DETERMINATION OF NITROGEN FERTILIZER REQUIREMENT IN BAMBARA GROUNDNUT (*VIGNA SUBTERRANEA* (L.) VERDC.)

BY

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DECLARATION

I, Keikanelwe Ntone hereby declare that the work presented in this dissertation was my own and has never been submitted for a degree at this or any other university.

Signed: ....

Date: ....

APPROVAL

This thesis of MS KEIKANELWE NTONE is approved as fulfilling part of the requirements of the award of the degree of Master of Science in Agronomy (Crop Science) by the University of Zambia.

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ABSTRACT

This study was carried out during the 1993 /94 cropping season at the University of Zambia (UNZA) Farm and Lusitu Sub-Research Station which are situated in Agroecological Zones II and I (medium and low rainfall), respectively. The objective was to determine the nitrogen fertilizer requirement for Bambara groundnut using accessions of different yielding potential. A split plot design was used, with six accessions (ZAVs 3, ZAVs 7, ZAVs 120, ZAVs 6, ZAVs 5 and ZAVs 8) and five nitrogen levels (0, 15, 30, 45 and 60 kg N/ha) as main and sub plots, respectively. The accessions were chosen on the basis of yielding potential, i.e., low (ZAVs 6 and ZAVs 8), medium (ZAVs 7 and ZAVs 120) and high (ZAVs 3 and ZAVs 5) as judged by results of a study carried out during the 1992/93 season. The yield parameters measured were: days to 50 % flowering, days to maturity, number of leaves per plant, number of stems per plant, number of branches per plant, number of nodes per plant, number of pods per plant, plant spread, plant height, 100 seed weight and grain yield. However, due to severe moisture deficit, yield was measured at UNZA Farm only. The total nitrogen content of leaves at pod formation and in the soil after harvesting were also measured. The results indicated that at both locations, nitrogen fertilizer did not have any effect on yield and all yield attributes measured except plant spread and number of pods per plant. However, accessions responded differently to N fertilizer, but this was true for ZAVs 7 only. Highest yields were obtained with 15 kg N /ha (321 kg/ha)grain, while the lowest was obtained with 30 kg N/ha (65.70 kg/ha) while other treatments had similar. Yield was positively correlated with number of leaves per plant, plant height and the number of pods per plant. The nitrogen fertilizer levels did not have any significant effect on plant N content as well as on N content of the soil after harvesting. Location had an effect on some yield attributes, i.e., plants at UNZA Farm were taller and wider with a higher number of stems than those at Lusitu. Plants at Lusitu had 3.66 % N content which was higher than UNZA Farm's 3.13 % N. The experiment was seriously affected by moisture and temperature stress. The average yield at UNZA farm was 183 kg/ha. A concrete conclusion cannot be made from this experiment. It is therefore recommended that the experiment be repeated under a controlled environment in order to get a more accurate and reliable conclusion.

DEDICATION

To my parents Mr and Mrs Koswane for their love and support. To my children Aobakwe, Gaone and Bonolo and their father Gago, for their love and patience.

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1.0 INTRODUCTION

Bambara groundnut (*Vigna subterranea* (L) Verdc.) belongs to the Leguminosae, subfamily Papilionoideae, but further refinement of its taxonomic position has been the object of much controversy. According to Begemann (1988), the crop was first mentioned in the literature by Marcgrav de Liebstad (1648 as cited by Goli *et al.*, 1991) who referred to it as "Mandubi d 'Angola". In 1763, Linnaeus described the plant and gave it the botanical name *Glycine subterranea,* in accordance with his system of nomenclature. Du Petit-Thouars (1806 as cited by Goli *et al.*, 1991) found the crop growing in Madagascar under the vernacular name "voajo". He adapted this to make the generic name *Voandzeia* to which he added Linnaeus' epithet. The scientific name then became *Voandzeia subterranea*. This nomenclature was widely accepted by later workers. As recently as the 1970's, Marechal *et al*. (1978), undertook detailed botanical studies and found great similarities between Bambara groundnut and plant species of the genus *Vigna*. Verdcourt (1978, 1980) found that their results corroborated with those of his own study and seized the opportunity to propose the generic name *Vigna subterranea* (L.) Verdc. This is the current accepted scientific name of Bambara groundnut.

The centre of origin of Bambara groundnut has been a matter of discussion, but now it is generally accepted that wild plants are found from the Jos Plateau and Yola (Northern Nigeria) to Garua (Cameroon), and possibly also in the Central African Republic too

(Hepper, 1963). The occurrence of all these wild forms supports Hepper's belief that the site of origin of Bambara groundnut lies between North Eastern Nigeria and Northern Cameroon. From its proposed centre of origin, the Bambara groundnut has been dispersed throughout tropical Africa, from Senegal to Kenya and from the Sahara to South Africa. Outside the African continent, Bambara groundnut has been reportedly carried as far as India, Sri Lanka, Indonesia, New Caledonia and South America (especially Brazil) (Goli *et al.*, 1991). Overall, however, it seems that the degree of cultivation outside Africa is insignificant.

Bambara groundnut is grown in hot dry regions which are marginal for other pulses (Duke *et al.* 1977). Its optimum day temperature range is 20-28°C. However, the crop is susceptible to water logging, although it can withstand heavy rainfalls except during fruiting and harvesting. It is reported to tolerate 500 mm to 1400 mm rainfall. This crop is best adapted to 900 mm to 1200 mm rainfall depending on rainfall distribution (Begemann, 1988). Bambara groundnut is adapted to a wide range of soils especially light or sandy loams with pH 5.0 - 6.5 and it does better on very poor soils where most other crops fail (Doku *et al.*, 1971).

Production , consumption and sale of Bambara groundnut are mostly for local requirement, hence production statistics are not readily available. However, of the leguminous crops in Africa, Bambara groundnut ranks third in production after groundnut and cowpeas (Linnemann and Azam-Ali, 1992). Estimated world production is 330 000 tons annually, of which about half is produced in West Africa. In Zambia, Bambara groundnut is grown in all the three major agro-ecological zones. The annual rainfall for the three zones are as follows: Zone I, above 1 000 mm; Zone II, between 800 and 1 000 mm and Zone III receives below 800 mm. Bambara groundnut is cultivated by small scale farmers in small areas, mostly for subsistence and for little cash income. There are no official estimates of the extent of area cultivated and grain produced in Zambia (Begemann; 1990, Linnemann, 1990).

Bambara groundnut is mainly used for human consumption. The seeds are consumed immature or fully ripe. Ripe seeds are hard and therefore difficult to grind. Usually they are either pounded to flour and boiled to a stiff porridge or soaked and then boiled. They can also be roasted. In restaurants in Angola and Mozambique, boiled and salted seeds are often served as appetizers. Commercial canning of Bambara groundnut in gravy is a successful industry in Ghana (Johnson, 1968). Some of the methods of processing are vegetable milk processing and the preparation of mixtures of Bambara groundnut flour with maize meal or rice flour. Bambara groundnut may also be used as an animal feed (Linnemann, 1987).

The seeds of Bambara groundnut are favoured for their nutritional value and versatility. These seeds are often referred to as a complete food because they contain relatively better balance of protein (16-22 %) fat (5-6 %) and carbohydrate (42-60 %) (Poulter and Caygill, 1980). The other valuable trait of the Bambara groundnut plant include symbiotic fixation of nitrogen in the soil (Brooks *et. al.,* 1988). This means it is useful in crop rotation because it may improve the nitrogen status of the soil.

Presently, cultivated local land races have very low yield (300 kg /ha) and mature in 4-5 months (Begemann, 1990). The absence of suitable high yielding varieties, and lack of proper agronomic management practices are the commonly observed production constraints of Bambara groundnut in Zambia (Mbewe and Lungu, 1990). Since Bambara groundnut is grown as a low-input subsistence crop, recommendations for optimal fertilizer requirement are scarce.

Nitrogen is a important plant nutrient, the supply of which can be controlled by man. Plants normally contain between 1 and 5% by weight of this nutrient. In addition to its role in the formation of proteins, nitrogen is an integral part of chlorophyll, which is the primary absorber of light energy needed for photosynthesis. An adequate supply of nitrogen is associated with vigorous vegetative growth and the green colour. An imbalance of nitrogen or an excess of this nutrient in relation to other nutrients, such as phosphorus, potassium and sulphur can prolong the growing period and delay crop maturity. On the other hand, stimulation of heavy vegetative growth early in the growing season can be a serious disadvantage in regions where soil moisture supplies are often low. Early season depletion of soil moisture without adequate replenishment prior to the grain filling period can depress yield.

Early stages of legume establishment in nitrogen poor soils may be retarded due to N stress. During seedling development, the supply of N reserves from the seed diminishes and growth of the seedling becomes dependent on available soil N until an effective N_2 fixing symbiosis is established. Differences in response to mineral N occur between legume species and can be influenced by rhizobial strain (Schomberg and Weaver, 1990), hence the need to determine the fertilizer nitrogen requirement for Bambara groundnut. The N requirement can be defined as the minimum crop N uptake associated with maximum yield or crop quality (Liu, 1991). While fertilizer N requirement studies have been carried out for other crops including some legumes, very little work has been done on Bambara groundnut fertilizer requirement in Zambia.

1.2 OBJECTIVE

The objective of this experiment was therefore, to determine the fertilizer N requirement for Bambara groundnut.

2.0 LITERATURE REVIEW

2.1 Bambara groundnut yield

Bambara groundnut is an indeterminate herbaceous annual plant with submerged trailing stems formed by downward compression of a much branched plant. It shows wide variation in growth habit but may be classified into two broad groups; open or spreading types with long trailing stems, and compact or bunched types with short trailing stems (Doku and Karikari, 1971). The hypogeal germination of the cultivated forms usually takes 7 to 15 days. Flowering starts 30 to 55 days after sowing and may continue until the plant dies (Linnemann and Azam-Ali, 1992). Fertilized flowers develop into fruits on or beneath the soil surface. Reproductive development is not inhibited by light, unlike groundnut where the pegs have to penetrate the soil surface before further development takes place. The pod grows first, reaching its mature size about 30 days after fertilization. The seeds develop in the subsequent 10 days. Early maturing genotypes reach maturity 90 days after sowing. Late maturing genotypes may require 150 days or more (Linnemann and Azam-Ali, 1992).

