

**EFFECT OF SOIL MOISTURE STATUS ON GROWTH,  
DEVELOPMENT, YIELD AND SEED QUALITY OF BAMBARA  
GROUNDNUT (*VIGNA SUBTERRANEA* (L) VERDC.)**

**BY**

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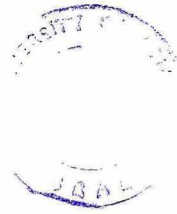
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## DECLARATION

I hereby declare that, except for references to the works of other researchers, which have been duly cited, this thesis has neither in whole nor in part been presented for another degree elsewhere. It is the result of my own investigation.

  
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## DEDICATION

To my family for love and support they gave, up to this stage of my education.



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## ABSTRACT

Studies were conducted from October, 2001 to June, 2002 at Crop Science Department, University of Ghana, Legon, to determine the effect of soil moisture on growth, development, yield and seed quality of bambara groundnut (*Vigna subterranea* (L.) Verdc.), using two varieties: Jabajaba and Chichele Balgu. Three soil moisture regimes, viz. 30-40%, 50-60% and  $\geq 70\%$  of field capacity were imposed two weeks after planting till final harvest. Leaf number, leaf area, nodule number, dry matter production, pod yield and harvest indices decreased significantly at 30-40% moisture level, with 50-60% recording the highest values for these parameters in both Jabajaba and Chichele Balgu.

Pod and seed yields were similar at 30-40% and  $\geq 70\%$  moisture regimes, and these were significantly lower than at 50-60% moisture regime. The 50-60% moisture was most effective in terms of grain yield and dry matter production in bambara groundnut. Although Jabajaba demonstrated better adaptation to moisture stress and higher yield potential than Chichele Balgu did, reproductive yield was generally low, largely due to poor partitioning of dry matter into seeds as expressed in their harvest indices.

Qualitative assessments of seeds revealed that soil moisture had significant effect on seed size, protein and tannin contents. Hundred-seed weight was lower at 30-40% moisture than at  $\geq 70\%$  moisture, but highest at 50-60% moisture. The protein content at 30-40% moisture was higher than protein content at  $\geq 70\%$  moisture, but lower than protein content at 50-60% moisture. However, protein content in Jabajaba was higher than in Chichele Balgu, whilst the level of tannins was higher in Chichele Balgu than in Jabajaba.

The tannin content was lower at  $\geq 70\%$  moisture than at 50-60% moisture, whilst 30-40% moisture recorded the highest. Moisture regime of 30-40% was detrimental to growth, development, yield and seed quality of bambara groundnut. Hence, optimum moisture conditions seem very necessary for good quality seed production in bambara groundnut.

Selecting varieties with high protein and low tannin contents and growing them under optimum moisture and climatic conditions will improve the quality of bambara groundnut. Cream seeded varieties (Jabajaba) seemed most promising and viable alternative to improve the diet of men and animals.

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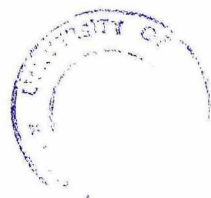


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## CHAPTER ONE

### 1.0 INTRODUCTION

Moisture is an important determinant of crop growth and yield and therefore plays an important role in food sufficiency. For instance, improved high yielding varieties of crops introduced during the green revolution do not yield to their maximum in semi - arid Africa due to inadequate and erratic rainfall (Collinson, 1997). However, there is some evidence that bambara groundnut (*Vigna subterranea*) can produce variable and small, but significant yields under limited soil moisture where other crops like groundnut fail (Babiker, 1989; Linnemann and Azam-Ali, 1993). However, in field conditions where low soil moisture is the most common constraint (Rachie, 1974), pod yields of the crop are low and variable (Stanton *et al.*, 1966).

A successful crop in an ecological niche that is produced and consumed by the inhabitants must have dietary pattern that provides the minimum requirements of all 40-45 essential nutrients, in addition to the energy sources – carbohydrates, fat and protein (Juliano, 1999). Bambara groundnut is a low production cost legume and provides these nutrient elements in several dish preparations and hence its wide production in sub-Saharan Africa.

In Ghana, the crop is produced and used in a variety of ways as flour in cakes, porridge, or boiled and seasoned in local cuisine. Bambara groundnut provides a source of protein, with values ranging from 14 – 23 % (Ofori *et al.*, 2001). The crop could therefore play an important role in the improvement of protein supply to the rural population, and hence reduce protein mal-nutrition (Plahar and Nti, 1995). The availability of protein in human nutrition greatly depends on the levels of its anti-nutritional factors like tannins. However the levels of both protein and tannins in a plant may vary with the prevailing agroclimatic and soil moisture conditions (Vadivel and Janardhanan, 2000a).

Increased production of bambara groundnut would not only improve the quality of local diet, but could also provide farmers with additional income as the seeds can attract market price well above the average for similar legumes (Coudert, 1984). It could also lead to greater diversity of field crops thus having positive effects on stability and reliability of food production. It produces not only seeds for human consumption, but vegetative parts as fodder, especially for draft animals. In terms of production and utilisation, the crop is reported to be the third most important leguminous crop south of the Sahara, being exceeded only by cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogaea*) (Doku *et al.*, 1978).

Bambara groundnut has received very little research attention in most of the countries where it thrives (Norman and Chongo, 1992). The crop has been grown in Ghana over the years with some attempts at improving yield through selection from among farmers' varieties or landraces. There is a dearth of knowledge of bambara groundnut water requirements, which can provide support for decision making in agricultural planning. There is therefore the need to assess the salient physiological features of bambara groundnut using principal factors such as soil and water, which can be adjusted across a pre-determined range. In this way, key potential attributes can be identified to define the types of agricultural environments and agronomic practices that are likely to be suitable for bambara groundnut.

Agronomic studies are not conclusive on the optimum moisture for optimum seed yield and quality of bambara groundnut in Ghana. This calls for critical evaluation of agronomic and nutritional quality of the crop under different moisture regimes. The study therefore aims at determining the effect of soil moisture status on growth, development, seed yield and seed quality of bambara groundnut.

## CHAPTER TWO

### 2.0 LITERATURE REVIEW

#### 2.1 GROWTH AND DEVELOPMENT OF BAMBARA GROUNDNUT

##### 2.1.1 Growth habit

Bambara groundnut belongs to the family Leguminosae and subfamily Papilionoideae. It is a herbaceous, intermediate, annual plant with creeping stems just above the ground level. Differences in the length of internodes result in bunched, semi-bunched (intermediate) and spreading types. The general appearance of the plant is bunched leaves arising from branched stems, which form a crown on the soil surface. Erect petioles contain trifoliolate leaves produced at the nodes of the prostrate stems. It has its flowers occurring in pairs on peduncles at the petiole base. After pollination and fertilisation, the peduncles lengthens thus bringing the ovaries underground which develop to form pods (Doku, 1968)

##### 2.1.2 Growth and development

Plant growth and development generally, depend on the partitioning of photosynthates to the various plant organs especially the grain. Growth analysis where leaf area and plant dry weight are taken at regular intervals during the growth of the plant until maturity are useful in computing net assimilation and crop growth rates. Changes in dry weights of the various plant organs indicate how assimilates are partitioned into these organs (Linnemann, 1994).

Landraces or strains that are superior in channelling assimilates to the grain can easily be identified and used as parents in breeding programmes to improve grain yield. Under low

moisture condition, leaf number and leaf area may be reduced and thus decreasing the photosynthetic activity (Adjetey and Ayihi, 1999).

### **2.1.3 Leaf area and leaf number per plant**

In some bambara groundnut varieties, leaf blade, petiole and whole leaf dry weights increase up to their maximum at 69 days after anthesis (DAA) after which they decline sharply (Norman and Chongo, 1992). At anthesis, petiole and leaf blade account for 11.8 and 56.9% of total plant dry weight but declined to 9.1 and 30.6% respectively at seed maturity. It is also known that number of leaves increased from about 144 to about 290 leaves per plant at 76 days after anthesis, but fell drastically at maturity (Norman and Chongo, 1992). Leaf number per plant declines with low moisture but increases under adequate water. According to Goli *et al.*, (1997) number of leaves per plant could vary from 4 to 14, 11 to 20, 20 to 300, or even 8 to 328, depending on the growth stage, and the variety.

High leaf number and leaf area increase the photosynthetic capacity of the crop and thereby increasing dry matter. Vegetative growth may cease within eleven weeks after planting within which period the dry matter production is high, and prior to mature leaf senescence and abscission sets in resulting in a decrease in dry matter (Adjetey and Ayihi, 1999). The indices of growth such as leaf area, number of leaves and dry matter, increased with increasing amount and frequency of water application. Inadequate water supply has been reported to lead to inhibition of growth processes such as cell division and cell enlargement (Slatyer, 1967), leading to reduction in leaf area and growth.

#### **2.1.4 Shoot dry matter**

Stems and leaf dry matter production in some varieties of bambara groundnut are known to increase steadily and reaches a maximum at 76 days after anthesis and then declines. At anthesis shoots (stems+leaves) of some landraces account for 14.8% of total plant dry weight but reduces to 7.3% at 83 days after anthesis (Norman and Chongo, 1992). Shoot dry matter yields increases with an increasing amount and frequency of water application (Bunce, 1978; Adjetey and Ayihi, 1999).

#### **2.1.5 Roots dry matter**

Norman and Chongo, (1992) working with some cultivars found that root dry weight reached a maximum at 76 days after anthesis, and then decreased. At anthesis, root dry matter accounted for 5.5 % of the total dry matter and declined to 1.5% of the total dry matter at 83 days after anthesis. Collinson, *et al.*, (1996) also reported that root dry weight appeared to be higher in well watered soil, except at later part of the season where least irrigated plants had higher root weight because, higher assimilates are required for pod development.

#### **2.1.6 Flowering**

Bambara groundnut is a short day plant and is known to start flowering 5 to 6 weeks after sowing, and will stop producing flowers between 9 and 10 weeks after sowing depending on the photoperiod (Linnemann, 1994). According to Norman and Chongo (1992), flowering started 7 weeks after seedling emergence and reached anthesis 3 days thereafter, in some landraces during rainy season in Swaziland. Karikari *et al.*, (1997), also reported that in Botswana days to first flowering were between 44 - 60 days after sowing depending on the variety, and generally all plants reached 50 % flowering within 80 days.

Goli *et al.*, (1997) also reported days to first flower appearance in Kenya being between 37 – 55 days with an average of 38 days; and days to 50 % flowering ranging from 37 – 70 days with an average of 43 days. Harris and Azam-Ali (1993) on the other hand, had mean time to 50% flowers being 47 days. In Burkina Faso, days to 50 % flowering has been reported ranging from 30 – 36 days (Séréomé, 1989; Kiwallo, 1991), while reports in Togo indicated that number of days from first flowering to 50 % flowering varied from 37 – 45 days (Nambou, 1997). In Cameroon, Nguy-Ntamag, (1997) reported that flowering in the rainy season occurred 57 – 69 days after planting, with an average of 64 days after planting.

It has been stated that, soil moisture has no influence on flowering, and plants in the most stressed conditions produce flowers over a longer period, which can be associated with delayed pod production (Collinson *et al.*, 1996). According to Ramolemana *et al.*, (1999), at any given soil moisture level, dry matter accumulation was fast between onset of flowering and podding (7 – 11 weeks after sowing), indicating the period for high moisture demand for shoot growth being between onset of flowering and podding. It has been however reported that, cream landraces produced earlier and more flowers and also matured earlier than red landraces (Karikari *et al.*, 1997). Low soil moisture during flowering may result in increased abortion of flowers and limited pod development (Collinson *et al.*, 1996)

#### **2.1.7 Nodulation and nodule dry weight**

Bambara groundnut has well-developed taproot with profuse geographical lateral roots with some roots having nodules which can fix atmospheric nitrogen with appropriate symbiotic rhizobia (Ramolemana, 1999). Bambara groundnut nodulates freely like cowpea but specific rhizobium strains are exceptionally effective in promoting growth is Bradyrhizobium. Bradyrhizobium strains are known to be easily inoculated unto bambara groundnut resulting in the formation of

abundant nodules. There has been no significant increase in the number and weight of nodules between 68 and 105 days after sowing (DAS), but an increase in nitrogenase activity in nodules.

Nodulation can improve legume growth and seed yield, and inefficient rhizobium strains in nodulation may be detrimental to legume production (Fening *et al.*, 2001). There has been high significant variation of landraces in yield and N-harvest index, and the amount of nitrogen fixed may not be a guide to high pod and seed yields. However, in soybean, plants with more nodules are known to produce higher shoot dry matter yields than less nodulated plants (Kumaga and Etu-Bonde, 2000). Also, significant correlation does exist between N-harvest index per plant and pod and seed yields of the plant. High-yielding bambara groundnut landraces are known to be those with bunchy growth habit which nodulate equally well (Kishinevsky *et al.*, 1996).

Soil reaction does not impair nodulating capacity in bambara groundnut, except at very low pH values (Uguru and Ezeh, 1997). According to Kumaga and Etu-Bonde (2000) soils with pH above 6 favour nodulation of soybean (*Glycine max* (L.) Merrill) in the presence of indigenous rhizobium than others, and some varieties also have inherently poor nodulating ability. Bambara groundnut is known to grow and yield well in Vertisols, whilst Entisols and Inceptisols depress nodulation, growth and yield (Uguru and Ezeh, 1997). Ramolemana, *et al.*, (1999) reported that nodulation and root growth depend on phosphorus level of the soil, but an increase in nodulation and root growth due to phosphorus does not necessarily translate into increased shoot growth and seed yield.

The historically marked variation in farm yields (600 – 3000 kg/ha) of bambara groundnut in Africa (Rachie and Silvestre, 1977) and the fact that high-yielding cultivars from one country can perform poorly in another (NAS, 1979); suggest that there are considerable differences in the

symbiotic efficacy of native bradyrhizobia which nodulate the species. Therefore interest in increasing bambara groundnut production in Africa should target symbiotic effectiveness as a way to yield improvement (Dakora and Muofhe, 1997). Since farmers do not apply chemical fertilisers to bambara groundnut, the nitrogen requirement is met by natural N<sub>2</sub>-fixation, as indicated in several nodulation studies (Samasegaram *et al.*, 1993).

The bradyrhizobia nodulating African legumes such as bambara groundnut, Kersting's bean and cowpea have the ability to survive in soils with the differing moisture, temperature and pH levels found in Africa. However, boron supply is found to be effective in symbiosis in bambara groundnut and hence N<sub>2</sub> fixation, and insufficient boron supply causes a marked decrease in nodule formation in bambara groundnut (Dakora and Muofhe, 1997). For instance, under low boron supply, nodule number per plant was 11 on the average in Zimbabwe and number of nodules did not relate to plant density (Mabika and Mafongoya, 1997). This low nodule number is due to the fact that, most farmers do not inoculate seeds with bradyrhizobium at planting. In Ghana, number of nodules per plant has been reported ranging from 92 –318 (Thompson and Dennis, 1977; Mafongoya, 1988).

## **2.2 Factors influencing growth and development of bambara groundnut**

Individual cultivars of bambara groundnut are not in themselves very adaptable, eventhough the crop can be found in vastly different environments. For instance high-yielding types from one location may fail when grown elsewhere due to different environmental conditions, particularly soil fertility and moisture conditions, temperature and photoperiod (Linnemann, 1994).

### 2.2.1 Soil conditions

Bambara groundnut is a food crop cultivated for its subterranean pods. The cultivation of the crop is of particular importance in semi-arid areas where it has distinct agro-ecological niche: adverse growing conditions such as limited moisture supply and low soil fertility, depress yields to lesser extent than for other legumes such as groundnut (National Research Council, 1979). According to Ameyaw and Doku (1983), yield under available moisture regime of 40% is more than ten times that under 75% available moisture, indicating low optimum moisture requirements.

Under irrigation, increased moisture availability is important for nodule growth, and more nodulation could be responsible for high shoot growth rate (Ramolemana *et al.*, 1999). Also, the ease of penetration of the soil at field capacity during pegging is an important factor in the cultivation of bambara groundnut. Good soil drainage therefore is essential and the crop needs to be planted in loose light soil to facilitate the rhizobium in root nodules and to enhance development of the buried pods and easier harvest (Uguru and Ezech, 1997).

Bambara groundnut is relatively tolerant to drought, poor soils and savanna habitat than other legumes grown in Ghana but prefers well-drained sandy loam soils with pH 5.0-6.5 and can tolerate pH as low as 4.3 (Doku, 1995). However, low pH of 4.6 is known to limit phosphorus availability, since the optimal pH for phosphorus availability is reported to be between 6.0 – 7.0 (Brady, 1974). Therefore, under such low soil pH conditions, particularly in semi-arid African countries like Ghana, organs such as roots and nodules with high phosphorus demand, will be given priority (Kang and Nangju, 1983; Israel, 1987, Othman *et al.*, 1991). Also low soil moisture, as a common problem in semi-arid Africa; inevitably limits availability of phosphorus in soil solution for plant uptake.

Under moisture deficits or fluctuating soil moisture, there is reduction of K-fixation to roots and shoots, soil K mobility and plant K-uptake, and hence plant growth, compared with moderate moisture condition (Brown and Zeng, 2000). According to reports of Wu, *et al.*, (2000), moderate water stress of 50-60% field capacity promoted the development of roots system in wheat whereas high soil moisture favoured leaves and stem growth. Lower water deficit soils significantly reduced crop productivity.

A growth substance such as cytokinin, which promotes the attraction and retention of, assimilates and retards the senescence of green leaves, can fluctuate based on soil moisture level. Reports indicate that cytokinin contents in saturated soils are lower than that in less saturated soils, during the early stages of development. Cytokinins enhance sink capacity by attracting metabolites, retards senescence and prolong flowering period (Michael and Seiler-Kelbitsch, 1972). Also, abscisic acid (ABA) in both leaves and grains under water deficit appear to be higher than those receiving more water, and the higher the ABA, the earlier the leaf senescence during grain filling (Yang *et al.*, 2001).

Studies in wheat indicated that water deficits enhanced leaf senescence in plants by accelerating loss of leaf nitrogen and chlorophyll and increasing lipid peroxidation (Yang *et al.*, 2001). Studies in common beans also indicated that water stress results in growth reduction due to the closure of stomata leading to the reduction in CO<sub>2</sub> intake by the plant (Adiku *et al.*, 2001). According to Wu *et al.*, (2000) wheat leaf growth rate was reduced when soil moisture content was lower than 60% of field capacity, which decreased total leaf area, and decrease the yield. Increases in soil moisture from 45-55% increased photosynthetic rate but not up to 50-60%. Above 60% soil moisture content, there was no positive change in the photosynthetic rate. Parylak, (2000) reported in a triticale pot experiment that, grain yield was more affected by 30 %

moisture stress at grain filling and at maturity, and reduction of soil moisture up to the flowering, except anthesis stage did not affect the grain yield. Adequate soil moisture of 70% during grain filling promoted grain yield.

### **2.2.2 Rainfall conditions**

Rainfall between 600-1200 mm per annum and an altitude up to 1520 m high could be enough to obtain successfully, optimum seed yields in bambara groundnut. The crop is however susceptible to waterlogging (Doku 1968), probably due to the sensitive nature of the root nodules to anaerobic conditions (Wien *et al.*, 1979). Karikari (1969) compared planting during rainy and dry season at Legon and observed that yields were significantly lower during the rainy season, indicating optimum water requirement for the crop. Diseases such as Cercospora leaf spot and fusarium wilt which could significantly reduce yield are common under continuous water supply and high relative humidity (Karikari, *et al.*, 1997). Under inadequate rainfall, yields can be improved with supplementary water application (Elia and Mwandemele, 1986).

### **2.2.3 Temperature and photoperiod**

Generally, plant development is predominantly controlled by temperature (Bailey and Boisvert, 1991). Temperature has some effect on times from sowing to the appearance of the first open flower. However, days from sowing until the appearance of the first open flower are affected by both temperature and photoperiod in some varieties of bambara groundnut. Linnemann, (1994) found that temperatures with photoperiods as 20.2 °C with 14h/d, 24.1 °C with 16h/d, and 28.1 °C, with 10 h/d, were found delaying flowering in some varieties. Earliest flowering times appears to be 38 days after sowing (DAS) in 10 h/d at 28.1 °C and latest was 64 DAS in 16h/d at 28.1 °C. Photoperiods were however found more limiting at warmer temperatures. Though, there are variations in temperature and photoperiod sensitivity, as well as other climatic variables, in

bambara groundnut genotypes, the crop is known to thrive and yield well on high temperatures, low relative humidity and in bright sunshine, especially in savana regions of Africa (Linnemann, 1994).

The crop establishment of bambara groundnut could depend critically on temperature at germination, as it affects not the timing and spread of germination, but the fraction of seed population that finally germinates (Mabika, 1991; Kocabas *et al.*, 1996,). Bambara groundnut has a period of flexible duration at its disposal from vegetative stage to flowering, and a fixed period from the onset of flowering to maturity as many legumes supposedly have as all the work on the prediction of flowering suggests (Summerfield *et al.*, 1991).

In groundnut there are conspicuous differences in the time to flowering, podding and total duration of growth between dry and rainy seasons in Niger (Ong, 1986). During the rainy season in Kenya, the normal time to maturity in some varieties was about 105 days. It has been stated that longer maturity periods of 130 days after sowing and germination delays in bambara groundnut is due to lower temperatures in December, whilst the shorter day length throughout the post-rainy season, delays plant development (Linnemann, 1994). Under varying temperatures for instance, pod maturity period of bambara groundnut ranged between 120 – 155 days after sowing, but with the cream landraces producing more flowers and also maturing earlier than the red landraces (Karikari *et al.*, 1997).

#### **2.2.4 Pest and diseases**

Bambara groundnut is relatively tolerant to diseases and pests, than other legumes grown in Ghana. However, disease agents such as fungi, viruses, nematodes and insect pests could attack the plant leading to crop failure (Doku, 1995). Fungi such as *Ascochyta phaseolunum*,

*Collectotrichum capsici* and *Corticium solani* are known to attack bambara groundnut especially in the season where relative humidity is very high. Crops under irrigation and waterlogging conditions are usually respectively attacked by *Cercospora* leaf spot and fusarium wilt (Karikari, *et al.*, 1997). In Kenya, Nigeria and Tanzania, there are infections of *Erysiphe polygon* and *Fusarium oxysporium*.

However, there are many others, which do not reduce yield seriously, such as *Sclerotium rolfsii*, *Phaseolus manihoti*, *Phyllosticta voandzeiae*, *Rhizoctonia laticola* and *Sphaerotheca voandzeiae*. In Ghana, leaf spot, *Phyllosticta spp* and late blight, *Corticium solani* have been reported in bambara groundnut (Doku, 1995). Viruses such as cowpea-aphid borne mosaic virus (Rossel *et al.*, 1985) and peanut mottle virus (Li *et al.*, 1991) have been reported attacking the crop.

According to Thottappilly and Rossel (1997), eight viruses common to cowpea, cucumber and southern bean were found attacking bambara groundnut in Nigeria. Nematodes (*Meloidogyne spp*) attack could facilitate *Fusarium spp* infection, and yield can be reduced considerably by nematodes if the crop is grown in infested areas, especially in sandy soils (Gwekwerere, 1997). Weevils such as *Callosobruchus maculatus* (Karikari *et al.*, 1997) and *Callosobruchus subinnotatus* (Mbata, 1990) have been found attacking bambara groundnut seeds.

## **2.3 SEED YIELD AND COMPONENTS OF SEED YIELD**

### **2.3.1 Seed yield**

Yield is one of the most important aspects to be considered in efforts to improve the level of production. Yield as a quantitative character however, can be influenced by the environment and may not have high heritability (Johnson, 1989). As a result, seed yield in Africa averages between 650 – 850Kg/ha (Stanton *et al.*, 1966), with large differences between countries.

For instance yield in Ghana has been reported ranging between 500 – 800 Kg/ha (Doku, 1995) and 527 – 1123 Kg/ha, decreasing with decreasing amount of water applied (Adjetey and Ayihi, 1999). Yield reported in Botswana ranged between 163 – 197 Kg/ha (Karikari *et al.*, 1995), and in Burkina Faso between 500 – 800Kg/ha (Drabo, 1987). Also, yield ranging from 400 – 1400kg/ha of unshelled pods (Mabika and Mafongoya, 1997), and high as 3870Kg/ha (Johnson, 1968), have been reported in Zimbabwe. Seed yield is also known to vary among landraces or varieties as it has been reported that Zimbabwe red yielded about 1700 Kg/ha with the lowest yield occurring in the cream seeded landraces (Karikari *et al.*, 1997).

From the above, the response to direct selection of landraces for seed yield may be unpredictable unless there is good control of environmental variation (Ofori, 1996). For instance, grain yield per plant is known to be highly correlated with days after anthesis which is weather dependant, and grain yield per plant also correlating strongly with Harvest Index, which ranged from 2.2 % at 20 days after anthesis to 36.6 % at maturity.

