 DAS resulted into higher shoot dry matter plant^{-1}. For the short rain season, planting on the ridge recorded significantly ($P \leq 0.05$) high values of shoot dry matter only at 63 DAS.

Significant ($P \leq 0.05$) interactions between types of seedbed and population density were recorded in all cases except at 63 DAS for the short rain season.

Table 15. Shoot (leaf and stem) Dm (g) plant^{-1} at 35 DAS.

	Plants m^{-2}	Shoot Dm (g) plant^{-1} (R_S)				Shoot Dm (g) plant^{-1} (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 = (35x30) cm	(9)	2.2 bc[1]	2.5 abc[1]	1.4 de[1]	2.0 b[2]	2.0 bcde[1]	1.6 efg[1]	2.3 bc[1]	2.0 b[2]
T_2 = (25x30) cm	(13)	2.3 abc	3.0 a	2.2 bc	2.5 a	2.4 b	1.87 efg	2.8 a	2.8 a
T_3 = (15x30) cm	(22)	1.3 e	1.9 cde	2.7 ab	2.0 b	2.8 a	1.4 g	1.8 deg	2.0 b
T_4 = (5x30) cm	(66)	2.1 bcd	2.2 bc	1.8 cde	2.0 b	2.2 bcd	1.5 fg	1.9 cde	1.9 b
Mean		2.0	2.4	2.0		2.3 a[3]	1.6 b	2.2 a	

SE: Subplots (S) = 0.13	SE: Subplots (S) = 0.07
SE: Mainplots (M) = 0.36	SE: Mainplots(M) = 0.12
SE: (MxS) = 0.23	SE: (MxS) = 0.12
CV: = 18.82%	CV: = 9.78%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 16. Shoot (leaf and stem) Dm (g) $plant^{-1}$ at 63 DAS.

	Plants m^{-2}	Shoot Dm (g) $plant^{-1}$ (R_S)				Shoot Dm (g) $plant^{-1}$ (R_I)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	12.5	19.0	11.5	14.3 a[2]	7.4 bcd[1]	7.5 bcd[1]	8.8 abc[1]	7.98
T_2 – (25x30) cm	(13)	9.0	12.7	12.1	11.3 b	7.5 bcd	3.3 e	10.9 a	7.2
T_3 – (15x30) cm	(22)	9.4	12.2	9.2	10.2 b	10.1 ab	9.2 abc	5.0 de	8.3
T_4 – (5x30) cm	(66)	5.9	11.3	6.3	7.8 c	6.7 cd	6.6 cd	8.6 abc	7.3
Mean		9.2 b[3]	13.8 a	9.2 b		7.9 a[3]	6.7 b	8.5 a	

SE: Subplots (S) = 0.6	SE: Subplots (S) = 0.5
SE: Mainplots (M) = 0.32	SE: Mainplots(M) = 0.28
SE: (MxS) = 1.04	SE: (MxS) = 0.82
CV: = 16.54%	CV: = 18.47%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 17. Shoot (leaf and stem) Dm (g) plant^{-1} at 91 DAS.

	Plants m^{-2}	Shoot Dm (g) plant^{-1} (R_S)				Shoot Dm (g) plant^{-1} (R_I)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	22.6 cde[1]	25.6 bc[1]	28.7 ab[1]	25.6 a[2]	8.5 bc[1]	6.8 d[1]	5.8 de[1]	7.0 b[2]
T_2 – (25x30) cm	(13)	23.4 cd	18.0 fg	30.2 a	23.9 a	9.8 ab	8.2 c	10.7 a	9.6 a
T_3 – (15x30) cm	(22)	15.2 g	20.8 def	19.4 ef	18.5 b	9.2 bc	6.6 d	6.6 d	7.5 b
T_4 – (5x30) cm	(66)	8.7 h	11.1 h	8.0 h	9.3 c	5.1 e	4.9 e	6.5 d	5.5 c
Mean		17.5	18.9	21.6		8.1 a[3]	6.6 b	7.3 ab	

SE: Subplots (S) – 0.7	SE: Subplots (S) – 0.25
SE: Mainplots (M) – 1.4	SE: Mainplots(M) – 0.25
SE: (MxS) – 1.2	SE: (MxS) – 0.45
CV: – 10.44%	CV: – 10.06%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.1.10 Root dry matter (g) plant^{-1}

Interactions between type of seedbed and population density were significant ($P \leq 0.05$) for the long rain season crop at 35 and 63 DAS (Tables 18 and 19).

Values were generally low for all seedbed types and plant populations. Generally, however, root growth was most favourable on flat seedbeds during the long rains or in the furrow during the short rains (Table 18-20). The response to plant population was variable showing a tendency for enhanced root growth at the lower plant populations at 9 and 13 plants m^{-2}.

Table 18. Root (pegs) dry matter (g) plant^{-1} at 35 DAS

	Plants m^{-2}	Root Dm (g) plant^{-1} (R_S)				Root Dm (g) plant^{-1} (R_I)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	0.13	0.18	0.42	0.25	0.13 ab[1]	0.15 ab[1]	0.12 ab[1]	0.14
T_2 – (25x30) cm	(13)	0.17	0.18	0.16	0.16	0.14 ab	0.12 b	0.14 ab	0.13
T_3 – (15x30) cm	(22)	0.10	0.13	0.16	0.13	0.18 a	0.11 b	0.10 b	0.13
T_4 – (5x30) cm	(66)	0.09	0.13	0.11	0.11	0.14 ab	0.11 b	0.12 b	0.12
Mean		0.12	0.16	0.21		0.15	0.12	0.12	
SE: Subplots (S) – 0.056						SE: Subplots (S) – 0.01			
SE: Mainplots (M) – 0.05						SE: Mainplots(M) – 0.01			
SE: (MxS) – 0.087						SE: (MxS) – 0.02			
CV: – 40%						CV: – 11.35%			

[1] Values in the main table followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 19. Root (pod and peg) dry matter (g) $plant^{-1}$ at 63 DAS

	Plants m^{-2}	Root Dm (g) $plant^{-1}$ (R_S)				Root Dm (g) $plant^{-1}$ (R_I)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 - (35x30) cm	(9)	0.80	1.03	0.29	0.71	0.30 efg[1]	0.29 fgh[1]	0.38 de[1]	0.32 bc[2]
T_2 - (25x30) cm	(13)	0.60	0.43	0.60	0.54	0.39 cd	0.21 hi	0.48 b	0.36 b
T_3 - (15x30) cm	(22)	0.35	0.37	0.28	0.33	0.72 a	0.46 bc	0.20 i	0.46 a
T_4 - (5x30) cm	(66)	0.88	0.45	0.14	0.49	0.32 def	0.24 ghi	0.36 def	0.30 c
Mean		0.66	0.57	0.33		0.43 a[3]	0.30 c	0.35 b	

SE: Subplots (S) - 0.1	SE: Subplots (S) - 0.01
SE: Mainplots (M) - 0.09	SE: Mainplots(M) - 0.01
SE: (MxS) - 0.16	SE: (MxS) - 0.03
CV: - 53.06%	CV: - 11.77%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 20. Root (pod and peg) dry matter (g) plant^{-1} at 91 DAS.

	Plants m^{-2}	Root Dm (g) plant^{-1} (R_5)				Root Dm (g) plant^{-1} (R_1)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	1.4 de[1]	0.9 ef[1]	4.6 b[1]	2.3 b[2]	2.4 b[1]	1.3 c[1]	0.7 c[1]	1.5 b[2]
T_2 – (25x30) cm	(13)	1.1 ef	1.1 ef	6.7 a	3.0 a	2.9 b	0.77 c	3.1 b	2.3 a
T_3 – (15x30) cm	(22)	3.2 c	1.8 d	1.3 de	2.1 b	4.1 a	1.0 c	1.1 c	2.1 a
T_4 – (5x30) cm	(66)	1.3 de	1.0 ef	0.6 f	1.0 c	1.4 c	0.8 c	1.2 c	1.2 b
Mean		1.7 b[3]	1.2 c	3.3 a		2.7 a[3]	1.0 c	1.5 b	

SE: Subplots (S) – 0.11	SE: Subplots (S) – 0.16
SE: Mainplots (M) – 0.12	SE: Mainplots(M) – 0.05
SE: (MxS) – 0.20	SE: (MxS) – 0.28
CV: – 16.46%	CV: – 27.42%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.1.11 Root: shoot ratio

Root : shoot ratio is presented in Tables 21, 22 and 23. In both seasons, differences in root : shoot ratio measured at 35 DAS were not significant ($P \leq 0.05$) for seedbed types, plant population and the interaction of the two factors (Table 21). Types of seedbed x plant population density interactions were significant only at 91 DAS for the short rain season (Table 23).

At 63 DAS planting on the flat produced significantly ($P \leq 0.05$) higher root : shoot ratio values than planting on the ridge or furrow for both short and long rain seasons (Table 22). At 91 DAS during the short rain season (Table 23) planting on the flat or furrow resulted into higher root : shoot ratio compared to planting on the ridge. There was a tendency for root : shoot ratio to increase with increase in population density for bambaranuts planted on the ridge. The trend was reversed for bambaranuts planted in the furrow (Table 23). For the long rain season, planting on the flat resulted in higher values for root : shoot ratio (Table 23). In general, root: shoot ratio tended to increase with increase in population density for bambaranuts planted on the flat or furrow.