Most pods contain only one seed but a few genotypes have two, three, or even four seeded pods. It was observed during plant exploration that cultivars grown in Cameroon in particular and in Congo tend to have more seeds per pod. The length of the pod is generally proportional to the number of seeds per pod. However, the number of pods per plant tends to decrease as the number of seeds increases (Goli *et al.*, 1991).

Karikari (1972) observed that the yield of Bambara groundnut is positively correlated to morphological characteristics of the plant. He reported a higher range of 808 to 1100 kg /ha from bunch cultivars than from semi-bunch types whose yield ranged from 714 to 767 kg /ha. The relationship of yield to yield components has been reported. Mbewe and Lungu (1990) worked with 26 accessions and observed that the yield was positively correlated with number of branches per plant, harvest index, number of pods per plant, 100 seed weight and number of nodes per plant.

Variability in Bambara groundnut yield is evident; a range of 1972 to 2054 kg /ha was realized in variety trials. Yields as low as 56 kg /ha have been reported in Zambia (Begemann, 1988). Average yield at the peasant level with no inputs, ranges from 300 to 800 kg /ha (Duke *et al.* 1977; Begemann, 1988). With sound cultural practices such as optimum plant density, soil fertilization, yields could probably be higher in accessions which have been carefully selected for specific environments. In semi-arid Botswana, many subsistence farmers are growing Bambara groundnut. However, there is no reliable source of seed and agronomic information. Observations suggest that yields are highly variable and crop failure is common (Harris and Azam-Ali, 1993).

2.2 Moisture and temperature stress effects on yield

Drought stress has been shown to reduce critical growth processes such as photosynthesis, cell division and N_2 fixation (Brown *et al.*, 1985). Different crops have different critical growth stages for water stress. Maize for example, is particularly sensitive to water stress at the tasselling stage, wheat is especially sensitive to water stress during anthesis (Sionit *et al.*, 1980). A number of field experiments have been carried out to determine the critical growth stage for legume crops such as soybeans, beans and groundnut. Pod filling was found to be the critical period when the above legumes need adequate water for maximum yields (Brown *et al.*, 1985; Pritoni *et al.*, 1990; Pilbeam et al., 1990; Eck *et al.*, 1987; Gallegos and Shibata, 1989). It was also observed that for soybeans and beans, water stress at this growth stage does not only reduce the grain yield but also reduce the number of seeds per pod, plant height, number and length of internodes, and protein and oil yields (Pritoni *et al.*, 1990; Pilbeam *et al.*, 1990; Gallegos and Shibata, 1989). Experiments have also shown that the determinate and indeterminate cultivars of soybean and beans respond differently to water stress. The determinate cultivars being more hard hit than the indeterminate (Kadhem *et al.*, 1985; Gallegos and Shibata, 1989). In groundnut, the effect of soil water deficit occurring during the pod filling phase is also influenced by the indeterminate nature as well as the subterranean fruiting habit of the crop. This is because soil water availability in the top 4 to 5 cm of the profile is of critical importance for peg and pod development (Nageswara-Rao *et al.*, 1985).

Bambara groundnut is generally known to grow well in areas of marginal rainfall. The result of the experiments which were carried out by Ameyaw and Doku (1983) support this idea. It was found that for all the yield attributes the effect of 75 % available moisture (AM) (lowest moisture stress) and 30 % (AM) (highest moisture stress) treatments were comparable and severer than those of the intermediate treatments (40 and 50 % (AM)) effect which were also comparable. Elia and Mwandemele (1986) observed that decreased water availability reduced the number of flowers per plant, the percentage of fertile pollen, plant dry weight, plant height and number of branches per plant, which shows that although Bambara groundnut grows well in areas of marginal rainfall, yields are higher if there is sufficient water to improve seed setting. Kutsch and Schuh (1983) also reported that the Bambara groundnut accession they used in their experiment required at least 75 days of sufficient water supply in order to give maximum yields. Although the yield and yield attributes of Bambara groundnut are reduced by severe water stress, Brough and Azam-Ali (1992) observed that the grain proximate composition is not affected by water stress like other legume crops.

Heat stress is a major factor limiting the productivity and adaptations of crops, especially when temperature extremes coincide with critical stages of plant development (Chen *et al.*, 1982). The rate of temperature change and the duration and the degree of high temperature contribute to the intensity of heat stress (McWilliam 1980). High temperatures, especially night temperatures have been observed to cause high percentage of indehiscent anthers in beans resulting in low to no pod formation accompanied by a high rate of flower abcission (Warrang and Hall, 1983). Different crops have different optimum temperatures under which they perform well. Duke *et. al.* (1977) reported that an annual mean temperature of 19 - 27 °C is recommended for Bambara groundnut production. The optimum day temperature for this crop is reported to be 20 - 28 °C (Duke, 1981). Time to maturity of Bambara groundnut appears to vary indirectly with temperature (Johnson, 1968). Specific temperature effects on the growth and yield of Bambara groundnut seem to be scarce.

2.3 **Pests and Diseases**

Bambara groundnut is widely known to be less susceptible to diseases than groundnut, possibly because it is often grown in small scale intercropping systems and also as a result of the wide genetic diversity of Bambara groundnut cultivated (Johnson,1968). Recently however, there have been reports of fungal and viral infections and the following diseases have been reported on Bambara groundnut: Cercospora leaf blight *(Cercospora canescens)*, Leaf spots (*Macrophomina phaseolina, Mycosphaerella pinodos*), Slerotium root rot (*Sclerotium rolfsii)* and Ascochyta blight (*Ascochyta phaseolurum*) (Begemann, 1990). Powdery mildew, rust, sooty mold, root rot nematode and a mosaic virus have also been observed on this crop.

The occurrence of seed borne diseases was investigated in Burkina Faso. An analysis of eleven samples of Bambara groundnut seeds revealed the presence of the following fungi; *Macrophomina, Fusarium solani, Fusarium moniliforme, Botryodiplodia theobromae, Phoma* species and *Cephalosporium* species. Several viruses were found as well. A reduction in biomass yield of 63 % was associated with the disease pathogens which were found in the experiment. (Sereme, 1991). The effect of Cercospora leaf spot on three varieties of Bambara groundnut was investigated by artificial inoculation in the field in Ghana. The number of flowers and pods decreased significantly when the diseases occurred before flowering. Plants inoculated before flowering also produced small pods. Yield differences were not significant between plants inoculated at various stages after flowering and the control, but the depressive effect due to the diseases was reduced with delay in the time of infection (Lamptey and Ofei, 1977). In Zambia, a disease survey which was carried out in farmers' fields during 1987 - 89 cropping season revealed the importance of Scab in Luapula Province, Cercospora leaf blight in Western Province and Cercospora, Fusarium wilt and Root knot nematode in Eastern Province (GRZ / UNDP Food legumes, 1989). Hill (1978) reported that Phormosis leaf blight caused serious yield losses in several accessions at Kataba valley in the Western Province during the 1973/74 season. Cercospora leaf blight seem to be a potential threat in seasons with conducive environment. It is reported to have caused considerable damage to research trials in most seasons at Msekera Regional Research Station and Masumba sub-research station, resulting in total loss in yields in several highly susceptible accessions (GRZ/ UNDP Food Legumes, 1989). Mkangama (1992) also reported that Cecospora leaf blight caused poor crop growth and low yield in Bambara groundnut accessions during the 1990/91 season in Lusaka. Fusarium wilt is reported to have caused total crop failure in some research trials in Eastern Province (ARPT, 1989). Linnemann (1990) reported that germinating seeds of Bambara groundnut occasionally suffer damage from rats, termites, red ants, or cutworms which sever the seedlings at ground level. A list of the common insects of this crop include termites, jassids, aphids, grasshoppers and brachids (Kannaiyan *et al.*, 1989).

2.4 **Crop Nitrogen requirements and fertilization**

2.4.1 **Nitrogen requirements**

Nitrogen is taken by plants primarily as nitrate-N (NO_3-N) or ammonium-N (NH^+_4-N) ions. The actual process of N uptake by plants requires movement of ionic species of N to root surfaces for absorption. Most N movement occurs as NO_3-N in the convective flow of soil water to plant roots in response to the transpiration pull in the above ground portion of the crop. Aside from the moisture factor, rate of NO_3-N uptake is controlled by its concentration in the soil solution and plant metabolism (Olsen and Kurtz, 1982). The uptake of both N forms is reported to be temperature dependent; low temperatures depress the uptake (Zsoldos, 1972; Clarkson and Warner 1979,). Nitrogen uptake is also affected by the soil pH. NH^+_4-N uptake takes place best in a neutral medium and it is depressed as the pH falls, but for NO_3-N, a more rapid uptake occurs at low pH values (Rao and Rains, 1976) The two N forms are absorbed at equal rates at pH of 6.8. At pH 4.0 however, Michael *et al.* (1965) observed that the uptake of NO_3-N was considerably higher than that of NH^+_4-N.

The rate of N uptake by field crops is very rapid during the vegetative growth period (Olsen 1978), in preparation for the next growth stage. Harper (1974) observed that in cowpeas, maximum nitrate utilization occurred from full bloom. Legumes have shown to require adequate amounts of N during pod development and flowering (McElhannon and Mills, 1978; Brevedan *et al.*, 1978). Kawahara *et* al. (1986) observed that nitrogen is the major factor which determines the 100-seed weight, number of pods per node and number of nodes per plant. This explains why the requirement of N is high at flowering and pod development. Comparative uptake and utilization of N under field conditions is strongly influenced by environmental conditions throughout the growing season including the position of any available N in the rooting zone in relation to the available water supply and consequent root activity (Olsen and Kurtz, 1982).