Therefore, harvest index, seed size, seed number per plant, total plant dry weight, days to maturity, pod shell weight and pod number per plant, are major factors to be considered in order to achieve improvement in the yield of bambara groundnut (Norman and Chongo, 1992). However, the highest seed yields are expected when components of seed yield such as number of pods per plant, number of seeds per pod and seed weight are maximised (Ofori, 1996).

## 2.3.2 Components of seed yield

### 2.3.2.1 Number of pods per plant

Pod numbers such as 42 and 47 per plant have been reported by Collinson *et al.*, (1996) under adequate moisture. According to Adjetey and Ayihi (1999), pod number per plant ranges between 11 – 22, decreasing with less amount of water received. It has been recorded that, number of pods per plant could vary widely depending on the stage of harvest.

For instance studies in Botswana indicated that, pod number per plant for bambara ranges between 3 – 39 and 2 – 43, increasing with increasing number of days after anthesis (Norman and Chongo, 1992). Pod number per plant ranging from 13 – 38 depending on the season has been reported in Zimbabwe (Chibudu, 1997). Also, pods per plant, ranging from 10 – 201 with a mean of 23, has been recorded in Nigeria (Goli, *et al.*, 1997); whilst pod growth varying from 0.52 – 0.72 g with an average of 0.61 g per pod has been recorded in Cameroon (Nguy-Ntamag, 1997). Harvest index, which was expressed as ratio of pods to the whole plant, ranged from 0.42 – 0.49, with an average of 0.45 under rainfall condition in Cameroon (Nguy-Ntamag, 1997).

Seed yields per plant are known to be reduced by an early induction of podding (Norman and Chongo, 1992). Early induction cause plants to use assimilates for early reproductive growth. This limits the plants' source capacity and consequently, yielding ability. Plants, which start to pod early, use the longer period they have between the onset of podding and harvest to continue to produce pods, but in comparatively small numbers. Late induction gives higher yields but also a more synchronised development, and hence maturity of pods (Linnemann, 1987).

### 2.3.2.2 Number of seeds per pod

Most varieties of bambara groundnut are single seeded pods but pods with 2 –3 seeds are available. For instance, pods with 3 seeds were frequently found in ecotypes in Congo (Goli *et al.*, 1991) and 1 – 2 with mean value of 1.1 seeds per pod in Nigeria (Goli *et al.*, 1997).

### 2.3.2.3 Seed weight

Seed sizes (100 – seed weight) of bambara groundnut ranges between 25 – 60g, with average size of about 37 g (Doku *et al.*, 1978). Seed size of 53 g has been recorded in Botswana. In Nigeria, a 100 - seed weight of eleven accessions, ranging between 50.7 – 135.5 g, with an average of 79.1g has been reported (Taminu *et al.*, 1990). According to Goli *et al.*, (1997), a 100-seed weight in some varieties of bambara groundnut in Nigeria ranged between 10 – 89 g with an average of 43 g, whilst seed yield per plant ranged from 0.03 – 97 g with an average of 11.51 g. In Ghana, seed weight between 43 – 49 g has been reported by Adjetey and Ayihi (1999), whilst Ofori *et al.*, (2001) reported seed sizes ranging between 34 – 63 grams.

Studies carried out in Cameroon reported seed yield between varieties varying from 13.4 – 47.16 g/plant, with an average of 28.89 g/plant, whilst seed weight varied from 0.38 – 0.47 g per seed with an average of 0.43 g per seed (Nguy – Ntamag, 1997). Seed weights however are known to vary depending on the prevailing agroclimatic and soil moisture conditions (Jarillo *et al.*, 1998) eventhough the trait is reported to be highly heritable (Gowda *et al.*, 1999).

## 2.4 SEED QUALITY OF BAMBARA GROUNDNUT

### 2.4.1 Protein content

Nutritional studies on bambara groundnut indicated that, the crop is comparable to cowpea. It contains on the average 19.3% protein (Karikari 1971) whilst cowpea contains 18-24% protein, with soybean having the highest protein content of 32-40% (Watson 1971). It has been recorded that, the chemical score for the bambara groundnut protein from FAO (1982) data is 49, which compares favourably with groundnut (52), Soybean (50) and cowpea (40) (Linnemann and Azam-Ali, 1993).

In addition, present studies in Ghana on twenty-five (25) accessions of bambara groundnut indicated that depending on the cultivar, the seeds could have protein values ranging from 14 - 23 %. In the study, the average was 18.5% and highest range was between 20 to 23 % (Ofori *et al.*, 2001). According to Doku *et al.*, (1978), protein content of six (6) cultivars of bambara groundnut, of which only three (3) were from Ghana, ranged from 17.3-20.1% with the average being 18.3%. In this report, the creamy varieties had the highest whilst the light brown had the lowest, similar to those reported by Brough and Azam-Ali (1992).

Protein content of some two varieties of cowpea and a cream variety of bambara groundnut collected in greater Accra region of Ghana had also been studied (Austin 1974). In the study bambara groundnut protein content was 18.8%, almost the same as that reported by Doku *et al.*, (1978). However, bambara groundnut protein content studied in Botswana varied from 8.2-16.6% in nine landraces, with red and black seeds having higher protein content than light seeded ones (cream and white) (Gibbons, 1994).

There had been such determinations in many cereals and other legumes, and the protein differences are attributed to visual seed-coat colour differences. However there are also differences in protein content within similar seed-coat colour pattern, which could probably be due to other prevailing factors under which they were grown (Deetz *et al.*, 1996).

#### 2.4.2 Tannins as anti-nutritional factors

Food and feed legumes usually contain anti-nutritional factors, and tannins are present in bambara groundnut, especially in the seed coat colour (Poulter, 1981). There are two classified groups of tannins, hydrolyzable tannins and condensed tannins. Hydrolyzable tannins are hydrolysed by acids or enzymes into smaller molecules such as gallic acid, ellagic acid and glucose. Typical hydrolyzable tannin is gallotannin (Griffith and Moseley, 1980).

Though there is limited information on the tannins of bambara groundnut, some studies by Ofori *et al.*, (2001) on twenty-five accessions, indicated that, tannin content ranged from 0.25 – 2.27% (2.5 – 22.7 mg CE/g). In this study, cream seeds had the lowest tannin content with the black recording the highest. Similarly, Poulter (1981) reported tannin content on 8 accessions ranging from 0.36 – 0.94% (3.6 – 9.4 mg CE/g), with the lowest levels in the cream types and the highest in the red.

However, there had been several studies carried out on tannin levels of some other legumes. Papadopoulus *et al.*, (1985), for instance studied correlation between testa colour and tannin content of five cultivars of faba beans (*Vicia faba*) and indicated that tannin content was positively correlated to testa colour; being higher in brown to black cultivars. There had been

similar reports in studies on horse beans that tannins levels vary with the seed coat colour (Kosa *et al.*, 1977).

Plahar *et al.*, (1997) studied four cowpea cultivars and reported that condensed tannins were concentrated mainly in the seed coats of highly pigmented cultivars. The tannin content in the raw whole cowpea, ranged between 0.34 mg CE/g sample in the cream-seeded cultivar to 6.88 mg CE/g sample in the red (or 0.03-0.69%) with average of 3.67 mg CE/g sample (0.37%). Annih-Bonsu (1994) also studied four cowpea varieties and reported tannin range of 0.58-4.2mg CE/g of dry sample.

There have been several studies, which suggest that tannin content appeared in inverse relation to *in vitro* protein digestibility, with the relation by no means constant or uniform. Nevertheless, cultivars that demonstrated digestibility more than 70% with tannic acid levels below 0.5% (5 mg CE/g) were stated to be nutritionally superior (Van Wyke *et al.*, 1973). Plahar *et al.*, (1997) also reported that tannin concentrations of up to about 4.2 CE/g sample (or 0.42%) did not affect protein digestibility; and in all the four cowpea varieties studied tannin content ranged between 0.03-0.69% with respective acceptable digestibility of 77.8-75.5%.

Tannins are known to form tannin protein-complexes, which may not dissociate at physiological pH and may pass out in faeces, thereby causing the bound protein to escape digestion. Tannins are believed to be heat labile and could be inactivated by heat (Liener and Kadade 1980), but after a lengthy period of continuous heating. However, bambara groundnut seeds can be eaten raw like groundnut, in which case these anti-nutritional factors are bound to protein in protein-complexes forms. There are also possibilities of losing vital nutrients and flavours through prolonged cooking.

## 2.5 FACTORS INFLUENCING SEED QUALITY

Antinutritional factors for protein are protease (trypsin) inhibitors, tannins and phytate (Juliano, 1999). Tannins are polyphenolic compounds that form indigestible complexes with protein and other macromolecules, but under specific environmental conditions (El-Shemy *et al.*, 2000). Studies under two different seasons by Gowda *et al.*, (1999) indicated that grain yield, phenolics and tannins heritability was higher than protein, even though there were some differences in their levels between the seasons. Also, similar seeds of velvet bean from different agroclimatic regions of India differed in their crude protein, crude lipids and carbohydrates, and anti-nutritional factors such as total free phenolics, tannins and lectins with greater variations among them (Vadivel and Janardhanan, 2000a; 2000b).

It has been indicated that, under saturated soil moisture and humid weather, levels of protein and these anti-nutritional factors decline (Jarillo *et al.*, 1998). Also under higher sun exposure, tannin concentrations are known to increase in plants, but decrease under low sun exposure (Ganzhorn, 1995). Deetz *et al.*, (1996) indicated that natural sugar concentrations and glucose were low under severely restricted water supply, and that large-scale environmental conditions may determine chemical composition of seeds even under moist soils. In contrast to the above, Haukos and Smith (1995) reported that concentrations of phenolic acids were not related to irrigation levels. They also found no significant differences in carbohydrates, crude protein and crude fat contents within playa species under moist soil, except that differences were found among species of playas under the same moisture regime.

These reports on tannin and protein contents under prevailing agroclimatic and soil moisture conditions are quite interesting and worth noting. However such studies on bambara groundnut under different water regimes could as well be recommendable.



## CHAPTER THREE

### 3.0 MATERIALS AND METHODS

#### 3.1 Cultivars

Two (2) bambara groundnut cultivars with contrasting growth habit, Jabajaba (early and bunch) and Chichele Balgu (late and spreading), were used as planting materials. They were selected from the collection maintained at the Department of Crop Science, University of Ghana, Legon.

#### 3.2 Soil sampling and analysis

##### 3.2.1 Soil sampling.

The Haatso series, described under U. S. D. A, 1975 taxonomic classification as an entisol of quartzipsamment (Stella, 1989) and by Soil Survey Staff, (1992) as Typic Paleustalf was used for the study. The topsoil of the profile is sandy loam and consists of approximately 20 cm of pale brown-to-brown sand with weak, fine granular structure and has a loose and friable consistence. It contains fine and abundant common medium root. The parent material is sandstone (Soil Survey Staff, 1992). Samples of the soil were collected from Ap horizon at the depth of 0 - 15 cm from the University of Ghana farm. The soil after air-drying, was homogenised by passing it through 5 mm sieve. This soil was then used for the experimental studies.

##### 3.2.2 Soil analysis

Soil analysis was carried out at the Ecological Laboratory, University of Ghana, Legon.

Soil physical analysis carried out were:

(i) Particle size analysis of sand, silt and clay, using Bouyoucos (1962) Hygrometer method; (ii) Water Holding Capacity (WHC), using the Funnel method; and (iii) Bulk Density ( $\rho_b$ ), using Core Method.

Chemical analysis of soil involved:

- (i) Determination of pH, in 1:1 soil: water ratio, and in 1:2 soil: 0.01M CaCl<sub>2</sub> (White, 1969);
- (ii) Organic carbon and Organic matter determination, using Walkley and Black (1934) method.
- (iii) Nitrogen (N) determination, using Macro - Kjeldhal (AOAC, 1975) Method. (iv) Total and Organic phosphorus determination using Bray and Kurtz (1945) method; and Available phosphorus determination using Saunders and Williams (1955) (a modified Bray No. 1) methods. (v) Exchangeable Cations (EC) or Bases determination using ammonium acetate (1.0 M NH<sub>4</sub> OAC) at pH 7.0 method. Calcium (Ca<sup>2+</sup>), Magnesium (Mg<sup>2+</sup>), potassium (K<sup>+</sup>), and Sodium (Na<sup>+</sup>) were determined using flame photometry (Moss, 1961; Rayment and Higginson, 1992).

The results of the soil analysis are presented in Table 3.1 below.

Table 3.1: Physical and chemical characteristics of soil  
from Ap horizon at 0 – 15 cm depth

PHYSICAL								
	%Sand	% Silt	% Clay	Water Holding Capacity (%)			BulkDensity (g/cm <sup>3</sup> )	
Value	76.18	4.9	18.82	67.65			1.64	
CHEMICAL								
	pH In H <sub>2</sub> O	pH In CaCl <sub>2</sub>	Org. C (%)	Org. M (%)	N (%)	TP ppm	Org. P ppm	Av. P ppm
Value	5.7	4.8	0.36	0.62	0.08	86.25	36.5	6.85
Exchangeable Bases (Meq/100 g Soil)								
	Na <sup>+</sup>		Mg <sup>2+</sup>		K <sup>+</sup>		Ca <sup>2+</sup>	
Value	0.54		4.2		0.92		11.3	

Tp = Total phosphorus, Av.p = Available phosphorus, Org = Organic, M = Matter.

## **POT EXPERIMENTS**

Two pot experiments were conducted from November 2001 to February 2002 for the first experiment, and from March 2002 to June 2002 for the second experiment. The experimental layout, treatments and cultural practices were as follows:

### **3.3 Experimental layout**

Pots were arranged in a Randomised Complete Block Design (RCBD) on raised benches in a plastic shed at Crop Science Department, Legon. There were 4 replicates and each replicate contained 6 experimental units, and within each experimental unit were 6 pots. Thus, there were 36 pots in each replicate. In all 144 pots were used in each of the experiments.

### **3.4 Treatments**

In both experiments, variety and water were the main treatments. Varieties were Jabajaba and Chichele Balgu, whilst soil water treatments were;  $\geq 70\%$ , 50-60 % and 30-40 % field capacities. Thus, there were six treatment combinations.

### **3.5 Pot filling and planting**

Plastic pots measuring 23.2 cm high, 23.7 cm wide at the top and 8 cm at the base, with three holes perforated at the base were each filled with 8 kg of the sieved soil. Two Gypsum blocks were inserted into each pot and saturated with water at the start of experiments. They were then left overnight for the water to drain through. Pots were then weighed and through gypsum block cords their corresponding moisture contents were measured using moisture meter (Type: Meter-14.22, Eijkelkamp, Agrisearch Equipment, The Netherlands). Moisture content at this stage was at field capacity (i.e between 85-90%). Four seeds per pot of each of the two varieties (Jabajaba and Chichele Balgu) were then planted at a depth of 5 cm.

### 3.6 Cultural practices

Moisture content at field capacity was maintained through continuous weighing of pots, measuring of moisture contents and adding water according to the preliminary screen house studies on amount of water to be added at a given weight and moisture content to obtain required field capacity. When pots weight and moisture contents were low water was added using graduated measuring cylinder (1000 ml) till plants were 2 weeks old.

At 15 days after sowing, the plants were thinned to two per pot. The pots were then mulched with wood shavings to minimise water evaporation from the soil surface. At this stage pots were frequently weighed and moisture contents recorded, since transpirational losses were increasing at higher temperatures. As soil moisture content of the pots decreased, they were then maintained at the various moisture levels of 30-40%, 50-60% and  $\geq 70\%$  after thinning till final harvest at maturity.

Hand picking of weeds was carried out when necessary. Insect pests such as leafhoppers and cartapillers were controlled through routine spraying with Cymethoate at the rate of 5 ml/L, whilst diseases such as leaf spot, *Phyllostica spp*, and late blight, *Corticium solani* were controlled using Kocide at the rate of 2.5 g/L when necessary.

### 3.7 Data collection and analysis

#### 3.7.1 Climatic data

In both experiments 1&2, data were collected on temperature using thermometer, relative humidity using hygrometer, and on sunshine hours using sunshine recorder.

The mean monthly climatic data in experiment 1 are presented in Table 3.2 below.

Table 3.2: Monthly mean climatic data from November 2001 to February 2002

Month	Temperature		Relative Humidity		Sunshine hours (h/d)
	Min.(°C)	Max.(°C)	Min.(%)	Max. (%)	
November	24.3	31.7	65	92	8.4
December	25.0	32.0	66	93	7.9
January	24.4	31.7	56	85	4.6
February	25.1	32.6	61	88	6.9

The mean monthly climatic data in experiment 2 are presented in Table 3.3 below.

Table 3.3: Monthly mean climatic data from March 2002 to June 2002

Month	Temperature		Relative Humidity		Sunshine hours (h/d)
	Min.(°C)	Max.(°C)	Min.(%)	Max.(%)	
March	25.3	32.8	62	90	6.8
April	25.0	32.5	65	90	7.4
May	24.9	31.8	68	91	8.1
June	25.4	29.7	63	81	8.2

### 3.7.2 Harvesting

In both experiments, one pot per treatment per replication was harvested at the following stages: vegetative (3 weeks after planting), flowering (5, 7 or 8 weeks after planting), early-pod formation (7, 9 or 10 weeks after planting), pod-filling (9, 11 or 12 weeks after planting) and maturity (11, 13 or 14 weeks after planting), covering a period of 3 to 13 weeks from planting in

experiment 1, and 3 to 14 weeks from planting in experiment 2. In the first experiment, sequential harvesting was done, at 3, 5, 7, 9, and 11 weeks after planting for the Jabajaba variety, and 3, 7, 9, 11, and 13 weeks after planting for the Chichele Balgu variety. Days to harvesting in Jabajaba in experiment 1 were the same as in experiment 2, whilst those of Chichele Balgu were 3, 8, 10, 12, and 14 weeks after planting in experiment 2. With the exception of nodule dry weight, all data collected were the same as in experiment 1.

Measurements taken in both experiments were number of functional leaves per plant, number of stems per plant, number of nodules per plant and number of pods per plant; leaf area (using Leaf Area Meter Type: AM 100-256-002. ADC, England); and their respective fresh and dry weights using electronic weighing balance. Each plant was divided into leaflets, stems, roots and pods (> 0.5 cm diameter). Each plant component was oven-dried at 80 °C for 48 hours before weighing. Final harvest was done at maturity (77 days from planting for Jabajaba and between 91 and 98 days for Chichele Balgu). At maturity, the parenchymatous layer of pods surrounding the embryo disappeared, with the leaves turning yellow and beginning to dry. Harvested leaves, stems, and roots fresh and dry weight, and leaf area were measured.

### 3.7.3 Components of seed yield

The harvested pods from each experiment were sun-dried, counted, weighed and shelled. The seeds were also counted and sun-dried to 11-12 % moisture before seed sizes were determined.

### 3.7.4 Determination of protein and tannin levels of seeds

Tannin and protein contents of the seeds in each experiment were also determined at dry weight levels. Wholesome forty seeds of each treatment combination for each variety were ground in an ultra-centrifugal mill (Type: Staufen M20, No. 79219, Germany) and then passed through 0.3

mm sieve. The flour was defatted with petroleum ether (spirit) (boiling point: 40-60 °C), after excess solvent extraction by drying in a vacuum evaporator at 50 °C. Half a gram (0.5g) of the flour sample from each treatment combination per variety was used in duplicates for each extract, for the protein and tannin determinations.

#### 3.7.4.1 Protein determination

The Macro-Kjeldahl method of AOAC (1975) was used for crude protein determination; mainly by digestion of amino nitrogenous compounds to ammonium sulphate (NH<sub>4</sub>SO<sub>4</sub>) by sulphuric acid (H<sub>2</sub>SO<sub>4</sub>); distillation by sodium hydroxide (NaOH) and titration with H<sub>2</sub>SO<sub>4</sub> to estimate the nitrogen. Percentage nitrogen was estimated using the formula:

$$\%N = \frac{(\text{Blank-Titre}) \times \text{Normality} \times 0.014 \times 100}{\text{Sample weight (mg)}}$$

Percent crude protein = %N x Factor of 5.71 (WHO 1973).

#### 3.7.4.2 Tannin determination

The Vanillin-hydrochloric acid method (Price *et al.*, 1978) was used for tannin estimation based on the formation of colour complex absorbed at 500nm; generally called the Catechin Equivalent (CE). This reaction is specific for leucoanthocyanidins, although anthocyanins and dihydrochalcones may interfere to some extent (Price *et al.*, 1978).

#### 3.7.5 Data analysis

The data from both experiments were analysed using Genstat 5.2 statistical programme. It is assumed that any treatment effect in the experiment is reflected in the means. Therefore the Least Significant Difference (LSD) was used to separate moisture and variety treatments means.

## CHAPTER FOUR

### 4.0 RESULTS

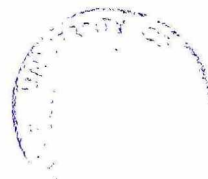
#### EXPERIMENT 1

##### 4.1 Effect of soil moisture status on bambara groundnut development

###### 4.1.1 Leaf production

Soil moisture did not have any significant effect ( $P < 0.05$ ) on leaf development at three weeks after planting. However, there were significant differences ( $P < 0.05$ ) between varieties in the number of leaves produced. In the subsequent harvests, soil moisture had significant effect ( $P < 0.05$ ) on the number of leaves produced. There was a significantly higher leaf production in Chichele Balgu at 50-60% moisture than at 30-40% and  $\geq 70\%$  moisture levels (Figure 4.1). There were no significant interaction effects on the number of leaves produced. Leaf production per plant especially in Jabajaba were highest at  $\geq 70\%$  moisture level up to 5 weeks after planting and thereafter leaf number was constant till 11 weeks for all the moisture treatments.

Chichele Balgu recorded significantly higher number of leaves per plant than Jabajaba towards early podding and maturity stages at all the moisture regimes. In both varieties, leaf number rose to a maximum, and then started declining towards maturity due to leaf senescence. The highest number of leaves per plant found at 50-60% soil moisture was about 22 for Jabajaba and 34 for Chichele Balgu. However, there were no significant difference between 50-60% and  $\geq 70\%$  moisture levels in total leaf area for Jabajaba compared to Chichele Balgu. The least number of leaves per plant in both varieties was recorded at 30-40% moisture level (Table 4.1).



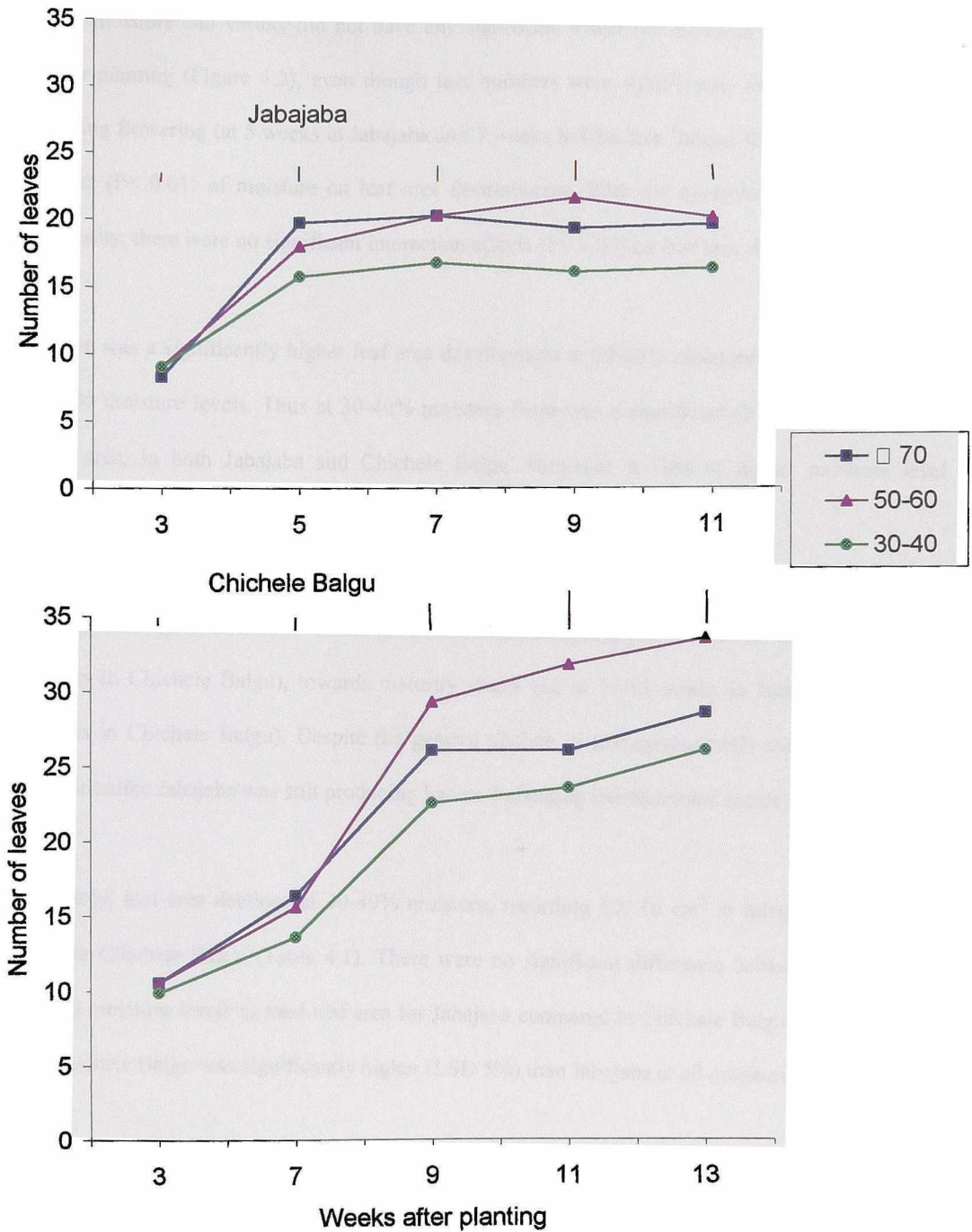


Fig 4.1: Effect of soil moisture level on leaf number per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

#### 4.1.2 Leaf area development

Soil moisture and variety did not have any significant effect ( $P < 0.05$ ) on leaf area at 3 weeks after planting (Figure 4.2), even though leaf numbers were significantly different (Figure 4.1). During flowering (at 5 weeks in Jabajaba and 7 weeks in Chichele Balgu), there was a significant effect ( $P < 0.01$ ) of moisture on leaf area development. With the exception of final harvest at maturity, there were no significant interaction effects ( $P < 0.05$ ) on leaf area development.