Table 21. Root : shoot ratio plant^{-1} at 35 DAS

	Plants m^{-2}	Root : shoot ratio plant^{-1} (R_S)				Root: shoot ratio plant^{-1} (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	0.310	1.082	0.078	0.157	0.068	0.064	0.055	0.062
T_2 – (25x30) cm	(13)	0.071	0.059	0.074	0.068	0.061	0.066	0.051	0.059
T_3 – (15x30) cm	(22)	0.094	0.064	0.065	0.074	0.065	0.077	0.055	0.065
T_4 – (5x30) cm	(66)	0.047	0.069	0.066	0.061	0.066	0.076	0.062	0.068
Mean		0.130	0.069	0.07		0.065	0.071	0.056	

SE: Subplots (S) = 0.03	SE: Subplots (S) = 0.0003
SE: Mainplots (M) = 0.04	SE: Mainplots(M) = 0.0002
SE: (MxS) = 0.08	SE: (MxS) = 0.0006
CV: = 45.78%	CV: = 23.78%

Table 22. Root : shoot ratio $plant^{-1}$ at R_5 63 DAS

	Plants m^{-2}	Root : shoot ratio $plant^{-1}$ (R_5)				Root: shoot ratio $plant^{-1}$ (R_t)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 = (35x30) cm	(9)	0.170	1.056	0.025	0.084	0.042	0.038	0.044	0.041
T_2 = (25x30) cm	(13)	0.066	0.035	0.045	0.049	0.053	0.069	0.044	0.056
T_3 = (15x30) cm	(22)	0.038	0.031	0.031	0.033	0.075	0.051	0.035	0.054
T_4 = (5x30) cm	(66)	0.147	0.039	0.023	0.070	0.047	0.032	0.042	0.041
Mean		0.105 a[3]	0.041 b	0.031 b		0.054 a[3]	0.048 b	0.041 c	

SE: Subplots (S)	= 0.02	SE: Subplots (S)	= 0.0003
SE: Mainplots (M)	= 0.01	SE: Mainplots(M)	= 0.0003
SE: (MxS)	= 0.04	SE: (MxS)	= 0.0006
CV:	= 40%	CV:	= 29.04%

[3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 23. Root : shoot ratio plant^{-1} at 91 DAS

	Plants m^{-2}	Root : shoot ratio plant^{-1} (R_s)				Root: shoot ratio plant^{-1} (R_l)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	0.061 d[1]	0.037 d[1]	0.158 ab[1]	0.085	0.288	0.196	0.109	0.197
T_2 – (25x30) cm	(13)	0.045 d	0.060 d	0.148 bc	0.084	0.313	0.095	0.294	0.234
T_3 – (15x30) cm	(22)	0.208 a	0.088 d	0.071 d	0.123	0.450	0.157	0.344	0.317
T_4 – (5x30) cm	(66)	0.147 bc	0.092 cd	0.077 d	0.105	0.280	0.176	0.188	0.215
Mean		0.115 a[3]	0.069 b	0.114 a		0.333 a[3]	0.156 b	0.234 ab	

SE: Subplots (S) – 0.01	SE: Subplots (S) – 0.03
SE: Mainplots (M) – 0.003	SE: Mainplots(M) – 0.03
SE: (MxS) – 0.002	SE: (MxS) – 0.06
CV: – 35.33%	CV: – 44.53%

[1,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.2 Yield and yield components

4.2.1 Number of plants at harvest

During both seasons types of seedbed, population density and their interactions significantly ($P \leq 0.05$) affected the number of plants at harvest (Table 24).

For both seasons, bambaranuts planted in the furrow resulted into the highest number of plants at harvest. Bambaranuts planted on the ridge produced the lowest number of plants for both the short and long rain seasons.

During both seasons, the number of plants harvested increased as population density was increased (Table 24). Bambaranuts planted in the furrow at 66 plants m^{-2} recorded the highest significant ($P \leq 0.05$) interactions during both seasons. During the short rain season planting on the ridge at 9 plants m^{-2} resulted into the lowest significant ($P \leq 0.05$) interactions. During both seasons, the crop planted on the flat or ridge at 66 plants m^{-2} resulted into the lowest number of plants at harvest.

Table 24. Number of plants at harvest

	Plants m^{-2}	No. of plants m^{-2} (R_S)				No. of plants m^{-2} (R_I)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	10.0 de[1]	5.0 e[1]	9.0 de[1]	8.0 d[2]	10.0 ef[1]	8.0 f[1]	10.0 ef[1]	9.3 d[2]
T_2 – (25x30) cm	(13)	14.0 cd	14.0 cd	16.0 cd	15.0 c	14.0 de	13.0 de	16.0 de	14.3 c
T_3 – (15x30) cm	(22)	22.0 c	21.0 c	21.0 c	21.0 b	23.0 c	18.0 cd	18.0 cd	20.0 b
T_4 – (5x30) cm	(66)	41.0 b	38.0 bc	63.0 a	47.0 a	36.0 b	39.0 b	66.0 a	47.0 a
Mean		22.0 b[3]	20.0 b	27.0 a		21.0 b[3]	20.0 b	28.0 a	

SE: Subplots (S) – 1.36	SE: Subplots (S) – 1.35
SE: Mainplots (M) – 1.05	SE: Mainplots(M) = 1.44
SE: (MxS) – 2.35	SE: (MxS) = 2.34
CV: – 15.26%	CV: – 15.16%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.2.2 Pod yield (kg) ha^{-1}

During both seasons, differences in pod yield ha^{-1} were significantly ($P \leq 0.05$) affected by types of seed bed, population density and the interaction of the two factors (Table 25)

Pod yield was significantly ($P \leq 0.05$) higher for bambaranuts planted on the ridge or flat during both the short and long rain season, respectively. During the short rain season, population density at 9 m^{-2} produced the highest yield. Generally, pod yield ha^{-1} declined with increase in population density during the short rain season. There was, however, a lot of variation in yield as population density increased. The highest pod yield was recorded at 22 plants m^{-2}. Significant ($P \leq 0.05$) interactions were observed for bambaranuts planted on the ridge at 9 plants m^{-2} during the short rain season and thereafter declined. Pod yield increased with increase in population density from 9 to 13 plants m^{-2} for bambaranuts planted on the flat or in the furrow. Thereafter, pod yield declined for bambaranuts planted on the flat but was variable for the crop planted in the furrow.

During the long rain season, the highest significant ($P \leq 0.05$) interactions in pod yield ha^{-1} was realised at the density of 22 plants m^{-2} from bambaranuts planted on the flat (Table 25) Although there was no specific trend for both flat and ridge x population density interactions, increase in population density for bambaranuts planted in the furrow enhanced pod yield ha^{-1} up to 22 plants m^{-2}. Generally, population density at 66 plants m^{-2} was favourable for high pod yield ha^{-1} across all types of seed bed x population density interactions with bambaranuts planted on the flat at 66 plants m^{-2} producing the lowest (Table 25)

Table 25 Pod yield (kg) ha^{-1} at harvest.

	Plants m^{-2}	Pod yield (kg) ha^{-1} (R_S)				Pod yield (kg) ha^{-1} (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	319.6de[1]	723.9 a[1]	569.9c[1]	537.9a[2]	678.2b[1]	577.4bc[1]	423.5cd[1]	559.7b[2]
T_2 – (25x30) cm	(13)	437.0 cd	335.3 d	708.0 b	460.1 b	590.7bc	448.7 cd	520.2 bc	519.9 b
T_3 – (15x30) cm	(22)	428.9 cd	447.6 cd	343.8 d	406.8 b	1065.3 a	518.3 bc	587.9 bc	723.8 a
T_4 – (5x30) cm	(66)	330.7 d	347.8 d	460.2 c	379.6 b	319.9 d	392.0 cd	465.0 cd	392.3 c
Mean		379.0 c[3]	587.9 a	520.5 b		663.5a[3]	484.1 b	499.2 b	

SE: Subplots (S) – 37.60	SE: Subplots (S) – 34.03
SE: Mainplots (M – 12.47	SE: Mainplots(M) – 17.50
SE: (MxS) – 65.12	SE: (MxS) – 58.94
CV: – 22.75%	CV: – 18.60%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.2.3 Grain yield (kg) ha^{-1}

In both seasons, differences in grain yield ha^{-1} at harvest were significant ($P \leq 0.05$) for seedbed type, population density and the interaction of the two factors (Table 26)

Planting in the furrow during the short rain season enhanced grain yield. Grain yield increased with increase in plant population from 9 to 13 plants m^{-2} during the short rain season for bambaranuts planted on the flat and in the furrow and thereafter declined. Planting on the ridge was least favourable in grain yield production.

Significant ($P \leq 0.05$) interactions in grain yield ha^{-1} resulted from bambaranuts planted in the furrow at 13 plants m^{-2} for the short rain season crop. Grain yield was lowest for the crop planted on the flat at the population density of 66 plants m^{-2}. Grain yield was very variable for bambaranuts planted on the ridge across all population density interactions. In general, population density at 66 plants m^{-2} depressed grain yield for bambaranuts planted on the flat or ridge.

During the long rain season, planting on the flat resulted into significantly ($P \leq 0.05$) higher grain yield ha^{-1} (Table 26) Planting in the furrow or ridge, however, depressed grain yield. Grain yield values for the long rain season were far superior than those of the short rain season crop. There was no specific trend for population density. Population density at 22 plants m^{-2} favoured grain yield ha^{-1}. Although there was no specific trend for population density, indications are that yield generally increased with population density up to 22 plants m^{-2} after which there was a marked decline in grain yield.

During the long rain season, bambaranuts planted on the flat at 22 plants m^{-2} produced the highest significant ($P \leq 0.05$) interactions. Similarly, planting on the flat at 66 plants m^{-2}

depressed grain yield. Planting on the ridge at 9 plants m^{-2} enhanced grain yield. There was a tendency for grain yield to decrease with increase in population density from 9 to 13 plants m^{-2} for bambaranuts planted on the flat or ridge. The reverse was true for bambaranuts planted in the furrow. In general, plant population at 66 plants m^{-2} across all types of seedbed depressed grain yield.

Table 26 Grain yield (kg) ha^{-1} at harvest.