2.4.2. **Nitrogen fertilization**

For high crop productivity, the soil root system must supply N in the quantities needed by the crop. High utilization must also be ensured by optimizing the fertilizer N rate, timing and application methods. The application of an optimal amount of N is considered the most important single N management factor affecting crop productivity and efficiency (Liu, 1991). *Information from analysis of both soil and plant tissue is very* important in determining N fertilizer needs of crops. The N requirement can be measured by investigating crop yields with different levels of N fertilization and / or by determining the correlation between tissue N concentration (or N content) and yield performance (Liu, 1991). The critical N level or concentration in the tissue and / or in the soil can also be used as a tool for determining the N requirement of crops. Critical level or concentration is defined as the level of N in the plant or soil which divides the zone of deficiency from the zone of adequacy (Liu, 1991). This critical N concentration is generally determined by growing crops which are well supplied with other nutrients other than N, and adding N in increments until an adequate or excessive level is reached (Liu, 1991). The most meaningful definition of critical N concentration for efficient growers is, the level of N below which crop yield, quality or performance is unsatisfactory. For example, in maize, about 3.0 % N in the leaf opposite and below the uppermost ear at silking time is considered a critical level (Tisdale *et al.*, 1985). Quantification of the N requirements of crops is useful in making decisions on how much N fertilizer should be applied for different crops.

Researchers have observed that a starter dose of N fertilizer may be needed by legumes for early growth and during the entire growing season especially in soils with low nitrogen content

(Eaglesham, *et al.*, 1983; Henson and Bliss, 1991; Reddy *et al.*,1990). However, there are some reports that show that the use of N fertilizer may have a negative effect on nodulation. Peck and MacDonald (1984) and Zhegqi *et al.* (1972) observed that N fertilizer has an influence on nodulation. Soybean plants which were grown in soils with N but without N fertilizer had many nodules while there were few or no visible nodules on plants grown in soils with N plus N fertilizer. Olifentoye (1986) also observed an inhibitory effect on nodulation by N fertilizer on cowpeas. In some cases, the use of N fertilizer in legumes does not show any significant effect on grain yield. For example, Olifentoye (1986) did not observe any N fertilizer effect on grain yield of cowpeas.

Information on fertilizer requirements for Bambara groundnut is scarce. However, Dadson and Brooks, (1989) reported differential response by some accessions to N fertilizer, so it is not surprising to find that observations from previous experiments vary. In West Africa, which is the major growing area for Bambara groundnut, the use of starter N fertilizer is recommended (Dadson and Brooks, 1989; Tanimu and Yayock, 1990). However, Tanimu and Yayock (1989) reported that N fertilizer did not have any effect on Bambara groundnut yield in an experiment carried out in Nigeria. In Zambia, very little work on Bambara groundnut fertilizer has been documented and for the few experiments documented the use of fertilizer did not show any effect on grain yield but on the vegetative part (ARPT, 1986; Lungu and Mbewe,1986). Musonda (1988) on the other hand reported that

Bambara groundnut grain yield responded to 79 kg N / ha and 68 kg K_2O / ha, respectively.

3.0 MATERIALS AND METHODS

3.1 Sites and design

The experiment was carried out at the University of Zambia (UNZA) Farm and at Lusitu Sub-Research Station which are located at Lat:15^0 18′ S Long: 28^0 36′ E and Lat: 17^0 28′ S Long: 28^0 42′ E, respectively. It was carried out during the 1993/94 cropping season. Six accessions of Bambara groundnut, two high yielding i.e. (ZAVs 3 and ZAVs 5) accessions; two medium yielding accessions (ZAVS 7 and ZAVS 120) and two low yielding accessions (ZAVS 6 and ZAVS 8) were used together with five levels of nitrogen (0, 15, 30, 45 and 60 kg N/ ha) making a total of 30 experimental units. The seeds used were from the previous year's experiment. The accessions are among the local accessions held by the University of Zambia, Crop Science Department. A split plot design was used; the six accessions formed the main plots while the five nitrogen levels formed the subplots, with three replications at each site.

UNZA Farm is in agro-ecological Zone II which normally receives 800 to 1000 mm annual rainfall. The plot at UNZA Farm was located on Oxic Paleustelalf soils (Chinene, 1988). Other soil characteristics of the plot at UNZA Farm are in Appendix 9. Lusitu Sub-Research Station falls in agro-ecological Zone III which receives less than 800 mm rainfall annually. Banda (1988) classified the soil in this location as Typic Paleustalf. For other soil characteristics for Lusitu Sub-Research station see

Appendix 10. The plot at Lusitu was fallow the previous year while that at UNZA Farm was used for maize.

3.2 **Field work**

Ploughing and planting at both sites were done in December 1993. The plots were ploughed and disced to a fine tilth. Each main plot had five subplots which in turn had six rows 0.4 m apart and 3 m long. Before planting rows were raised into ridges about 0.3 m high; intra-row spacing was 0.2 m. Basal dressing fertilizer at the rate of 30 kg / ha P_2O_5 (Triple super phosphate) and 60 kg /ha K_2O (Murate of potash), was applied to all the plots before planting. The fertilizers were applied along the ridges and mixed with the soil. The five levels of nitrogen (0, 15, 30, 45 and 60 kg N/ha) were also applied before planting in small furrows on the sides of the ridges and these were covered after application. Urea was the source of N. Planting was later done on top of the ridges. Planting was done on the 10th and 16th December at UNZA Farm and Lusitu, respectively.

Weeding was done as necessary. At UNZA Farm, it was done more often because for the months of January and February, the site had good rains and weeding was done every three weeks. After weeding ridges were raised.

3.3 **Pests and diseases**

At UNZA Farm, the crop was attacked by aphids (Aphididae sp.) at

21 days after emergence and they were controlled by an application of Dursban at the rate of 0.75 L / ha. The insect was effectively controlled. At 63 days, aphids infested the crop again. This time Adrazin 40 W.S.C was used at the rate of 0.3 L / ha. There was no aphid problem at Lusitu, but when Bambara groundnut plants were 50 days old, they were attacked by a white fringed beetle (*Brachyrhinae*) which is a leaf chewing insect. It was controlled by applying Adrazin at the rate of 0.3 L /ha. The control measure was very effective. At Lusitu there were no disease problems. At UNZA Farm two disease symptoms were observed and they were both caused by fusarium species. When the crop was 49 days old it showed some disease symptoms, (fungal leaf spot); leaves had brown spots which were from the margins. This disease was controlled by applying Bonomyl at the rate of 0.12 kg / ha. The disease symptoms were spread evenly in the plots. When the plants were 73 days old another disease symptom was observed. Crops were wilting and turning yellow but the tap root was still intact. Like the other disease symptoms, no pattern was observed, diseased plants were scattered throughout the field. No disease control measure was taken because the crop was already under drought stress.

3.4 **Data Collection**

Days to 50 % flowering was recorded from the day when 50 % of the plants had emerged to the day when 50 % of the plants had flowered. Days to maturity was also recorded from the day when 50 % of the plants had emerged to the time when 50 % of the plants had shown signs of maturity. Plant height and spread were done at pod-formation stage on six randomly selected plants on rows three and four, for the height the ruler was placed at the centre of the plant. Plant spread was measured at the top of the canopy of the plant. For the number of stem per plant, leaves per plant, branches per plant, and nodes per plant six plants were selected randomly from rows three and four at harvesting and the parameters were determined before the plant dried up. Pods per plant were calculated by dividing the number of pods from each plot by the number of plants from that plot after harvesting. Yield was first measured per plot in grams then converted to yield per hectare. Hundred seed weight was taken from randomly selected air dried seeds.

Leaf sampling for total nitrogen analysis was done at pod formation stage. For this purpose, new leaves, and about 4 cm of the petiole were collected from all the plants in rows two and five. Checks for nodules were done at flowering and pod formation stage but were not found on any accession at both sites.

After harvesting soil samples for total nitrogen were collected on rows three and four (harvest rows) using a 20 cm soil auger. Four samples were taken per plot, then mixed together and half of it taken in labelled brown paper bags to the laboratory for total soil N analysis.

3.5 Sample analysis

3.5.1 Plant tissue analysis

The leaves were dried in the oven at 80 °c for 48 hours. Then to obtain homogeneous powder, the samples were ground using a Wiley Mill, fitted with a 1 mm sieve. Between samples, the mill was thoroughly cleaned in order to avoid cross contamination. The ground samples were stored in well labelled sealed polyethylene bags. The tissue samples were then used for analysis as follows:

(a) Digestion procedure of plant tissue

1. 0.50 g of oven dried ground plant material was weighed and put into a digestion tube.
2. 3.5 ml of H_2SO_4 - salicylic acid mixture was added; after 30 minutes, 1.0 g $NaSO_3$ was added and the sample shaken.
3. After 15 minutes, 3 ml H_2SO_4 and 1.0 g catalyst mixture (100 parts K_2SO_4, 10 parts $CuSO_4$ and 1 part Se powder) were added.
4. The sample tube was then placed into the Digestion Block set at 410 ^{0}C and the sample was digested for 45 minutes.
5. The digestion tube was then removed from the block and allowed to cool for 15 minutes.

(b) Distillation

1. The digestion tube containing the digested sample was placed on the distillation unit and distilled into 25 ml of boric acid indicator solution for 15 minutes.
2. To the diluted sample was added 25 ml of 40% NaOH to make

the solution alkaline.

3. The distillate was titrated with 0.1M HCl and the amount of HCl used for the titrate to change colour to that of boric acid, was then recorded.

(c) **Calculations**

Total nitrogen is reported as percentage on oven-dry basis, using the following formula:

$$\%N = \frac{(TS - TB) \times 0.14 \times 10^{-3} \times 100/10 \times 100}{\text{Weight of oven dry plant material (.5g)}}$$

TS = Titrate, ml standard acid for sample

TB = Titrate, ml standard acid for blank

3.5. 2 Soil analysis

Soil samples were air dried, and sieved through a 2 mm mesh. Labelled plastic bags were used to keep the samples.

(a) **Digestion**

1. 1.0 g of soil sample was weighed into tubes.
2. 4 g of mixed catalyst, was added, after which 10 ml of concentrated H_2SO_4 was dispensed into each sample tube
3. The sample tubes were then placed into the digestion block set at 410 ^{0}C and digested for 45 minutes.
4. The tubes were then removed from the digestion block and cooled for 15 minutes.

(b) **Distillation**

The procedure was the same as that of the plant material.

(c) **Calculations**

The method used for plant material samples also applied for soil samples.

3.6 Statistical analysis

Data analysis was done using the computer MSTAT programme. The analysis of variance was carried out as described in Gomez and Gomez (1984). Duncan's Multiple Range Test was used to separate the means. A correlation analysis was run using the same computer programme.