There was a significantly higher leaf area development at 50-60% moisture than at 30-40% and  $\geq 70\%$  moisture levels. Thus at 30-40% moisture there was a significant ( $P < 0.05$ ) reduction in leaf area, in both Jabajaba and Chichele Balgu. However, a 70% or higher moisture level recorded significantly higher leaf number than 30-40% moisture regime.

There was a general decline in leaf area from mid-pod filling (i.e at 7 weeks in Jabajaba and 9 weeks in Chichele Balgu), towards maturity stages (i.e at 11-13 weeks in Jabajaba and 12-14 weeks in Chichele Balgu). Despite the general decline in leaf area towards maturity, Chichele Balgu unlike Jabajaba was still producing leaves, indicating indeterminate nature of the variety.

The total leaf area declined at 30-40% moisture, recording 193.16 cm<sup>2</sup> in Jabajaba and 233.46 cm<sup>2</sup> in Chichele Balgu (Table 4.1). There were no significant difference between 50-60% and  $\geq 70\%$  moisture levels in total leaf area for Jabajaba compared to Chichele Balgu. Total leaf area in Chichele Balgu was significantly higher (LSD 5%) than Jabajaba at all moisture regimes.

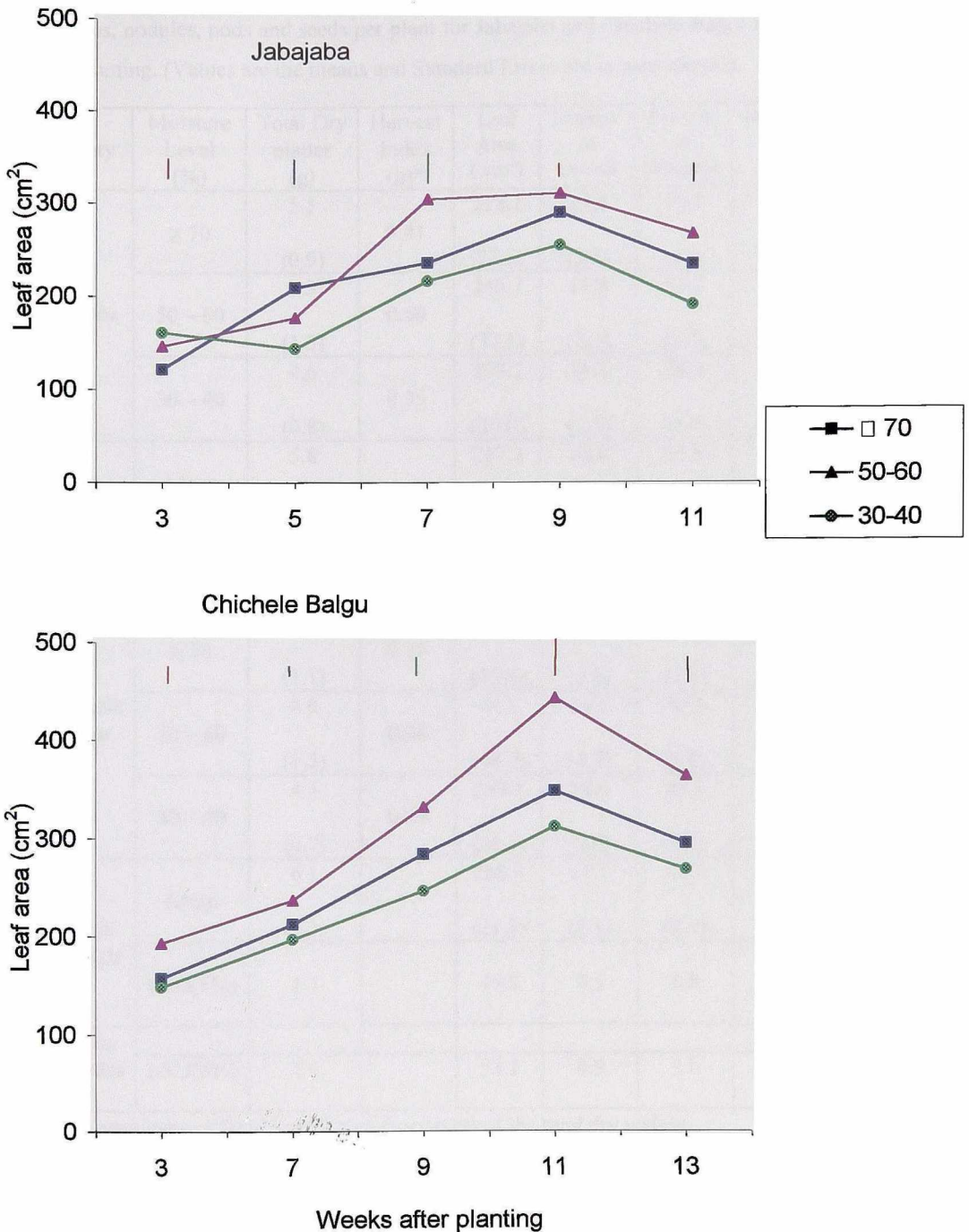


Fig 4.2: Effect of soil moisture level on leaf area per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

Table 4.1: Effect of soil moisture on total dry matter, harvest indices, total leaf area and number of leaves, nodules, pods and seeds per plant for Jabajaba and Chichele Balgu from 7 to 14 weeks after planting. (Values are the means and Standard Errors are in parentheses).

Variety	Moisture Level (%)	Total Dry matter (g)	Harvest Index (h)*	Leaf Area (cm <sup>2</sup> )	Number of Leaves	Number of Nodules	Number of Pods	Number of Seeds
Jabajaba	≥ 70	5.5 (0.9)	0.41	218.1 (27.5)	17.4 (2.3)	23.7 (4.7)	6.3 (1.4)	5.6 (1.4)
	50 – 60	7.3 (1.3)	0.50	240.7 (33.5)	17.8 (2.3)	33.3 (7.7)	8.7 (2.0)	8.2 (2.2)
	30 – 40	4.6 (0.8)	0.35	193.2 (20.0)	14.8 (1.5)	20.4 (4.7)	4.5 (1.3)	3.6 (1.3)
Within Jabajaba	Mean	5.8 (1.0)		217.3 (15.6)	16.6 (1.2)	25.8 (3.5)	6.5 (1.2)	5.8 (1.3)
	LSD(5%)	0.9		33.4	2.5	7.4	2.7	2.9
Chichele Balgu	≥ 70	5.8 (1.1)	0.25	258.6 (33.6)	21.5 (3.5)	30.8 (6.4)	2.6 (1.5)	2.4 (1.5)
	50 – 60	8.0 (1.5)	0.34	313 (44.9)	24.1 (4.7)	40.3 (8.8)	4.7 (1.9)	4.2 (2.1)
	30 – 40	4.4 (0.7)	0.14	233.5 (28.5)	18.9 (3.2)	25.7 (5.6)	1.3 (0.9)	1.3 (0.9)
Within Chichele	Mean	6.1 (1.1)		268.4 (21.3)	21.5 (2.1)	32.3 (4.1)	2.9 (1.1)	2.6 (1.1)
	LSD(5%)	1.1		45.8	4.5	8.8	2.5	2.5
Among Varieties	LSD(5%)	1.4		53.1	4.9	11	3.4	3.3

- Harvest index = Seed weight as a proportion of the total dry weight.

#### 4.1.3 Nodule development

Generally there were progressive increases in number of nodules from vegetative stage, reaching a peak at mid-pod filling stages and thereafter it began to decline. Both moisture and variety had significant effect on nodulation ( $P < 0.05$ ) at all stages of growth. There were no significant interaction effects ( $P < 0.05$ ) on nodulation. Chichele Balgu, an open type variety recorded a higher number of nodules than Jabajaba, a bunch type (Figure 4.3).

The maximum number of nodules were recorded between early podding and mid-pod filling stages in both Jabajaba and Chichele Balgu. During these stages, 50-60% moisture recorded the highest nodule number, in which Jabajaba had 50 nodules per plant and Chichele Balgu, 54 nodules. The highest moisture regime recorded an average of 33 nodules per plant in Jabajaba and 41 nodules per plant in Chichele Balgu, whilst the 30-40% moisture regime had on the average 31 nodules per plant in Jabajaba and 36 nodules per plant in Chichele Balgu. The nodules produced in both Jabajaba and Chichele Balgu were smaller in size.

The total number of nodules showed that, less nodules were produced under 30-40% moisture level, where Jabajaba recorded 20 per plant and Chichele Balgu with 26 nodules per plant (Table 4.1). At all the moisture regimes, significant number ( $P < 0.05$ ) of nodules were produced by Chichele Balgu than Jabajaba. However, the nodule number at 50-60% moisture was significantly higher ( $P < 0.05$ ) than at 30-40% and  $\geq 70\%$  moisture regimes (Table 4.1).

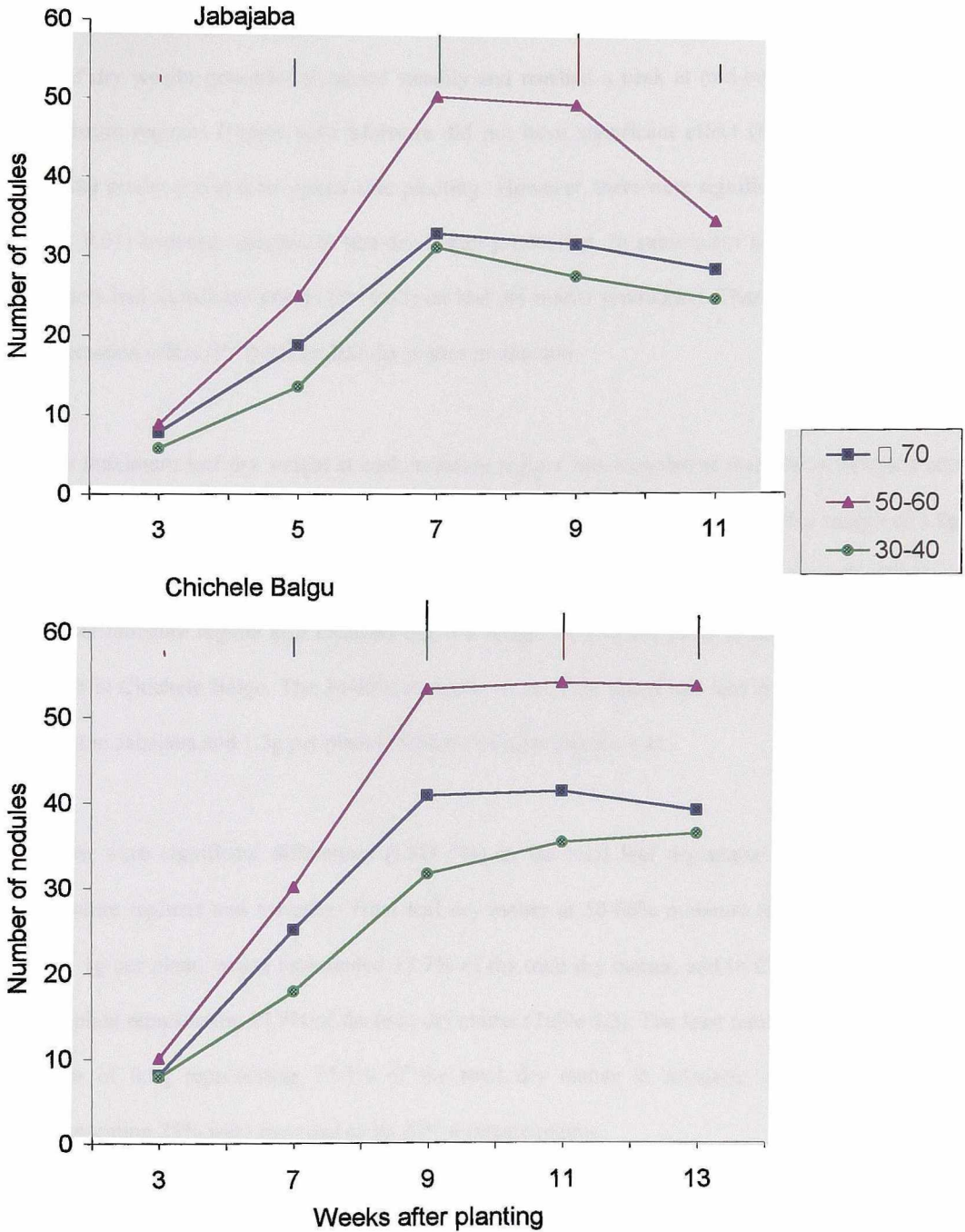


Fig 4.3: Effect of soil moisture level on number of nodules per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

## 4.2 Effect of soil moisture status on bambara groundnut growth

### 4.2.1 Leaf dry matter production

Leaf dry weight generally increased steadily and reached a peak at mid-pod filling stage at all moisture regimes (Figure 4.4). Moisture did not have significant effect ( $P < 0.05$ ) on leaf dry matter production at three weeks after planting. However, there were significant differences ( $P < 0.01$ ) between varieties in leaf dry matter production. In subsequent harvests moisture and variety had significant effects ( $P < 0.05$ ) on leaf dry matter production. There were no significant interaction effect ( $P < 0.05$ ) on leaf dry matter production.

The maximum leaf dry weight at each moisture regime was recorded at maturity in Jabajaba and mid-pod filling in Chichele Balgu. During these stages Jabajaba recorded leaf dry weight of 1.5g per plant whilst Chichele Balgu recorded 2g per plant, both at 50-60% moisture. The 70% or higher moisture regime also recorded leaf dry weight of 1.2g per plant in Jabajaba and 1.6g per plant in Chichele Balgu. The 30-40% moisture on the other hand had leaf dry weight of 1 g per plant in Jabajaba and 1.5g per plant in Chichele Balgu (Figure 4.4).

There were significant differences (LSD 5%) in the total leaf dry matter production among moisture regimes and varieties. Total leaf dry matter at 50-60% moisture recorded in Jabajaba was 1g per plant, which represented 13.7% of the total dry matter, and in Chichele Balgu, 1.4g per plant representing 17.5% of the total dry matter (Table 4.2). The least total leaf dry weight per plant of 0.8g representing 17.4% of the total dry matter in Jabajaba, and 1.1g per plant representing 25% were recorded at 30-40% moisture regime.

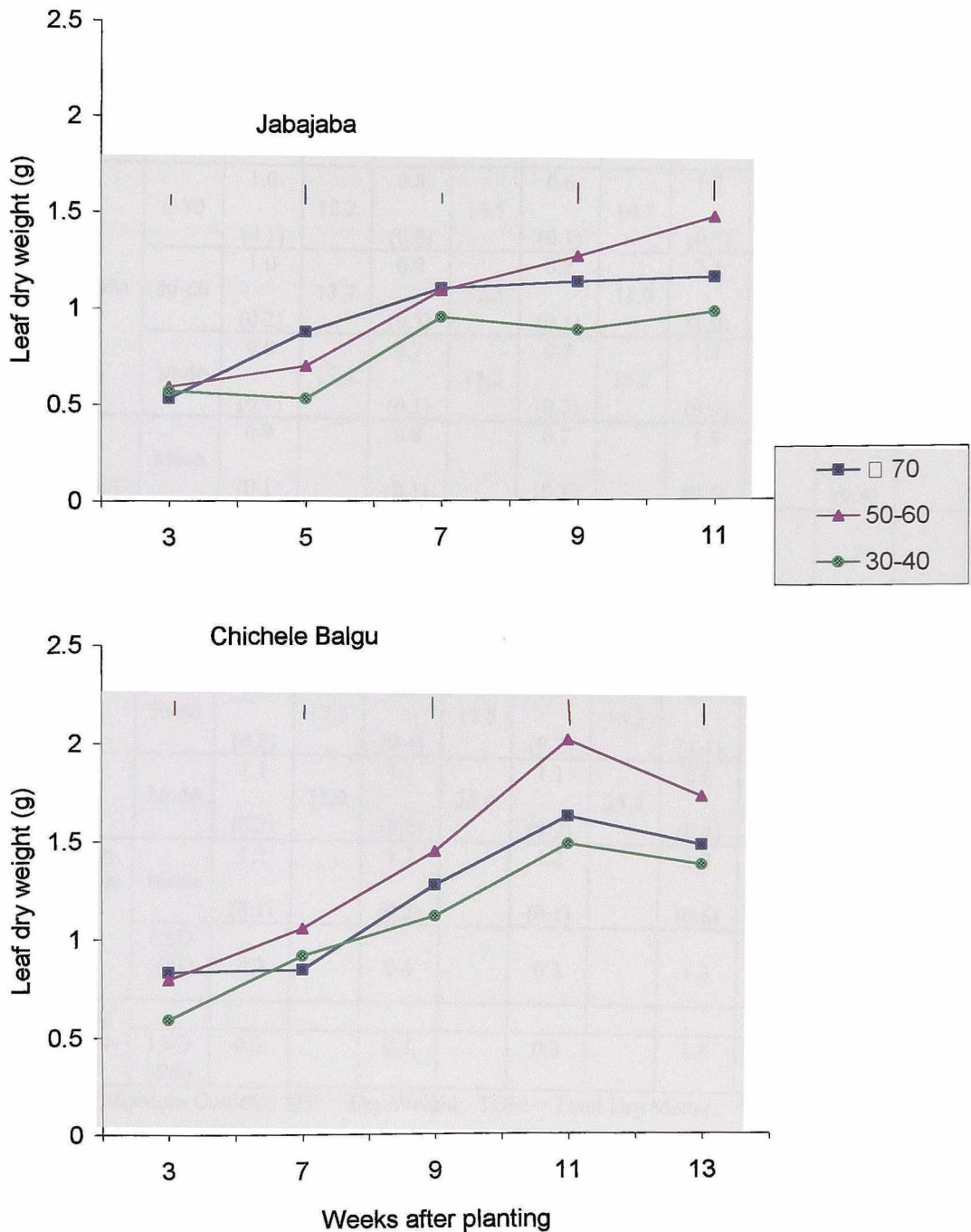


Fig 4.4: Effect of soil moisture level on leaf dry weight per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

Table 4.2: Effect of soil moisture on total dry matter of leaves, stems, roots, pods and seeds of Jabajaba and Chichele Balgu at maturity (Values are the means and standard errors are in parentheses).

Variety	Soil MC (%)	LEAVES		STEMS		ROOTS		PODS*		SEEDS	
		DW (g)	% of TDM	DW (g)	% of TDM	DW (g)	% of TDM	DW (g)	% of TDM	DW (g)	% of TDM
Jabajaba	≥ 70	1.0 (0.1)	18.2	0.8 (0.8)	14.5	0.6 (0.1)	10.9	1.7 (0.7)	30.9	1.4 (0.5)	25.5
	50-60	1.0 (0.2)	13.7	0.9 (0.3)	12.3	0.8 (0.1)	11.0	2.5 (1.0)	34.2	2.1 (0.9)	28.8
	30-40	0.8 (0.1)	17.4	0.7 (0.1)	15.2	0.7 (0.2)	15.2	1.4 (0.5)	30.4	1.0 (0.4)	21.7
Within Jabajaba	Mean	0.9 (0.1)		0.8 (0.1)		0.7 (0.1)		1.9 (0.5)		1.5 (0.4)	
	LSD (5%)	0.2		0.2		0.2		1.2		1.0	
Chichele Balgu	≥ 70	1.2 (0.2)	20.7	1.2 (0.3)	20.7	1.1 (0.2)	19.0	1.3 (0.8)	22.4	1.0 (0.7)	17.2
	50-60	1.4 (0.2)	17.5	1.4 (0.4)	17.5	1.3 (0.2)	16.3	2.1 (1.1)	26.3	1.8 (1.1)	22.5
	30-40	1.1 (0.2)	25.0	1.1 (0.2)	25.0	1.1 (0.2)	25.0	0.6 (0.4)	13.6	0.5 (0.4)	11.4
Within Chichele	Mean	1.2 (0.1)		1.2 (0.2)		1.2 (0.1)		1.3 (0.6)		1.1 (0.5)	
	LSD (5%)	0.2		0.4		0.3		1.3		1.2	
Among Varieties											
	LSD (5%)	0.3		0.4		0.3		1.6		1.5	

MC = Moisture Content; DW = Dry Weight; TDM = Total Dry Matter \* = Including Seeds

Table 4.2: Effect of soil moisture on total dry matter of leaves, stems, roots, pods and seeds of Jabajaba and Chichele Balgu at maturity (Values are the means and standard errors are in parentheses).

Variety	Soil MC (%)	LEAVES		STEMS		ROOTS		PODS*		SEEDS	
		DW (g)	% of TDM	DW (g)	% of TDM	DW (g)	% of TDM	DW (g)	% of TDM	DW (g)	% of TDM
Jabajaba	≥ 70	1.0 (0.1)	18.2	0.8 (0.8)	14.5	0.6 (0.1)	10.9	1.7 (0.7)	30.9	1.4 (0.5)	25.5
	50-60	1.0 (0.2)	13.7	0.9 (0.3)	12.3	0.8 (0.1)	11.0	2.5 (1.0)	34.2	2.1 (0.9)	28.8
	30-40	0.8 (0.1)	17.4	0.7 (0.1)	15.2	0.7 (0.2)	15.2	1.4 (0.5)	30.4	1.0 (0.4)	21.7
Within Jabajaba	Mean	0.9 (0.1)		0.8 (0.1)		0.7 (0.1)		1.9 (0.5)		1.5 (0.4)	
	LSD (5%)	0.2		0.2		0.2		1.2		1.0	
Chichele Balgu	≥ 70	1.2 (0.2)	20.7	1.2 (0.3)	20.7	1.1 (0.2)	19.0	1.3 (0.8)	22.4	1.0 (0.7)	17.2
	50-60	1.4 (0.2)	17.5	1.4 (0.4)	17.5	1.3 (0.2)	16.3	2.1 (1.1)	26.3	1.8 (1.1)	22.5
	30-40	1.1 (0.2)	25.0	1.1 (0.2)	25.0	1.1 (0.2)	25.0	0.6 (0.4)	13.6	0.5 (0.4)	11.4
Within Chichele	Mean	1.2 (0.1)		1.2 (0.2)		1.2 (0.1)		1.3 (0.6)		1.1 (0.5)	
	LSD (5%)	0.2		0.4		0.3		1.3		1.2	
Among Varieties	LSD (5%)	0.3		0.4		0.3		1.6		1.5	

MC = Moisture Content; DW = Dry Weight; TDM = Total Dry Matter \* = Including Seeds

#### 4.2.2 Stem dry matter production

There were significant effects ( $P < 0.05$ ) by variety on stem dry matter production at three weeks after planting. Soil moisture did not have any significant effect on stem dry matter production till early podding. Generally, there were marginal increases in stem dry weight in the varieties at each moisture treatment from vegetative to early-podding stages, which occurred between 3-7 weeks in Jabajaba and between 3-9 weeks in Chichele Balgu, after planting (Figure 4.5). After early podding, there were significant effects ( $P < 0.05$ ) of moisture on stem dry matter production.

There was a significant increase in stem dry matter in Jabajaba between 9-11 weeks after planting, but a decline in stem dry matter in Chichele Balgu between 11-13 weeks after planting. The maximum stem dry matter production in Chichele Balgu occurred between early-podding to mid-pod filling (9-11 weeks after planting), while that in Jabajaba was between mid-pod filling and maturity (9-11 weeks after planting). The 50-60% soil moisture recorded the highest stem dry weight of 1.6g per plant in Jabajaba, and 2.3g per plant in Chichele Balgu. The more than 70% moisture had mean dry matter per plant of 1.1g in Jabajaba and 1.9g per plant in Chichele Balgu. The 30-40% moisture regime also recorded 0.9g of stem dry matter per plant in Jabajaba and 1.6g per plant in Chichele Balgu (Figure 4.5).