	Plants m^{-2}	Grain yield (kg) ha^{-1} (R_S)				Grain yield (kg) ha^{-1} (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	246.8d[1]	323.8c[1]	416.4b[1]	329.0a[2]	499.0b[1]	403.5bcd[1]	312.3de[1]	405.0b[2]
T_2 – (25x30) cm	(13)	326.1c	172.0e	519.2a	339.1a	455.7bc	337.7cde	341.4cde	378.3b
T_3 – (15x30) cm	(22)	297.3c	238.3d	240.7d	258.8b	746.6a	382.3bcde	334.7cde	487.9 a
T_4 – (5x30) cm	(66)	169.3e	197.5de	313.2c	226.6c	257.9e	314.4de	307.7de	293.3 c
Mean		259.9b[3]	232.9b	372.4a		489.8a[3]	359.5b	324.0 b	

SE: Subplots (S) = 9.49	SE: Subplots (S) = 22.01
SE: Mainplots (M) = 6.53	SE: Mainplots(M) = 10.96
SE: (MxS) = 16.44	SE: (MxS) = 38.12
CV: = 9.87%	CV: = 16.88%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.2.4 Shelling percentage

Highest shelling percentage was recorded at the spacing of 13 and 22 plants m^2 across all types of seedbed for the short rain season crop (Table 27. Shelling percentage increased significantly ($P \leq 0.05$) with increase in population density from 9 to 13 plants m^2 and thereafter declined. Shelling percentages were generally higher during the long rain season and planting on the flat or ridge resulted into significantly ($P \leq 0.05$) high shelling percentages especially at 22 plants m^2 (Table 27)

4.2.5 The 100-seed weight

The 100-seed weight did not show any significant ($P \leq 0.05$) differences for types of seedbed x plant population density interactions for both the short and long rain season (Table 28) During the long rain season, however, planting on the flat or furrow resulted in the highest 100-seed weight. Generally, seed mass decreased with increase in population density.

4.2.6 Above ground dry matter

In general above ground dry matter increased with increase in population density across all types of seedbed x population density interactions for the short rain season (Table 29 Above ground dry matter yield for the long rain season was variable. Above ground dry matter was significantly ($P \leq 0.05$) lower for furrow than for flat and ridge and the short rain season crop produced higher values for above ground dry matter than the long rain season crop.

Table 27 Shelling percentage

	Plants m^{-2}	Shelling percentage (R_S)				Shelling percentage (R_I)			
		Type of seedbed				Type of seedbed			
		Flat	Ridge	Furrow	Mean	Flat	Ridge	Furrow	Mean
T_1 = (35x30) cm	(9)	66.9 ab[1]	54.8 b[1]	65.2 ab[1]	52.3 c[2]	74.1abc[1]	70.4 bc[1]	74.0abc[1]	72.8 a[2]
T_2 = (25x30) cm	(13)	75.5 a	73.7 a	73.4 a	74.2 a	78.8 ab	75.3 ab	72.8 abc	75.6 a
T_3 = (15x30) cm	(22)	70.1 ab	61.2 ab	70.3 ab	67.2 ab	80.6 a	85.5 a	66.8 c	75.9 a
T_4 = (5x30) cm	(66)	51.9 b	61.2 ab	68.3 ab	60.4 bc	70.6 bc	74.0 abc	56.8 d	67.1 b
Mean		66.1	62.7	69.3		76.0 a[3]	75.0 a	67.6 b	

SE: Subplots (S) = 3.62	SE: Subplots (S) = 1.48
SE: Mainplots (M) = 4.99	SE: Mainplots(M) = 0.94
SE: (MxS) = 6.27	SE: (MxS) = 2.56
CV: = 17.11%	CV: = 6.09%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 28 The 100 seed weight (g)

	Plants m^{-2}	100-seed weight (g) (R_S)				100-seed weight (g) (R_l)			
		Type of seedbed				Type of seedbed			
		Flat	Ridge	Furrow	Mean	Flat	Ridge	Furrow	Mean
T_1 – (35x30) cm	(9)	31.6	27.1	27.9	28.9	36.6	29.9	30.4	32.3
T_2 – (25x30) cm	(13)	32.2	27.8	33.4	31.1	29.8	29.4	33.4	30.9
T_3 – (15x30) cm	(22)	244	34.1	25.5	28.0	34.9	23.9	29.2	29,3
T_4 – (5x30) cm	(66)	28.0	31.4	26.6	28.7	30.7	22.6	28.0	27.1
Mean		29.1	30.1	28.4		33.0 a[3]	26.5 b	30.3 ab	

SE: Subplots (S) – 1.90	SE: Subplots (S) – 1.78
SE: Mainplots (M) – 0.87	SE: Mainplots(M) – 1.21
SE: (MxS) – 3.28	SE: (MxS) – 3.08
CV: – 19.50%	CV: – 17.83%

[3] Value in the marginal mean followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

Table 29.Above ground dry matter (kg) ha^{-1} at harvest

	Plants m^{-2}	Above ground dry matter (kg) ha^{-1} (R_S)				Above ground dry matter (kg) ha^{-1} (R_L)			
		Type of seedbed				Type of seedbed			
		Flat S_1	Ridge S_2	Furrow S_3	Mean	Flat S_1	Ridge S_2	Furrow S_3	Mean
T_1 – (35x30) cm	(9)	853.3 e[1]	691.2 f[1]	701.4 f[1]	748.6 c[2]	918.1 b[1]	851.8 bc[1]	864.0 bc[1]	878.0a[2]
T_2 – (25x30) cm	(13)	719.6 f	546.1 g	830.9 e	698.9 d	764.7cde	676.2 def	1271.6 a	904.2 a
T_3 – (15x30) cm	(22)	1031.2 d	1022.0 d	897.2	916.8 b	780.1bcd	570.5 fg	696.3def	682.3 b
T_4 – (5x30) cm	(66)	1760.2 b	2031.1 a	1436.8 c	1747.1 a	624 0 ef	469.5 g	922.2 b	672.2 b
Mean		1093.1 a[3]	1073.8ab	915.6 b		772.0 b[3]	642.0 c	938.5 a	

SE: Subplots (S) – 12.37

SE: Mainplots (M) – 41.20

SE: (MxS) – 21.42

CV: – 11.13%

SE: Subplots (S) – 26.11

SE: Mainplots(M) – 23.28

SE: (MxS) – 45.22

CV: – 9.99%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.2.7 Harvest index (HI)

Generally, the short rain season crop had lower HI values than the long rain season crop (Table 30) except for the crop planted in the furrow during the short rain season. Furthermore, planting in the furrow during the short rain season resulted into significantly ($P \leq 0.05$) higher HI values, especially at lower population densities, than the long season crop. During the short rain season (Table 30) HI tended to decrease with increase in populationdensity. Regardless of the types of seedbed, HI values were lowest at 66 plants m^{-2}.

In the long season (Table 30) HI tended to increase with increase in population density for bambaranuts planted on the ridge but there was no definite trend in HI values for bambaranuts planted in the furrow. In general, planting in the furrow had comparatively lower ($P \leq 0.05$) HI valued than planting on the flat or ridge. Harvest index was highest for bambaranuts planted on the flat at 22 plants m^{-2}.

Table 30. Harvest index.

	Plants m^{-2}	Harvest index (R_S)				Harvest index (R_L)			
		Type of seedbed				Type of seedbed			
		Flat	Ridge	Furrow	Mean	Flat	Ridge	Furrow	Mean
T_1 = (35x30) cm	(9)	25. d[1]	49.3 b[1]	59.9 a[1]	44.7 a[2]	54.5b-e[1]	47.7d-g[1]	36.4 efg[1]	46.2 b[2]
T_2 = (25x30) cm	(13)	45.3 b	22.4 d	62.5 a	43.4 a	59.0 bcd	50.3 b-f	29.5 g	46.2 b
T_3 = (15x30) cm	(22)	32.2 c	23.3 d	34.5 c	30.0 b	95.8 a	67.1 bc	48.4 c-g	70.4 a
T_4 = (5x30) cm	(66)	9.6 e	9.7 e	21.8 d	13.7 c	41.4 d-g	69.0 b	33.8 fg	48.1 b
Mean		28.0 b[3]	26.2 b	44.7 a		62.7 a[3]	58.5 a	37.0 b	

SE: Subplots (S) = 1.28	SE: Subplots (S) = 3.37
SE: Mainplots (M) = 0.89	SE: Mainplots(M) = 3.19
SE: (MxS) = 2.22	SE: (MxS) = 5.83
CV: = 11.65%	CV: = 19.16%

[1,2,3] Values in the main table or marginal means, respectively, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) by Duncan's Multiple Range Test (DMRT).

4.3 Correlation coefficients

This study showed (Tables 31, 32) that grain yield for both seasons was positively correlated with peg and pod numbers, leaf, stem, pod and kernel dry matter. On the other hand flower number was highly correlated with yield during the short rain season but had a negative correlation during the long rain season. Both leaf number and plant height were positively correlated to grain yield during the long rain season.

During the short rain season stem dry matter and plant height, peg number and leaf number, pod number and leaf number, stem dry matter and flower number, pod number and peg number, leaf dry matter and peg number, pod dry matter and peg number, kernel dry matter and stem dry matter were positively correlated to each other (Table 31). During the long rain season (Table 32), however, leaf number and plant height, pod number and plant height, kernel dry matter and flower number, pod dry matter and peg number, pod dry matter and leaf dry matter, kernel dry matter and stem dry matter, leaf dry matter and number of pods were positively correlated.

4.3.1 Coefficients of determination

Results of coefficient of determination (R^2) analysis are given in Tables 33 and 34. Important parameters of growth which contributed to bambaranut grain yield are presented in Table 33 for the short rain season and Table 34 during the long rain season.

Table 31. Correlation coefficients between pairs of different parameters of bambaranut growth and yield (short rain season).