4.0 RESULTS

4.1 General

The rainfall and temperature data for the cropping seasons 1992 / 93 and 1993 / 94 (December to April) for the two locations are given in Appendices 1 to 8. However, the rainfall data for Lusitu do not include normal rainfall because the meteorological station is new. The rainfall amount as far as the Bambara groundnut is concerned for the year 1993/94 was in the tolerated range at UNZA Farm (533.80 mm). However, it was below the optimum range of 900 mm to 1200 mm. Rainfall at this location fell mainly in December to February. Lusitu had an inadequate rainfall (377.44 mm) which was also poorly distributed (Appendices 2 and 4).

Temperatures at UNZA Farm were within the range tolerated by Bambara groundnut (Appendices 7 and 8). Lusitu had high temperatures, the daily means for all the five months were above the tolerated temperature range of 20 - 28 °C (Appendix 5). The daily maximums were very high especially in dry months (Appendix 6). Generally, the year was not good for the crop as it had both moisture and temperature stress. Data on the nutritional status of the soil for the two plots before planting is shown in Appendices 9 and 10. The pH at both sites was within the required range of 5.0 - 6.5.

Bambara groundnut took 15 to 21 days to emerge. At UNZA Farm emergence was good (average was 70 %) while at Lusitu it was much lower (average was 50 %).Seedlings at Lusitu were attacked by rats which were a problem for that whole region; however, no control measure was taken except gap filling which was done at both sites. At Lusitu general crop growth was very slow because of moisture and temperature stress. Flowering at this location started at 40 days after emergence. However, the number of flowers was very low (2 to 3 flowers per plant). After 46 days flowers were seen on 50 % of the plants. At UNZA Farm, flowering started 35 days after emergence and 50 % of the plants had flowered after 46 days. At this location rainfall stopped 2-3 weeks after the plants had started flowering. As a result, about 50 % of the flowers wilted because of high temperatures which were experienced in March and the first half of April. About thirty percent of the plants wilted and dried up at UNZA Farm while at Lusitu, about 60 % of the plants dried up due to the drought by the end of April. Accessions and nitrogen level did not have any effect on days to maturity and they were 125 at Lusitu and 119 at UNZA Farm.

4.2 **Number of Leaves per Plant**

Accessions performed differently in terms of number of leaves per plant at UNZA farm, with accession ZAVs 8 having the highest number of leaves (66.16). However, the number of leaves produced by ZAVs 8 were statistically the same as those produced by ZAVs 6 and ZAVs 120. On the other hand, ZAVs 5 had the lowest (50.30) which was similar to ZAVs 3 and ZAVs 7 (table 1). At Lusitu, accessions performed the same with regard to number of leaves. After combining the data for the two locations, accessions performed the same. The nitrogen level did not affect the number of leaves at both locations (Tables 2 and 4), respectively. A combined data analysis showed that location had no significant effect on leaves. The accession x nitrogen level interaction did not show any effect, This result was similar at both locations.

Table 1. Performance of accessions at UNZA Farm.

Accession	100 Seed wt (g)	# Pods / plant	Yield kg/ha	#Leaves / plant	# stems / plant	# nodes / plant	# Branches / plant	Spread (CM)	Height (cm)	Plant N (%)	Soil N (%)
ZAVS 3	50.50 a /1	6.01 bc	137.2 a	51.97 cd	4.37 a	51.27 a	12.97 a	31.33 a	20.30 a	3.13 a	0.19 a
ZAVS 5	47.74 a	5.39 c	169.62 a	50.30 d	4.22 a	49.48 a	14.33 a	30.46 a	20.30 a	3.12 a	0 19 a
ZAVS 7	50.04 a	7.61 ab	222.41 a	50.38 bcd	4.20 a	61 77 a	12.24 a	28.82 a	20.28 a	3.17 a	0.17 a
ZAVS 120	46.22 a	8.34 a	203 78 a	59.21 abc	5.03 a	49.86 a	13.43 a	27.38 a	19.16 a	3.32 a	0.17 a
ZAVS 6	48.11 a	8.54 a	205.53 a	59.70 ab	4.77 a	59.93 a	14.38 a	30.98 a	20.06 a	3.03 a	0.19 a
ZAVS 8	50.59 a	7.10 abc	174.38 a	66.16 a	4.95 a	61.01 a	15.05 a	30.95 a	20.57 a	3.21 a	0 18.a

1/ Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at P <= 0.05

Table 2. Effecct of N level on parameters mesaured at UNZA Farm.

N levels (kg/ha)	100 Seed wt (g)	# pods / plant	Yield (kg/ha)	# Leaves / plant	# stems /plant	# nodes / plant	# Branches / plant	Spread (cm)	Height (cm)	Plant N (%)	Soil N (%)
0	48.61 a	/1 7.53 a	197,48	56,95	4,51	57,28	14,1	29,43 a	19,52 a	3,13 a	0,18 a
15	50.21 a	7.24 a	184,03	56,75	4,68	55,57	13,14	30,48 a	20,31 a	3,13 a	0,18 a
30	50.63 a	6.06 a	172,32	54,91	4,68	55,76	13,61	29,71 a	20,06 a	3,07 a	0,17 a
45	48.33 a	8.08 a	192,04	57,14	4,65	52,21	14,07	30,36 a	20,44 a	3,17 a	0,18 a
60	46.55 a	6.91 a	173.23 a	61,51	4,63	56,94	13,76	29,95 a	20,22 a	3,31 a	0,19 a

/1 Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at P <= 0.05

Table 3. Performance of accessions at Lusitu.

Accessions	# Leaves / plant	# stems / plant	# nodes / plant	# Branches / plant	Spread (cm)	Height (cm)	Plant N (%)	Soil N (%)
ZAVS 3	56.62 a /1	3,83	62,81 a	9.02 a	20.62 a	16.02 a	3.75 a	0.12 a
ZAVS 5	38.37 a	2,65	43,61 a	7.43 a	16.03 a	13.15 a	3.75 a	0.12 a
ZAVS 7	46.19 a	2,67	48,12 a	8.21 a	17.37 a	14.28 a	3.56 a	0.13 a
ZAVS 120	53.25 a	3,05	60,27 a	10.42 a	17.75 a	14.12 a	3.92 a	0.13 a
ZAVS 6	41.06 a	3,42	45,37 a	8.78 a	19.03 a	15.73 a	3.98 a	0.12 a
ZAVS 8	45.71 a	3,57	50,66 a	9.23 a	19.97 a	15.53 a	3.81 a	0.12 a

/1 Means in the same colum followed by the same letter are not significantly different according Dancan's Multiple Range Test at $P <= 0.05$

Table 4. Effect of N level on parameters measured at Lusitu.

N levels kg/ha	# Leaves / plant	# stems / plant	# nodes / plant	# Branches / plant	Spread (cm)	Height (cm)	Plant N (%)
0	52.63 a 1/	3,12 ab	56,81 a	8.94 a	18.51 a	15.44 a	3.79 a
15	47.86 a	3,01 ab	54,92 a	8.38 a	18.55 a	14.72 a	3.68 a
30	45.98 a	3,46 a	50,44 a	8.48 a	18.01 a	14.37 a	3.81 a
45	46.99 a	3,41 a	50,48 a	9.91 a	18.85 a	15.01 a	3.81 a
60	40.88 a	2,61 b	46,41 a	8.53 a	18.41 a	14.51 a	3.73 a

1/ Means in the same column followed by the same letter are not different according to Dancan's Multiple Range Test at $P <= 0.05$

4.3 Plant Height

The height of plants was not affected by accession and nitrogen level (Tables 1, 2, 3, and 4). The accession by nitrogen level interaction was also not significant. This result was similar at both locations. However, height was affected by location, i.e., UNZA Farm had taller plants (20.08 cm) than those at Lusitu (14.81 cm) (Table 5).

4.4 Plant Spread

Plant spread was not affected by accession and nitrogen level (Tables 1, 2, 3 and 4). The accession by nitrogen level interaction was not significant. This result was similar at both locations. However, a combined location analysis showed that plants at UNZA Farm had a wider spread (31.00 cm) than those at Lusitu (18.50 cm) (Table 5).

4.5 Number of stems per Plant

Number of stems per plant was not affected by accession and nitrogen level at UNZA Farm (Tables 1 and 2). However, at Lusitu nitrogen level affected number of stems per plant although accession had no effect (Tables 3 and 4). With respect to N level plants under the 60 kg/ha treatment were shorter than those under the 30 and 45 kg/ha treatments, respectively (table 4). The accession by nitrogen level interaction had a significant effect on number of stems at Lusitu; i.e. accession ZAVs 3 x 30 kg N/ha gave the highest number of stems (4.58) while the lowest (1.8) was from ZAVs 5 x 60 kg N/ha. However, at UNZA Farm the accession by nitrogen level interaction did not show any significant effect. A combined location analysis showed that plants at UNZA Farm had more stems (4.6) than those at Lusitu (3.2) (Table 5).

Table 5. Overall Comparison of Yield and Yield attributes at UNZA Farm and Lusitu, respectively.

Character	UNZA Farm	Lusitu
No. Leaves / plant	47.24	46.87
Plant height (cm)	20.09* [1/]	14.81*
Plant spread (cm)	30.05*	18.46*
No. Stems / plant	4.56*	3.90*
No. Branches / plant	13.62	8.85
No. nodes / plant	56.62	51.81
No. Pods / plant	7.164	– [2/]
100 Seed wt (g)	48.86	–
Yield (kg /ha)	183.00	–
% N in Plants	3.13*	3.66*
% N in Soil	0.181*	0.125*

1/ * Significantly different at $P \leq 0.05$

2/ - Data not collected due to premature plant death at Lusitu

4.6 Number of branches per Plant

Branching was not affected by accession and nitrogen level (Tables, 1, 2, 3 and 4). The accession by nitrogen level interaction was not significant. This result was similar at both locations. A combined location analysis showed that location had no significant effect on branching (Table 5).

4.7 Number of nodes per Plant

Accessions and nitrogen level had no effect on number of nodes per plant at both locations (Tables 1, 2, 3 and 4). Accession by nitrogen level interaction was not significant at both locations. Moreover, a combined location analysis showed that location did not have any effect on number of nodes per plant (Table 5).