The highest total stem dry matter, was recorded at 50-60% moisture, with 0.9g per plant representing 12.3% of the total dry matter in Jabajaba and 1.4g per plant which represented 17.5% of the total dry matter in Chichele Balgu. The least total dry matter was found in each of the varieties at 30-40% moisture level. At all moisture regimes, there was significantly higher ( $P < 0.05$ ) stem dry matter in Chichele Balgu than in Jabajaba (Table 4.2)

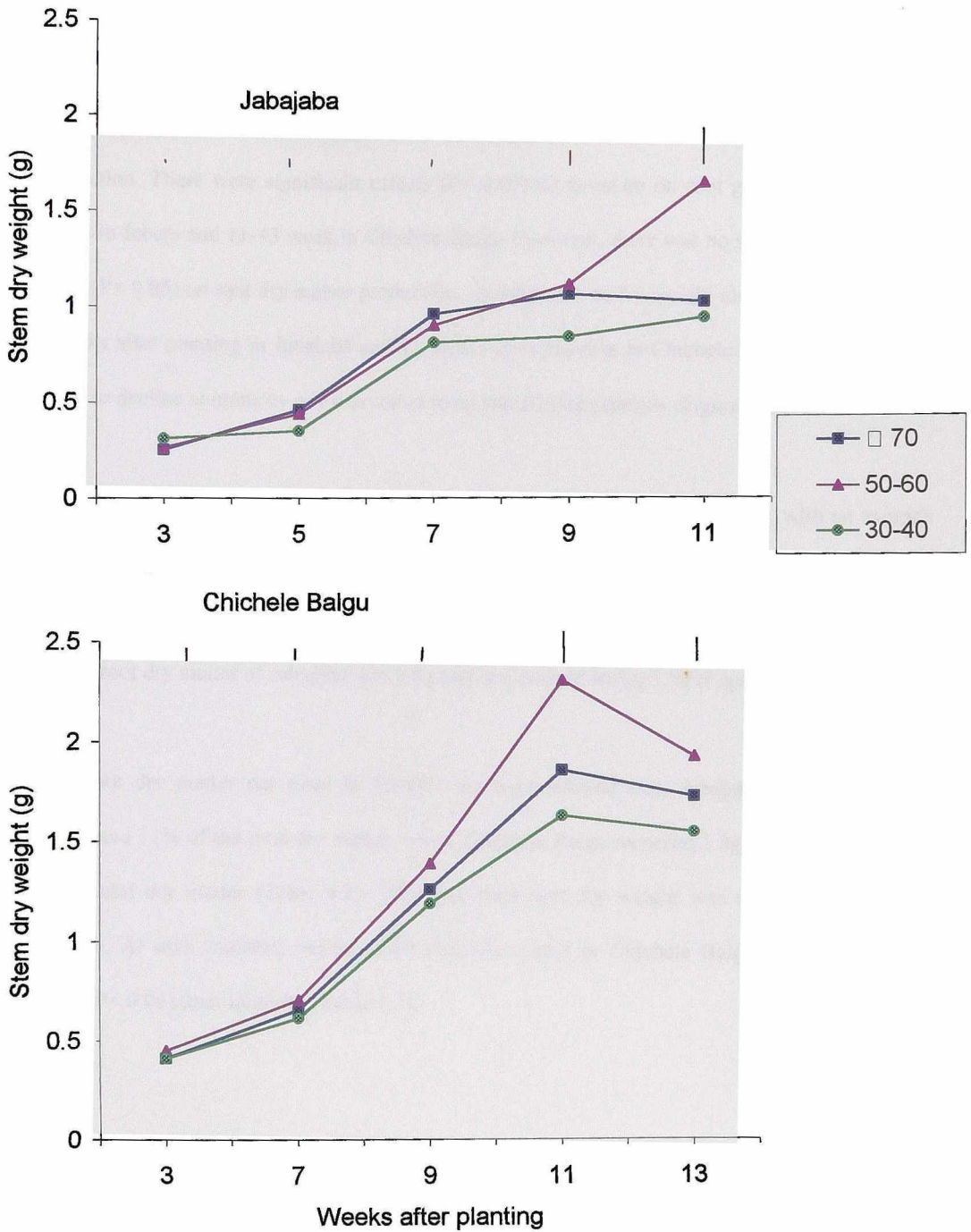


Fig 4.5: Effect of soil moisture levels on stem dry weight per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

#### 4.2.3 Root dry matter production

There were no significant effects ( $P < 0.5$ ) of moisture and variety on root growth at three weeks after planting. When flowering was about 50% (at 5 weeks after planting in Jabajaba and 7 weeks after planting in Chichele Balgu), variety had significant effect ( $P < 0.05$ ) on root dry matter production. There were significant effects ( $P < 0.05$ ) of moisture on root growth, between 9-11 weeks in Jabaja and 11-13 week in Chichile Balgu. However, there was no significant interaction effect ( $P < 0.05$ ) on root dry matter production. In general root dry weight increased steadily up to 9 weeks after planting in Jabajaba and 11 weeks after planting in Chichele Balgu, and thereafter began to decline at maturity as observed in most annual plant species (Figure 4.6).

The highest root dry weight per plant was recorded at 50-60% moisture level, with an average value of 1.1g in Jabajaba and 2.2g in Chichele Balgu. The more than 70% moisture also had the highest root dry matter of 0.8g in Jabajaba and 1.6g in Chichele Balgu. At 30-40% moisture, highest root dry matter of Jabajaba was 0.8g and in Chichele Balgu 1.8g (Figure 4.6).

Total root dry matter per plant at 50-60% moisture showed that, Jabajaba had 0.8g, which represented 11% of the total dry matter, whilst Chichele Balgu recorded 1.3g representing 16.3% of the total dry matter (Table 4.2). The least total root dry weight was recorded at 30-40% moisture. At each moisture regime, total root dry matter in Chichele Balgu was significantly higher ( $P < 0.05$ ) than Jabajaba (Table 4.2).



#### 4.2.3 Root dry matter production

There were no significant effects ( $P < 0.5$ ) of moisture and variety on root growth at three weeks after planting. When flowering was about 50% (at 5 weeks after planting in Jabajaba and 7 weeks after planting in Chichele Balgu), variety had significant effect ( $P < 0.05$ ) on root dry matter production. There were significant effects ( $P < 0.05$ ) of moisture on root growth, between 9-11 weeks in Jabaja and 11-13 week in Chichile Balgu. However, there was no significant interaction effect ( $P < 0.05$ ) on root dry matter production. In general root dry weight increased steadily up to 9 weeks after planting in Jabajaba and 11 weeks after planting in Chichele Balgu, and thereafter began to decline at maturity as observed in most annual plant species (Figure 4.6).

The highest root dry weight per plant was recorded at 50-60% moisture level, with an average value of 1.1g in Jabajaba and 2.2g in Chichele Balgu. The more than 70% moisture also had the highest root dry matter of 0.8g in Jabajaba and 1.6g in Chichele Balgu. At 30-40% moisture, highest root dry matter of Jabajaba was 0.8g and in Chichele Balgu 1.8g (Figure 4.6).

Total root dry matter per plant at 50-60% moisture showed that, Jabajaba had 0.8g, which represented 11% of the total dry matter, whilst Chichele Balgu recorded 1.3g representing 16.3% of the total dry matter (Table 4.2). The least total root dry weight was recorded at 30-40% moisture. At each moisture regime, total root dry matter in Chichele Balgu was significantly higher ( $P < 0.05$ ) than Jabajaba (Table 4.2).

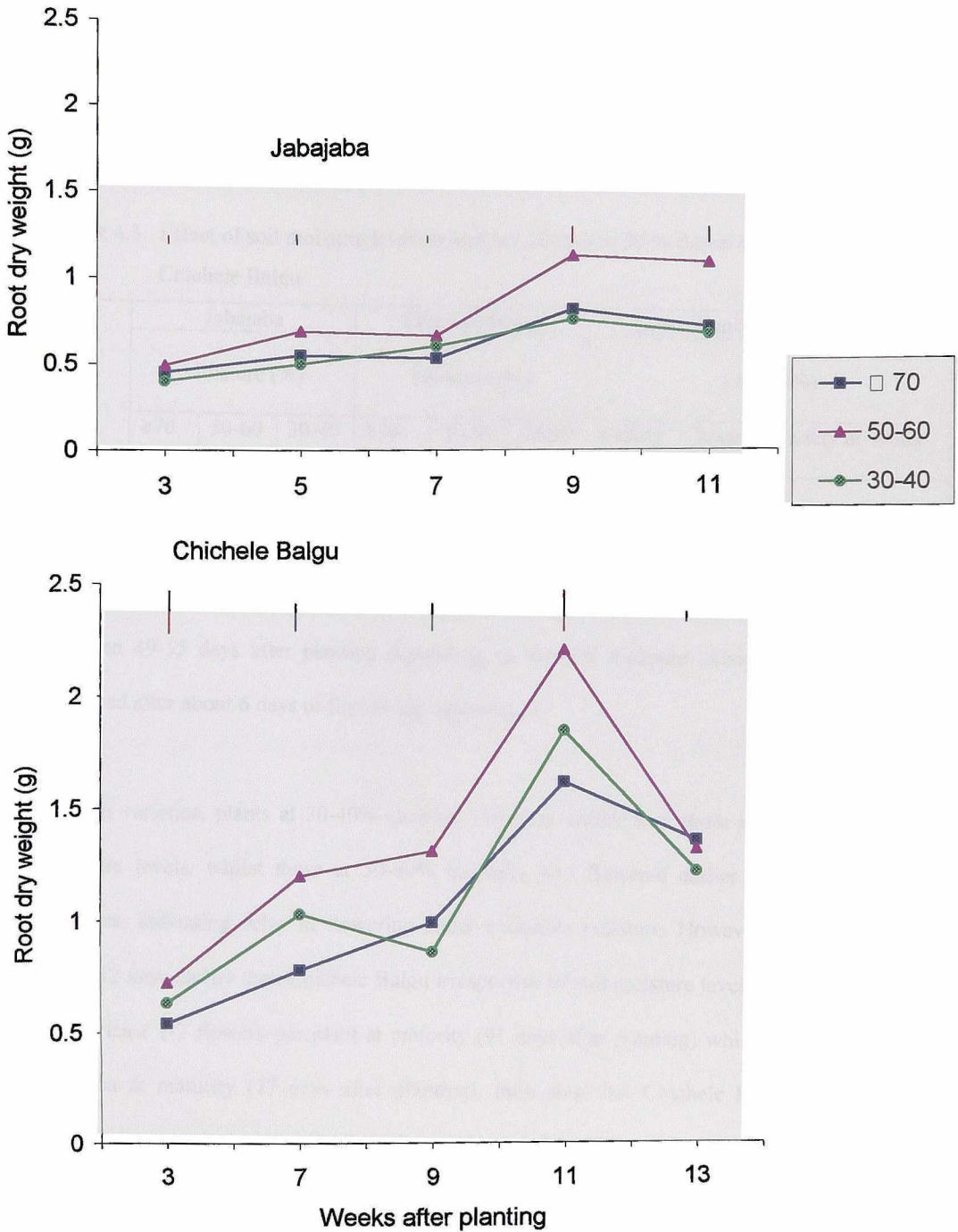


Fig 4.6: Effect of soil moisture level on root dry weight per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

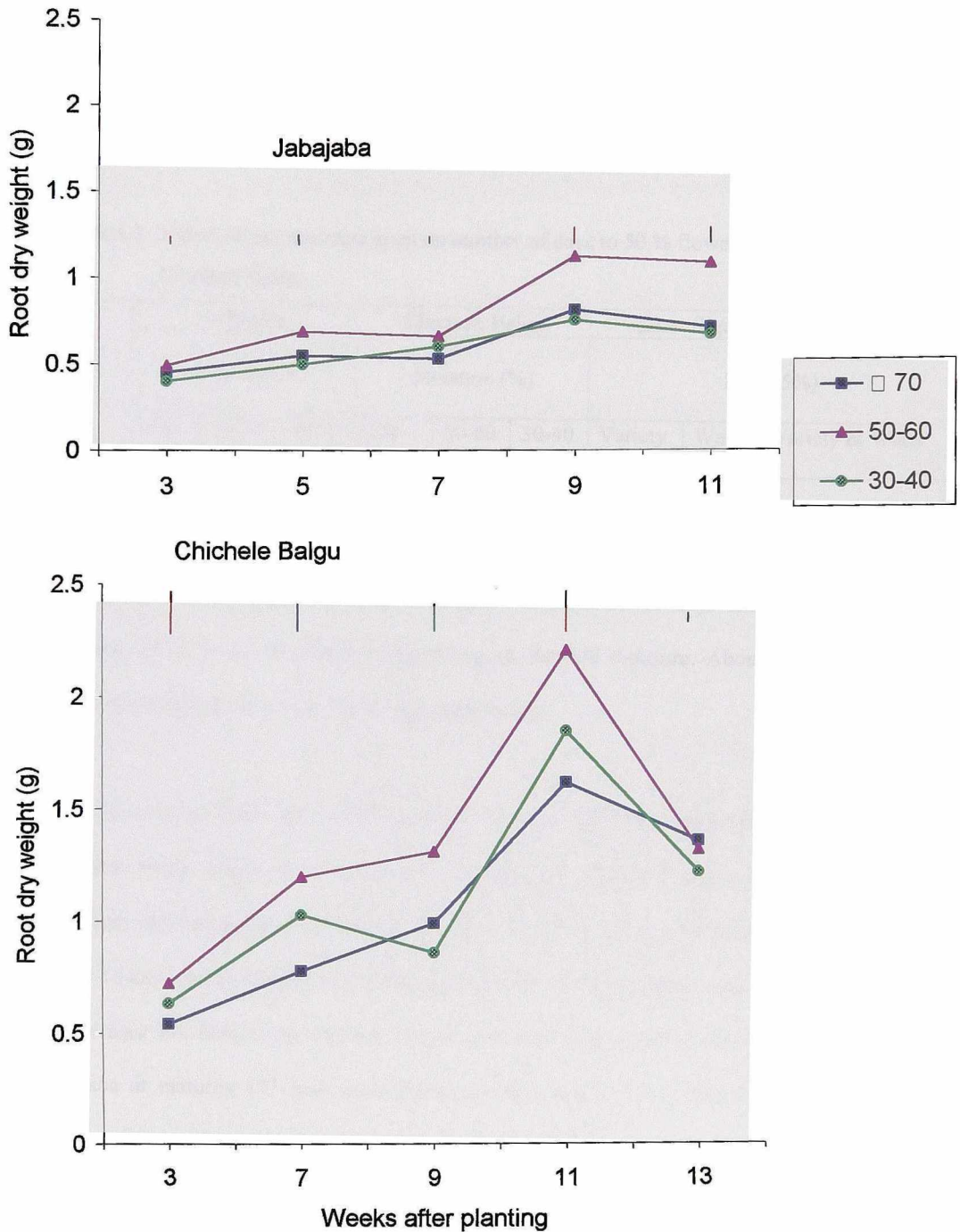


Fig 4.6: Effect of soil moisture level on root dry weight per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

### 4.3 Effect of soil moisture status on reproductive development of bambara groundnut

#### 4.3.1 Days to flowering

Soil moisture significantly ( $P < 0.05$ ) affected days to 50% flowering in bambara groundnut (Table 4.3).

Table 4.3. Effect of soil moisture level on number of days to 50 % flowering of Jabajaba and Chichele Balgu.

	Jabajaba			Chichele Balgu			Least Significant Differences		
	Moisture (%)			Moisture (%)			LSD (5%)		
	≥70	50-60	30-40	≥70	50-60	30-40	Variety	Water	Variety & Water
Days	42.0	40.0	37.5	54.5	52.3	49.3	0.9	1.1	1.5

About 50% of the plants flowered in Jabajaba between 38-42 days and in Chichele Balgu between 49-55 days after planting depending on the soil moisture. About 50% of the plants flowered after about 6 days of first flower appearance.

In both varieties, plants at 30-40% moisture flowered earlier than those at 50-60% and ≥70% moisture levels, whilst those at 50-60% moisture also flowered earlier than those at ≥70% moisture, indicating delay in flowering under excessive moisture. However Jabajaba flowered about 12 days earlier than Chichele Balgu irrespective of soil moisture level. Chichele Balgu still had at least 1-2 flowers per plant at maturity (91 days after planting) whilst there was none in Jabajaba at maturity (77 days after planting), indicating that Chichele Balgu is more of an indeterminate variety. Also, Chichele Balgu plants at 30-40% moisture produced flowers over a longer period, than the other two moisture levels.

#### 4.3.2 Pod development

Pod initiation started 7 weeks after planting in Jabajaba and 9 weeks after planting in Chichele Balgu. Generally, there were progressive increases in pod number per plant from early pod initiation, reaching a peak at maturity. Soil moisture and variety had significant effects ( $P < 0.05$ ) on number of pods produced in bambara groundnut (Table 4.4). Except at the maturity stage, there were no significant interaction effects between cultivar and moisture ( $P < 0.05$ ) on pod development. During pod initiation (at 7 weeks in Jabajaba and 9 weeks in Chichele Balgu), Jabajaba had at least one pod per plant, but none for Chichele Balgu at 30-40% moisture. However, 50-60% moisture recorded about 3.8 pods per plant in Jabajaba and 1.5 pods per plant in Chichele Balgu (Table 4.4). There were no clear-cut differences between 50-60% and  $\geq 70\%$  moisture levels in total pod number per plant in Jabajaba compared to Chichele Balgu. In all the moisture regimes, Jabajaba recorded significantly higher number of pods than Chichele Balgu (Table 4.1).

At maturity, pod production was poor in both Jabajaba and Chichele Balgu at 30-40% moisture, with less than 6 pods per plant in Jabajaba and less than 4 pods in Chichele Balgu. Pod production was highest at 50-60% moisture, with Jabajaba producing more pods (12.3) than Chichele Balgu (9.5 pods). At 70% moisture level or higher there were 8.8 pods per plant in Jabajaba and 6.5 pods in Chichele Balgu (Table 4.4). Jabajaba therefore appeared to be superior to Chichele Balgu in pod production under all the soil moisture regimes. Generally, pod production per plant followed similar trend in both cultivars but was lower than that reported by Adjetey and Ayihi (1999) and Collinson *et al.*, (1996).

#### 4.3.3 Seed development

Seed formation in both Jabajaba and Chichele Balgu started about 5-7 days after pod initiation at 7 and 9 weeks after planting in Jabajaba and Chichile Balgu respectively (Table 4.4). There were significant effects ( $P < 0.05$ ) of moisture and variety on seed production from early pod development to maturity. The interaction between cultivar and soil moisture did not have any significant effect ( $P < 0.05$ ) on number of seeds produced at pod initiation; but rather at mid-pod filling stage of 9 weeks in Jabajaba and 11 weeks in Chichele Balgu. Between 7 and 9 weeks after planting, seed number per plant at 30-40% moisture was 0.3 in Jabajaba and zero in Chichele Balgu (Table 4.4). The 50-60% moisture also recorded an average seed number per plant of 2.8 in Jabajaba and an average of 0.5 in Chichele Balgu, whilst that of  $\geq 70\%$  moisture had an average of 2 seeds per plant in Jabajaba and 0.3 seed per plant in Chichele Balgu (Table 4.4).

At maturity, seed number per plant at 30-40% soil moisture rose to 5 in Jabajaba and 3.5 in Chichele Balgu. The highest seed number was recorded at 50-60% moisture, with an average seed number per plant of 12.2 in Jabajaba and 9.5 in Chichele Balgu (Table 4.4). There was one seed per pod in both varieties, and there were few pods without seeds, especially in Chichele Balgu probably due to late podding.

The total number of seeds was higher in Jabajaba than in Chichele Balgu (Table 4.1). However, 50-60% moisture recorded the highest total number of seeds per plant of 8.2 in Jabajaba and 4.2 in Chichele Balgu. The lowest seed number was recorded at 30-40% moisture. There were significant effects ( $P < 0.05$ ) of moisture on the total number of seeds produced in both varieties (Table 4.1). However, there were no clear-cut differences between 50-60% and  $\geq 70\%$  moisture levels in total seed number per plant in Jabajaba.

Table 4.4: Effect of soil moisture on reproductive growth and development of Jabajaba and Chichile Balgu. (Values are the means and standard errors are in parenthesis).

Variety	Soil Water (%)	Reproductive development						Reproductive growth					
		Number of pods			Number of seeds			Pod dry weight (g)			Seed dry weight (g)		
		(WAP)			(WAP)			(WAP)			(WAP)		
		7	9	11	7	9	11	7	9	11	7	9	11
Jabajaba	≥70	2.8	7.5	8.8	2.0	6.8	8.0	0.2	1.7	3.2	0.4	1.0	2.7
		(0.2)	(1.4)	(1.5)	(0.3)	(1.7)	(1.6)	(0.1)	(0.2)	(1.2)	(0.1)	(0.2)	(1.1)
	50-60	3.8	10.0	12.3	2.8	9.5	12.3	0.2	2.9	4.4	0.21	2.0	4.1
		(0.2)	(2.2)	(2.4)	(0.6)	(2.1)	(2.5)	(0.1)	(0.5)	(1.1)	(0.1)	(0.4)	(1.1)
	30-40	1.3	6.5	5.8	0.3	5.5	5.0	0	1.7	2.4	0	1.2	2.0
		(0.1)	(1.2)	(1.1)	(0.1)	(1.3)	(0.8)		(0.3)	(0.7)		(0.3)	(0.5)
		(WAP)			(WAP)			(WAP)			(WAP)		
		9	11	13	9	11	13	9	11	13	9	11	13
Chichile Balgu	≥70	0.3	1.0	6.5	0.3	0.8	6.3	0	0.5	3.3	0	0.3	2.8
		(0.1)	(0.3)	(1.9)	(0.1)	(0.3)	(1.3)		(0.2)	(1.2)		(0.1)	(0.9)
	50-60	1.5	3.0	9.5	0.5	2.5	9.5	0.2	1.2	4.8	0.1	0.9	4.5
		(0.3)	(1.2)	(2.2)	(0.2)	(1.1)	(2.4)	(0.1)	(0.4)	(1.7)	(0.1)	(0.6)	(1.6)
	30-40	0	0.5	3.5	0	0.5	3.5	0	0.2	1.7	0	0.1	1.4
			(0.1)	(1.4)		(0.1)	(1.5)		(0.1)	(0.8)		(0.1)	(0.2)

WAP = Weeks After Planting.

#### 4.4 Effect of soil moisture status on reproductive growth of bambara groundnut

##### 4.4.1 Pod dry weight

Pod growth increases somewhat slowly and reached a peak at maturity as shown in Table 4.4. There were significant effects ( $P < 0.05$ ) of moisture on pod dry weight per plant from early pod development to maturity. However, there was no significant effect ( $P < 0.05$ ) of variety on pod dry weight at early pod development, and at maturity, but at mid-pod filling the effect was significant. There was no significant interaction effect ( $P < 0.05$ ) on pod dry weight from early pod development to maturity. Pod dry weight increased linearly from 7-11 weeks after planting

in Jabajaba and 9-13 weeks after planting in Chichele Balgu. Rapid increases in pod dry weight were between 9-11 weeks after planting in Jabajaba and 11-13 weeks after planting in Chichele Balgu (Table 4.4).

The total pod dry weight per plant as presented in Table 4.2, showed that Jabajaba had 2.5g per plant which represented 34.2% of the total dry matter, and Chichele Balgu with 2.1g representing 26.3% of the total dry matter, at 50-60% moisture. The least total pod dry weight per plant was recorded at 30-40% moisture (Table 4.2).

#### 4.4.2 Seed dry weight

There were increases in seed dry weight at each moisture level from 9-11 weeks in Jabajaba and 11-13 weeks after planting in Chichele Balgu (Table 4.4). There was no significant effect ( $P < 0.05$ ) of moisture on seed dry weight at 7 and 9 weeks after planting in Jabajaba and Chichele Balgu respectively, but the effect of variety on seed dry weight was significant ( $P < 0.05$ ). At 9 weeks in Jabajaba and 11 weeks in Chichele Balgu after planting, both soil moisture and variety significantly ( $P < 0.05$ ) affected seed dry weight per plant. At maturity there was a significant effect ( $P < 0.05$ ) of moisture on seed dry weight, but the effect of variety was not significant.

Seed dry weight at maturity was highest at 50-60% moisture, with Jabajaba recording 4.1g per plant and in Chichele Balgu 4.5g per plant. The highest moisture level also recorded an average seed dry weight of 2.7g per plant in Jabajaba and 2.8g per plant in Chichele Balgu. However, 30-40% moisture recorded the lowest average seed dry weight of 2 g per plant in Jabajaba and 1.4g per plant in Chichele Balgu (Table 4.4).