Parameter	1	2	3	4	5	6	7	8	9	10
1. Plant height	1.000									
2. Leaf number	-0.260	1.000								
3. Flower number	0.068	-0.159	1.000							
4. Number of pegs	-0.098	0.421	-0.221	1.000						
5. Number of pods	-0.206	0.349	-0.208	0.573	1.000					
6. Leaf DM	-0.020	-0.277	-0.175	0.249	0.081	1.000				
7. Stem DM	0.136	-0.334	0.368	-0.740	-0.397	-0.683	1.000			
8. Pod DM	0.039	0.072	-0.208	0.462	-0.110	0.078	-0.405	1.000		
9. Kernel DM	0.080	-0.178	0.061	-0.796	-0.463	-0.382	0.716	-0.704	1.000	
10. Grain yield kg/ha^{-1}	-0.098	-0.001	0.633**	0.362**	0.561**	0.416**	0.093	0.628**	0.670**	1.000

** Significance at ($P \leq 0.01$)

Table 32. Correlation coefficients between pairs of different parameters of bambaranut growth and yield (long rain season).

Parameter	1	2	3	4	5	6	7	8	9	10
1. Plant height	1.000									
2. Leaf number	0.233	1.000								
3. Flower number	-0.253	-0.063	1.000							
4. Number of pegs	-0.479	-0.238	-0.277	1.000						
5. Number of pods	0.201	-0.032	0.025	0.007	1.000					
6. Leaf DM	-0.138	-0.236	-0.081	0.267	0.198	1.000				
7. Stem DM	-0.124	-0.090	0.043	-0.183	-0.309	-0.554	1.000			
8. Pod DM	-0.140	-0.198	-0.235	0.157	-0.336	0.165	-0.217	1.000		
9. Kernel DM	-0.031	-0.072	0.394	-0.267	-0.069	-0.294	0.269	-0.742	1.000	
10. Grain yield kg/ha^{-1}	0.259	0.511**	-0.179	0.209	0.801**	0.491**	0.607**	0.865**	0.790**	1.000

** Significance at ($P \leq 0.01$).

Table 33. Coefficient of determination of grain yield to some bambaranut growth parameters (short rain season).

Parameter	Coefficient of determination
Kernel DM	0.45
Flower number	0.40
Pod DM	0.39
Pod number	0.31
Leaf DM	0.17
Peg number	0.13

Table 34. Coefficient of determination of grain yield to some bambaranut growth parameters (long rain season)

Parameter	Coefficient of determination
Pod DM	0.75
Pod number	0.64
Kernel DM	0.62
Stem DM	0.37
Leaf number	0.26
Leaf DMp2633X0.24	

5.0 DISCUSSION

5.1 Vegetative growth

In this study differences in emergence percentages occurred between different types of seedbed. During both seasons differences in emergence rates were significant ($P \leq 0.05$) from 6-10 DAS and 6-13 DAS for the short and long rain season crop, respectively. These figures fall within the ranges reported by Temu (1994).

In both seasons bambaranuts planted on the ridge had the lowest rate of emergence compared to seeds planted in the furrow or on the flat. These results concur with earlier findings on groundnuts where Wood (1970) reported decreases in seedling establishment of up to 6% of expected plant population in groundnuts planted on raised beds. Low rates of emergence on bambaranuts planted on the ridge could be attributed to a larger area of the soil surface being exposed to evaporation which in turn affected the amount of moisture available in the top 2.5 to 4 cm of the soil surface where the seed was placed.

During both seasons emergence rates were also slowest at higher population densities especially for the seeds planted on the ridge. These results also agree with previous findings on groundnuts where Wood (1970) reported a decline in percentage establishment in Spanish groundnuts as the seed rate was increased. In this study decreases in emergence rates with increase in population density was attributed to differences in the within row competition for soil moisture.

Generally, the short rain season crop was taller than the long rain season crop. During the short rain season bambaranuts planted on the ridge were taller than those on the flat and furrow. Bambaranuts planted on the flat were, however, taller than those planted on the ridge or furrow during the long rain season. These differences arose because of changes in moisture availability. Such differences in the growth of bambaranuts because of changes in soil moisture content have similarly been reported in earlier findings (Chavula, 1991) where excessively wet conditions suppressed the growth of bambaranuts. This was attributed to possible anaerobic conditions created in the subterranean environment. In this study, ridges served as micro-watershed with a lot of water draining into the furrow during rainfall and/or irrigation. However, during excessive rains, furrows became excessively wet to the point of being waterlogged. Such conditions were not conducive for the growth of bambaranuts planted in the furrow during the long rain season. During the long rain season, on the other hand, planting on the flat bed enhanced plant height because of good drainage.

Plant height increased with increase in plant population for the short rain season. The reverse was true for the long rain season crop. Edje et al. (1974) and Arnon (1987) ascribed increased plant height in beans to plant competition for light. Reduction in plant height with increase in plant population in beans have also been reported in other studies (Kasuga and Rweyemamu, 1988). In general, one would have expected plant height to increase with increase in population density as plants compete for light. While this was the case for the long rain season crop, it was not the case for the short rain season crop. Two possible reasons could have accounted for the reduction in plant height with increase in population density. Firstly, an early attack of powdery mildew caused by (*Sphaerotheca voandzeiae* (Bour.) and leaf spot caused by (*Cercospora voandzeiae* (Bour.), started from about 35 DAS for the long rain season crop. The on set of the disease was delayed in the short rain season crop and was observed to begin at 77 DAS. Secondly, the long rain season crop was generally less vigorous in growth as compared to the short rain season crop (Plate 2) because of the effect of the disease and excessively wet conditions which reduced plant growth.

The ability of plants to intercept light depends, among other factors, on the number of leaves, and size of leaves the plant produces (Temu, 1994). In order to maximize solar radiation plants must intercept as much solar radiation as possible for dry matter production.

Short rain season crop at 76 DAS

Long rain season crop at 76 DAS

Plate : 2 Visual comparison of crop performance during the two seasons

During the early days of growth, the long rain season crop was generally taller and more uniform than the crop planted in the short rain season. During the period of maximum rowth (63 DAS), however, the short rain season crop surpassed the long rain season crop in leaf area values. Differences in temperature during the short and long rain season crop could have affected the expansion of leaves. During the months of November, 1994 to February, 1995 when the short rain season trial was conducted the mean ambient temperature was about 26°C. There was a general decline of about 5°C in the mean ambient temperature from March to June, 1995 when the long rain season trial was conducted (Appendix 1). In an experiment on field beans (Bull, 1968) and cowpeas (Littleton *et al.*, 1979) it was reported that the relative rate of increase in leaf area plant^{-1} was closely related to daily maximum ambient temperature. They concluded that leaves that expanded during warmer periods of the season were slightly larger than those that expanded during cooler periods, therefore, resulting into higher values for leaf area plant^{-1}. In this study, the relatively high values of leaf area plant^{-1} during the short rain season could, therefore, be attributed to the leaves that expanded during the warmer part of the season. These leaves were slightly larger than the ones that expanded during cooler periods when the long rain season trial was conducted. Overall, the highest leaf area plant^{-1} was attained at 63 DAS after which there was a decline. Three factors accounted for this decline. First, the onset of leaf senescence and the death and fall of leaves due to an infestation of powdery mildew and Cercospora leaf spot. Secondly, a reduction in radiation from 17.50 MJ m^{-2} in March to 12.05 MJ m^{-2} in May affected dry matter accumulation which eventually affected leaf area expansion (Appendix I). Thirdly, excessive rainfall during the long rain season affected growth in the latter stages from 63 DAS onwards. Too much moisture has been reported to reduce leaf area and leaf area index (Chavula, 1991).

In this study the trend for changes in LAI were similar to those of leaf area plant^{-1}. Characteristically, there was a period of slow initial increase in LAI (21-49 DAS) followed by a sharp increase up to 63 DAS and then followed by a decline beyond this period. These results agree with the findings of Littleton et al. (1979) who reported of a decline in LAI for various annual crops which included cowpeas. This trend was ascribed to a more rapid loss of old tissue compared to the relatively slower rate of producing new tissue.

In general, leaf area index increased with increase in population density. This, however, did not necessarily result in high yields. Weber et al. (1966) working on soybeans reported that conditions that maximise LAI are not conducive to high yields because of excessive competition for resources especially light. The highest LAI values for the long (9.8) and short rain seasons (5.8) were recorded at a population density of 66 plants m^{-2}. On the average, the short rain season crop also recorded the highest LAI values than the long rain season crop for bambaranuts planted on the ridge and furrow. Excessively wet conditions probably had an effect on nutrient uptake by plants. A reduction in sunshine hours (Appendix 1) during the long rain season from 6.6 in February to 4.2 in May also slowed the rate of photosynthesis and dry matter accumulation which in turn reduced the overall plant size. The slow growth of plants as measured in terms of height after 63 DAS coincided with pod formation and implied that dry matter was translocated from stems to pod production and that more dry matter was lost in the stem than could be replaced because assimilates were directed to the grain (Ishag, 1973a).

The number of flowers $plant^{-1}$ were significantly ($P \leq 0.05$) affected by types of seedbed both during the short and long rain season. Generally, flower production $plant^{-1}$ for the short rain season crop was low at 63 DAS but increased considerabl up to 91 DAS. During the short rain season, the reduction in flower production $plant^{-1}$ was ascribed to the luxuriant shoot growth the maintenance of which became strong competitive sinks for assimilates that would otherwise be allocated to flower, peg and pod production (Ishag, 1973b; Ameyaw and Doku, 1983). Competition was more intense at 66 plants m^{-2} across all types of seedbed.

Flower production tended to increase with increase in population up to 13 plant m^{-2} above which flower production declined. This is in agreement with the findings of Ojehomon and Bamiduro (1971) who reported of depressed flower production at high population densities in cowpeas. Decreases in flower production as population density was increased could be ascribed to intraplant competition which becomes more intense at higher population densities. As population density is increased, resources for the individual plant become limiting resulting into high intra-plant competition for assimilates. This culminated in a compensatory variation among the yield components such as flowers, pegs and pods in response to partitioning assimilates.