4.8 Number of pods per plant

Plants at Lusitu did not form pods at all. At UNZA Farm, the number of pods of accessions showed differed significantly i.e., accessions ZAVs 6 and ZAVs 120 had the highest number (8.5 and 8.3 respectively), but were not significantly different from ZAVs 7 and ZAVS 8; the lowest (5.3) was from ZAVs 5 which was similar to ZAVs 3 and ZAVs 8 (Table 1) Nitrogen level had no effect on number of pods per plant (Tables 2 and 4). The accession by nitrogen level interaction showed a significant effect on number of pods. Accession ZAVs 120 by 45 kg N /ha gave the highest number (12.8 pods) per plant while ZAVs 7 x 30 kg N /ha had the lowest number.

4.9 100 seed weight

100 seed weight was not affected by accession and nitrogen level (Tables 1 and 2). Moreover, accession by nitrogen level interaction effect was also not significant

4.10 Yield (kg/ha)

Generally, the yield was low. Yield was not affected by accession and nitrogen level (Tables 1 and 2). The accession by nitrogen level interaction effect was, however, significant. Accession ZAVs 7 x 15 kg N /ha had the highest yield (321 kg /ha), while ZAVs 7 x 30 kg N/ha had the lowest.

4.11 Nitrogen (%) in plant materials

Plant nitrogen content was not affected by accession and nitrogen level at both locations (Tables 1, 2, 3 and 4). The accession by nitrogen level interaction effect was not significant. However, a combined location analysis showed that plants at Lusitu had more N content (3.66 %) than those at UNZA Farm (3.13 %) (Table 5). Accession ZAVs 120 had the highest N content (3.32 %) and ZAVs 8 had the lowest (3.03 %) (Table 1).

4.12 Nitrogen (%) in the soil

The soil nitrogen content after harvesting was not affected by accession and nitrogen level at both locations (Tables 1, 2, 3 and 4). The accession by nitrogen level interaction effect was not significant. However, a combined location analysis showed that UNZA Farm had more soil N content (0.18 %) than Lusitu (0.125 %) (Table 5).

4.13 Correlation

Yield was positively correlated to number of leaves (r =0.23), plant height (r = 0.32) and number of pods per plant (r = 0.72) (Table 6). All possible correlations were done, and the following yield components had significant correlations: number of leaves were correlated to number of stems (r = 0.40), number of branches (r = 0.42) and number of nodes per plant (r = 0.73). Number of stems had a positive correlation with number of nodes (r = 0.36). Number of branches correlated with number of nodes (r = 0.37). Plant height and plant spread were correlated (r = 0.50). 100 seed weight and plant spread were also correlated (r = 0.36). Total nitrogen in the soil after harvesting was negatively correlated to 100 seed weight (r = -0.26). Most of the yield components have shown to be correlated to number of leaves (Table 6).

TABLE 6: Phenotypic correlation coefficients between grain yield components and agronomic characteristics of six Bambara groundnut accessions

	spread	height	leaves	stems	branches	nodes	pods	100 seed wt	soil N	plant N	yield
spread	1										
hieght	0.5 *	1									
leaves	0.06	0.01	1								
stems	0.08	0.17	0.39 * *	1							
branches	0.13	0.01	0.42 * *	0.36 * *	1						
nodes	0.01	0.06	0.73 * *	0.23 *	0.37 * *	1					
pods	0.03	0.03	0.18	0.28 * *	0.03	0.05	1				
100 seed	0.36 *	0.16	0.12	0.05	0.01	0.13	-0.09	1			
soil N	0.1	0.03	-0.12	0.11	0.05	-0.03	-0.17	-0.26 *	1		
plant N	-0.01	0.14	0.02	0.05	-0.12	-0.12	-0.12	-0.04	0.14	1	
yield	0.16	0.33 * *	0.23 *	0.09	0.03	0.14	0.72 * *	0.18	-0.13	0.04	1

* Significant at $P < 0.05$

* * Signifficant at $P < 0.01$

5.0 DISCUSSION

Bambara groundnut yield is influenced by rainfall and its distribution (Begemann, 1988). This is supported by the yields which were obtained from the two locations using the same accessions in 1992 /93 cropping season and this (1993 /94) cropping season's yield of 0 kg/ha at Lusitu with a rainfall of 377 mm (Appendix 2) and 183 kg /ha at UNZA Farm with a rainfall of 533.80 mm (Appendix 4). Nkumba (1993) reported a yield of 62 kg /ha at Lusitu with a rainfall of 462 mm (Appendix 1) and 646 kg /ha at UNZA Farm with 691.6 mm rainfall (Appendix 3). The 183 kg/ha is below the reported average yield of 300 to 800 kg/ha at peasant level (Duke, 1977; Begemann, 1988) but it is above 56 kg /ha which has been reported in Zambia (Begemann, 1988). Yield depression in Bambara groundnut in drought years has been reported before at Sesheke, where a yield of 0 kg/ha was obtained in 1973 /74 cropping season (Zambia, 1975).

The results of this experiment showed that location had an effect on the following yield components: plant height, plant spread, number of stems per plant as well as on the total N (%) content of plant material and of the soil after harvesting. The main factor which distinguishes the two locations is their agro-climatic conditions. This implies that temperature and /or rainfall had an effect on yield components. Plant starvation induced by high temperature has been considered to be an important contributor to plant growth and yield depression (Chen, *et al.*, 1982). This agrees with what was observed because Lusitu had higher temperatures (Appendices 5 and 6) than UNZA Farm (Appendices 7 and 8). Water stress in soybean has been observed to reduce plant height and plant spread (Gallegos and Shibata, 1989; Pilbaem *et al.*, 1990; Pritoni *et al.*, 1990) which supports the results of this experiment. Elia and Mwademele (1986) also made the same observation on Bambara groundnut. The effect of the two Fusarium diseases which were observed at UNZA Farm on yield was not quantified.

Even though yield of Bambara groundnut has been observed to be correlated to number of branches, number of stems, number of nodes, number of pods and 100-seed weight (Nkumba, 1993; Mbewe and Lungu, 1990; Begemann, 1988; Karikari, 1972), the results of this experiment did not fully concur with what has been previously reported. The yield was positively correlated to number of pods per plant, plant height and number of leaves per plant only. These yield components which have been found to be correlated to yield have also been reported to be reduced by water stress in soybean (Gallegos and Shibata, 1989; Pilbeam *et al.*, 1990; Pritoni *et al.*, 1990), therefore this result might be reflecting this water stress effect.

Accessions which were used did not differ in yield and yield attributes except in terms of number of pods per plant at UNZA Farm. Accession ZAVs 6 and ZAVs 120 had the highest number of pods although it was not significantly different from ZAVs 7 and ZAVs 8, while ZAVs 5 had the lowest number of pods even though it was not statistically different, which is not in agreement with Nkumba's (1993) findings. He reported ZAVs 120, ZAVs 6 and

ZAVs 5 accessions as being medium, low and high yielding, respectively. The result supports the fact that accessions respond differently to environmental stress conditions, e.g. water stress (Begemann, 1988).

Nodulation did not occur at both locations probably because of the high N content of the soil, as it is reported to have an inhibitory effect on nodule development (Olifentoye, 1986). Peck and MacDonald (1984) also observed that snap bean plants which were grown on soils with N fertilizer plus soil N had few or no nodules. This might be the explanation for the finding in this experiment, as nitrogen fertilizer did not show any effect on yield and most of the measured yield components. The availability and /or compatibility of the host plant and the local rhizobium strain in the soil could have also influenced nodulation since Bambara groundnut has not been grown in these areas before, and as Somasegaran (1990) observed, Bambara groundnut is specific for its rhizobial requirement for effective symbiosis.

Soil nitrogen content before planting at UNZA Farm was higher than at Lusitu (Appendices 9 and 10) partly because of the previous use of the land and /or the type of the soil and climatic conditions of the two locations. The land at UNZA Farm was used for maize the previous year and there might have been some residual N from the previous year. At Lusitu, the land was fallow the year before and the grass which grew there was grazed by animals so the residual effect might have been minimal. After harvesting, soil N content at UNZA Farm was still higher than at

Lusitu (Table 5) because of the initial difference and probably weed decomposition had some effect as weeding at UNZA Farm was done more often than at Lusitu.

Total plant N content was higher at Lusitu than at UNZA Farm (Table 5) which was in contrast to Masyhudi and Patterson (1991)'s observation that water deficit reduces the total N accumulation in soybean. The high N content in leaves might have been due to the fact that plants at Lusitu were smaller than those at UNZA Farm and the total N concentration was higher as a result of the low dry matter, since N content is on total DM basis.

Nitrogen level did not show any significant effect on yield and yield components except number of stems per plant. This result does not agree with Kawahara *et al.* (1986) who concluded that nitrogen is the major factor which determines number of nodes per plant as well as number of pods per plant. This could probably be explained by the effect of sufficient levels of N in the soil before planting. The result is in contrast to Dadson and Brooks (1989)'s observation that nitrogen level had an effect on pod dry weight, and seed yield as the yield and 100-seed weight were not affected by N level in this experiment.

The fact that accession x nitrogen level interaction had an effect on number of pods per plant and grain yield at UNZA Farm is in agreement with Dadson and Brooks (1989)'s findings that some Bambara groundnut accessions are able to utilize N better than others. This suggests that it might be possible to use different level(s) of N for different genotypes.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The nitrogen levels used in the experiment (0,15,30 45 and 60 kg N /ha) did not have any significant effect on yield which is in agreement with the previous experiments, that N fertilizer does not have any effect on Bambara groundnut yield in Zambia. However, this could have been due to moisture and temperature stress which have been shown to be important in Bambara groundnut despite the fact that it is a crop that does well in dry and high temperature areas. The results also suggest that it would be possible to utilize different levels of N for different genotypes, although the result is not conclusive.

A concrete conclusion can not be made from this experiment. It is therefore, recommended that the experiment should be carried out in a controlled environment with a large number of accessions to get a more accurate and reliable conclusion.

REFERENCES

Adaptive Research Planning Team, 1989. Bambara groundnut. In: Status report on agronomy research in the wetlands. Adaptive Research Planning Team, Mongu, Western Province, Zambia.