The total seed dry weight per plant at 30-40% moisture was the lowest, with Jabajaba recording 1 g per plant, representing 21.7% of the total dry matter, and in Chichele Balgu 0.5g per plant representing 11.4% of the total dry matter. The highest seed dry weight in both varieties was recorded at 50-60% moisture (Table 4.2). There were significant effects ( $P < 0.05$ ) of both moisture and variety on seed dry weight.

#### **4.5 Effect of soil moisture status on dry matter partitioning in bambara groundnut**

The values of the pod: leaf, pod: stem, pod: root, seed: leaf, seed: stem, seed: root and seed: pod dry matter ratios are presented in Table 4.5. It was observed that the highest contributions of leaves, stems and roots dry matter to pods were found at 50-60% moisture. The leaves, stems and roots dry matter contributions to pods at  $\geq 70\%$  moisture were greater than that of 30-40% moisture. However in both Jabajaba and Chichele Balgu, root dry matter contribution to pods at 50-60% moisture in Jabajaba (3.1) was higher than in Chichele Balgu (1.6). Also, pod: stems ratio recorded 2.9 in Jabajaba and 1.6 in Chichele Balgu, was higher than pod: leaf ratio of 2.5 in Jabajaba and 1.4 in Chichele Balgu. As a result, the pod dry weight contributed greatly to seed dry weight at each moisture regime, as indicated by seed: pod ratio in Table 4.5.

Seed: stem, leaf and root ratios also indicated that the highest root dry matter contribution to seed dry matter was at 50-60% moisture, where ratio in Jabajaba (2.6) was higher than in Chichele Balgu (1.4). The lowest ratios were recorded at 30-40% moisture. At the  $\geq 70\%$  moisture the contribution of pod dry weight to seed dry weight in Jabajaba (0.9), was higher than in Chichele Balgu (0.8). Seed: pod ratio at 50-60% moisture in Jabajaba was 0.8 and in Chichele Balgu 0.9, whilst that of 30-40% moisture recorded seed: pod ratio of 0.7 in Jabajaba and 0.8 in Chichele Balgu (Table 4.5).

Table 4.5: Effect of soil moisture on dry matter ratios of Jabajaba and Chichele Balgu.

Variety	Moisture Level (%)	Pod:Leaf Ratio	Pod:Stem Ratio	Pod:Root Ratio	Seed:Leaf Ratio	Seed:Stem Ratio	Seed:Root Ratio	Seed:Pod Ratio
Jabajaba	≥ 70	1.8	2.2	2.8	1.4	1.8	2.3	0.8
	50-60	2.5	2.9	3.1	2.1	2.4	2.6	0.8
	30-40	1.7	2.1	2	1.3	1.6	1.5	0.8
Chichele Balgu	≥ 70	1.1	1.1	1.2	0.9	0.9	1.0	0.8
	50-60	1.5	1.6	1.6	1.3	1.4	1.4	0.9
	30-40	0.6	0.6	0.7	0.5	0.5	0.5	0.8

#### 4.6 Effect of soil moisture status on seed quality of bambara groundnut

Qualitative assessment of Jabajaba and Chichele Balgu indicated that seed size; protein and tannin content could vary depending on the soil moisture content. There were significant effects ( $P < 0.05$ ) of moisture on seed size, protein and tannin contents (Table 4.6).

For Jabajaba 100-seed weight, protein and tannin contents were significantly affected ( $P < 0.05$ ) by moisture. In Chichele Balgu, there was a significant effect ( $P < 0.05$ ) of moisture on 100-seed weight and protein content, but that of tannin content was not significant (Table 4.6). There were significant differences ( $P < 0.05$ ) between the two varieties in 100-seed weight, tannin and protein contents of seeds.

Seed size and protein content in both varieties at 50-60% moisture were significantly higher than that at 30-40% and  $\geq 70\%$  moisture regimes. Also, there were significant effects ( $P < 0.05$ ) of variety on seed size (100-seed weight), protein and tannin content. Chichele Balgu recorded larger seed sizes and tannin content than Jabajaba at each of the moisture regimes. Although, lowest 100-seed weights were recorded at 30-40% moisture in both varieties, protein and tannin contents at 30-40% moisture were higher than that at  $\geq 70\%$  moisture (Table 4.6). Tannin contents at 30-40% were higher than that at 50-60% and  $\geq 70\%$  moisture regimes.

Table 4.6: Effect of soil moisture level on seed quality of Jabajaba and Chichele Balgu (on dry matter basis). (Values are the means and standard errors are in parenthesis).

Variety	Moisture Content (%)	100-Seed Weight (%)	Protein Content (%)	Tannin Content (%)
Jabajaba	≥ 70	28.7 (0.5)	20.8 (0.4)	0.2 (0.1)
	50 – 60	30.2 (0.9)	23.6 (0.7)	0.4 (0.1)
	30 – 40	26.4 (0.4)	21.6 (1.5)	0.4 (0.1)
Within Jabajaba	Mean	28.4 (1.1)	22.0 (1.0)	0.4 (0.1)
	LSD(5%)	2.7	2.5	0.2
Chichele Balgu	≥ 70	38.2 (0.2)	17.2 (1.7)	1.2 (0.2)
	50 – 60	40.83 (1.2)	19.3 (1.8)	1.4 (0.1)
	30 – 40	36.4 (0.6)	18.8 (0.3)	1.5 (0.1)
Within Chichele Balgu	Mean	38.5 (1.2)	18.4 (1.2)	1.4 (0.1)
	LSD(5%)	3.2	2.6	0.27
Among Varieties	LSD(5%)	2.6	2.7	0.2

From the results, it could be deduced that tannin contents increased as seed size decreased under inadequate soil moisture, and when soil moisture was adequate, tannin content decreased as seed size increased. However under excessive soil moisture level, tannin content tended to decrease regardless of the seed size. The above associations of seed size and tannin content under each moisture regime were the reverse with the protein content in Chichele Balgu in particular (Table 4.6).

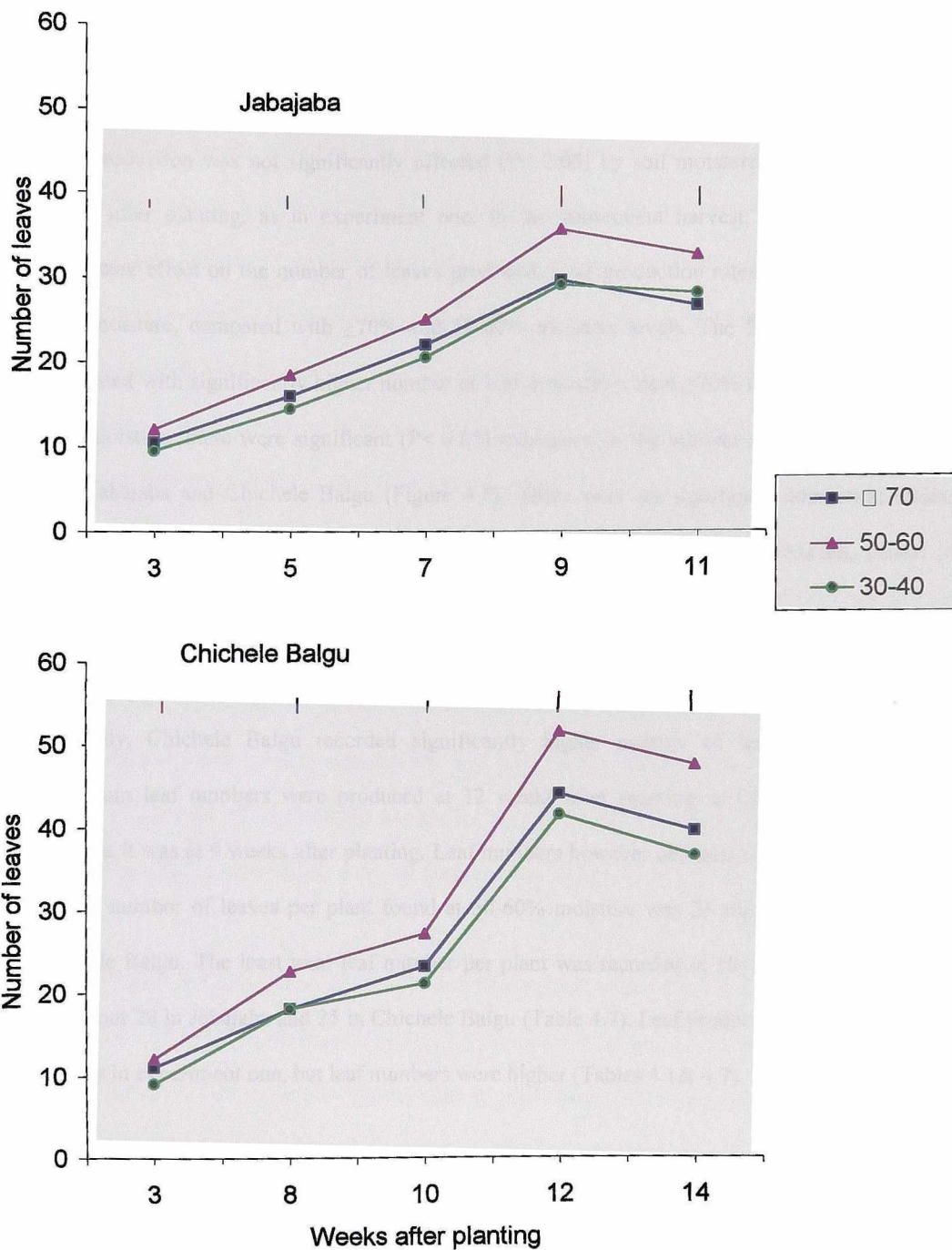


Fig 4.7: Effect of soil moisture level on leaf number per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

## EXPERIMENT 2

### 4.7 Effect of soil moisture status on bambara groundnut development

#### 4.7.1 Leaf production

Leaf production was not significantly affected ( $P < 0.05$ ) by soil moisture and variety at three weeks after planting, as in experiment one. In the subsequent harvest, soil moisture had a significant effect on the number of leaves produced. Leaf production rates were reduced at 30-40% moisture, compared with  $\geq 70\%$  and 50-60% moisture levels. The 50-60% moisture was associated with significantly higher number of leaf production than  $\geq 70\%$  moisture level. At 30-40% moisture, there were significant ( $P < 0.05$ ) reductions in the number of leaves produced in both Jabajaba and Chichele Balgu (Figure 4.7). There were no significant interaction effects between cultivar and soil moisture ( $P < 0.05$ ) on the number of leaves produced, except at physiological maturity.

Generally, Chichele Balgu recorded significantly higher number of leaves than Jabajaba. Maximum leaf numbers were produced at 12 weeks after planting in Chichile Balgu but in Jabajaba it was at 9 weeks after planting. Leaf numbers however declined towards maturity. The highest number of leaves per plant found at 50-60% moisture was 25 for Jabajaba and 32 for Chichele Balgu. The least total leaf number per plant was recorded at 30-40% moisture, which was about 20 in Jabajaba and 25 in Chichele Balgu (Table 4.7). Leaf production followed similar trend as in experiment one, but leaf numbers were higher (Tables 4.1& 4.7).

#### 4.7.2 Leaf area development

Leaf area at 3 weeks after planting was significantly different ( $P < 0.05$ ) between varieties and moisture regimes (Figure 4.8), even though leaf numbers between varieties and moisture regimes were not significantly different (Figure 4.7). During flowering (at 5 weeks in Jabajaba and 8 weeks after planting in Chichile Balgu), soil moisture did not have significant effect ( $P < 0.05$ ) leaf area. At early podding (7 weeks in Jabajaba and 10 weeks after planting in Chichile Balgu) and maturity (11 weeks in Jabajaba and 14 weeks after planting in Chichile Balgu), Chichile Balgu recorded significantly higher ( $P < 0.05$ ) leaf area than Jabajaba at all moisture regimes. With the exception of final harvest at maturity, there were no significant interaction effects between variety and moisture ( $P < 0.05$ ) on leaf area development.

Maximum leaf area was recorded at mid-pod filling (at 9 weeks in Jabajaba and 12 weeks after planting in Chichele Balgu) (Figure 4.8). At mid-pod filling, leaf area recorded at 30-40% moisture was significantly lower ( $P < 0.05$ ), than that of 50-60% and  $\geq 70\%$  moisture regimes. After mid-pod filling towards maturity leaf area began to decline. Even though there was general decline in leaf area, Chichele Balgu was producing new leaves, indicating that Jabajaba was more determinate. The pattern of leaf area development was similar to that of Experiment 1.

The total leaf area was lowest at 30-40% moisture regime with values of 255.9 cm<sup>2</sup> in Jabajaba and 323.9 cm<sup>2</sup> in Chichele Balgu (Table 4.7). However, total leaf area was significantly higher (LSD 5%) at 50-60% moisture regime, than at  $\geq 70\%$  and 30-40% moisture regime. Total leaf area in Chichele Balgu was significantly higher (LSD 5%) than Jabajaba at each moisture regime (Table 4.7). However leaf area was higher in both varieties compared to experiment one (Tables 4.1 & 4.7).

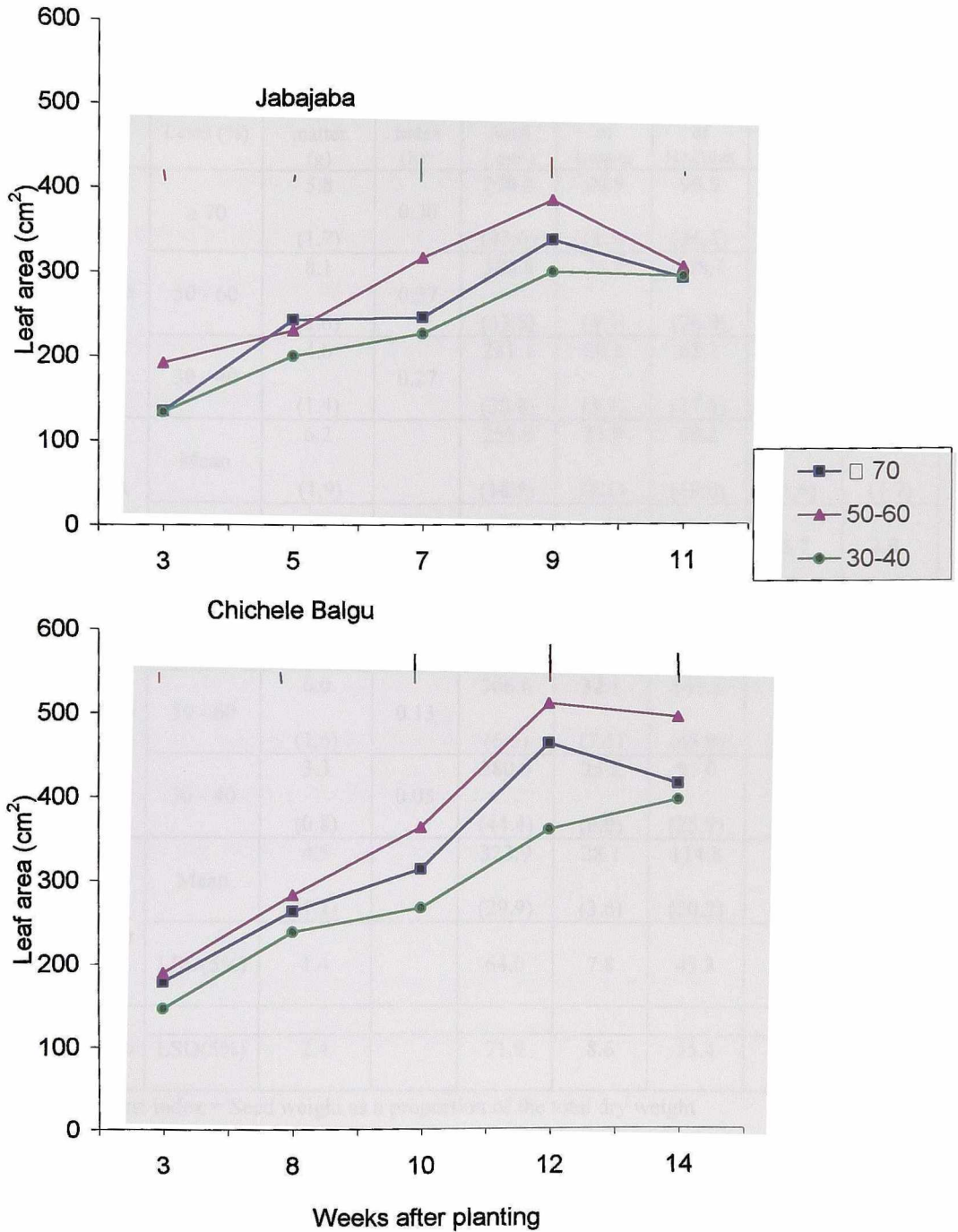


Fig 4.8: Effect of soil moisture level on leaf area per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

Table 4.7: Effect of soil moisture on total dry matter, harvest indices, leaf area and leaf number, number of nodules, pods and seeds per plant of Jabajaba and Chichele Balgu.

(Values are the means and Standard Errors are in parentheses).

Variety	Moisture Level (%)	Total Dry matter (g)	Harv. Index (h)*	Leaf Area (cm <sup>2</sup> )	Number of Leaves	Number of Nodules	Number of Pods	Number of Seeds
Jabajaba	≥ 70	5.8 (1.7)	0.30	250.8 (33.6)	20.9 (3.5)	99.9 (36.5)	6.7 (2.2)	6.3 (2.0)
	50 - 60	8.1 (2.6)	0.37	285.8 (33.8)	24.7 (4.3)	108.4 (38.0)	10.5 (2.6)	9.7 (3.1)
	30 - 40	4.6 (1.4)	0.27	231.1 (30.8)	20.2 (3.7)	62.3 (17.9)	4.7 (1.2)	4.3 (1.5)
Within Jabajaba	Mean	6.2 (1.9)		255.9 (18.5)	21.9 (2.1)	90.2 (18.0)	7.3 (1.6)	6.8 (1.7)
	LSD(5%)	2.1		39.7	.6	38.6	3.7	3.9
Chichele Balgu	≥ 70	4.3 (1.1)	0.08	325.1 (5.4)	27.1 (6.3)	111.6 (34.4)	1.7 (0.8)	1.3 (0.9)
	50 - 60	6.0 (1.6)	0.13	366.6 (6.6)	32.1 (7.5)	141.7 (45.9)	2.8 (1.1)	2.3 (1.27)
	30 - 40	3.3 (0.8)	0.05	280.0 (44.4)	25.2 (6.0)	91.0 (25.9)	0.7 (0.3)	0.5 (0.4)
Within Chichele	Mean	4.5 (1.2)		323.9 (29.9)	28.1 (3.6)	114.8 (20.2)	1.7 (0.6)	1.4 (0.6)
	LSD(5%)	1.4		64.0	7.8	43.3	1.4	1.5
Among Varieties								
	LSD(5%)	2.4		71.9	8.6	55.4	3.7	3.8

- Harvest index = Seed weight as a proportion of the total dry weight

#### 4.7.3 Nodule number

Generally there was a steady increase in nodule number from vegetative stage (3 weeks in Jabajaba and 6 weeks after planting in Chichile Balgu), which reached a peak at mid-pod filling stage (9 weeks in Jabajaba and 12 weeks after planting in Chichile Balgu) after which the numbers began to decline (Figure 4.9). There was a significant effect ( $P < 0.05$ ) of variety on nodule number at all stages of growth. Also, with the exception of early podding stage, there was a significant effect ( $P < 0.05$ ) of moisture on nodulation at the other growth stages. There was significant interaction between moisture and variety ( $P < 0.05$ ) on nodulation, except at flowering and early podding stages.

Maximum nodule numbers were recorded between early podding and mid-pod filling stages in both varieties. At mid-pod filling, 50-60% moisture recorded the highest nodule number per plant of 201 in Jabajaba and 324 in Chichele Balgu. At  $\geq 70\%$  moisture, Jabajaba recorded 196 nodules per plant, whilst Chichele Balgu recorded 201 nodules per plant. The 30-40% moisture also had an average of 101 nodules per plant in Jabajaba and 157 nodules per plant in Chichele Balgu (Figure 4.9). The nodules produced in both Jabajaba and Chichele Balgu were observed to be brown in colour and larger than that of Experiment 1.

There was a general decline in nodule number at maturity probably due to nodule senescence. Fewer number of nodules were produced under 30-40% moisture level, where Jabajaba recorded 62.3 per plant and Chichele Balgu with 91 nodules per plant (Table 4.7). The number of nodules produced in Experiment 1 were higher than those in Experiment 2.

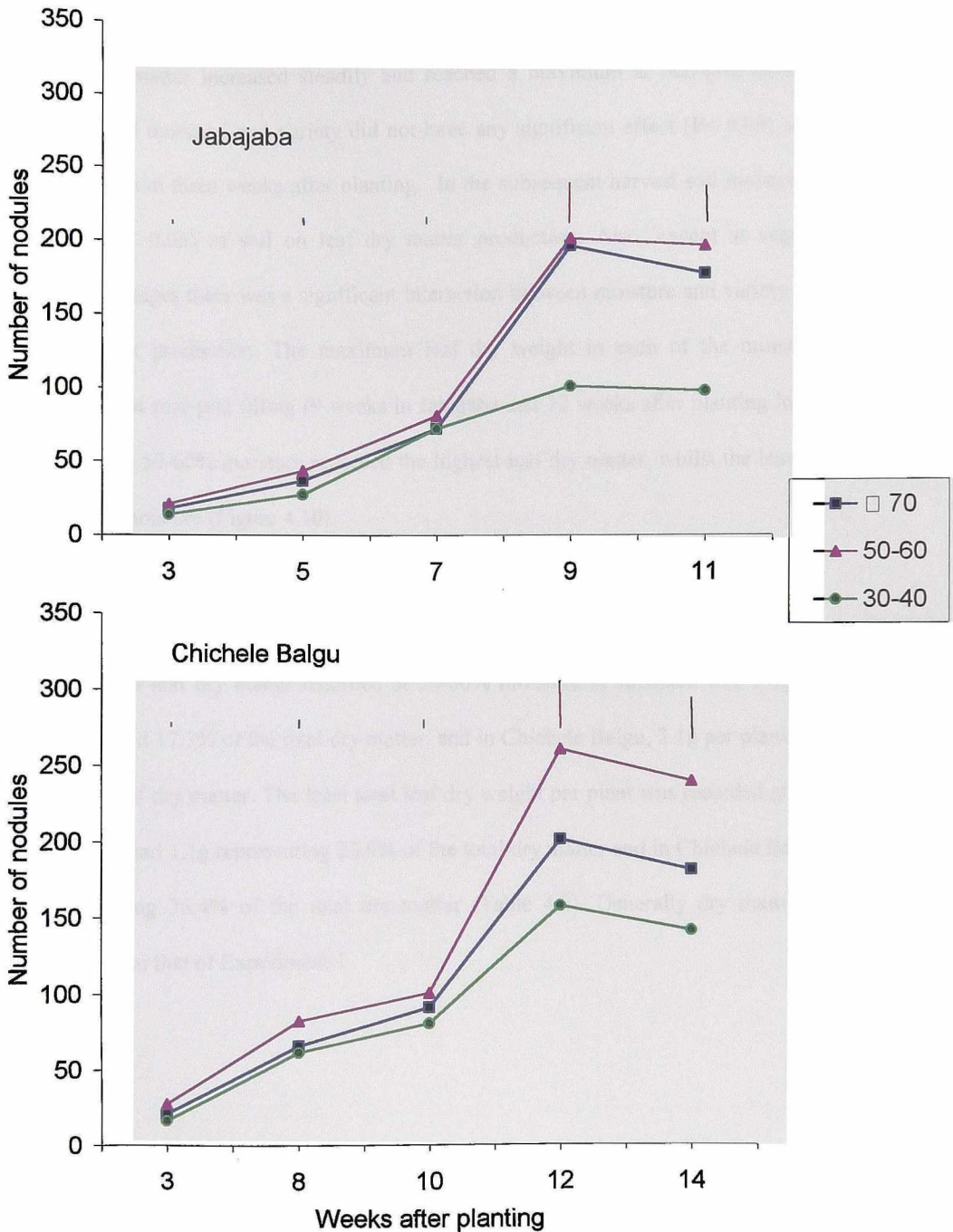


Fig 4.9: Effect of soil moisture level on number of nodules per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

#### **4.8 Effect of soil moisture status on growth of bambara groundnut**

##### **4.8.1 Leaf dry weight**

Leaf dry matter increased steadily and reached a maximum at mid-pod filling stages (Figure 4.10). Soil moisture and variety did not have any significant effect ( $P < 0.05$ ) on leaf dry matter production at three weeks after planting. In the subsequent harvest soil moisture had significant effect ( $P < 0.05$ ) of soil on leaf dry matter production. Also, except at vegetative and early podding stages there was a significant interaction between moisture and variety ( $P < 0.05$ ) on leaf dry matter production. The maximum leaf dry weight in each of the moisture regimes was recorded at mid-pod filling (9 weeks in Jabajaba and 12 weeks after planting in Chichile Balgu). In general 50-60% moisture recorded the highest leaf dry matter, whilst the least was recorded at 30-40% moisture (Figure 4.10).