The number of pods that were eventually produced per plant were much less than the number of pegs counted at 63 DAS and 91 DAS. During the short rain season less than 30% of the flowers at 63 DAS developed into pegs. These findings are in agreement with Elia (1985) who observed 68.43% flower abortion in a none eyed cream cultivar. Chavula (1991) ascribed such differences due to flower abortion and damage during watering.

Pod initiation started at about 55 DAS with 63-65 DAS being the period of maximum pod formation. Generally, the short rain season crop produced fewer pods $plant^{-1}$ than the long rain season crop. The coefficient of variation (120.37%) in pod production during the short rain season was very high because there were a number of samples which recorded no pods $plant^{-1}$. Furthermore, bambaranuts planted in the furrow produced more pods than those on ridges and flat during the short rain season while planting on the ridge enhanced pod production during the long rain season. Generally, in the long rain season where planting was done in the furrow podding was poor because the soil was relatively wetter than on the ridge or flat bed. This confirms previous findings that high levels of moisture, which was more pronounced in furrows during the long rain season, reduces flower, peg and pod production in bambaranuts (Ameyaw and Doku, 1983). Relatively wetter conditions in the furrows during the long rain season became a stress factor. This in turn reduced soil aeration and affected nutrient availability (Squire, 1990). Hurd and Spratt (1987) reported of decreases in nutrient concentration as the water content of the soil is increased.

Pod production was generally lower at 66 plants m^{-2} regardless of type of seedbed. Decreases in the number of pods $plant^{-1}$ with increases in plant population have been reported in groundnuts (Eliesen and Freira, 1992) and beans (Edje et al.,1971). Decreases in pod production in this study were ascribed to high intra-plant competition at high population densities. Usually with increase in plant density, the combined demand for nutrients and light exceeds the needs of each individual plant resulting into competition for these resources.

In this study, planting on the ridge for the short rain season produced more shoot dry matter at 35 DAS. This is also reflected in leaf area $plant^{-1}$ and leaf area index values. Shoot dry matter tended to increase with increase in population density up to 13 plants m^{-2}. This was because plant competition was less intense at this stage and the effect of increased population density was not critical. However, with the advance of the season (63-91 DAS) there was a tendency for shoot dry matter to decrease with increase in population density especially for bambaranuts planted on the ridge or flat. This was especially the case during the short rain season crop. The trend was, however, less distinct for the long rain season crop. These results are in agreement with Ishag (1973a) who reported of reduced plant size with increased population density in field beans. Plants are highly plastic in response to space. Usually if space is not limiting, plants produce more shoot dry matter in an attempt to fill the empty space. As population pressure is increased, however, shoot dry matter decreases. In this study decreases in shoot dry matter plant^{-1} with increase in population density can be ascribed to plant competition for resources of production which resulted into reduced plant size.

For the short rain season crop root dry weight tended to decrease with increase in population density and with the age of the plant. As plant population per unit area was increased, excessive plant competition reduced plant size and this eventually affected the sizes of the rest of the plant components such as roots.

During the long rain season, bambaranuts planted on the flat recorded the highest root:shoot ratio (1:0.45). The rest of the ratios were below 1:0.34. The short rain season crop had the highest root:shoot ratio of 1:1 for the crop planted on the ridge at the density of 9 plants m^{-2} during the early stages of growth (35 and 63 DAS). The root:shoot ratios reported here are much lower than 1:2.5 reported for grass (*Lolium perenne*) where drought was not a serious factor (Hurd and Spratt, 1987). For the long rain season crop the 1:0.45 ratio recorded at 93 DAS indicates an increase in the weight of the subterranean parts which included pegs and pods and therefore reflects better performance in yield of the crop planted on the ridge. The 1:1 ratio for the short rain season crop indicates that root and shoot development were matched 1:1 during the early stages of growth since there were no pods at that stage. At 93 DAS the root:shoot ratio for the crop planted on the ridge declined to 0.04. This was reflected in the poor performance in yield of the crop planted on the ridge during the short rain season.

5.2 Yield and yield components

During the short rain season bambaranuts planted on the ridge at the density of 9 plants m^{-2} produced the highest pod yield but this did not necessarily result into high grain yield because of low shelling percentage. Shelling percentage was low because some pods were rotten. Pod rot was influenced by rains which fell in the month of February before the short rain season crop was harvested. In addition to this, grain filling was poor because of *Cercospora* leaf spot disease. *Cercospora* leaf spot has been reported to be a serious disease in bambaranuts. *Cercospora* leaf spot causes a great reduction of the photosynthetic capacity of the plant culminating into the production of small sized fruits and reduction in yield (Lamptey and Ofei, 1977).

During the short rain season, planting in the furrow at the density of 22 plants m^{-2} produced the highest grain yield. During the short rain season, when the supply of moisture seems to be limiting, planting bambaranuts in the furrow at the density of 13 plants m^{-2} would be considered optimum as any rise in population density beyond this point resulted into depressed pod and grain yields as well as shelling percentage. The results obtained in this study for the short rain season are in agreement with Cumberland (1978) who reported similar findings at densities of 7 and 14 plants m^{-2}. During the long rain season, however, the optimum population density was at 22 plants m^{-2} planted on the flat as any rise in beyond this point resulted into depressed pod and grain yield. Planting on the flat in the wet season has been reported to give high yields in Zambia (Kannaiyan, 1988), cited by Linnemann (1992). This was ascribed to good drainage. Grain and pod yields were depressed with increase in population for bambaranuts planted on the ridge. Increasing the plant population above 22 plants m^{-2} decreased yield $plant^{-1}$ due to increased intra- plant competition while sparsely spaced plants had adequate supply of growth resources of production (nutrients, moisture and light). Edje et al. (1975) attributed the reduction in yield $plant^{-1}$ of garden beans at high densities to a decrease in the number of flowers setting mature pods due to competition for photosynthates. Similar results were reported in soybeans (Weber et *al*., 1966), in field beans (Edje et *al*., 1974; Leakey, 1972) and in faba beans (Ishag, 1973b). Planting in the furrow during the short rain season enhanced pod and grain production. The reverse was true for the long rain season. The reason for these differences is that furrows acted as micro-watershed in which runoff water from seed weight reported in this study are lower than 44.20 g previously reported by Elia (1985) for a cream landrace. The low values in the 100-seed weight reported in this trial were attributed to poor pod filling as a result of a rapid decrease in leaf area from 77 DAS during the period of maximum pod filling due to disease.

Although grain yield accumulation decreased with increase in population density, above ground dry matter yield increased with increase in population density across all types of seedbed x population density interactions for the short rain season. There was high rate of dry matter conversion during the short rain season because of high radiation. There is evidence that dry matter accumulation is directly related to the amount of radiation intercepted (Chavula, 1991). High leaf area and LAI values for the short rain season crop could be ascribed to the allocation of a larger proportion of dry matter to leaves, reflecting that early in plant life, the priority is to establish a leaf canopy capable of synthesizing assimilates that would adequately support the plant. This was evident for the short rain season crop which was generally more robust with more leaves than the long rain season crop. However, with the advance of the season, mutual shading of the leaves may have affected the rate of photosynthesis in a negative way. As shaded leaves respire as actively as leaves receiving full sunlight, their total contribution to the total assimilation pool of the crop often becomes negative. The conversion of leaf dry matter into grain yield was, however, not directly related to grain yields as evidenced by the low yields for the short rain season crop. This phenomenon has been observed in other crops such as groundnuts where Sibuga et *al.* (1990) reported no increment advantage to higher grain yields with increase in leaf area.

During the short rain season, bambaranuts planted in the furrow recorded the highest harvest index (HI) while during the long rain season bambaranuts planted on the flat or ridge produced the highest HI values. It has been postulated (DeLoughery and Crookston, 1979) that a sparse stand will use the store of water in the soil rapidly than a dense stand and will therefore have a greater partition factor for grain. Such a stand will accumulate relatively more dry matter after grain filling begins. Because of this HI in dry condition usually increases as population density decreases. Harvest index increased from a density of 9 to 13 plants m^{-2} for bambaranuts planted in the furrow or flat for the short rain season beyond these population densities HI declined. The optimum plant population density for the long rain season crop was at 22 plants m^{-2} beyond which HI declined. Squire (1990) reported HI values of 30 to 60 for indeterminate crops under wet conditions. This is in agreement with values for bambaranuts grown during the long rain season, although some HI values (95.8) for bambaranuts planted on the flat are excessively high. This might have been due to sampling error. A value of about 65.0 would have been acceptable.

There were significant ($P \leq 0.05$) positive correlations between bambaranut yield and flower number (r=0.633), number of pegs (r=0.362), number of pods (r=0.561), leaf DM (r=0.416), pod DM (r=0.628) and kernel DM (0.670) during the short rain season. During the long rain season pod DM (r=0.865), number of pods (r=0.801), kernel DM (r=0.790), stem DM (r=0.609), leaf number (r=0.511) and leaf DM (r=0.491) were positively correlated to yield. The fact that the yield of bambaranuts was positively correlated to these variables indicates that yield can be appreciably increased by creating appropriate conditions that would increase values of these variables. On the basis of coefficient of determination pod DM, pod number and kernel DM were the most important factors that determined yield during the long rain season.

There was a wide variation in coefficient of determination between the short and long rain season crops. This implies that correlations are as a result of developmental processes rather than genetic. This agrees with Adams (1967) that correlations are caused by genetically independent components developing in a sequential pattern. They are free to vary in response to limited constant input of metabolites or an input which changes such that it becomes limiting at critical stages in the developmental sequence. Changing factors in the environment will automatically affect the performance of the measured parameters. From the coefficients of determination it could be concluded that the long rain season was more favourable for the bambaranut crop than the short rain season.