Ameyaw, C.E.G. and Doku E.V. 1983. Effects of soil moisture stress on the reproductive efficiency and yield of the Bambara groundnut *(Voandzeia subterranea)*. Tropical Grain Legume Bulletin 28: 23 - 29.

Banda, D. J. 1988. Semi-detailed soil survey of Chikwangala Farms. Soil survey report No. 188. Soil Survey Unit. Chilanga. 87 pp.

Begemann, F.1988. Eco-geographic differentiation of Bambara groundnut (*Vigna subterranea* (L.) Verdc) in the collection of the International Institute of Tropical Agriculture (IITA). Wissennch aflicher Fachverlag GieBen. Ph.D. dissertation. 153 pp.

Begemann, F.(ed.). 1990. Bambara groundnut improvement in Zambia. Proceedings of the First National Workshop on Bambara groundnut Improvement in Zambia, 5 July 1990. Lusaka Zambia, University of Zambia, School of Agricultural Sciences, Crop Science Department, Lusaka Zambia. 13 pp.

Brevedan, R.E., Egli, B.D. and Leggett, J.E. 1978. Influence of N nutrition on flower and pod abortion and yield of soybeans. Agron. J. 70: 81 - 84.

Brooks, C.B. Dadson, R.B. and Green, B.M. 1988. Evaluation of symbiotic effectiveness of elite and wild strains of *Bradyrhizobium* on cultivars of *Voandzeia subterranea* (L.) Thoaurs. Trop. Agric. 65:(1) 61 - 63.

Brough, S.H. and S.N. Azam-Ali, 1992. The effect of soil moisture on the proximate composition of Bambara groundnut (*Vigna subterranea* (L.) Verdc). J. of the Scie. of Food and Agric. 60: 179 - 203.

Brown, E.A., Caviness, C.E. and Brown, D.A. 1985. Response of selected soybean cultivars to moisture deficiency. Agron. J. 77: 274 - 278.

Chen Hwei-Hwang, Shen Zhen-Yan and Li P.H. 1982. Adaptability of crop plants to high temperature stress. Crop Scie. 22: 917 - 925.

Chenene, V. R. N. 1988. Detailed soil survey and land evaluation of the University Farm. Soil survey report No. 160. Department of Soil Science. University of Zambia. 108 pp.

Clarkson, T.D. and Warner, A.J. 1979. Relationship between root temperature and the transport of ammonium and nitrate ions by Italian and perennial rye grass (*Lolium multiflorum* and *Lolium perenne*). Plant Physiol. 64: 557 - 561.

Dadson, R.B. and Brooks, C.B. 1989. Responses of Bambara groundnut (*Voandzeia subterranea* (L.) Thouars) to applied nitrogen in Southern Togo. Trop. Agric. (Trinidad) 66:(2) 169 - 174.

Doku, E.V. and Karikari, S.K. 1971. Bambara groundnut. Econ. Bot., 25: (3) 225 - 262.

Duke, J.A., Okibgo, B.N., Reed, C.F. and Weder, J.K. P. 1977. *Voandzeia subterranea* (L.) Thoaurs Trop. Grain Legume Bull. 10: 8 - 11.

Duke, J.A. 1981. (*Voandzeia subterranea* (L.) Thouars. *In*: Handbook of legumes of World economic importance. Plenum Press, London UK. pp 307 - 310.

Du Petit -Thouars, L. M. A.1806. Genera Nova Madagascariensis.*In*: Goli, A. E. Begemann, F. and Ng, N. Q. Germplasm diversity in Bambara groundnut and prospects for crop improvement. *In*: Crop genetic resources of Africa vol. II. Proceedings of an International conference on crop genetic resources of Africa 17 - 20 October 1988. Ng, N. Q., Perrino, P. Attere, F. and Zedan, H.(eds.) Ibadan Nigeria. pp. 195 - 202.

Eaglesham, A.R.J., Sassouna, S. and Seegers, R. 1983. Fertilizer-N effects on N_2 fixation by cowpea and soybean. Agron. J. 75: 61 - 66.

Eck, H.V., Mathers, A.C. and Musick, J.T. 1987. Plant water stress at various growth stages and growth and yield of soybean. Field Crops Res. (Netherlands). 17: (1) 1 - 16.

Elia, F.M. and Mwademele, O.D. 1986.The effect of water deficit droughts on some plant characters in Bambara groundnut *(Vigna subterranea* (L.) Thouars.). Trop. Grain Legume Bull. 33: 34 - 50.

Gallegos, J.A. and Shibata, J.K. 1989. Effect of water stress on growth and yield of indeterminate dry bean (*Phaseolus valgaris* (L)). cultivars. Field Crops Res. (Netherlands) 20: (2) 81-93.

Goli, A.E., Begemann F. and Ng, N.G. 1991. *In*: Germplasm diversity in Bambara groundnut and prospects for crop improvement. *In*: Crop genetic resources of Africa vol. II. Proceedings of an international conference on crop genetic resources of Africa 17-20 October 1988. Perrino, N.Q., Attere, F. and Zedan, H. (eds.). Ibadan, Nigeria. pp 195 - 202.

Gomez, A. Kwanchai and Gomez, A. Arturo, 1984. Statistical Procedures for Agricultural Research, 2nd edition. John Willy and sons. Singapore. 680 pp.

GRZ / UNDP / Food legumes. 1989. Research annual report 1988/89. Ministry of Agriculture and Cooperatives, Department of Agricultural Research Branch. 135 pp.

Harper, J.E. 1974. Soil and symbiotic nitrogen requirements for optimum soybean production. Crop Sci. 14: 255 - 260.

Harris, D. and Azam-Ali, S.N. 1993. Implications of daylength sensitivity in Bambara groundnut (*Vigna subterranea*) for production in Botswana. J. of Agric. Sci. 120: 75 - 78.

Hepper, E.N. 1963. The Bambara groundnut *(Voandzeia subterranea)* and kersting's groundnut *(Kerstingiella geocarpa*) wild in West Africa. Kew Bull. 16: 395 - 407.

Henson, R.A. and Bliss, F.A. 1991. Effects of N fertilizer application timing on common bean production. Fertilizer Res. 29: (2) 133 - 138.

Hill, G.C.H. 1978. An appraisal of work carried out on Bambara groundnut in Zambia, 1972 - 77: Mt Makulu Central Research Station (Mimco).

Johnson, D.T. 1968. The Bambara groundnut, a review Rhodesia Agricultural J. 65: 1 - 4.

Kadhem, F.A., Specht, J.E. and Williams, J.H. 1985. Soybean irrigation serially timed during R1 to R6. II. Yield component responses. Agron. J. 77: 299 - 304.

Kannaiyan, J., Haciwa, H.C., Mbewe, M.N., Greenberg, D.C. and Mulila-Miti, J.M.,1989. Minor Legumes Resarch in Zambia. *In*: Proceedings of the National Workshop on Food Legume Research and Improvement in Zambia. 9 - 11 March, 1988, Mfuwe, Zambia. pp. 157 - 166.

Karikari, S.K. 1972. Correlation studies between yield and some agronomic characters in Bambara groundnut (*Voandzeia subterranea* Thouars). Ghana J. of Agric. Scie. 5: (1) 79 - 83.

Kawahara Masato, Hoshi Shinobu and Yoshida Yakashi. 1986. Soil management and nitrogen fertilization for increasing the yield of soybean in Japan. ASPAC Technical Bulletin 98: 13 pp.

Kutsh, H.and Schuh, H.J. 1983. Simplified computer-based modeling of water balance in defined crop stands. *In* informatique verarbeitung Agrawissenschaft, Reiner, I. and Geided, H. (eds.) Badschurmpest in der Land Wirttschaft, Stuttgart, 7: 239 - 353.

Lamptey, P. and Ofei, I.O. 1977. The effect of leaf spot caused by *Cecospara canescens* (Ellis and Martin) on the yield of Bambara groundnut (*Voandzeia subterranea* (L.) Thouars). Ghana J. of Agric. Sci. 10: (2) 113 - 115.

Linnemann, A.R. 1990. Cultivation of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) in Western Province, Zambia. Report of a field study. Tropical Crop Scie. Wegeningen, The Netherlands. 34 pp.

Linnemann, A.R. 1987. Bambara groundnut (*Vigna subterranea* (L.) Verdc.) a review. Abstracts on Trop. Agric. 12: (7) 91 - 95.

Linnemann, A.R. 1991. Preliminary observations on photoperiod regulation of phenological development in Bambara groundnut (*Vigna subterranea)*, Field Crops Res. 26: 285 - 304.

Linnemann, A.R., and Azam-Ali, S.N. 1992. Bambara groundnut (*Vigna subterranea* (L.) Verdc.). In Underutilized crops series II. Vegetables and pulses. Chapman and Hall London. 58 pp.

Liu, Dah-jiang 1991. Effecient use of nitrogen in crop production. ASPAC Extension Bull. 340: 10 pp.

Lungu, D.M. and Mbewe, D.M.N. 1986. Characterization of yield and nutritional quality of Bambara groundnut *(Voandzeia subterranea)*. Progress Report SACCAR Research Grant SRG-03. University of Zambia, Lusaka, Zambia. 12 pp.

Marcgrav de Liebstad, G. 1648. Historiae Rerum Brasiliae. *In*: Goli, A. E.,Begemann, F.and Ng, N. Q. Germplasm diversity in Bambara groundnut and prospects for crop improvement. *In*: crop genetic resources of Africa vol.II. Proceedings of an International conference on crop genetic resources of Africa 17 - 20 October 1988. Ng, N. Q., Perrino, P., Attere, F. and Zedan, H. (eds.) Ibadan, Nigeria. pp. 195 - 202.

Marechal, R., Mascherpa, J. M. and Stainer, F. 1978. Etude Taxonomique d'un groupe complexe d'especes genre phaseolus et polliniques, traitees par l'analyse iformatique. Boissiers 28: 1 - 173.

Masyhudi, M.F. and Patterson, R.P. 1991. The effect of water stress on nitrogen absorption of soybean. Indonesian J. of Crop Scie. Vol. 6:(2) 43-63.

Mbewe, D. N. and Lungu, D. 1990. Bambara groundnut improvement. *In*: Proceedings of first National Workshop on Bambara groundnut improvement in Zambia. Begemann, F.(ed.) Lusaka, Zambia. pp. 1 - 9.

