THE RESPONSE OF BAMBARA GROUNDNUT (*Vigna subterranean* (L.) Verdc) TO MOISTURE REGIMES IN TERMS OF GROWTH AND PRODUCTIVITY.

BY

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ABSTRACT

Two experiments were conducted in Morogoro, Tanzania to assess the physiological effects of moisture regimes on growth, development and yield of two bambra groundnut landraces. Each experiment was conducted under screen house and field conditions during the 1998 and 1999 growing season. In the first experiment, four moisture regimes were employed by supplying irrigation water equivalent to 500, 375, 250 and 125mm of rain per growing season starting from 21 days after sowing (DAS). In the second experiment, water stress was imposed by withholding water supply at vegetative stage (21 – 46 DAS), flowering stage (46 - 70 DAS) and pod filling stage (70 – 100 DAS). The experimental design was split-plot laid out in a randomized complete blocks with three replications. Two landraces (cream and red) constituted the main plot factors while the moisture regimes and water stress imposed at three growth stages constituted the sub plot-factors in the first and second experiments respectively. Sequential growth measurements were taken from single plant and two plants were uprooted at 46, 70, 100 and 120 DAS for screen house and field experiments, respectively, to measure number of leaves, flowers and pods and dry matter of leaves, stems, roots and pods. The sampled plants were pre-determined from 21 DAS to avoid bias. Plants in the inner two rows under field conditions were reserved only for final harvest. Decreased irrigation water and water stress imposed at vegetative stage did not significantly ($P<0.05$) affect the onset of flowering and maturity of the two bambara groundnut landraces. Similarly, decreased irrigation water did not affect the number of flowers upto 70 DAS. Late in the season, the most water stressed plants (the 250 and 125mm treatments) produced significantly more flowers than the well watered plants (the 500 and 375mm treatments). Water stress imposed at vegetative and flowering stages significantly reduced number of flowers per plant during the treatment periods. Leaf number, DM of leaves, stems, roots and LAI increased with increasing irrigation water from 125 to 500mm of rain equivalent. However, there were no significant differences between the 500 and 375mm; 375 and 250mm; or 250 and 125mm treatments, except at 100 DAS where the 500 and 375mm; and 375 and 250mm treatments showed significant differences for the above variables. Although root DM increased with increasing amount of irrigation water, the percentage of total DM partitioned to roots increased with decreasing amounts. Pod yield at final harvest also increased with increasing irrigation water. Two distinct categories were observed such that with few exceptions, most of the parameters reported above correlated well with the final yield. Pod yield did not differ significantly between the 500 and 375mm and between the 250 and 125mm treatments. Water stress at any of the three growth stages reduced number of leaves, DM of leaves, roots, stems, and LAI. However a significant difference in these variables was observed for water stress imposed at vegetative and flowering stages. After relieving water stress, re-growth was observed such that at final harvest there were no significant differences among the stressed plants, except for root DM. Pod yield was significantly reduced by water stress particularly at flowering. At this growth stage water stress is the most detrimental to bambara groundnut yield, followed by water stress at pod filling stage. There was no significant difference in shelling percentage across treatments. Pod yield was positively correlated with leaf number, leaf, stem and root dry matter and pod number; but negatively correlated with flower number. It was concluded that, onset of flowering is not affected by rainfall equivalent as low as 125mm if well distributed. However, rainfall or irrigation equivalent of less than 375mm per growing season is not recommended for optimum bambara groundnut production. On the other hand, under water stress conditions, bambara groundnut tends to partition more DM to roots than above ground parts, a mechanism considered to be associated with drought tolerance of the crop. Flowering stage was the most water sensitive with respect to growth and yield.

DECLARATION

I, **JAMHURI AMINI MASHA**, do hereby declare to the Senate of Sokoine University of Agriculture (SUA) that this dissertation is my own original work and has not been submitted for a higher degree award in any other University.

Signature Masha Date 30th JULY 2001

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DEDICATION

This dissertation is dedicated to:

1. My son, **ABEL.** Your words, "**BABA, DAD, AMKA**" encouraged me a lot.
2. My wife, **UPENDO** for your love and patience.
3. My parents, **ABEL** and **NAVONEIWA** who sent me to school from my childhood.
4. My **BROTHERS** and **SISTERS** for their encouragement and moral support.