There were significant effects ( $P < 0.05$ ) of moisture and variety on total leaf dry weight (Table 4.8). Total leaf dry matter recorded at 50-60% moisture in Jabajaba was 1.4g per plant, which represented 17.3% of the total dry matter, and in Chichele Balgu, 2.1g per plant representing 35% of the total dry matter. The least total leaf dry weight per plant was recorded at 30-40% in which Jabajaba had 1.1g representing 23.9% of the total dry matter and in Chichele Balgu 1.2g per plant representing 36.4% of the total dry matter (Table 4.8). Generally dry matter production was higher than that of Experiment 1.

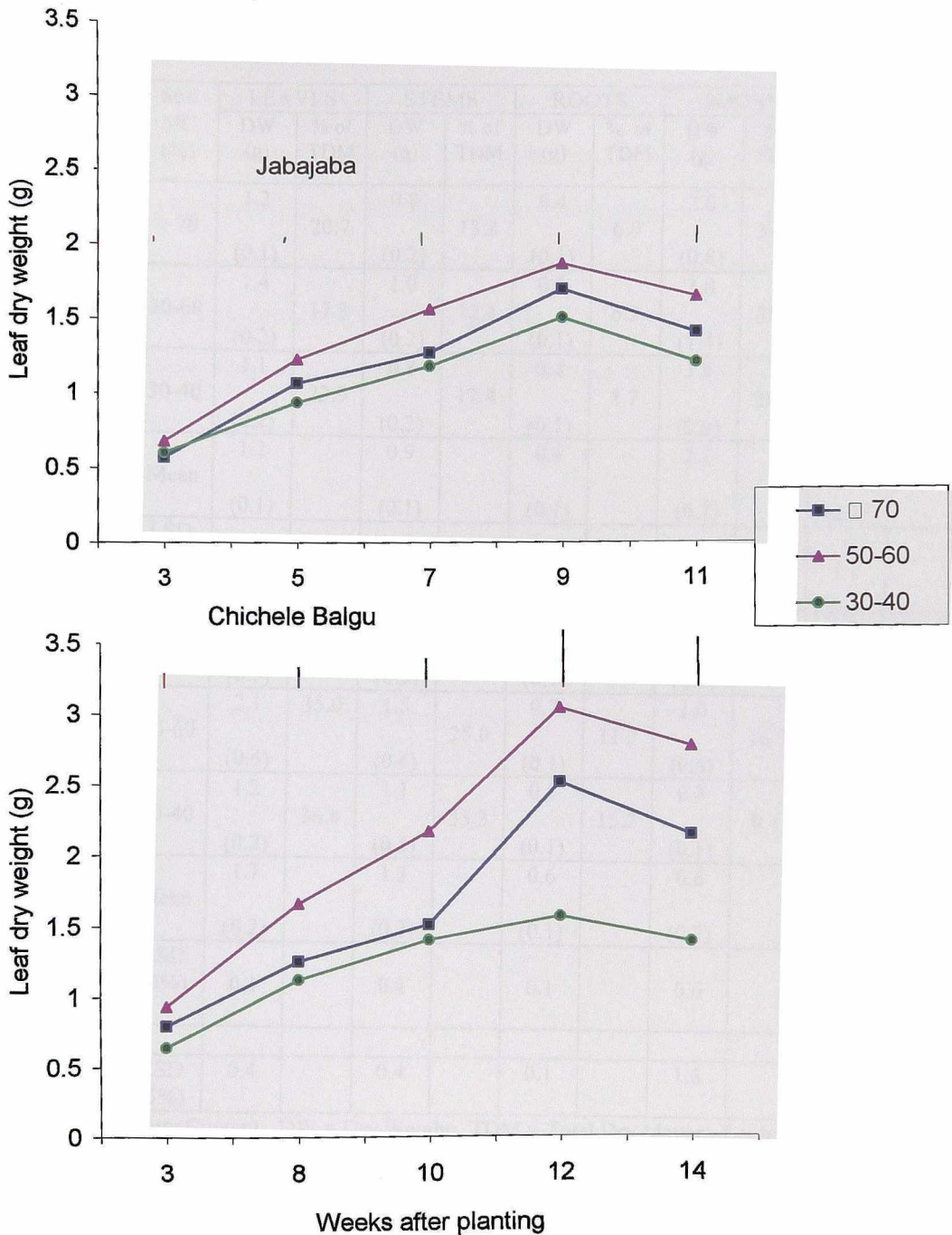


Fig 4.10: Effect of soil moisture level on leaf dry weight per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

Table 4.8: Effect of soil moisture on total dry matter of leaves, stems, roots, pods and seeds of Jabajaba and Chichele Balgu at maturity (Values are the means and standard Errors are in parentheses).

Variety	Soil MC (%)	LEAVES		STEMS		ROOTS		PODS*		SEEDS	
		DW (g)	% of TDM	DW (g)	% of TDM	DW (g)	% of TDM	DW (g)	% of TDM	DW (g)	% of TDM
Jabajaba	≥ 70	1.2 (0.1)	20.7	0.8 (0.2)	13.8	0.4 (0.1)	6.9	2.0 (0.8)	34.5	1.4 (0.5)	24.1
	50-60	1.4 (0.2)	17.3	1.0 (0.2)	12.3	0.5 (0.1)	6.2	3.0 (1.4)	37.0	2.2 (1.0)	27.2
	30-40	1.1 (0.2)	23.9	0.8 (0.2)	17.4	0.4 (0.1)	8.7	1.3 (0.6)	28.3	1.0 (0.5)	21.7
Within Jabajaba	Mean	1.2 (0.1)		0.9 (0.1)		0.4 (0.1)		2.1 (0.7)		1.5 (0.5)	
	LSD (5%)	0.2		0.2		0.1		1.6		1.1	
Chichele Balgu	≥ 70	1.7 (0.3)	39.5	1.3 (0.3)	30.2	0.5 (0.1)	11.6	0.5 (0.3)	11.6	0.3 (0.2)	7.0
	50-60	2.1 (0.4)	35.0	1.5 (0.4)	25.0	0.7 (0.1)	11.7	1.0 (0.6)	16.7	0.7 (0.4)	11.7
	30-40	1.2 (0.2)	36.4	1.1 (0.3)	33.3	0.5 (0.1)	15.2	0.3 (0.1)	9.1	0.2 (0.1)	6.1
Within Chichele Balgu	Mean	1.7 (0.2)		1.3 (0.2)		0.6 (0.1)		0.6 (0.2)		0.4 (0.2)	
	LSD (5%)	0.4		0.4		0.1		0.6		0.5	
Among Varieties	LSD (5%)	0.4		0.4		0.1		1.6		1.1	

MC = Moisture Content; DW = Dry Weight; TDM = Total Dry Matter \* = Including Seeds

#### 4.8.2 Stem dry weight

There was a significant effect ( $P < 0.05$ ) of variety on stem dry weight at three weeks after planting. Soil moisture did not have any significant effect ( $P < 0.05$ ) on stem dry matter until early podding (i.e., 7 weeks in Jabajaba and 10 weeks after planting in Chichile Balgu). The maximum stem dry matter production in Chichele Balgu occurred between early podding and mid-pod filling (i.e., 10-12 weeks after planting), while that in Jabajaba was between mid-pod filling and maturity (i.e., 9-11 weeks after planting). The highest stem dry weight was recorded at 50-60% moisture, whilst the least was recorded at 30-40% moisture in both Jabajaba and Chichele Balgu (Figure 4.11).

Total stem dry matter was highest at 50-60% moisture, with values of 1.0g per plant representing 12.3% of the total dry matter in Jabajaba and 1.5g per plant, which represented 25% of the total dry matter in Chichele Balgu. The least total dry matter was produced in each of the varieties at 30-40% moisture (Table 4.8). Stem dry matter was higher than in Experiment 1.

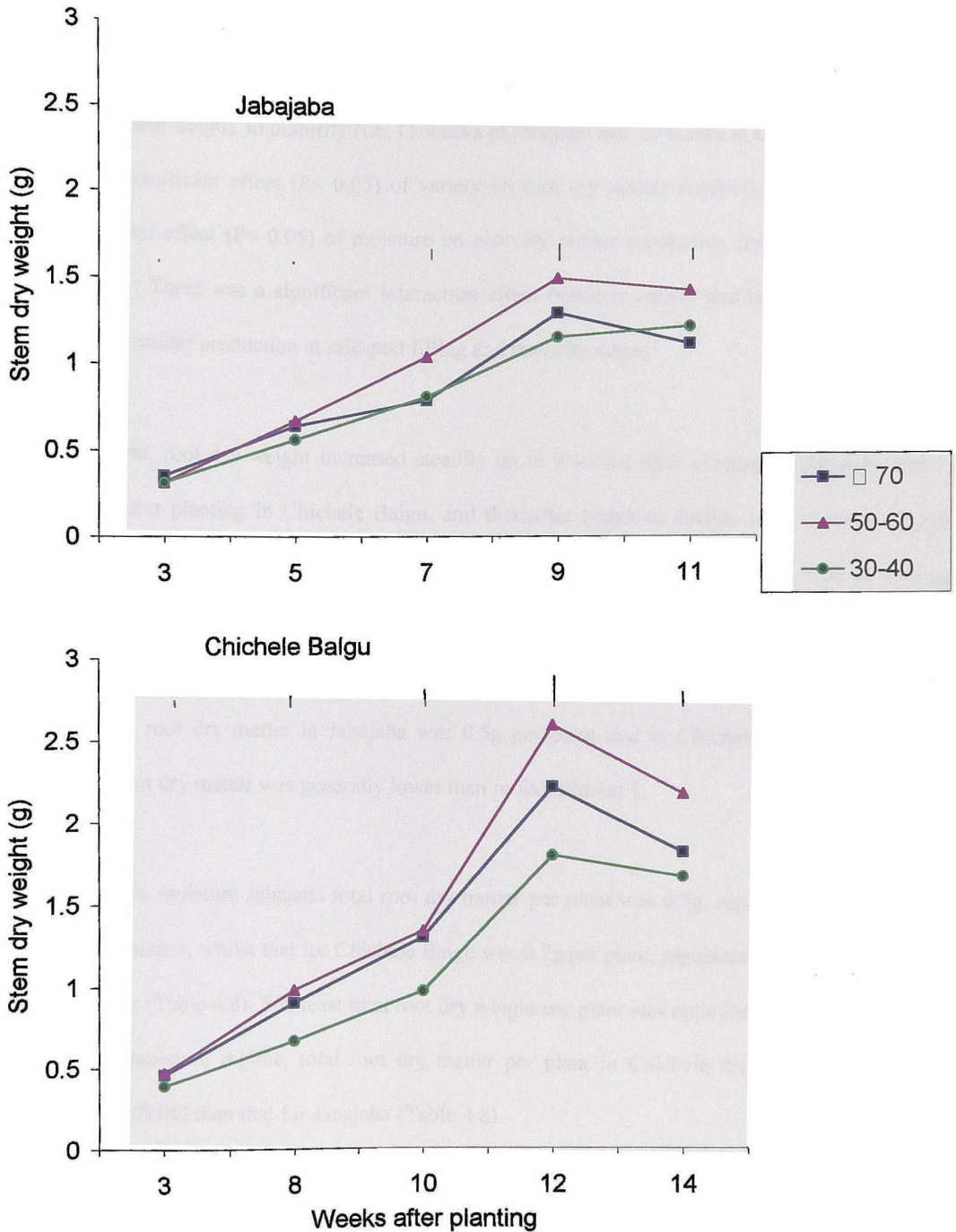


Fig 4.11: Effect of soil moisture levels on stem dry weight per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

#### 4.8.3 Root dry weight

Soil moisture and variety did not have significant effects ( $P < 0.05$ ) on root growth at three weeks after planting. From flowering (i.e. 5 weeks after planting in Jabajaba and 8 weeks after planting in Chichele Balgu), to maturity (i.e. 11 weeks in Jabajaba and 14 weeks in Chichele Balgu), there was a significant effect ( $P < 0.05$ ) of variety on root dry matter production. Also, there was a significant effect ( $P < 0.05$ ) of moisture on root dry matter production from mid-pod filling to maturity. There was a significant interaction effect between variety and moisture ( $P < 0.05$ ) on root dry matter production at mid-pod filling and maturity stages.

In general, root dry weight increased steadily up to 9 weeks after planting in Jabajaba and 12 weeks after planting in Chichele Balgu, and thereafter began to decline until maturity (Figure 4.12). The highest root dry weight per plant was recorded at 50-60% moisture, with an average value of 0.8g in Jabajaba and 0.9g in Chichele Balgu. The  $\geq 70\%$  moisture also had the highest root dry matter of 0.6g per plant in Jabajaba and 0.7g per plant in Chichele Balgu. At 30-40% moisture, root dry matter in Jabajaba was 0.5g per plant and in Chichele Balgu 0.6g (Figure 4.12). Root dry matter was generally lower than in Experiment 1.

At 50-60% moisture Jabajaba total root dry matter per plant was 0.5g, representing 6.2% of the total dry matter, whilst that for Chichele Balgu was 0.7g per plant, representing 11.7% of the total dry matter (Table 4.8). The least total root dry weight per plant was recorded at 30-40% moisture. At each moisture regime, total root dry matter per plant in Chichele Balgu was significantly higher ( $P < 0.05$ ) than that for Jabajaba (Table 4.8).

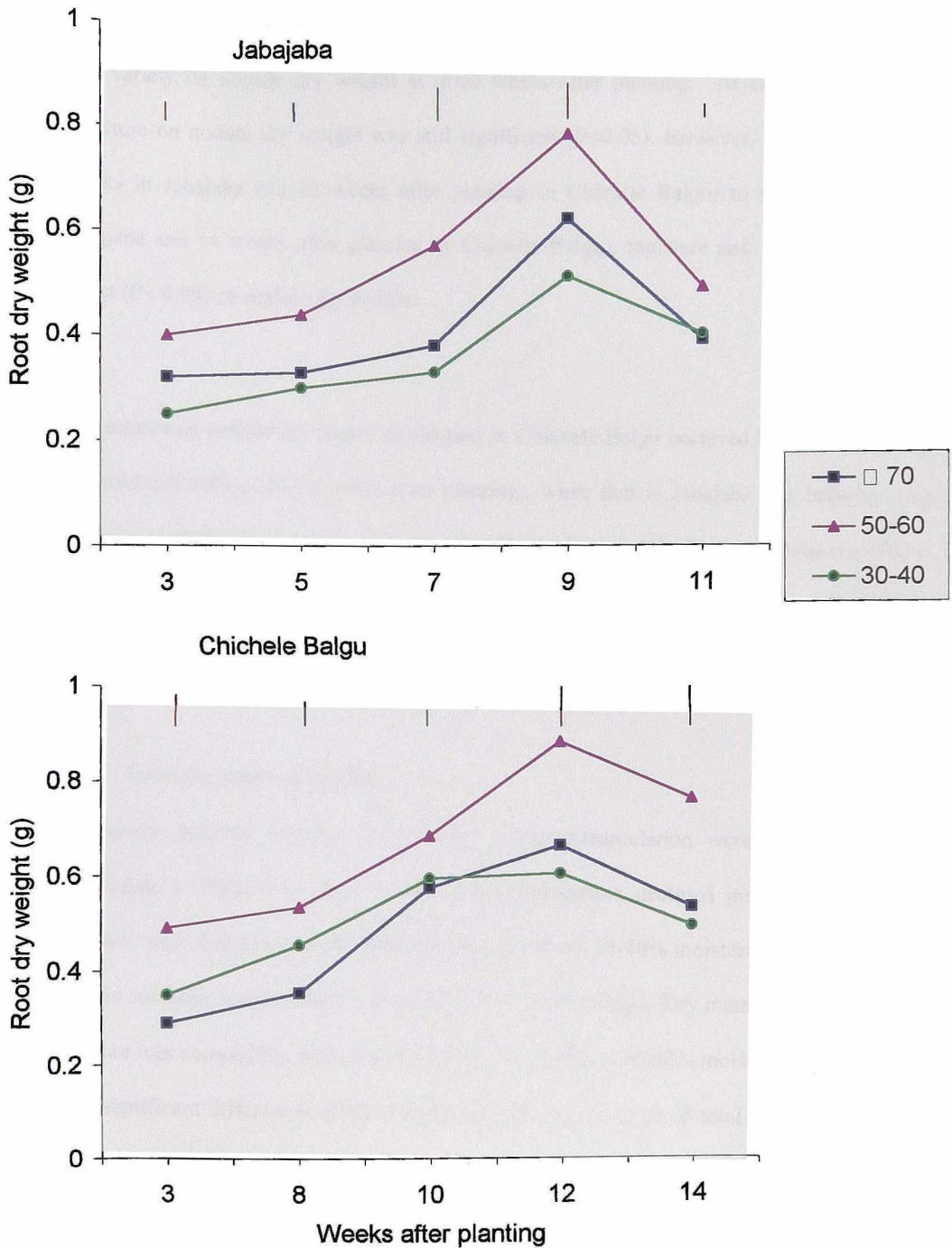


Fig 4.12: Effect of soil moisture level on root dry weight per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

#### 4.8.4 Nodule dry weight

There were significant effects ( $P < 0.05$ ) of moisture, variety and interaction between moisture and variety on nodule dry weight at three weeks after planting. At flowering, the effect of moisture on nodule dry weight was still significant ( $P < 0.05$ ). However, from early podding (7 weeks in Jabajaba and 10 weeks after planting in Chichile Balgu) to maturity (11 weeks in Jabajaba and 14 weeks after planting in Chichile Balgu), moisture and variety had significant effect ( $P < 0.05$ ) on nodule dry weight.

The maximum nodule dry matter production in Chichele Balgu occurred between early podding and mid-pod filling (10-12 weeks after planting), while that in Jabajaba was between mid-pod filling to maturity (9-11 weeks after planting). The highest nodule dry weight was recorded at 50-60% moisture, whilst the least occurred at 30-40% moisture in both Jabajaba and Chichele Balgu (Figure 4.13). Nodule dry weight followed a similar trend as nodule number.

#### 4.8.5 Total dry matter production

Differences between varieties in total dry matter accumulation were higher than that of experiment 1 (Tables 4.1 & 4.7). Dry matter production declined markedly with low soil moisture, such that the total dry matter production in the 30-40% moisture was less than 5 g per plant in Jabajaba and less than 4 g per plant in Chichele Balgu. Dry matter production at  $\geq 70\%$  moisture was comparable with that of 30-40%, but higher at 50-60% moisture (Table 4.7). There were significant differences (LSD 5%) among varieties in terms of total dry matter production (Tables 4.1 & 4.7).

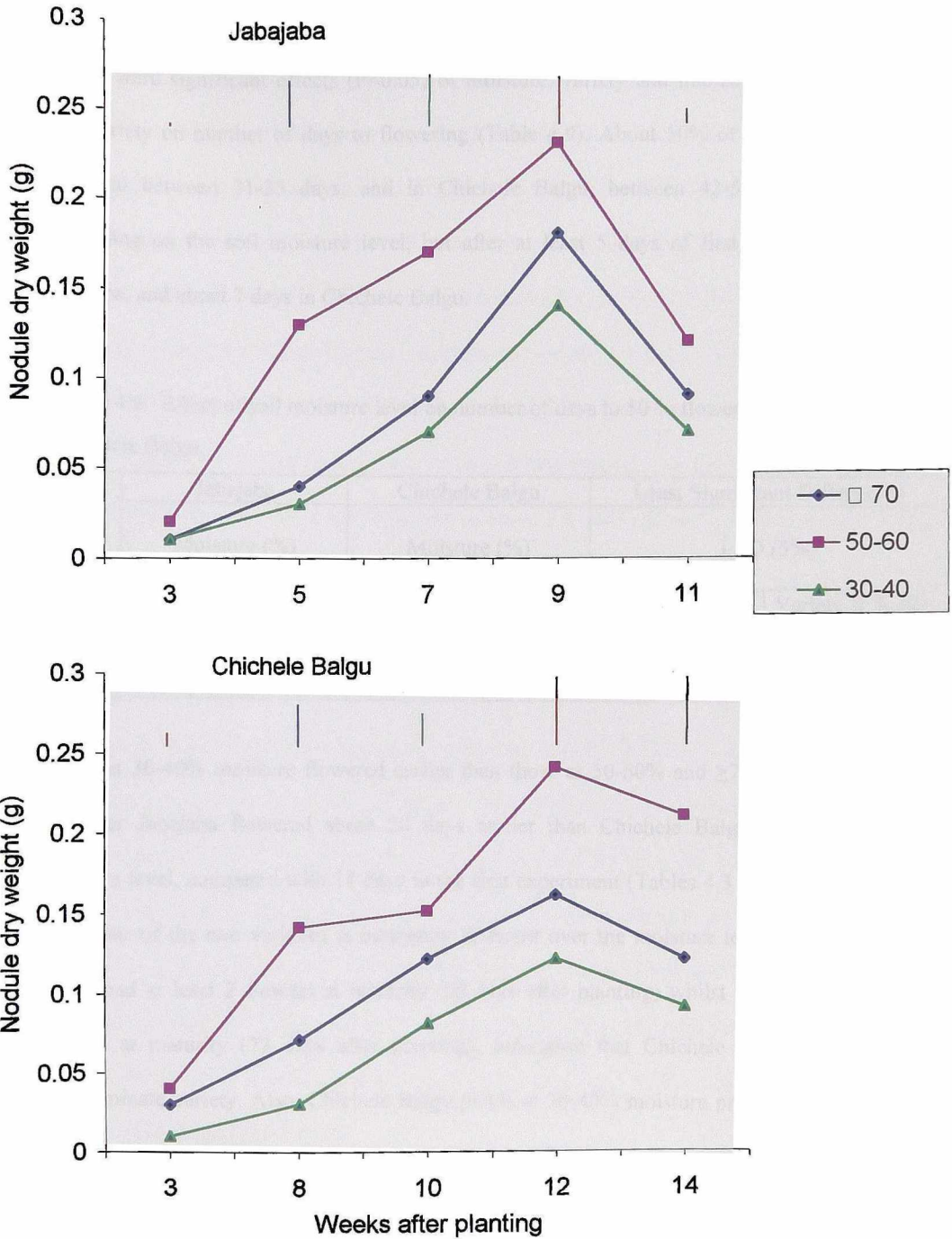


Fig 4.13: Effect of soil moisture level on nodule dry weight per plant of Jabajaba and Chichele Balgu (Vertical bars represent the mean standard error for the three moisture treatments)

#### 4.9 Effect of soil moisture on reproductive development of bambara groundnut

##### 4.9.1 Flower development

There were significant effects ( $P < 0.05$ ) of moisture, variety and interaction between moisture and variety on number of days to flowering (Table 4.9). About 50% of the plants in Jabajaba flowered between 31-35 days, and in Chichele Balgu, between 42-55 days after planting depending on the soil moisture level, but after at least 5 days of first flower appearance in Jabajaba, and about 7 days in Chichele Balgu.

Table 4.9. Effect of soil moisture level on number of days to 50 % flowering of Jabajaba and Chichele Balgu.

	Jabajaba			Chichele Balgu			Least Significant Differences		
	Moisture (%)			Moisture (%)			LSD (5%)		
	≥70	50-60	30-40	≥70	50-60	30-40	Variety	Water	Variety & Water
Days	35.0	33.0	30.5	54.5	49.5	41.5	1.6	1.9	2.7

Plants at 30-40% moisture flowered earlier than those at 50-60% and ≥70% moisture regimes. However Jabajaba flowered about 20 days earlier than Chichele Balgu irrespective of soil moisture level, compared with 14 days in the first experiment (Tables 4.3 & 4.9). The flowering behaviour of the two varieties is inherently different over the moisture levels. Chichele Balgu plants had at least 2 flowers at maturity (98 days after planting) whilst Jabajaba did not have flowers at maturity (77 days after planting), indicating that Chichele Balgu is more of an indeterminate variety. Also, Chichele Balgu plants at 30-40% moisture produced flowers over a longer period, resulting in delayed pod appearance. There was a general change in flowering pattern when compared with the first experiment.

#### 4.9.2 Pod development

Pod initiation started 7 weeks after planting in Jabajaba and 10 weeks after planting in Chichele Balgu (Table 4.10). Generally, there were steady increases in pod number per plant from early pod initiation (7 weeks in Jabajaba and 10 weeks in Chichile Balgu after planting) to the peak at maturity (11 weeks in Jabajaba and 14 weeks after planting in Chichile Balgu). Soil moisture and variety had significant effects ( $P < 0.05$ ) on number of pods produced. With the exception of mid-pod filling stage (9 weeks in Jabajaba and 12 weeks after planting in Chichile Balgu), there were significant interaction effects between moisture and variety ( $P < 0.05$ ) on pod development at pod initiation. During pod initiation, 30-40% moisture recorded 2 pods per plant in Jabajaba, but there was no pod in Chichele Balgu. Chichele Balgu at  $\geq 70\%$  moisture did not record any pod. The 50-60% moisture also resulted in the formation of about 3.8 pods per plant in Jabajaba and 0.5 pods in Chichele Balgu (Table 4.10).