McElhannon, W.S. and Mills, H.A. 1878. Influence of percent NO_3- / NH_4+ on growth, N absorption and assimilation by lima beans in solution culture. Agron. J. 70: 1027 - 1032.

McWilliam, J.R. 1980. Adaptation of plants to water and high temperature stress: Summary and synthesis-adaptation to high temperature stress. *In*: Adaptation of plants to water and high temperature stress. Turner, N.C. and Kramer P.J. (eds.) John Wiley and Sons Inc. New york. pp. 444 - 447.

Mengel, K. and Kirkby, E.A. 1987. Principles of Plant Nutrition. 4th ed. International Potash Institute. Switzerland. 687 pp.

Michael, G., Schumacher, H. and Marscher, H. 1965. Uptake of ammonium and nitrate and their distribution in the plant. Z. Pflanzenernar. Dung Bodenk. 110: 225 - 238.

Mkangama, C. 1992. The performance of different landraces of Bambara groundnut grown at different plant population densities in the Lusaka Province of Zambia. MSc thesis, University of Zambia, Lusaka, Zambia. 72 pp.

Musonda, M.V. 1988. Response of Bambara groundnut (*Vigna subterranea*) to levels of nitrogen, phosphorus and potassium, and the visual diagnostic approach to identifying mineral deficiencies. BSc thesis. University of Zambia, Lusaka, Zambia. 34 pp.

Nageswara-Rao, R.C., Sarda Singh, Sivakumar, M. V.K., Srivastava, K. L. and Williams J.H. 1985. Effect of water deficit at different growth phases of peanut. I. Yield responses. Agron. J. 77: 782 - 786.

Nkumba, E.N. 1993. Genetic attributes of Bambara groundnut. Msc thesis, University of Zambia, Lusaka, Zambia 42 pp.

Olifintoye, J.A. 1986. Cowpea (*Vigna unguicucula* (L.) Walp) response to different levels of phosphorus and nitrogen in the Guinea savanna of Nigeria. Philippine Agriculturalist. 69: (3) 411 - 418.

Olson R. A. 1978. The indispensable role of nitrogen in Agricultural production. *In*: Pratt, P.F. (ed.) National conference on management of nitrogen in irrigated Agriculture. U. S. Nat. Sci. Found., USEPA, and University of California, Riverside. pp 1 - 31.

Olson, R.A. and Kurtz, L.T. 1982. Crop nitrogen requirement, utilization, and fertilization. *In:* Stevesnson, F.T. (ed.) 1982. Nitrogen in Agricultural soils. Agron. J. 22. 567 - 604.

Peck, N. H.and MacDonald, G.E. 1984. Snap bean plants response to nitrogen fertilization. Agron. J. 76: 247 - 252.

Pilbeam, C.J., Hebblethwite, P.D. and Yusuf, A.A. 1990 Irrigation effects on the development and yield of determinate and indeterminate forms of autumn sown faba bean. J. of the Sci. of Food and Agric. 53: (4) 443 - 454.

Poulter, N.H. and Caygill, J.C. 1980. Vegetable milk processing and hydration charecteristics of Bambara groundnut (*Voandzeia subterranea* (L.) Thouars) J. Sci. Agric. 31: 1158 - 1163.

Pritoni, G., Venturi, G., and Amaducci M.T. 1990. Effect of adequate or inadequate water supply at critical growth phases of soybean: Pod filling phase. Errigazione e Drenaggio, 37 (4) 29 - 34.

Rao, K.P. and Rains, D.W. 1976. Nitrate absorption by barley. Plant Physiol. 57: 55 - 58.

Reddy, T.R., Rao, M. and Rao K.R. 1990. Response of soybean to nitrogen and phosphorus. Indian J. of agron. 35: (3) 303 - 310.

Schomberg, H.H. and Weaver, R.W. 1990. Early growth and denitrogen fixation by arrow leaf clover in response to starter nitrogen. Agron. J. 82: 946 - 951.

Sereme, P. 1991. Les maladies transmises par les semences de Voandzou au Burkina Faso. [Diseases transmitted by Bambara groundnut seeds in Burkina Faso]. Sahel Pv Info. 32: 2 - 5.

Sionit, N., Teare, I.D. and Kramer, P.J. 1980. Effects of repeated application of water stress on water status and growth of wheat. Physiol. of Plants. 50: 11 - 15.

Somasegaran Padman, Abaidoo, R.C. and Kumaga, F. 1990. Host - Bradyrhizobium relationships and nitrogen fixation in the Bambara groundnut (Voandzeia Subterranea (L.) Thouars nom. cons.) Trop. Agric. (Trinidad) 67: (2) 138 - 142.

Tanimu, B. and Yayock, J.Y. 1989. Bambara nut agronomy. *In*: Cropping Schemes Report. Legumes and Oilseed Research Progamme. Ahmadu Bello University, Institute of Agricultural Research, Zaria, Nigeria, pp. 136 - 140.

Tanimu, B. and Yayock, J.Y. 1990. Bambara. *In*: Cropping Scheme Report 1990. Legumes and oilseeds Research Programme. Ahmadu Bello University, Institute of Agricultural Research, Zaria, Nigeria. pp. 98 - 101.

Tisdale, S.L., Werner, L.N. and James, D.B. 1985. Soil fertility and fertilizers, 4th Edition. Macmillian Puplishing Company, New York, U. S. A. 754 pp.

Warrang, M.O.A. and Hall, A.E. 1983. Reproductive response of cowpea to heat stress: Genotypic differences in tolerance to heat at flowering. Crop Sci. 23: 1088 - 1092.

Verdcourt, B. 1978. The demise of two geocarpic legume genera. Taxon. 27: 219 - 222.

Verdcourt, B. 1980. The correct name for the Bambara groundnut. Kew Bulletin, 35. 474.

Zambia, 1975. Minor legumes. Bambara groundnut (Voandzeia sp.). *In*: Annual Report of the Reseach Branch of the Ministry of Rural Development 1973 - 1974. Republic of Zambia, Department of Agriculture, Zambia. 82 pp.

Zhegqi, Chen, Mckenzie, A. F. and McGill, A. M. 1982. Soybean nodulation and grain yield as influenced by N-fertilizer rate, plant population density and cultivar in Southern Quebec. Canadian J. of plant Sci. 72: (4) 1025 - 1031.

Zsoldos, F. 1972. Ion uptake by cold-injured rice roots. Plant and Soil. 37: 469 - 478.

APPENDICES

Appendix 1. Rainfall data for Lusitu during the 1992 / 93

Cropping Season

	Months				
Days	December	January	February	March	April
1	-	-	7.5	-	-
2	-	7.5	-	-	-
3	-	12.0	-	-	-
4	-	7.5	4.0	-	-
5	-	2.0	16.5	-	-
6	-	1.0	-	12.0	-
7	1.0	-	-	22.5	-
8	-	-	2.5	17.0	-
9	3.5	-	-	-	-
10	2.5	2.0	2.0	-	-
11	-	26.0	-	-	-
12	18.5	2.0	-	-	11.0
13	-	-	-	-	-
14	13.5	-	2.5	-	7.0
15	1.0	-	-	-	-
16	2.0	-	13.0	-	-
17	5.5	-	-	-	-
18	48.5	-	-	-	-
19	21.5	18.0	-	-	-
20	3.5	-	-	-	-
21	-	-	4.0	-	-
22	4.5	-	-	-	-
23	17.5	-	38.5	-	-
24	4.5	-	-	-	-
25	5.0	31.5	-	-	-
26	-	8.0	26.0	-	-
27	-	-	-	-	-
28	-	-	3.5	-	-
29	-	-	-	-	-
30	-	-	-	-	-
31	5.5	-	-	-	-
Total	157.7	117.5	119.5	51.5	18.0

Source : Department of Meteorological Services, Lusaka, Zambia (1993)

Appendix 2. Rainfall data for Lusitu during the 1993 / 94 Cropping Season

	Months				
Days	December	January	February	March	April
1	_	_	_	_	_
2	_	1.0	_	_	_
3	_	_	_	7.8	_
4	_	_	7.5	_	_
5	_	4.2	3.0	_	_
6	23.0	_	29.0	_	_
7	_	_	14.0	_	_
8	_	_	_	_	_
9	_	_	_	_	_
10	_	_	_	_	_
11	_	_	_	_	_
12	_	_	_	1.8	_
13	_	13.9	_	1.7	_
14	_	21.5	_	_	_
15	_	_	_	_	_
16	_	24.4	_	17.1	_
17	_	10.0	_	_	_
18	_	_	_	_	_
19	_	38.4	_	_	_
20	.84	_	_	_	_
21	_	_	_	_	_
22	_	_	_	_	_
23	16.3	_	_	_	_
24	8.5	_	_	_	_
25	_	1.9	_	_	_
26	_	46.5	_	_	_
27	_	3.1	_	_	_
28	_	_	8.9	_	_
29	_	22.0	_	_	_
30	_	_	_	_	_
31	_	_	_	_	_
Total	48.64	186.9	62.4	28.4	_

Source : Department of Meteorological Services, Lusaka, Zambia (1994)

Appendix 3. Rainfall data at the International Airport during the 1992 /93 cropping Season

		Months			
Days	December	January	February	March	April
1	-	-	-	12.6	-
2	-	-	6.2	-	-
3	-	-	-	14.7	-
4	-	8.0	4.2	-	-
5	-	2.0	6.6	-	-
6	0.5	11.9	-	-	-
7	6.7	3.8	2.9	5.0	-
8	-	-	19.8	-	-
9	15.7	55.4	-	-	-
10	6.4	5.3	3.8	-	-
11	10.1	-	-	-	-
12	4.7	4.2	1.8	-	12.6
13	-	10.0	7.8	1.4	-
14	14.6	-	5.3	-	50.6
15	0.7	0.8	-	-	-
16	14.0	-	6.3	-	-
17	42.0	-	13.2	-	-
18	13.2	-	-	-	-
19	4.5	-	-	-	-
20	25.0	-	-	-	-
21	1.3	5.4	10.9	-	-
22	14.6	-	20.8	-	-
23	3.0	-	21.3	-	-
24	40.5	9.9	7.9	25.6	-
25	-	22.6	7.8	27.3	-
26	-	1.3	7.7	-	-
27	3.0	-	4.2	-	-
28	18.6	3.6	-	-	-
29	-	-	-	-	-
30	-	-	-	-	-
31	-	-	-	-	-
Total	239.1	144.2	158.5	86.6	63.2
Normal	208.0	245.0	186.0	95.0	35.0