Let the grace of the **LORD** be upon them

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LIST OF ABBREVIATIONS AND SYMBOLS

ABA	Abscisic acid
ACM	Alsike clover mosaic
AM	Alfalfa mosaic
ANOVA	Analysis of variance
a.s.l	Above sea level
BCRS	Bean chlorotic ring spot
BLC	Bean local chlorosis
BN	Bean necrosis
cm	Centimeter
DAP	Days after planting
DM	Dry matter
DAS	Days after sowing
DMRT	Duncan Multiple Range Test
e.g.	For-example
FAO	Food and Agriculture Organization of the United Nations
Fig.	Figure
g	Gram
i.e.	That is
IITA	International Institute of Tropical Agriculture
Kg/ha	Kilogramme per hectare
LAI	Leaf area index

M_1	Main plot one
M_2	Main plot two
M^2	Squire meter
mm	Millimeter
MOA	Ministry of Agriculture
MSU	Michigan State University
NAEP	National Agriculture Extension Project
NPK	Nitrogen Phosphorus Potassium
NS	Non significant
PMV	Peanut mottle virus
ppm	Parts per million
RH	Relative humidity
SE	Standard error
SUA	Sokoine University of Agriculture
USA	United State of America
WCM	White clover mosaic
WP	Watable powder
%	Percentage
^0C	Degrees centigrade

1. CHAPTER ONE

1.0 INTRODUCTION

Bambara groundnut (*Vigna subterranea* (L) Verdc) is an indigenous African crop grown primarily for its seeds (Collinson *et al.*, 1996). After collecting small seeded forms of bambara groundnut, Hepper (1963), cited by Linnemann and Azam - Ali (1993), documented that the area of distribution of wild progenitors of bambara groundnut is from the Jos Plateau and Yola in northern Nigeria eastward to Garua in Cameroon, possibly as far as the Central Africa Republic. Plants grown from the collected seeds had a slender, trailing habit, which contrast sharply with the compact and sturdy habit of cultivated types.

For many centuries, bambara groundnuts has been cultivated in the tropical regions of Africa, South of Sahara (Purseglove, 1968). However, major producers are Nigeria, Niger, Ghana and Sierra Leone, but the crop is widely grown in East Africa and Madagascar (Purseglove, 1968). In Tanzania, bambara groundnut is grown in many regions, but it is common in Shinyanga, Dodoma, Singida, Tabora, Mwanza and Kagera (Tanzania: Ministry of Agriculture, 1968).

Bambara groundnut belongs to the family Leguminoseae, sub-family Papilionoideae. There is no cultivar of bambara groundnut in the strict sense (Linnemann and Azam-Ali, 1993), but locally, farmers who cultivate it, distinguish different seed lots by their appearance. The heterogeneous primitive cultivars tend to be trailing, while the better-selected ones are more clumped. However, whatever selection has taken place, have been casual and over long periods of traditional cultivation. Due to their very localized nature they can hardly be considered as landraces (Linnemann and Azam - Ali, 1993).

In most of the areas where bambara groundnuts are grown, it ranks third in importance after groundnut *(Arachis hypogaea* (L)) and cowpea (*Vigna unguculata* L.), among the most favoured grain legumes (Collinson *et al*., 1996). Bambara groundnut seeds are good source of protein, carbohydrates and fats. These seeds are often referred to as complete food because they contain protein, carbohydrates and fats in sufficient proportions to provide a nutritious food (Poulter and Caygill, 1980). Bambara groundnut is predominantly grown for human consumption although it may be used for feeding animals and soil fertilization. Immature seeds may be consumed fresh or grilled while the mature (ripen nuts) have to be boiled to render them edible. The mature seeds may also be made to stiff porridge (Brough and Azam - Ali, 1992).

As expected with its primitive cultivars, bambara groundnut yields vary considerably between sites, seasons and genotypes. Seed yields in Africa average between 650-850 kg/ha, with large differences between countries (Rachie, 1979). The factors ascribed to the low yields include inconsistency in planting rates and variations in seedbed types (Stanton *et al*., 1966) and late planting (Johnson, 1968). With late planting the common practice in bambara groundnut growing areas, the crop is likely to succumb water deficits, another possible reason for low yields.