IMPLICATIONS OF THE FINDINGS TO PRODUCTION METHODS AND PRODUCTIVITY OF BAMBARANUTS IN TANZANIA

Bambaranuts are grown under various systems in Tanzania. Although the bulk of the crop is grown under monoculture, mixed cropping is also practiced. Whether bambaranuts are grown as a sole crop or intercrop, flat, ridge, furrow or mound seedbed types are often used.
In Tanzania, farmers prefer planting most crops on ridges to facilitate hand weeding, to concentrate nutrients around the roots, to prevent water logging conditions, to allow good development of roots, tubers or nuts and to control soil erosion. The results of this trial have shown that planting bambaranuts on the ridge at higher population densities in areas such as Morogoro, Dodoma and Singida where rainfall is erratic may have serious implications on plant establishment and the eventual grain yield of bambaranuts.

Ridges have a desiccating effect on the soil thereby raising the soil temperature and reduce soil moisture. Since planting on the flat or furrow enhanced seed emergence during both seasons, encouraging farmers to plant bambaranuts on the flat or furrow seedbed would ensure optimum plant population per unit area and increase grain yield. In drier areas, a large canopy and tall plants are not conducive to high grain yield. Taller plants did not necessarily result into high grain yields. Actually, grain yield was negatively correlated to plant height especially during the short rain season. In the long analysis, the shorter crop yielded higher than the tall crop. Bunch varieties would, therefore, be suitable during the short rain season.

Results also suggest that leaf area index values at higher population densities did not necessarily produce high grain yield. In fact, population densities above 22 plants m^{-2} would not be practical for farmers. Similarily, population densities below 13 plants m^{-2} as practiced by most farmers in Tanzania contribute to low bambaranut yield. Lower population densities would only be useful in areas where bambaranuts are intercropped.

Grain yield was positively correlated to the number of flowers, pegs and pods during the short rain season. Flower production depends on optimum moisture availability. This implies that in order to realise high yields during the short rain season supplementary irrigation should be used where available in conjunction with planting either on the flat or furrow seedbed. While flower number was positively correlated to grain yield during the short rain season, it was negatively correlated to long rain season. Higher population densities at 66 plants m^{-2} reduced pod production.

Under conditions of moisture stress, root : shoot ratio usually increases. A high value of root : shoot ratio is an effective means of adaptation by plants to dry conditions. Higher root : shoot ratio values on the flat or furrow seedbed during the short rain season indicates better utilisation of soil moisture by such plants.

Seedbed types and population densities influenced grain yield and its components during both seasons. Planting bambaranuts on the flat or furrow seedbed enhanced grain yield, but were detrimental to grain yield during the long rain season. The yield (519.2 kg ha^{-1}) obtained in this trial for the crop planted in the furrow at 13 plants m^{-2} during the short rain season is slightly below the average yield of bambaranut in Tanzania of 650 kg ha^{-1} per year. However, the yield (746.6 kg ha^{-1} realized during the long rain season for the crop planted on the flat at 22 plants m^{-2} is above the average. The benefits of the combined yield (1265.8 kg ha^{-1} per year) would, therefore, contribute to bambaranut yield in Tanzania. The practicability of planting bambaranuts in furrows if introduced to farmers would also improve bambaranut production in Tanzania. Usually when preparing seedbed, one starts with a flat seedbed, popularly known as conventional tillage. The construction of furrows results into a ridge-furrow-system. This practice could open new possibilities in developing mixed cropping systems. In this trial, the possibility of planting two crops in a year especially in areas which receive bi-modal rainfall could increase the production of bambaranuts in Tanzania.

6.0 CONCLUSIONS AND RECOMMENDATIONS

This study has revealed that the growth and yield of bambaranuts is affected by different types of seedbed and varying population density. Marked differences in the growth and grain yield of bambaranuts were also apparent between the short and the long rain season crop. On the basis of these results, the following conclusions were drawn.

1. Planting bambaranuts on the ridge during the short rain season enhanced plant height, leaf area plant^{-1}, leaf area index and root:shoot ratio. Planting on the ridge durig the short rain season, however, reduced grain yield ha^{-1}.

2. Bambaranuts planted in the furrow enhanced flower, peg and pod production during the short rain season. Furrows were also favourable for root dry matter, grain yield ha^{-1} and harvest index. Planting bambaranuts in the furrow during the short rain season could be recommended in order to increase bambaranut yield.

3. Although bambaranuts planted in the furrow during the long rain season, were the tallest, produced highest leaf area plant^{-1} and had the highest shoot dry matter, pod and grain yield were suppressed. It is, therefore, recommended that planting in the furrow during the long rain season should be avoided. On the other hand, planting in the furrow would be beneficial in areas which receive intermittent rainfall as was the case during the short rain season.

4, Planting bambaranuts on the flat or ridge during the long rain season enhanced pod grain yield ha^{-1} and shelling percentage. Planting on the flat was also favourable for flower, peg, pod, root dry matter root:shoot ratio, the 100-seed weight and harvest index.

5. Increases in population density decreased some growth variables such as flowers, pegs, pods, shoot, root dry matter and leaf area plant^{-1}. Leaf area index was, however, enhanced by increases in population density.

6. Population density at 13 plants m^{-2} for the crop planted in the furrow produced the highest grain yield during the short rain season. Wider spacings under conditions of moisture stress are, therefore, necessary for increased yields in bambaranuts.

7. Population density at 22 plants m^{-2} for bambaranuts planted on the flat or ridge produced the highest grain yield during the long rain season. Planting on the flat or ridge at spacings closer than 13 plants m^{-2} is, therefore, recommended when soil moisture is not limiting.

8. Since the experiment was only done once during the short and long rain seasons because of time limitations, and that the results obtained did not show consistency for some of the variables recorded, it is recommended that further research be conducted over several seasons in order to strengthen the validity of these findings. Further research is also recommended for the possibility of intercropping bambaranuts with other crops such as maize especially for bambaranuts planted in the furrow so that the ridges are also used.

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APPENDICES

Appendix I

Summarized climatic data during the study period (1994/1995)

Month	Rainfall (mm)	Total Pan Evaporation (mm)	Mean Temperature ^{0}C	Mean Sunshine hours	Mean RH(%)	MJ M^{-2} Mean Radiation
September, 1994	5.6	164.6	23.45	7.1	63.48	18.18
October	26.0	195.3	23.05	7.6	69.84	17.40
November	43.5	172.0	25.4	7.3	69.88	18.13
December	49.2	182.9	26.25	7.3	71.79	18.20
January, 1995	142.2	193.1	26.30	7.3	73.38	18.77
February	98.5	164.4	26.15	6.6	71.20	18.30
March	202.0	142.3	25.65	6.2	80.00	17.58
April	246.9	210.2	24.70	5.4	80.85	16.02
May	134.2	93.1	23.25	4.2	84.21	12.05
June	0.0	95.5	20.70	6.1	48.85	14.59
July	1.3	112.8	21.40	6.8	69.42	14.94
August	28.8	123.6	22.60	7.5	71.26	17.14
Total	978.2	1849.8		79.4		201.3
Mean	81.5	154.2		6.6		16.8

Appendix II

Bambara groundnut germplasm collection data

1. Landrace name: Bambaranuts (Dodoma cream)

2. Country of origin: Tanzania

3. Date of collection: 4 November 1994

4. Location of collection site:
(market name/farmers name and kms from nearest town) Dodoma Produce Market. They were bought from Mr. Mashaka who was not even the original producer.

5. Latitude, longitude and altitude of collection site: 5^0 54'S; 35^0 57'E

6. If seed was not produced at collection site, then location of production: No information

7. Year of production of seed: 1992/93 growing season

8. Growth habit: *(spreading, semi-bunched or bunched)* Semi-bunched

9. Normal planting time: (*farmers knowledge*) March

10. Normal harvest time: June/July

11. Usually grown as a sole crop or in a mixed cropping system?

    Might have been grown in a mixed crop system. Bambaranut seed was mixed with yellow maize (*Zea mays*) and some groundnut seed.

12. Susceptibility to pests and diseases: Some of the seeds were infested by weevils

For the following evaluation please refer to the descriptors list (IBPGR, 1987):

13. Seed colour: Cream

14. Seed pattern: Cream/no eye

15. Eye colour: Whitish

16. Eye pattern: Oval

17. Variability in seed colour: *Take 250 g of seed and group into subgroups according to testa and eye pattern and colour, and determine the number of seeds in each subgroup and the weight of each subgroup.*

As presented in Plate 2

18. Typical seed weight: Not Determined

19. Variability in seed weight:
Take 250 g seed, divide individual seeds into classes of 0.1 g (0.31-0.4 g, 0.41-0.5 g, etc), determine the number of seeds within each weight class and the total weight of seeds in each weight class

Not determined

Appendix III

Leaf area index (LAI) calculation

Leaf weighing method

1. The sample consisted of 18 plants and out of this the area of a sub-sample of 6 plants was recorded.

2. The dry leaf weight of the sub-sample was recorded

3. The specific leaf area (SLA) of sub-sample was calculated by dividing the leaf area (LA) with the leaf dry weight (LDW)
4. The dry leaf weight of the remaining sample was then determined from the dry matter (DM) taken during sequential growth analysis.