Compared to Experiment 1, there was a poorer pod yield in Chichele Balgu, with less than 2 pods per plant at 30-40% moisture. Pod production was highest at 50-60% moisture, with Jabajaba producing 17 pods per plant, whilst that of Chichele Balgu was 5.5 pods per plant. At  $\geq 70\%$  moisture there were 11.5 pods per plant in Jabajaba and 3.5 pods per plant in Chichele Balgu (Table 4.10). Jabajaba appeared to be superior over Chichele Balgu in pod production. The total number of pods per plant at 50-60% moisture was 10.5 in Jabajaba and 2.8 in Chichele Balgu. This was followed by  $\geq 70\%$  moisture, with 30-40% recording the least pod number. However at each of the moisture regimes, Jabajaba recorded significantly higher number of pods ( $P < 0.05$ ) than Chichele Balgu (Table 4.10).

#### 4.9.3 Seed development

Seed formation in both Jabajaba and Chichele Balgu started about 5-8 days after pod initiation (i.e. 7 weeks in Jabajaba and 10 weeks after planting in Chichile Balgu). Norman and Chongo (1991) also reported seed formation about 6 days later after pod initiation in bambara groundnut. There were significant differences ( $P < 0.05$ ) between varieties on seed production from early pod development (7 weeks in Jabajaba and 10 weeks after planting in Chichile Balgu) to maturity (11 weeks in Jabajaba and 14 weeks after planting in Chichile Balgu). However, significant effect ( $P < 0.05$ ) of moisture on number of seeds produced occurred after pod initiation. It was at maturity that significant interaction effect between variety and moisture ( $P < 0.05$ ) on number of seeds produced was observed, indicating inherent differences of the varieties in seed production.

During early pod formation, the seed number per plant at 30-40% moisture was one in Jabajaba and none in Chichele Balgu. The 50-60% moisture regime also recorded an average seed number per plant of 3 in Jabajaba but there was no pod in Chichele Balgu, whilst that of  $\geq 70\%$  moisture had an average of 0.5 seeds per plant in Jabajaba but none in Chichele Balgu (Table 4.10).

At maturity, seed number per plant at 30-40% soil moisture rose to 7.5 in Jabajaba and 1.5 in Chichele Balgu. The highest seed number was recorded at 50-60% moisture, with seed number per plant of 17 in Jabajaba and 5.5 in Chichele Balgu. At  $\geq 70\%$  moisture, 10.5 seeds per plant was recorded in Jabajaba and 3.5 seeds per plant in Chichele Balgu (Table 4.10). Generally, there was one seed per pod in both varieties, even though there were some few pods without seeds, especially in Chichele Balgu. However seed numbers were not significantly different from pod numbers compared with that of Experiment 1.

#### 4.9.3 Seed development

Seed formation in both Jabajaba and Chichele Balgu started about 5-8 days after pod initiation (i.e. 7 weeks in Jabajaba and 10 weeks after planting in Chichile Balgu). Norman and Chongo (1991) also reported seed formation about 6 days later after pod initiation in bambara groundnut. There were significant differences ( $P < 0.05$ ) between varieties on seed production from early pod development (7 weeks in Jabajaba and 10 weeks after planting in Chichile Balgu) to maturity (11 weeks in Jabajaba and 14 weeks after planting in Chichile Balgu). However, significant effect ( $P < 0.05$ ) of moisture on number of seeds produced occurred after pod initiation. It was at maturity that significant interaction effect between variety and moisture ( $P < 0.05$ ) on number of seeds produced was observed, indicating inherent differences of the varieties in seed production.

During early pod formation, the seed number per plant at 30-40% moisture was one in Jabajaba and none in Chichele Balgu. The 50-60% moisture regime also recorded an average seed number per plant of 3 in Jabajaba but there was no pod in Chichele Balgu, whilst that of  $\geq 70\%$  moisture had an average of 0.5 seeds per plant in Jabajaba but none in Chichele Balgu (Table 4.10).

At maturity, seed number per plant at 30-40% soil moisture rose to 7.5 in Jabajaba and 1.5 in Chichele Balgu. The highest seed number was recorded at 50-60% moisture, with seed number per plant of 17 in Jabajaba and 5.5 in Chichele Balgu. At  $\geq 70\%$  moisture, 10.5 seeds per plant was recorded in Jabajaba and 3.5 seeds per plant in Chichele Balgu (Table 4.10). Generally, there was one seed per pod in both varieties, even though there were some few pods without seeds, especially in Chichele Balgu. However seed numbers were not significantly different from pod numbers compared with that of Experiment 1.

The total number of seeds per plant was higher in Jabajaba than Chichele Balgu at all the soil moisture regimes (Table 4.7). However, 50-60% moisture recorded the highest number of seeds per plant of 9.7 in Jabajaba and 2.3 in Chichele Balgu. The lowest seed number per plant was recorded at 30-40% moisture in both varieties. In terms of the total number of seeds produced, the varieties were significantly different ( $P < 0.05$ ) over the moisture regimes.

Table 4.10: Effect of soil moisture on reproductive growth and development of Jabajaba and Chichile Balgu. Standard errors are in parenthesis.

Variety	Soil Water (%)	Reproductive development						Reproductive growth						
		Number of pods			Number of seeds			Pod dry weight (g)			Seed dry weight (g)			
		(WAP)			(WAP)			(WAP)			(WAP)			
		7	9	11	7	9	11	7	9	11	7	9	11	
Jabajaba	≥70	1.5	7.0	11.5	0.5	7.0	10.0	0.1	2.0	3.9	0.1	1.6	2.4	
		(0.3)	(1.5)	(1.9)	(0.1)	(1.5)	(2.6)	(0.1)	(0.2)	(1.4)	(0.1)	(0.5)	(1.2)	
	50-60	5.5	9.0	17.0	3.0	9.0	17.0	0.4	2.1	6.5	0.1	1.7	4.7	
		(1.2)	(1.8)	(3.3)	(1.1)	(2.1)	(3.5)	(0.1)	(0.4)	(1.9)	(0.1)	(0.7)	(1.6)	
	30-40	2.0	4.5	7.5	1.0	4.5	7.5	0.2	1.0	2.7	0	0.9	2.1	
		(0.4)	(2.1)	(1.4)	(0.6)	(1.8)	(1.7)	(0.1)	(0.1)	(0.9)		(0.3)	(0.6)	
			(WAP)			(WAP)			(WAP)			(WAP)		
Chichile Balgu		10	12	14	10	12	14	10	12	14	10	12	14	
	≥70	0	1.5	3.5	0	0.5	3.5	0	0.3	1.4	0	0.1	0.9	
			(0.4)	(1.4)		(0.2)	(1.1)		(0.1)	(1.0)		(0.1)	(0.3)	
	50-60	0.5	2.5	5.5	0	1.5	5.5	0	0.4	2.5	0	0.1	1.9	
		(0.2)	(0.8)	(1.2)		(0.7)	(1.5)		(0.2)	(1.7)		(0.1)	(0.7)	
	30-40	0	0.5	1.5	0	0.1	1.5	0	0.1	0.6	0	0	0.4	
			(0.1)	(0.6)		(0.1)	(0.6)		(0.1)	(0.3)			(0.1)	

WAP = Weeks After Planting.

#### **4.10 Effect of moisture status on reproductive growth of bambara groundnut**

##### 4.10.1 Pod dry weight

Pod dry weight increased slowly and reached a peak at maturity. There were significant effects ( $P < 0.05$ ) of moisture and variety on pod dry weight from early pod growth to maturity. With the exception of early podding stage, there was significant interaction effect of moisture and variety ( $P < 0.05$ ) on pod dry weight, indicating varietal differences in pod production over soil moisture.

Pod dry weight increased linearly from 7-11 weeks after planting in Jabajaba and between 10-14 weeks after planting in Chichele Balgu (Table 4.10). Rapid increase in pod dry weight was between 9-11 weeks after planting in Jabajaba and 11-13 weeks after planting in Chichele Balgu. Pod dry weight was highest at 50-60% moisture, whilst the least was recorded at 30-40% moisture (Table 4.10).

The total pod dry weight per plant (Table 4.8), showed that Jabajaba produced 3.0g per plant which represented 37% of the total dry matter, while Chichele Balgu produced 1.0g representing 16.7% of the total dry matter, at 50-60% soil moisture. The least total pod dry weight per plant, and pod dry weight as a percentage of total dry matter was recorded at 30-40% moisture (Table 4.8). These values were lower than that for experiment one, especially in Chichele Balgu.

#### 4.10.2 Seed dry weight

There were significant increases in seed dry weight at all moisture levels from early seed development (7 weeks in Jabajaba and 10 weeks after planting in Chichile Balgu) to maturity (11 weeks in Jabajaba and 14 weeks after planting in Chichile Balgu). There was no significant effect ( $P < 0.05$ ) of variety and moisture on seed dry weight at early seed growth. From mid-pod filling (9 weeks in Jabajaba and 12 weeks after planting in Chichile Balgu) to maturity (11 weeks in Jabajaba and 14 weeks after planting in Chichile Balgu), both soil moisture and variety significantly ( $P < 0.05$ ) affected seed dry weight per plant. However, there was significant interaction effect of variety and moisture ( $P < 0.05$ ) on seed dry weight at maturity.

Seed dry weight was highest at 50-60% moisture at maturity, with Jabajaba recording an average value of 4.7g per plant and in Chichele Balgu, 1.9g per plant. The  $\geq 70\%$  moisture also recorded an average seed dry weight of 2.4g per plant in Jabajaba and 0.9g per plant in Chichele Balgu. However, 30-40% moisture recorded the lowest average seed dry weight of 2.1g per plant in Jabajaba and 0.4g per plant in Chichele Balgu (Table 4.10).

The total seed dry weight per plant at 30-40% moisture was the least, with Jabajaba recording 1.0g per plant, which represented 21.7% of the total dry matter, and in Chichele Balgu 0.2g per plant representing 6.1% of the total dry matter. The highest seed dry weight in both varieties was recorded at 50-60% moisture followed by  $\geq 70\%$  moisture (Table 4.8). There were significant differences (LSD 5%) between moisture regimes and varieties on seed dry weight (Table 4.8).

#### 4.11 Effect of soil moisture on dry matter partitioning in bambara groundnut

The ratios of pod: leaf, stem to root as well as seed: pod dry matter at each moisture level is presented in Table 4.11. It was clearly observed that the highest contributions of leaves, stems and roots dry matter to pods were found at 50-60% moisture. However their contributions to pods at  $\geq 70\%$  moisture was greater than that at 30-40% moisture.

However in both Jabajaba and Chichele Balgu, roots contribution to pod dry matter at 50-60% moisture in Jabajaba (5.6) was higher than in Chichele Balgu (1.4). This was followed by pod: stem ratio recording 3.0 in Jabajaba and 0.6 in Chichele Balgu, before the pod: leaf ratio of 2.2 in Jabajaba and 0.5 in Chichele Balgu. As a result, pod dry weight contributed greatly to seed dry weight at all moisture regimes, as indicated by seed: pod ratio in Table 4.11.

Seed: pod ratio at 50-60% moisture in Jabajaba was 0.7 and in Chichele Balgu was 0.7, whilst that of 30-40% moisture recorded seed: pod ratio of 0.8 in Jabajaba and 0.6 in Chichele Balgu. The highest contribution of pod dry matter to seeds was at 30-40% moisture, in Jabajaba. However the reverse was observed in Chichele Balgu (Table 4.11). Dry matter partitioning was lower than in Experiment 1.

Table 4.11: Effect of soil moisture on dry matter ratios of Jabajaba and Chichele Balgu.

Variety	Moisture Level (%)	Pod:Leaf Ratio	Pod:Stems Ratio	Pod:Root Ratio	Seed:Leaf Ratio	Seed:Stems Ratio	Seed:Root Ratio	Seed:Pod Ratio
Jabajaba	$\geq 70$	1.6	2.3	4.8	1.1	1.61	3.3	0.7
	50-60	2.2	3.0	5.6	1.6	2.2	4.0	0.7
	30-40	1.2	1.6	3.6	0.9	1.2	2.8	0.8
Chichele Balgu	$\geq 70$	0.3	0.4	1.1	0.2	0.2	0.7	0.6
	50-60	0.5	0.6	1.4	0.3	0.4	1.0	0.7
	30-40	0.2	0.2	0.4	0.1	0.1	0.3	0.6

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Seed: pod ratio at 50-60% moisture in Jabajaba was 0.7 and in Chichele Balgu was 0.7, whilst that of 30-40% moisture recorded seed: pod ratio of 0.8 in Jabajaba and 0.6 in Chichele Balgu. The highest contribution of pod dry matter to seeds was at 30-40% moisture, in Jabajaba. However the reverse was observed in Chichele Balgu (Table 4.11). Dry matter partitioning was lower than in Experiment 1.

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Variety	Moisture Level (%)	Pod:Leaf Ratio	Pod:Stems Ratio	Pod:Root Ratio	Seed:Leaf Ratio	Seed:Stems Ratio	Seed:Root Ratio	Seed:Pod Ratio
Jabajaba	$\geq 70$	1.6	2.3	4.8	1.1	1.61	3.3	0.7
	50-60	2.2	3.0	5.6	1.6	2.2	4.0	0.7
	30-40	1.2	1.6	3.6	0.9	1.2	2.8	0.8
Chichele Balgu	$\geq 70$	0.3	0.4	1.1	0.2	0.2	0.7	0.6
	50-60	0.5	0.6	1.4	0.3	0.4	1.0	0.7
	30-40	0.2	0.2	0.4	0.1	0.1	0.3	0.6

#### 4.12 Effect of soil moisture status on seed quality of bambara groundnut

There were significant effects ( $P < 0.05$ ) of moisture on seed size, protein and tannin contents (Table 4.12). 100-seed weight and protein content in Jabajaba, except for tannin content were significantly ( $P < 0.05$ ) affected by soil moisture. There was also significant effect ( $P < 0.05$ ) of moisture on 100-seed weight and protein content in Chichele Balgu, but that of tannin content was not significantly ( $P < 0.05$ ) affected by soil moisture. When both varieties were considered, there were significant differences (LSD 5%) in 100-seed weight, tannin and protein contents of seeds in Jabajaba and Chichele Balgu (Table 4.12).

Table 4.12: Effect of soil moisture status on seed quality of Jabajaba and Chichele Balgu (on dry matter basis). Values are the means and standard errors are in parenthesis.

Variety	Moisture Content (%)	100-Seed Weight (%)	Protein Content (%)	Tannin Content (%)
Jabajaba	≥ 70	29.2 (0.5)	17.8 (0.2)	0.2 (0.1)
	50 – 60	31.1 (0.8)	20.6 (0.6)	0.4 (0.1)
	30 – 40	26.5 (0.5)	18.4 (1.0)	0.4 (0.1)
Within Jabajaba	Mean	28.9 (0.6)	18.9 (0.6)	0.3 (0.1)
	LSD(5%)	2.7	2.7	0.2
Chichele Balgu	≥ 70	40.2 (0.3)	15.2 (1.4)	1.2 (0.1)
	50 – 60	42.7 (1.1)	17.2 (1.5)	1.4 (0.1)
	30 – 40	37.3 (0.6)	15.2 (0.5)	1.5 (0.1)
Within Chichele Balgu	Mean	40.1 (0.7)	15.8 (1.1)	1.4 (0.1)
	LSD(5%)	3.1	2.8	0.25
Among Varieties	LSD(5%)	2.7	2.7	0.2

Seed size and protein contents at 50-60% moisture were significantly higher than that at 30-40% and  $\geq 70\%$  moisture. Chichele Balgu recorded larger seed sizes and higher tannin content than Jabajaba. Although, lowest 100-seed weights were recorded at 30-40% moisture in both varieties, protein and tannin contents at 30-40% moisture were higher than that at  $\geq 70\%$  moisture. Also, tannin contents at 30-40% appeared higher than that at 50-60% and  $\geq 70\%$  moisture regimes.

From above data, qualitative assessment of Jabajaba and Chichele Balgu in terms of seed sizes, protein and tannin content could vary not only due to levels of soil moisture, but also the prevailing climatic conditions during plant growth. Even though plants were grown under similar moisture, the values of protein and tannin contents in the second experiment were lower than that of experiment one, whilst seed size was somewhat higher.

The tannin content increases as seed size decreases under inadequate soil moisture, and when soil moisture is adequate, seed size increases as tannin content decreases. Under excess soil moisture or humid conditions (Tables 3.3 & 4.12), tannin and protein content tend to decrease irrespective of the seed sizes. There were more variations in protein contents than in tannin contents and 100-seed weight (Tables 4.12 & 4.6).

## CHAPTER FIVE

### 5.0 DISCUSSION

#### 5.1 EFFECT OF SOIL MOISTURE ON BAMBARA GROUNDNUT DEVELOPMENT

There is some evidence that, bambara groundnut is a crop that can withstand drought stress, but this ability varies among varieties under a given climatic condition (Ramolemana, 1999). In this study, soil moisture and variety did not have a significant effect on the number of leaves produced at 3 weeks after planting indicating that the rate of leaf initiation was similar in Jabajaba and Chichele Balgu at the initial stages. Also, the lack of response to moisture treatments at 3 weeks could be due to initial water content of the soil and the impact of the mulch. In both varieties, more leaves were produced at 50-60% moisture than at 30-40 and  $\geq 70\%$  moisture, indicating that leaf production is highest under moderate soil moisture conditions, but declines when moisture is excessive or low. This agrees with the findings of Doku and Karikari (1971) that bambara groundnut performs poorly under waterlogging conditions, and that too much water does not lead to good development of bambara groundnut. There were no interaction effects of water and variety on leaf production, indicating that the number of leaves produced in bambara groundnut is a characteristic of the variety.

Leaf area development followed the same trend as leaf number. The significant effect of moisture and variety on leaf area development during early podding to mid-pod filling in Experiment 1 was an indication that, level of moisture and the type of variety grown determine to a large extent the leaf area developed. The declining leaf area at maturity, might have been due to the channelling of assimilates to reproductive development at the expense of leaf expansion. However, there was no significant effect of moisture on leaf area development at flowering in the second experiment, and this could have been due to the different planting period.

Adequate soil moisture increases cell turgor resulting in cell expansion and hence larger leaf areas, as reported by Collinson *et al.*, (1996). However, since the  $\geq 70\%$  moisture did not produce largest leaf area, it is an indication that too much water does not lead to ultimate leaf area development in bambara groundnut. The lowest leaf area per plant at 30-40% moisture regime might have been the result of inhibition of cell division and cell enlargement. This is in agreement with Slatyer (1967) that growth processes such as cell division and cell enlargement are inhibited under inadequate water supply, resulting in reduction in leaf area and general plant growth.

Nodule development is known to start at emergence after rhizobium has gained entry into the plant through root hairs (Whyte *et al.*, 1973), and this was observed at thinning. The variations observed in nodulation in Jabajaba and Chichele Balgu may be due to genetic variation between the two different varieties of bambara groundnut in their ability to form nodules. The differences in nodule number between moisture regimes suggest that, amount of water in the soil determines the extent of nodulation in bambara groundnut. Increased moisture availability was important for nodule growth, and increased nodulation might have contributed to higher stem growth rate between 7-9 weeks after planting in Jabajaba and 9-11 (10-12) weeks after planting in Chichele Balgu.

Jabajaba was more consistent in nodule production than Chichele Balgu at the three soil moisture levels and this agrees with Joseph (1996) that nodule production appears more consistent with the bunch type of bambara groundnut than the open type. These results suggest that symbiotic nitrogen fixation in root is more favoured under moderate moisture levels, whereas excess or low soil moisture results in less nodule formation.

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There was a general reduction in number of nodules produced after mid-pod filling, and this could have been due to nodule senescence. This result is consistent with those of Giller and Wilson (1991) that nodule senescence usually coincides with seed development and the period of  $N_2$ -fixation is longer if senescence of nodules is delayed, and thus nitrogen fixation is increased at pod filling. Generally, nodules in the first experiment were smaller and less dark in colour than in the second experiment. Even though the reason for this is not known, smaller and less dark nodules are reported to be due to insufficient boron (Dakora and Muefhe, 1997).

It has been stated that, the total amount of nitrogen fixed by an organism is a function of the total dry matter yield of the plant (Dixon and Wheeler, 1986). The highest nodule number at 50-60% moisture might have resulted in highest nitrogen fixation, and hence the highest dry matter yield observed (Tables 4.1 & 4.7). In this study, nodule numbers appeared to agree with that reported in Ghana (92-318 nodules) by Thompson and Dennis (1977), but higher than that reported in Zimbabwe (11 nodules) by Mabika and Mafongoya (1997).

## **5.2 EFFECT OF SOIL MOISTURE ON BAMBARA GROUNDNUT GROWTH**

Leaf dry matter production indicated that soil moisture could determine the rate of leaf growth in bambara groundnut. However, leaf dry matter production in Jabajaba and Chichele Balgu at any growth stage was significantly different regardless of the amount of water applied. This indicates that the level of soil moisture is important in leaf dry matter production in bambara groundnut, but the quantity produced at a given soil moisture regime will depend on the type of variety.

The higher leaf dry matter per plant at 50-60% moisture (Tables 4.2 & 4.8) resulted from a larger leaf area for more light interception, leading to higher rate of transpiration and thereby facilitating more carbon dioxide assimilation through photosynthesis. This agrees with Squire (1990) that

larger leaf areas allow for an increased transpiration rate and also facilitates more carbon dioxide assimilation and interception of radiation, which are processes related to dry matter synthesis. Therefore, the highest leaf dry matter at 50-60% moisture indicates that, moderate soil moisture is required for bambara groundnut leaf growth, whilst less dry weight at  $\geq 70\%$  and 30-40% moisture regimes indicate that neither excess nor low soil moisture is good for bambara groundnut leaf growth.

Jabajaba accumulated more assimilates in the leaves at maturity for pod growth and maturity, whilst Chichele Balgu accumulated more assimilates in the leaves at mid-pod filling for pod growth and maturity. In general leaf dry matter at all soil moisture regimes at different stages of growth were greater in Chichele Balgu than in Jabajaba. This could be that photosynthates in the older leaves were channelled to new leaves at the expense of older leaves, which subsequently senesced. The larger leaf area at 50-60% moisture might have contributed to a high photosynthate production and hence highest dry matter production of the plants (Tables 4.2 & 4.8).

Stem growth was not significantly affected by soil moisture between the vegetative and early podding stages in the first experiment and between the vegetative and flowering stages in the second experiment. Probably, there was enough water from the roots to the xylem sap, which compensated for the initial moisture treatment effects in both experiments.

However, soil moisture had a significant effect on stem growth from early-podding to maturity in both experiments, indicating that at pod initiation, developing pods serve as sinks and demand more assimilates for their growth. Therefore depending on the soil moisture level, assimilates produced in stems are channelled to pod growth resulting in leaf senescence and subsequent dropping of leaves, and plants at low moisture level are likely to loose more leaves resulting in

less dry matter production. Thus the larger reduction of stem dry matter in Chichile Balgu than in Jabajaba at maturity could have been due to greater leaf senescence in Chichele Balgu.

Significant increases in stem dry matter in bambara groundnut was between the onset of flowering and mid-pod filling. Considering Chichele Balgu in particular, the results agree with those of Norman and Chongo (1992), who concluded that dry matter accumulation in bambara groundnut is more rapid between flowering and mid-pod filling. Adequate moisture supply during this period will greatly enhance dry matter production. This was achieved at the 50-60% moisture level in this study.

Also higher nodule production coincided with higher stem dry matter production, which agrees with the findings of Kumaga and Etu-Bonde (2000) that in soyabean, more nodulated plants produced higher stem dry matter yields than less nodulated ones. Therefore to achieve optimal stem growth and hence stem dry matter production in bambara groundnut, soil moisture stress should be reduced between the onset of flowering and mid-pod filling whilst preventing occurrence of excessive water in the soil. This is however difficult to practise by farmers in semi-arid Africa who rely solely on erratic and unpredictable natural rainfall.

The study showed that roots are less affected in their growth by differences in soil moisture levels between vegetative and early podding stages. Thus soil moisture stress affects stem growth more than root growth in bambara groundnut. It was also observed that under moisture stress, bambara groundnut plants may partition more assimilates to roots just before early podding. These results seem to contradict those by other workers (Ramolemana *et al.*, 1996; Collinson *et al.*, 1996; Nyamudeza, 1989) that moisture had no significant effect on root growth at any stage of bambara groundnut growth, except at final harvest. However, there were no significant interaction ( $P < 0.05$ ) between water and variety on root dry matter production at any growth stage, which clearly

indicates that irrespective of soil moisture, root growth in Jabajaba and Chichele Balgu were different.

The significant increases in root growth, which occurred at 50-60% moisture during pod filling, resulted in higher root dry matter than those at 30-40% and  $\geq 70\%$  moisture regimes. This could have benefited stem growth, particularly at the period when moisture demand for stem growth was high at 9 and 11 or 9 and 12 weeks after planting for Jabajaba and Chichele Balgu respectively (Figures 4.6 and 4.8).