The cultivation of bambara groundnut is of particular importance in semi-arid areas of Africa. In such regions, the crop has been found to thrive and produce yields under adverse conditions, such as limited water supply and low soil fertility (Wassermann *et al.*, 1983). Doku (1969) and Doku and Karikari (1971) reported that, bambara groundnut is adapted to a wide range of soils; it is drought tolerant and thrives well under conditions of high temperatures and low rainfall, where most other pulses would fail. However, there is little information regarding productivity of bambara groundnut in relation to the capture and use of natural resources, such as solar radiation and water. Furthermore, the adaptations that enable the crop to tolerate drought are not well-understood (Collinsion *et al.*, 1996). Due to the limited information of the ecophysiological requirements of bambara groundnut, there is a need for a systematic study on the crop water requirements to establish its moisture- yield relationships. Availability of such information will contribute to its agronomic improvement. This study therefore aimed at investigating the ecophysiological effects of moisture regimes on growth, development and yield of bambara groundnuts. Two landraces (cream and red) are selected for the study because are the most common in Tanzania.The specific objectives were to study the effect of total water supply on:

1. The onset of flowering and maturity.
2. Dry matter partitioning to various organs and pod yield. Also
3. The most moisture sensitive phase in bambara groundnut growth and production was to be determined.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origins and distribution of bambara groundnut.

The fact that bambara groundnut originated from Africa has never been in doubt, but the exact area(s) of origin on the continent are still being studied (Doku, 1996). Hepper (1963) and Begemann (1988) cited by Doku (1996) agreed that West Africa is the centre of origin. Begemann made analysis of quantitative and qualitative characters of some 2000 IITA accessions collected from West, Central, Eastern and Southern Africa observed some variability of these accessions that decreased sharply as one moved eastward and southward from West Africa, indicating that West Africa is the centre of origin. From this area, bambara groundnut is cultivated in many countries in Africa. It was then taken to Brazil and Surinam early in the 17th century, and later taken to Philippines and Indonesia probably by Arabs (Purseglove, 1968).

2.2. Taxonomy, ecology and adaptation of bambara groundnut.

2.2.1 Taxonomy.

Bambara groundnut belongs to the family Leguminosae and sub - family Papilionoideae. Earlier, the plant was termed *Glycine subterranea* (Linnemann and Azam - Ali, 1993). Du-Petit-Thouars (1806) cited by Linneman and Azam - Ali (1993) changed the generic name to *Voandzeia*. The generic name *voandzeia* was derived from the Malagasy term "Voanjo"meaning seeds that satisfies (Stanton, 1966; Karikari, 1971). In 1980, the name was changed to *Vigna subterranea* (L) Verdc. after detailed taxonomic studies (Verdicourt, 1980).

2.2.2 Ecology.

FAO (1984) defined crop water requirements, as the depth of water needed to meet the water loss through crop evapotranspiration of a disease free crop. To any crop, water requirements depend on the soil and climatic factors.

Successful cultivation of bambara groundnut requires moderate and evenly distributed rainfall from sowing to flowering. Although its optimum rainfall requirements has not yet been established, it is nevertheless suggested to range between 750 - 900mm per annum (Temu, 1994). In Madagascar, maximum yields were reported at 1200 mm of rain per annum (Temu, 1994). Even at rainfall less than 500mm, the crop can grow and produce average yields (Duke *et al.*, 1973). These results confirm that bambara groundnut is adapted to a wide range of soil moisture conditions. Moreover, it has been reported that the crop withstands heavy rainfall except during the flowering and maturity periods (Ameyaw and Doku, 1983; Ramolemana *et al.*, 1996).

Bambara groundnut can grow well on any well drained soil, light sand loam with pH ranging from 5.0 - 6.5 is most suitable (Doku and Karikari, 1971), but can tolerate pH as low as 4.3 (NAS, 1979). Soils rich in nitrogen tend to encourage vegetative growth at the expense of pod formation (Johnson, 1968) and so are to be avoided. Calcareous soils are unsuitable, but those rich in phosphorus and potassium would be beneficial (Hepper, 1970).