5. Leaf area of the remaining sample was calculated by multiplying the LDMW of remaining sample by the specific leaf area.

$$LA_{\text{remaining sample}} = LDMW \times SLA$$

6. Total leaf area (TLA) of the sample was obtained by adding leaf area of remaining sample plus leaf area of sub-sample.

$$TLA = LA_{\text{sub-sample}} + LA_{\text{sub sample}}$$

7. Leaf area index (LAI) was calculated by dividing TLA by total ground area.

Appendix IV

Statistical significance of analyzed variables for short rain season (R_S) seed emergence

Days after sowing (DAS)	Seedbed	Population	Seedbed x Population
6	*	*	*
7	S	S	S
8	S	S	S
9	NS	S	NS
10	NS	S	NS
11	NS	S	NS
12	NS	S	NS
13	NS	S	NS
14	NS	S	NS
15	NS	S	NS
16	NS	S	NS

NS = Not significance

* = Significance at ($P \leq 0.05$)

Appendix V

Statistical significance of analyzed variables for long rain season (R_L) seed emergence

Days after sowing (DAS)	Seedbed	Population	Seedbed x Population
6	S	S	S
7	S	S	S
8	S	S	S
9	S	S	S
10	S	S	S
11	S	S	S
12	NS	S	NS
13	NS	S	NS
14	NS	S	NS
15	NS	S	NS
16	NS	S	NS

NS = Not significance

S = Significance at ($P \leq 0.05$)

Appendix VI

Summary of analysis of variance for seed emergence for type of seedbed (Main Plots)

DAS	Treatment mean square	Error mean square	F value (2,4)*
Short rain season			
6	-	-	-
7	$3.2x10^3$	51.21	64.37
8	$1.0x10^4$	727.9	13.86
9	$3.7x10^3$	662.54	5.71
10	683.44	130.99	5.22
11	120.36	34.99	3.44
12	39.36	27.11	1.45
13	29.78	19.40	1.53
14	31.03	19.44	1.60
15	15.75	28.21	0.56
16	42.86	17.99	2.38
Long rain season			
6	$1.2x10^3$	81.51	15.86
7	$1.2x10^4$	76.32	160.01
8	$2.6x10^4$	181.07	145.47
9	$1.8x10^4$	327.86	57.54
10	$2.0x10^5$	417.32	49.43
11	$1.4x10^4$	418.11	34.27
12	$4.9x10^3$	897.83	5.47
13	604.53	$1.0x10^3$	0.56
14	744.25	$1.1x10^3$	0.67
15	597.00	$1.0x10^3$	0.56
16	531.75	$1.0x10^3$	0.53

* Tabulated value for $P \leq 0.05$ = 6.94

Appendix VII

Summary of analysis of variance for seed emergence for type of seedbed (sub-plot factor)

DAS	Treatment mean square	Error mean square	F value (3,18)*
Short rain season			
6	-	-	-
7	4.8×10^3	154.59	31.56
8	5.3×10^4	1.2×10^3	42.25
9	1.9×10^5	874.65	222.03
10	3.6×10^5	464.24	782.89
11	4.9×10^5	145.02	3.3×10^3
12	4.9×10^5	92.94	5.3×10^3
13	4.9×10^5	79.09	6.2×10^3
14	4.9×10^5	79.47	6.2×10^3
15	4.9×10^5	80.76	6.1×10^3
16	4.9×10^5	75.35	6.6×10^5
Long rain season			
6	675.27	43.95	15.37
7	2.1×10^4	32.76	648.87
8	5.3×10^4	143.43	370.92
9	9.3×10^4	613.17	151.99
10	1.4×10^5	437.37	339.81
11	2.4×10^5	1.1×10^3	204.07
12	3.1×10^5	1.7×10^3	181.20
13	3.6×10^5	1.1×10^3	311.57
14	3.7×10^6	1.4×10^3	208.65
15	3.6×10^6	1.1×10^3	318.94
16	3.6×10^5	1.1×10^3	317.65

* Tabulated value for $P \leq 0.05$ = 3.16

Appendix VIII

Summary of analysis of variance for seed emergence for main-plot x sub-plot

DAS	Treatment mean square	Error mean square	F value (3,18)*
Short rain season			
6	-	-	-
7	1.5×10^3	154.59	10.08
8	2.1×10^3	1.2×10^3	1.71
9	1.8×10^5	874.65	2.15
10	350.19	464.24	0.75
11	92.32	145.02	0.64
12	18.62	92.94	0.20
13	13.85	79.09	0.18
14	14.62	79.47	0.18
15	23.79	80.76	0.29
16	14.86	75.35	0.197
Long rain season			
6	464.10	43.95	10.56
7	5.0×10^3	32.76	153.94
8	1.2×10^3	143.43	86.56
9	8.5×10^3	613.17	13.97
10	1.2×10^5	437.37	28.55
11	1.2×10^4	1.1×10^3	10.36
12	3.2×10^3	1.7×10^3	1.89
13	634.95	1.1×10^3	0.53
14	774.10	1.4×10^3	0.53
15	543.30	1.1×10^3	0.47
16	564.38	1.1×10^3	0.49

* Tabulated value for $P \leq 0.05$ - 3.66

Appendix IX

Statistical significance of analyzed variables (short rain season)

Parameter	DAS	Type of seedbed	Population density	Population x type of Seeds
Plant height	35	NS	*	NS
Plant height	63	*	NS	NS
Plant height	91	NS	NS	NS
Leaf area	35	NS	*	*
Leaf area	63	*	*	*
Leaf area index	35	NS	*	NS
Leaf area index	63	NS	*	NS
No. of flowers	63	NS	*	*
No. of flowers	91	*	*	*
No. of pegs	63	*	*	*
No. of pegs	91	NS	*	*
No. of pods	63	NS	NS	NS
No. of pods	91	*	*	*
Shoot dry matter	35	NS	*	*
Shoot dry matter	63	*	*	*
Shoot dry matter	91	NS	*	*
Root dry matter	35	NS	NS	NS
Root dry matter	63	NS	NS	NS
Root dry matter	91	*	*	*
Root: shoot ratio	35	NS	NS	NS
Root: shoot ratio	63	*	NS	NS
Root: shoot ratio	91	*	NS	*

NS = non significance * = Significant at ($P \leq 0.05$)

Appendix X

Statistical significance of analyzed variables (long rain season)

Parameter	DAS	Type of seedbed	Population density	Population x type of Seeds
Plant height	35	NS	*	*
Plant height	63	*	NS	NS
Plant height	91	NS	NS	*
Leaf area	35	*	*	*
Leaf area	63	*	*	*
Leaf area index	35	NS	*	NS
Leaf area index	63	*	*	*
No. of flowers	63	*	NS	*
No. of flowers	91	*	*	*
No. of pegs	63	*	*	*
No. of pegs	91	*	*	*
No. of pods	63	*	*	*
No. of pods	91	*	*	*
Shoot dry matter	35	*	*	*
Shoot dry matter	63	*	NS	*
Shoot dry matter	91	*	*	*
Root dry matter	35	NS	NS	*
Root dry matter	63	*	*	*
Root dry matter	91	*	*	*
Root: shoot ratio	35	NS	NS	NS
Root: shoot ratio	63	*	NS	NS
Root: shoot ratio	91	*	NS	*

NS – Non significance   * = significant at ($P \leq 0.05$)

Appendix XI

Statistical significance of analyzed variables (yield and yield components)

Parameter	Type of seedbed	Population density	Type of seedbed population density
Short rain season	*	*	*
No. of plant M^{-2}	*	*	*
Pod yield kg ha^{-1}	*	*	*
Grain yield kg ha^{-1}	*	*	*
Shelling %	*	*	*
Harvest index	*	*	*
100-seed weight (g)	NS	NS	NS
Biological yield	NS	*	*
Long rain season			
No. of plants M^{-2}	*	*	*
Pod yield kg ha^{-1}	*	*	*
Grain yield kg ha^{-1}	*	*	*
Shelling %	*	*	*
Harvest index	*	*	*
100-seed weight (g)	*	*	*
Biological yield	*	*	*

NS - Non significance

* - significance at ($P \leq 0.05$)

Appendix XII

Summary of analysis of variance for types of seedbed during the short rain season (Main plots)

Parameter	DAS	Treatment mean square	Error mean square	F (2,4)*
Plant height	35	8.94	14.53	0.61
Plant height	63	51.62	0.977	52.81
Plant height	91	3.02	1.25	2.42
Leaf area	35	$1.8x10^4$	$1.9x10^4$	0.92
Leaf area	63	$3.7x10^6$	$2.1x10^3$	1696.70
Leaf area index	35	0.070	0.255	0.27
Leaf area index	63	8.00	1.51	5.29
No. of flowers	63	4.62	0.86	5.39
No. of flowers	91	143.21	1.77	81.04
No. of pegs	63	0.490	0.035	13.97
No. of pegs	91	50.84	8.28	6.14
No. of pods	63	0.303	0.130	2.33
No. of pods	91	149.48	1.56	95.73
Shoot dry matter	35	1.24	1.54	0.81
Shoot dry matter	63	74.25	1.26	58.82
Shoot dry matter	91	52.56	22.2	2.37
Root dry matter	35	0.017	0.030	0.56
Root dry matter	63	0.36	0.130	2.74
Root dry matter	91	14.48	0.180	80.55
Root: shoot ratio	35	0.015	0.011	1.37
Root: shoot ratio	63	0.020	0.002	8.63
Root: shoot ratio	91	0.008	0.0001	17.28

* Tabulated value for $P \leq 0.05$ - 6.94

Appendix XIII

Summary of analysis of variance for population density during the short rain season

Parameter	DAS	Treatment mean square	Error mean square	F (3,18)*
Plant height	35	26.99	7.90	3.42
Plant height	63	5.61	4.10	1.37
Plant height	91	3.94	2.14	1.84
Leaf area	35	1.3×10^4	2.8×10^3	4.71
Leaf area	63	5.3×10^6	2.9×10^3	1.7×10^3
Leaf area index	35	4.13	0.101	40.77
Leaf area index	63	41.19	7.10	6.51
No. of flowers	63	4.62	0.94	5.39
No. of flowers	91	456.41	6.67	68.45
No. of pegs	63	0.275	0.077	3.58
No. of pegs	91	2.3×10^3	24.78	92.92
No. of pods	63	0.164	0.073	2.24
No. of pods	91	106.62	2.16	49.40
Shoot dry matter	35	0.64	0.16	3.96
Shoot dry matter	63	65.91	3.26	20.21
Shoot dry matter	91	485.69	4.06	119.51
Root dry matter	35	0.031	0.028	1.13
Root dry matter	63	0.22	0.076	2.85
Root dry matter	91	6.28	0.117	53.65
Root: shoot ratio	35	0.018	0.017	1.06
Root: shoot ratio	63	0.034	0.003	1.46
Root: shoot ratio	91	0.003	0.001	2.41

* Tabulated value for $P \leq 0.05$ - 3.16

Appendix XIV

Summary of analysis of variance for types of seedbed x population density during the short rain season.