Source : Department of Meteorological Services, Lusaka, Zambia (1993)

Appendix 4. Rainfall data at the Lusaka International Airport during the 1993 /94 Cropping Season

	Months				
Days	December	January	February	March	April
1	3.0	-	31.0	-	-
2	13.2	-	-	-	-
3	39.2	32.2	-	-	-
4	-	-	6.0	-	-
5	19.0	6.0	-	-	-
6	0.6	-	23.0	-	-
7	-	-	-	-	-
8	-	-	6.4	-	-
9	-	-	5.3	-	-
10	-	-	72.0	-	-
11	-	-	-	-	-
12	0.5	-	-	-	-
13	-	-	-	-	-
14	-	2.0	-	-	-
15	-	-	-	-	-
16	-	-	0.06	-	-
17	-	1.5	-	-	-
18	-	18.2	-	-	-
19	1.0	1.3	-	-	-
20	-	-	-	-	-
21	-	9.0	-	-	6.9
22	12.0	-	2.0	-	-
23	0.9	0.4	-	-	1.6
24	-	-	-	-	-
25	-	-	-	-	-
26	15.0	5.0	-	-	-
27	23.4	1.0	-	-	-
28	-	-	-	-	-
29	12.4	11.5	-	-	-
30	34.1	8.4	-	-	-
31	-	-	-	-	-
Total	174.3	96.5	145.7	_	8.5
Normal	208.0	245.0	186.0	95.0	35.0

Source : Department of Meteorological Services, Lusaka, Zambia (1994)

Appendix 5. Daily Mean Temperature for Lusitu during the 1993 /94 Cropping Season

			Months		
Days	December	January	February	March	April
1	39.55	28.90	30.05	27.90	31.30
2	33.00	29.65	29.55	28.00	31.20
3	31.90	31.40	29.90	27.60	30.05
4	30.70	27.60	29.20	28.25	29.50
5	31.45	28.45	29.50	28.15	28.70
6	31.75	27.95	28.15	27.80	27.55
7	30.70	27.75	25.95	27.45	27.30
8	32.15	28.40	26.05	28.85	28.65
9	32.30	30.10	27.70	30.45	29.25
10	30.50	29.75	27.85	31.10	28.95
11	30.90	29.45	28.55	30.60	29.10
12	30.20	30.25	28.65	37.10	29.80
13	30.05	31.75	28.50	29.25	27.55
14	29.30	28.00	31.05	30.70	27.55
15	27.20	25.10	28.75	31.90	28.00
16	28.90	27.30	30.15	28.80	28.25
17	31.35	27.15	29.25	29.00	27.60
18	30.90	28.10	30.45	30.10	29.60
19	32.20	29.65	29.55	29.30	29.05
20	31.10	27.20	30.85	28.30	26.80
21	30.55	28.80	27.85	28.70	32.30
22	27.60	29.25	28.95	28.25	31.65
23	30.40	30.60	27.30	24.40	28.40
24	26.30	28.35	28.55	28.50	29.20
25	28.90	27.75	27.75	28.70	26.95
26	29.60	27.50	28.40	29.00	25.35
27	31.10	27.50	29.30	29.60	24.24
28	29.80	30.50	28.80	29.55	23.95
29	31.80	28.40	_	31.00	25.20
30	30.70	26.15	_	30.20	25.80
31	29.60	27.20	_	31.00	_
Means	30.40	28.61	28.81	29.34	30.48

Source : Department of Meteorological Services, Lusaka, Zambia (1994)

Appendix 6. Daily Maximum Temperature for Lusitu during the Cropping Season 1993 /94

	Months				
Days	December	January	February	March	April
1	36.00	33.50	36.70	34.90	38.00
2	36.70	38.10	35.70	35.00	38.40
3	38.20	37.90	35.60	33.60	35.60
4	37.80	31.90	34.50	33.80	35.50
5	36.50	33.90	32.90	33.60	36.20
6	37.80	32.90	27.90	37.50	36.30
7	38.80	35.80	29.60	37.50	36.30
8	37.80	37.80	31.40	37.80	37.00
9	35.40	35.50	32.80	38.20	37.00
10	36.60	35.90	32.70	39.20	36.20
11	35.40	35.50	34.70	31.70	36.00
12	35.60	38.90	34.60	38.00	36.00
13	37.60	34.00	38.20	39.00	36.20
14	37.40	31.60	34.90	33.90	34.50
15	32.00	27.20	35.00	38.80	37.30
16	33.90	31.60	35.00	35.60	38.00
17	36.70	31.80	35.00	36.40	38.20
18	37.90	33.60	36.40	36.50	39.70
19	38.50	36.80	35.60	35.60	38.60
20	39.40	32.40	38.20	34.60	36.60
21	38.00	35.60	33.70	35.50	38.40
22	35.60	34.00	33.00	36.00	37.80
23	33.20	35.60	32.60	37.20	33.40
24	36.50	32.20	33.00	37.20	34.80
25	30.20	31.50	34.60	37.50	28.90
26	33.20	31.00	34.60	38.50	31.20
27	35.60	32.40	35.20	39.60	31.50
28	37.90	38.00	35.40	38.40	32.40
29	35.00	32.30	_	37.50	34.50
30	27.20	30.30	_	38.20	33.50
31	33.30	30.50	_	38.40	_
Means	35.88	33.87	34.26	36.55	35.79

Source : Department of Meteorological Services, Lusaka, Zambia (1994)

Appendix 7. Daily Mean Temperature at the Lusaka International Airport During the 1993 /94 Cropping Season

	Months				
Days	December	January	February	March	April
1	22.20	25.95	21.90	21.20	20.90
2	23.45	24.15	22.80	22.10	24.70
3	23.75	24.15	21.60	21.20	19.95
4	23.10	23.35	22.60	21.40	21.60
5	24.05	20.65	20.95	21.00	21.20
6	22.70	20.15	21.80	19.50	20.10
7	20.75	20.05	22.35	22.35	21.20
8	22.10	21.55	20.45	21.90	20.00
9	23.50	21.95	21.05	22.70	19.50
10	24.30	21.10	22.05	22.80	22.65
11	—	23.10	21.40	23.00	23.35
12	—	24.46	21.75	—	22.20
13	22.40	23.00	20.10	23.10	20.35
14	22.00	20.25	19.90	22.80	22.70
15	21.80	18.50	21.20	22.90	20.85
16	22.65	18.90	20.95	23.70	19.50
17	22.70	20.40	20.35	22.20	21.00
18	23.90	20.40	20.35	23.30	22.45
19	24.60	22.15	22.45	22.70	24.75
20	23.55	24.00	22.25	20.70	21.70
21	23.40	23.30	23.55	21.90	25.45
22	23.65	21.95	21.50	21.20	22.80
23	19.55	22.65	20.00	22.40	20.90
24	21.85	21.80	20.00	22.50	23.70
25	23.25	22.10	19.90	—	20.65
26	23.60	21.75	20.65	—	17.90
27	23.15	22.40	20.50	23.10	17.85
28	22.35	23.10	21.30	22.70	18.50
29	23.65	21.0	—	24.60	19.90
30	23.30	24.55		21.80	18.50
31	22.20	17.50	—	—	—
Mean	22.30	21.12	21.31	21.41	21.23

Source : Department of Meteorological Services, Lusaka, Zambia (1994)

Appendix 8. Daily Maximum Temperature at the Lusaka International Airport during the 1993 /94 cropping season

	Months				
Days	December	January	February	March	April
1	27.20	33.90	25.90	26.70	30.60
2	28.30	33.30	27.20	26.50	31.00
3	28.70	32.70	27.50	25.80	27.40
4	29.60	29.50	27.80	25.80	27.30
5	31.10	23.30	25.10	25.60	26.60
6	28.90	23.80	26.60	26.50	27.90
7	27.30	23.90	26.20	27.90	28.90
8	28.20	27.60	23.90	30.00	29.00
9	30.00	27.80	24.60	30.60	29.30
10	30.60	27.90	26.60	30.10	30.10
11	–	31.70	25.00	31.20	29.60
12	–	31.70	28.00	26.00	28.60
13	27.80	28.20	27.20	31.10	26.70
14	27.80	23.70	25.60	30.60	29.20
15	27.60	26.60	27.90	30.20	27.80
16	27.90	26.30	26.20	30.00	28.00
17	27.10	23.30	24.20	28.30	31.00
18	28.40	26.10	27.80	30.10	31.10
19	30.80	26.80	28.70	28.50	30.80
20	28.70	30.00	28.60	28.10	29.90
21	28.00	28.90	28.60	28.30	31.40
22	28.80	26.80	25.00	28.60	29.60
23	22.10	26.70	23.20	30.20	23.90
24	26.50	26.10	24.40	30.20	28.90
25	30.00	25.50	26.20	–	22.90
26	28.80	25.30	26.50	32.10	22.30
27	27.80	25.80	26.00	32.70	23.50
28	26.20	28.00	26.20	31.80	24.70
29	28.60	31.20	–	30.00	26.60
30	28.60	31.50	–	27.50	25.60
31	28.90	25.80	–	–	–
Mean	27.57	27.73	26.31	29.02	27.57

Source : Department of Meteorological Services, Lusaka, Zambia (1994)

Appendix 9. Soil Characteristics at UNZA farm

Soil Characteristics	Units	Results
pH ($CaCl_2$)		5.20
Total nitrogen	%	0.18
Extractable phosphorus	mg / kg	4.34
Exchangeable potassium	meq / 100 g	0.23
Exchangeable calcium	meq / 100 g	1.00
Exchangeable magnesium	meq / 100 g	0.50

Appendix 10. Soil Characteristics at Lusitu

Soil character	Units	Results
pH ($CaCl_2$)		6.30
Total nitrogen	%	0.13
Extractable phosphorus	mg / kg	4.13
Exchangeable potassium	meq / 100 g	0.74
Exchangeable calcium	meq / 100 g	1.90
Exchangeable magnesium	meq / 100 g	0.50