Since root growth is reported to depend on soil phosphorus level (Ramolemana *et al.*, 1999), there should have been similar increases in root growth of the varieties at 30-40%, 50-60% and  $\geq 70\%$  moisture levels to attribute root growth in bambara groundnut to available phosphorus level in Table 3.1. Therefore phosphorus levels in soil may be inevitable for root development in bambara groundnut, but adequate moisture is needed for the transport of phosphorus to the plant roots before flowering, for subsequent plant growth and development.

Nodule dry matter followed a similar pattern as nodule number, increasing gradually from three weeks after planting, reaching the peak at mid-pod filling and began to decline towards maturity. This decline in nodule dry weight at maturity stage might have been due to nodule senescence. Soil moisture however significantly affected nodule growth in both varieties, but the effect at 30-40% moisture was more in Chichele Balgu than in Jabajaba. Eventhough there were more nodules in Chichele Balgu than in Jabajaba, the nodule dry weight was not significantly different between them. This is an indication that the specific nodule weight was higher in Jabajaba than in Chichile Balgu.

### **5.3 EFFECT OF SOIL MOISTURE ON REPRODUCTIVE DEVELOPMENT OF BAMBARA GROUNDNUT**

The results of experiment 1 indicate that moisture and type of variety can influence differences in flowering date in bambara groundnut. However the second experiment indicated that, there could be other factors contributing to number of days to flowering apart from soil moisture and type of variety. According to Linnemann, (1994) some bambara groundnut varieties are unaffected by daylength, whilst Linnemann and Azam-Ali, (1993) indicated that temperature and photoperiod can influence flowering and pod production. Therefore differences in flowering days in both varieties, especially in Chichele Balgu, could have been due to variations in temperature and daylength during flowering.

This divergence in the response of the two varieties to flowering days would suggest that there are differences in their photoperiodic sensitivity to flowering, with the response by Jabajaba being consistent with quantitative short day photoperiodic sensitivity, compared with Chichele Balgu. According to Doku and Karikari (1970b), 40 days are required after flower fertilisation for mature pods and seed production, but this may depend on soil moisture status and type of variety. Therefore when harvesting is done earlier in Chichele Balgu, immature and mature pods are likely to be produced with varying seed sizes. However, the patterns of flowering are similar for the two varieties but the time of flowering is different because both Jabajaba and Chichele Balgu started early flower production in the 30-40% moisture as a coping mechanism to reproduce under low moisture.

There was more pod development in Jabajaba than in Chichele Balgu, which implies that more assimilates, from leaves were channelled to pod production in Jabajaba than in Chichele Balgu. However the low pod number at 30-40% moisture could have been due to death of some pegs

before they could initiate pods. This agrees with Elia and Mwandemele (1986) and Collinson *et al.*, (1996) that number of pods per plant is reduced by decreased water availability. The present results however are contradictory to that reported by Ameyaw and Doku (1983) that pod number per plant was about ten times higher at 40% moisture than 75% moisture. Generally, soil moisture is important in determining pod production in bambara groundnut (Collinson *et al.*, 1996).

Jabajaba matured earlier than Chichele Balgu without flowers at the time of harvesting, but Chichele Balgu had at least two flowers, indicating that Jabajaba is more determinate. Hence there was the possibility that such late flowers could not form pods, and hence the low number of pods observed in Chichele Balgu. In terms of pod production, it could also be deduced that Jabajaba is more efficient in low soil moisture levels than Chichele Balgu, and at areas where rainfall is erratic, Jabajaba, which matured earlier and produces relatively more pods than Chichele Balgu should be grown.

According to Doku and Karikari (1970a) the fertility coefficient is higher in bunch varieties of bambara groundnut than in open types. Phenological appearance shows that Jabajaba is bunched and Chichele Balgu is spreading and hence the fertility coefficient of Jabajaba is expected to be higher than Chichele Balgu as indicated in total pod number per plant in Tables 4.1 & 4.7. Reports by Karikari (1972) also indicated that bunch cultivars of bambara groundnut flower early, mature early and have high number of pods and seeds per plant, which are characters mostly correlated with seed yield of the crop. Therefore low seed yield in 30-40% moisture could have been the result of poor growth leading to poor pod and seed production (Tables 4.1 & 4.7).

Pod production appears to be higher in Jabajaba than Chichele Balgu and a similar trend was reported by Defeatsror (1996), in which he recorded an average of 36 pods per plant in Jabajaba. Similarly, Pauline (1998) recorded an average of 11 pods per plant in Jabajaba, whilst Coblavie (1995) recorded 36 for the minor season and 49 for the major season, which were higher than the other varieties. Even though, delayed pod formation could have resulted in low pod numbers recorded in Chichile Balgu, allowing those immature pods to fully mature, may lead to rotting of early-formed pods, as indicated by Goli and Ng (1988). However, late inductions are known to give higher yield but in a more synchronised development and hence pod maturity (Linnemann, 1987).

#### **5.4 EFFECT OF SOIL MOISTURE ON REPRODUCTIVE GROWTH OF BAMBARA GROUNDNUT**

Seed dry weight was not significantly affected by soil moisture during early pod development, indicating that seed development was not significantly affected by moisture at early podding in Jabajaba and Chichele Balgu. However, the significant effect of variety on seed dry weight could be an indication that the differences in seed dry weight between Jabajaba and Chichele Balgu were due to inherent differences. The significant effect of moisture from mid-pod filling to maturity could be that, the demand for assimilates increased at this late stage of seed development.

Seed weight in Jabajaba and Chichele Balgu in the first experiment was not significantly different at maturity, but the reverse was observed in the second experiment. This could have been that apart from soil moisture, differences in temperature, relative humidity and sunshine hours influence assimilate production for seed development (Tables 3.2 & 3.3). Even though total dry matter production was higher in Chichele Balgu than Jabajaba, this was not translated into seed

yield. Generally, the results of this study were characterised by very poor reproductive yield, especially in Chichile Balgu as indicated by harvest indices in Tables 4.1 & 4.7.

Assuming that the potential yield of a crop is determined by the amount of dry matter produced during the growing period, the larger decreases in bambara groundnut yield at 30-40% and  $\geq 70\%$  moisture regimes, could be an indication of poor dry matter production for pod and seed development. According to Ofori (1996), seed yields are expected to be high provided, pod number per plant, seed number per pod and seed dry weight are maximised. Therefore the reason for the substantial reduction in growth and in yield components (i.e pod number per plant, seed number per pod and seed dry weight) at 30-40% moisture may imply that, a relatively moderate soil moisture exist for bambara groundnut to give maximum yield.

However, the poor pod production may not be due to the inability of the varieties to produce pods, since Jabajaba demonstrated a substantial yield potential at 50-60% moisture. Jabajaba therefore has greater potential in dry matter partitioning to the reproductive structures than Chichele Balgu. Since Jabajaba seeds are creamy in colour and that of Chichele Balgu are red in colour, this observation confirms the earlier indication by Norman and Chongo (1992) that white landraces were superior to red landraces in terms of dry matter partitioning to reproductive growth under the same soil moisture and weather conditions.

The low yield usually obtained by farmers in the semi-arid areas of Africa, where the crop is popular, may be attributed to inadequate moisture supply, particularly at the period of rapid growth (i.e. between early podding to mid-pod filling). However, bambara groundnut appears to use available water frugally through slow leaf area development, therefore conserving water so that there is sufficient for the crop to survive through the productive periods and produce some yield. The low yield at  $\geq 70\%$  moisture goes to support the reports by Stanton *et al.*, (1966) that

bambara groundnut yields are reduced by high amount of water, and hence bambara groundnut is not grown in the forest zones of Africa which have high rainfall.

Pod and seed weights were generally low and leaf, stem and root growth did not appear to make any significant contribution to pod and seed production as indicated in their ratios in Tables 4.5 & 4.9. Pod dry weight contribution to seed weight in Jabajaba was higher than in Chichele Balgu at each moisture regime. The differences in dry matter production between first and second experiments subsequently resulted in differences in the ratios between the two experiments.

However the low dry matter production and partitioning to reproductive yield, even under optimum moisture conditions, requires further investigation. The question that arises is whether photoperiod and temperature would be enough to account for the differences in crop development, growth and yield at those moisture regimes? Therefore, some of the causes of the poor pod yield could be inadequate soil moisture and soil nutrient levels, as well as climatic variables like temperature and photoperiod.

## **5.5 EFFECT OF SOIL MOISTURE ON SEED QUALITY OF BAMBARA GROUNDNUT**

Seed size is no doubt an important quality trait in bambara groundnut, but this trait within a given variety could vary under different moisture regimes (Tables 4.12 & 4.6). Selection for seed size may lead to production of seeds with high or low protein and tannin content depending on the available moisture. In bambara groundnut production, seed size and pods per plant are characters upon which good seed yielding varieties are chosen (Ofori *et al.*, 2001). However, selection for high yield through pods per plant without considering moisture and climatic conditions under which those varieties were grown could lead to production of pods with small seed sizes.

In seasons when moisture is low and erratic, there is the possibility of obtaining seeds that are small in size, low in protein and high in tannic acid contents, especially if the red seeded varieties are grown. Therefore knowledge of seed size, protein and tannin levels of a variety even though important for an overall selection of good quality seeds in bambara groundnut, it is necessary to also consider moisture and climatic conditions under which plants are grown.

From the first and second experiments, there were no definite seed colour patterns as in protein and tannin levels of Jabajaba and Chichele Balgu at each moisture regime. Therefore selection for high quality seeds should be based on quantitatively determined levels of protein and tannin and not through visual selection based on seed colour. Protein contents varied greatly between first and second experiments, and between moisture regimes, and since protein is a quantitative trait, good varieties could be selected based on protein irrespective of seed sizes.

However, selection cannot be based on protein content without considering the tannin levels of the seeds, which seems to have little variations under varying climatic and soil moisture conditions. The tendency of tannin concentration to increase with decreasing soil moisture and also increasing with the intensity of seed coat colour, may serve as basis for selection, but this cannot be done if the protein content is very low. The first and second experiments clearly indicated that protein content could decrease under more humid and moist conditions (Tables 4.1 & 4.6) agreeing with reports by Deetz *et al.*, (1996). However, according to Jarillo *et al.*, (1998), large-scale environmental conditions may determine chemical composition of seeds even under moist soil.

The results of this study indicated that seed size, protein and tannin content of seeds of a given bambara groundnut variety, may vary depending on the level of soil moisture and climatic conditions under which they are grown. Therefore, since rainfall in Africa and for that matter Ghana, is some times inadequate and erratic these seed quality traits could vary within and among varieties, especially if obtained from different localities. Therefore it could be stated that the results of Ofori *et al.*, (2001) where bambara groundnut accessions from different locations with similar seed colour had different seed sizes, protein and tannin contents could have been influenced to some extent by soil moisture and climatic conditions under which they were grown.

The higher protein content in Jabajaba (cream seeded variety) than Chichele Balgu (red seeded variety), contradicts results of Gibbons (1994) that red seeded bambara groundnut landraces had higher protein content than cream seeded ones. However, the higher content of tannin in Chichele Balgu than in Jabajaba, agrees with results of Ofori *et al.*, (2001), Papadopoulos *et al.*, (1985) and Plahar *et al.*, (1997) that cream or white seeds have lower tannin contents than red or black seeds.

Though Jabajaba seeds had higher protein content in these studies, not all-cream seeded varieties may have such high protein content, even under similar soil moisture regimes, since seed size and climatic conditions could play important role in determining protein levels in a given bambara groundnut variety. However farmers, especially those along the coast of Ghana who are mostly cultivating the cream seeded varieties like Jabajaba, may be doing so due to unpalatable and astringent nature of the red seeded varieties like Chichele Balgu. In the northern savanna zones of Ghana, farmers are cultivating both cream and red seeded varieties for multiple dish preparations. Seeds with high concentrations of anti-nutritional factors such as tannins are known to affect protein digestibility when consumed (Plahar *et al.*, 1997) and may not be used in weaning food formulations (Plahar and Nti, 1995).

According to Van Wyk *et al.*, (1973) tannic acid levels below 0.5% are nutritionally superior with digestibility of not less than 70%. Where tannin content appeared above 0.95%, digestibility ranged from 24 to 62%. Therefore, it could be said that Jabajaba, with tannic acid levels ranging from 0.34% to 0.35%, is nutritionally superior to Chichele Balgu, which had tannin content ranging from 1.37% to 1.39%. Therefore, consumption of Chichele Balgu could lead to excessive gas formation due to indigestible oligosaccharides (Bressani *et al.*, 1982a; 1982b).

It therefore appears that red seeded landraces of bambara groundnut are likely to have higher tannin content under inadequate moisture conditions (Tables 4.6 & 4.12), which may occur in semi-arid regions. However, tannic acid could serve as defence mechanism against animals, and may protect seeds against pest, fungal and bacterial attack (Swain, 1979). Therefore, selecting and cultivating cream seeded varieties implies lowering plant defence mechanism, hence rendering them to pest and pathogenic attack.

There are indications that, assimilates channelled to seeds during their growth and development, appear to concentrate more in seeds under 30-40% moisture, resulting in high concentrations of anti-nutritional factors like tannins. However,  $\geq 70\%$  moisture seemed to reduce tannin concentrations, and excess moisture could reduce the levels of these anti-nutritional factors and improve protein utilisation. Also, 50-60% moisture appears to favour good seed size and protein content than at 30-40% and  $\geq 70\%$  moisture regimes.

## CHAPTER 6

### CONCLUSIONS AND RECOMMENDATIONS

Moisture significantly affected days to flowering, maturity, dry matter, pod and seed production as well as harvest indices of Jabajaba and Chichele Balgu. The 50-60% moisture increased shoot dry weight, nodule dry weight, pod and seed yield, whilst the 30-40% moisture did not. The corresponding harvest indices were substantially lower at 30-40% moisture than those at 50-60% and  $\geq 70\%$  moisture. Jabajaba flowered earlier than Chichele Balgu, while plants at 30-40% moisture flowered earlier than 50-60% and  $\geq 70\%$  moisture, which may be a coping mechanism to reproduce under low moisture. Even though moisture is important for pod development in bambara groundnut, but the level of soil moisture is very crucial.

Jabajaba exhibited higher seed yield potential than Chichele Balgu at all moisture regimes. Chichele Balgu however continued to flower at maturity, which led to the presence of some immature pods during final harvest. The period for high moisture demand for shoot growth was between early pod initiation and mid-pod filling stages. Therefore, reducing moisture stress between flowering and mid-pod filling stages is necessary for good pod development, and subsequent seed yield in bambara groundnut. Even though adequate soil moisture is inevitable for crop production, soil nutrient status and climatic variables like temperature and photoperiod are necessary for growth, development and yield of bambara groundnut. The low yields associated with bambara groundnut in the field may not only be due to soil moisture but the required temperature and daylength during pod-filling. Therefore low yields achieved in the semi-arid areas may be the result of inadequate supply of soil moisture and climatic conditions at certain growth stages of the plant.

Qualitative assessment of seeds revealed differences in 100-seed weights, protein and tannin contents under different soil moisture and climatic conditions. Therefore, it appears large-scale environmental conditions may determine chemical composition of seeds even under adequate moisture. Protein content appears to have higher variations than seed sizes and tannin contents under different moisture and climatic conditions. Therefore, there are inherent seed quality differences in each of the varieties at any prevailing environmental conditions.

More anti-nutritional factors appeared to have concentrated in seeds at 30-40% moisture, which subsequently resulted in high concentrations of tannins, since  $\geq 70\%$  moisture recorded the lowest tannin concentrations. However, 50-60% moisture favoured seed size and protein content than at 30-40% and  $\geq 70\%$  moisture regimes. There were differences in grain yield, tannin, and protein contents between the first and second experiments whose climatic conditions were different. Therefore, adequate moisture and suitable climatic conditions are very necessary for good quality seed production in bambara groundnut. Generally cream seeded varieties (Jabajaba) appear to have higher yield potential and better seed quality than dark seeded varieties (Chichele Balgu).

It is therefore recommended that the cultivation of bambara groundnut should be based on the availability of soil moisture and suitable climatic conditions. In addition, strategies for improving bambara groundnut must include selecting landraces or varieties for enhanced nodulation under different moisture regimes, since moisture seems to have effect on nodule formation. Research efforts should also aim at providing a better understanding of nodule formation and  $N_2$ -fixation in bambara groundnut under different moisture regimes. Therefore the potential in bambara groundnut could be enhanced if different moisture regimes and climatic variables could be incorporated in a research on available germplasm, as integral part of plant breeding programme, to improve both yield and seed quality of bambara groundnut.

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**APPENDICES****EXPERIMENT 1**

## APPENDIX 1

NUMBER OF LEAVES PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	DF	MEAN SQUARES				
		Vegetative	50% Flowering	Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	12.042**	45.375**	280.167**	400.167**	693.375**
Water (B)	2	0.542**	23.292**	54.875**	95.375**	63.292**
AB	2	1.542	0.875	7.042	6.792	11.625*
Error	15	1.508	1.586	3.044	9.500	2.219
Total	23					

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

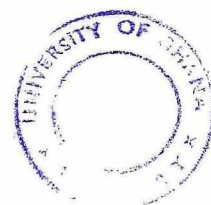
## APPENDIX 2

LEAF AREA PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	DF	MEAN SQUARES				
		Vegetative	50% Flowering	Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	3038	8370.1**	18	79690**	36951.5**
Water (B)	2	1793	4012.2**	10023**	25878**	14924.5**
AB	2	2005	1916.8	575	968	695.3
Error	15	1195	702.1	1378	2040	665.6

\*\* Significant at both 5% and 1% level of probability



## APPENDIX 3

LEAF DRY WEIGHT PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	DF	MEAN SQUARES				
		Vegetative	50% Flowering	Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	0.17854**	0.31970**	0.317400**	2.23260**	0.62404**
Water (B)	2	0.02779	0.05765*	0.115763**	0.41780**	0.36728**
AB	2	0.04104	0.10812**	0.021712	0.03285	0.01016
Error	15	0.02274	0.01315	0.007417	0.04042	0.03899

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 4

STEM DRY WEIGHT PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	DF	MEAN SQUARES				
		Vegetative	50% Flowering	Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	0.138017**	0.338438* *	0.86640**	5.08760**	1.64850**
Water (B)	2	0.001929	0.018404	0.04412	0.45195**	0.63102**
AB	2	0.004004	0.003387	0.02015	0.11278	0.09952
Error	15	0.004201	0.009926	0.01917	0.06459	0.08796

\*\* Significant at both 5% and 1% level of probability

## APPENDIX 5

ROOT DRY WEIGHT PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	DF	MEAN SQUARES				
		Vegetative	50% Flowering	Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	0.21282*	1.03750**	1.19707**	3.90427**	1.32540**
Water (B)	2	0.02906	0.07074	0.16352	0.16002*	0.53603**
AB	2	0.01238	0.05515	0.07607	0.13527	0.09399
Error	15	0.03852	0.02596	0.09668	0.04381	0.04964

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 6

NUMBER OF NODULES PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	DF	MEAN SQUARES				
		Vegetative	50% Flowering	Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	8.1667**	170.67**	92.04*	360.38**	1204.167**
Water (B)	2	13.8750**	294.13**	888.87**	878.37**	397.167**
AB	2	1.5417	2.04	28.79	11.38	43.167**
Error	15	0.4444	10.20	15.34	20.40	5.922

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 7

NUMBER OF PODS PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	Degrees of Freedom	MEAN SQUARES		
		Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	24.0000**	253.500**	35.042**
Water (B)	2	8.0417**	19500*	78.167**
AB	2	0.8750*	0.500	0.167
Error	15	0.2333	3.567	2.719

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 8

POD DRY WEIGHT PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	Degrees of Freedom	MEAN SQUARES		
		Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	0.02600	12.3841**	0.0301
Water (B)	2	0.08385**	2.9026*	13.2878**
AB	2	0.00782	0.1203	0.6648
Error	15	0.01254	0.5258	0.8601

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 9

NUMBER OF SEEDS PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	Degrees of Freedom	MEAN SQUARES		
		Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	12.0417**	216.000**	24.000**
Water (B)	2	4.6667**	19500**	88.292**
AB	2	2.1667**	2.000	0.875
Error	15	0.2083	2.222	2.978

\*\* Significant at both 5% and 1% level of probability

## APPENDIX 10

SEED DRY WEIGHT PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	Degrees of Freedom	MEAN SQUARES		
		Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	0.17510*	5.5681**	0.0000
Water (B)	2	0.07276	1.7136**	13.9726**
AB	2	0.06180	0.1205	0.5412
Error	15	0.03272	0.2567	0.7353

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 11

NUMBER OF DAYS TO 50% FLOWERING

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
Variety (A)	1	888.1667	888.1667	908.35**	< 0.001
Water (B)	2	95.5833	47.7917	48.88**	< 0.001
AB	2	0.5833	0.2917	0.30	0.746
Error	15	14.6667	0.9778		

\*\* Significant at both 5% and 1% level of probability

**EXPERIMENT 2**

## APPENDIX 12

NUMBER OF LEAVES PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	DF	MEAN SQUARES				
		Vegetative	50% Flowering	Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	0.000	30.083**	4.083	645.333**	432.000**
Water (B)	2	6.083	20.583**	28.583**	84.083**	70.333**
AB	2	1.750	1.083	0.583	1.583	13.000*
Error	15	1.733	1.083	0.883	1.133	1.333

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 13

LEAF AREA PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	DF	MEAN SQUARES				
		Vegetative	50% Flowering	Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	869.550*	3400.3	7100.5**	33895.9**	56686**
Water (B)	2	2625.45**	1690.80	8939.4**	15172.6**	3472.66**
AB	2	549.74*	252.0	193.3	1699.6	2089.62**
Error	15	94.89	781.8	402.7	510.7	9.809

\*\* Significant at both 5% and 1% level of probability

## APPENDIX 14

LEAF DRY WEIGHT PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	DF	MEAN SQUARES				
		Vegetative	50% Flowering	Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	0.08501	0.54613**	0.097200**	2.34967**	1.40083**
Water (B)	2	0.02156	0.05009**	0.10581**	1.49651**	0.84241**
AB	2	0.02861	0.19001**	0.00557	0.74707**	0.22526**
Error	15	0.01895	0.00465	0.03449	0.01901	0.00536

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 15

STEM DRY WEIGHT PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	DF	MEAN SQUARES				
		Vegetative	50% Flowering	Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	0.03968**	0.13441**	0.29767**	2.91068**	1.20968**
Water (B)	2	0.00381	0.04328	0.09003	0.53081**	0.15861**
AB	2	0.00143	0.01266	0.0292	0.14568	0.02618*
Error	15	0.00182	0.00823	0.01335	0.00532	0.00309

\*\* Significant at both 5% and 1% level of probability

## APPENDIX 18

NODULE DRY WEIGHT PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	DF	MEAN SQUARES				
		Vegetative	50% Flowering	Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	0.4089**	0.00041	0.0000	0.0033**	0.00701**
Water (B)	2	8.4088**	0.01126*	0.00698**	0.0179**	0.00813**
AB	2	0.1088*	0.00031	0.00078	0.0004*	0.00166*
Error	15	0.8333	0.00187	0.000573	0.0001	0.00016

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 19

NUMBER OF PODS PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	Degrees of Freedom	MEAN SQUARES		
		Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	24.0833**	85.333**	216.750**
Water (B)	2	6.0833**	10.5833*	45.750**
AB	2	3.5833*	1.5833	7.750
Error	15	0.5500	0.6000	0.750

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 20

POD DRY WEIGHT PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	Degrees of Freedom	MEAN SQUARES		
		Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	0.10268**	6.52688**	24.9985**
Water (B)	2	0.02520*	0.507701*	8.5380**
AB	2	0.01560	0.21960	1.0855*
Error	15	0.00395	0.03465	0.1686

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 21

NUMBER OF SEEDS PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	Degrees of Freedom	MEAN SQUARES		
		Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	6.7500**	114.0833**	200.0833**
Water (B)	2	1.7500**	9.000**	46.5833**
AB	2	1.7500**	2.3333	8.5833**
Error	15	0.4833	0.6833	0.7500

\*\* Significant at both 5% and 1% level of probability

## APPENDIX 22

SEED DRY WEIGHT PER PLANT

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	Degrees of Freedom	MEAN SQUARES		
		Early-Pod Formation	Mid-Pod Filling	Maturity
Variety (A)	1	0.02001*	5.36003**	11.38801**
Water (B)	2	0.00481	0.24842*	4.53623**
AB	2	0.00481	0.16636	0.48923**
Error	15	0.00669	0.04097	0.01309

\*\* Significant at both 5% and 1% level of probability

\* Significant at 5% level of probability

## APPENDIX 23

NUMBER OF DAYS TO 50% FLOWERING

## ANALYSIS OF VARIANCE TABLE

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
Variety (A)	1	736.333	736.333	649.71**	< 0.001
Water (B)	2	155.167	77.583	68.46**	< 0.001
AB	2	37.167	18.583	16.40**	0.006
Error	15	5.667	1.133		

\*\* Significant at both 5% and 1% level of probability