Parameter	DAS	Treatment mean square	Error mean square	F (6,18)*
Plant height	35	12.32	7.90	1.56
Plant height	63	6.02	4.10	1.47
Plant height	91	4.00	2.14	0.14
Leaf area	35	$1.6x10^4$	$2.8x10^3$	5.72
Leaf area	63	$3.2x10^5$	$2.9x10^3$	109.54
Leaf area index	35	0.05	0.10	0.52
Leaf area index	3	4.81	0.68	7.10
No. of flowers	63	8.29	0.94	8.84
No. of flowers	91	273.36	6.67	40.99
No. of pegs	63	0.24	0.077	3.12
No. of pegs	91	346.42	24.78	13.98
No. of pods	63	0.145	0.073	1.98
No. of pods	91	102.14	2.16	42.32
Shoot dry matter	35	0.884	0.16	5.51
Shoot dry matter	63	7.15	3.26	2.19
Shoot dry matter	91	40.19	4.06	9.89
Root dry matter	35	0.018	0.028	0.63
Root dry matter	63	0.178	0.076	2.35
Root dry matter	91	10.97	0.117	93.74
Root: shoot ratio	35	0.013	0.017	0.77
Root: shoot ratio	63	0.004	0.003	1.34
Root: shoot ratio	91	0.011	0.001	9.21

* Tabulated value for $P \leq 0.05$ = 3.66

Appendix XV

Summary of analysis of variance for types of seedbed mainplots factor A (long rain season)

Parameter	DAS	Treatment mean square	Error mean square	F (2,4)*
Plant height	35	4.68	7.73	0.61
Plant height	63	70.16	4.12	17.01
Plant height	91	28.66	6.77	4.23
Leaf area	35	4.8×10^4	1.2×10^3	38.93
Leaf area	63	1.6×10^5	596.09	269.26
Leaf area index	35	0.35	0.01	25.72
Leaf area index	63	0.29	1.14	0.26
No. of flowers	63	390.63	3.01	129.99
No. of flowers	91	61.93	1.91	32.43
No. of pegs	63	787.98	20.61	38.24
No. of pegs	91	174.97	9.90	17.68
No. of pods	63	0.324	0.299	1.09
No. of pods	91	85.73	0.83	103.24
Shoot dry matter	35	1.97	0.18	10.90
Shoot dry matter	63	10.26	0.93	11.03
Shoot dry matter	91	6.91	0.731	9.45
Root dry matter	35	0.003	0.021	5.14
Root dry matter	63	0.054	0.002	35.83
Root dry matter	91	9.36	0.035	264.51
Root: shoot ratio	35	0.001	0.0001	6.16
Root: shoot ratio	63	0.001	0.0001	13.79
Root: shoot ratio	91	0.094	0.012	7.74

* Tabulated value for $P \leq 0.05$ = 6.94

Appendix XVI

Summary of analysis of variance for population density during the long rain season (sub-plots)

Parameter	DAS	Treatment mean square	Error mean square	F (3,18)*
Plant height	35	27.95	2.14	13.06
Plant height	63	2.45	15.44	0.16
Plant height	91	5.11	4.91	1.04
Leaf area	35	$9.5x10^3$	551.19	17.36
Leaf area	63	$3.1x10^4$	950.91	32.65
Leaf area index	35	3.99	0.01	689.38
Leaf area index	63	30.41	1.15	26.43
No. of flowers	63	9.55	3.59	2.66
No. of flowers	91	31.11	0.62	50.30
No. of pegs	63	201.84	10.19	19.80
No. of pegs	91	56.43	11.18	5.05
No. of pods	63	13.25	0.182	72.84
No. of pods	91	48.64	0.76	63.67
Shoot dry matter	35	0.32	0.04	8.14
Shoot dry matter	63	2.31	2.01	1.15
Shoot dry matter	91	25.04	0.552	45.37
Root dry matter	35	0.0001	0.0001	1.01
Root dry matter	63	0.042	0.002	23.51
Root dry matter	91	2.42	0.230	10.55
Root: shoot ratio	35	0.0001	0.0001	0.5585
Root: shoot ratio	63	0.001	0.0001	2.94
Root: shoot ratio	91	0.025	0.011	2.19

* Tabulated value for $P \leq 0.05$ = 3.16

Appendix XVII

Summary of analysis of variance for types of seedbed population density during the long rain season

Parameter	DAS	Treatment mean square	Error mean square	F (6,18)*
Plant height	35	27.66	2.14	12.93
Plant height	63	8.41	15.44	0.54
Plant height	91	35.77	4.91	7.28
Leaf area	35	$9.0x10^3$	551.19	16.49
Leaf area	63	$2.7x10^5$	950.91	292.38
Leaf area index	35	0.08	0.01	13.80
Leaf area index	63	0.78	1.15	0.68
No. of flowers	63	74.41	3.59	20.72
No. of flowers	91	82.83	0.618	133.94
No. of pegs	63	230.82	10.19	22.65
No. of pegs	91	774.73	11.18	69.28
No. of pods	63	11.99	0.182	65.97
No. of pods	91	52.09	0.764	68.19
Shoot dry matter	35	0.356	0.040	8.95
Shoot dry matter	63	18.26	2.01	9.10
Shoot dry matter	91	4.35	0.552	7.89
Root dry matter38X35		0.002	0.0001	7.39
Root dry matter	63	0.074	0.002	40.86
Root dry matter	91	2.51	0.230	10.91
Root: shoot ratio	35	0.0001	0.0001	0.211
Root: shoot ratio	63	0.0001	0.0001	2.33
Root: shoot ratio	91	0.016	0.011	1.43

* Tabulated value for $P \leq 0.05$ = 3.66

Appendix XVIII

Summary of analysis of variance for yield and yield components (short rain season)

Factor A (Types of seedbed)	Treatment mean square	Error mean square	F (2,4)*
No. of plants M^{-2}	28.86	13.28	6.24
Pod yield kg ha^{-1}	1.3×10^{5}	1.8×10^{3}	73.09
Grain yield kg ha^{-1}	6.5×10^{4}	511.93	128.28
Shelling %	651.25	299.14	2.18
Harvest Index	1.2×10^{3}	9.70	128.47
100-seed weight	8.99	9.01	0.99
Biological yield	1.1×10^{5}	2.0×10^{4}	5.52

* Tabulated value for $P \leq 0.05$ = 6.94

Factor B (Population density			F (3,18)**
No. of plants M^{-2}	2.4×10^{3}	16.62	149.58
Pod yield kg ha^{-1}	2.4×10^{5}	1.2×10^{4}	19.06
Grain yield kg ha^{-1}	2.6×10^{4}	810.83	32.96
Shelling %	789.14	118.08	6.68
Harvest index	1.8×10^{3}	14.74	127.65
100-seed weight	16.46	32.36	0.51
Biological yield	2.1×10^{6}	1.3×10^{4}	164.22

**Tabulated value for $P \leq 0.05$ - 3.16

Appendix XIX

Summary of analysis of variance for yield and yield components during the long rain season.

Factor A	Treatment mean square	Error mean square	F (2,4)*
No. of plants M^{-2}	234.11	24.69	9.48
Pod yield kg ha^{-1}	1.1×10^5	3.6×10^3	32.36
Grain yield kg ha^{-1}	9.1×10^4	1.4×10^3	63.43
Shelling %	257.62	10.58	24.34
Harvest Index	2.2×10^3	121.74	18.65
100-seed weight	130.22	17.65	7.38
Biological yield	2.6×10^5	6.5×10^3	40.78

* Tabulated value for $P \leq 0.05$ = 6.94

Factor B			F (3,18)**
No. of plants M^{-2}	2.1×10^3	16.44	128.65
Pod yield kg ha^{-1}	1.6×10^5	1.0×10^4	16.15
Grain yield kg ha^{-1}	5.7×10^4	4.3×10^3	13.27
Shelling %	149.57	19.68	7.60
Harvest index	1.2×10^3	102.08	12.31
100-seed weight	45.49	28.41	1.60
Biological yield	1.3×10^5	6.1×10^3	13.06

* Tabulated value for $P \leq 0.05$ = 3.16

Appendix XX:

Summary of analysis of variance for yield and yield components (type of seedbed x plant population)

Parameter	Treatment mean square	Error mean square	F (6,18)*
Short rain season			
No. of plant M^{-2}	274.00	16.62	16.49
Pod yield kg ha^{-1}	$2.9x10^5$	$1.2x10^4$	22.83
Grain yield kg ha^{-1}	$2.2x10^4$	810.83	27.77
Shelling %	445.49	118.08	3.78
Harvest index	393.00	14.74	26.66
100-seed weight (g)	45.46	32.36	1.40
Biological yield	$1.1x10^5$	$1.3x10^4$	8.99
Long rain season			
No. of plants M^{-2}	209.56	16.44	12.75
Pod yield kg ha^{-1}	$7.5x10^4$	$1.0x10^4$	7.27
Grain yield kg ha^{-1}	$3.4x10^4$	$4.3x10^3$	7.9
Shelling %	75.40	19.68	3.83
Harvest index	468.27	102.08	4.59
100-seed weight (g)	22.82	28.41	0.80
Biological yield	$8.0x10^4$	6134.39	13.06

* Tabulated value for $P \leq 0.05$ = 3.66

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