2.2.3 Adaptation.

From ecological point of view, the crop seems to be adapted to a wide range of environmental conditions. Its compact growth habit appears to be an adaptation to grow in hot and windy environments (Temu, 1994). It is adapted to poor soils and areas of low rainfall (Temu, 1994; Sibuga *et al*., 1996). However, adaptation mechanisms to drought (low rainfall) are not well understood.

Although bambara groundnut is found in vastly different environments in Africa and elsewhere, there are indications that individual cultivars are not themselves adaptable (Rachie and Roberts, 1974; Temu, 1994). High yielding cultivars from one location may fail when grown elsewhere. For example, the Tanzanian high yielding cultivars yielded poorly in Zambia (Rachie, 1979), whereas some cultivars from north west Tanzania have proved unsatisfactory in the drier climates and different soils of central Tanzania (Kinyawa, 1969; Rachie and Roberts, 1974; Elia and Mwandemele, 1986).

2.3 Economic importance and uses of barbara groundnuts

2.3.1 Economic importance

Barbara groundnuts have been given several nicknames such as famine, drought relief, insurance and food security crop. The main reason of being given such names is its ability to yield well in less favourable growing conditions particularly under moisture stress or unreliable rainfall as compared to closely related legume species such as cowpea (*Vigna unguculilata)* (Rowland, 1993; Linnemamnn and Azam - Ali, 1993).

Although much of the literature states that, bambara groundnut is resistant to pests and diseases, it has been reported to be attacked by several pests and diseases. Sibuga *et al.* (1994) reported the crop to be susceptible to fungal damage such as mildew and cercospora leaf spots. Other fungal pathogens reported to attack bambara groundnut include, *Ascochyta phaseolorum* which cause leaf blight, *Cercospora canescens*, *Cercospora voandzeia* which causes powdery mildew (Duke *et al.*, 1977; Teri and Keswani, 1981). Bambara groundnut is also prone to viral diseases. Among them are alfalfa mosaic (AM), alsike clover mosaic (ACM), bean chlorotic ring spot (BCRS), bean local chlorosis (BLC), bean mosaic (BM), bean necrosis (BN), white clover mosaic (WCM) and peanut mottle virus (PMV) (Duke *et al.*, 1977; Li *et al.*, 1991). Shelled bambara groundnut seeds have been reported to be susceptible to bruchids (*Callesobruchus masculatus* (F) and *C. subinotatus* (Pic), (Amuti and Larbi, 1981). Root - knot nematode *(Moloidogyne javanica* and *Moloidogyne incognita* can seriously affect the yield of bambara groundnut (Martin, 1959; Johnson, 1968). The level of nematode infestation is much greater on light textured soils (Johnson, 1968). Therefore, if we study more careful it is likely to discover more pests and diseases that might have been overlooked because of the general pest and diseases free attitude towards the crop.

Bambara groundnut being a legume crop has an advantage of fixing atmospheric nitrogen, providing source of nitrogen for the following crop (Linnemann and Azam - Ali, 1993). Mkurumbira (1985) reported that, bambara groundnuts have higher residual nitrogen effect than groundnut, maize or fallow. Consequently, there was no need to apply nitrogen to maize, when grown after bambara groundnut in the rotation. In contrast, nitrogen was required when maize was grown after a previous maize crop or fallow. The table below summarizes the nitrogen residual effect of groundnut, bambara groundnut, fallow and maize crop on the subsequent grain and yield of maize grown without applied nitrogen.

Table 1. Residual effects of groundnut, bambara groundnut, maize and fallow on the grain and stover yield (Kgha^{-1}) of a subsequent maize crop.

	Groundnut	Bambara groundnut	Maize	Fallow
Grain	6190	7560	3880	4280
Stover	9740	12050	6690	7840

Adapted from Mkurumbira (1985).

Furthermore, being relatively free from pests and diseases, its inclusion in the tropical cropping sequence (rotation) may delay serious build up of pests and diseases in the succeeding crop in the rotation.

2.3.2 Uses

Bambara groundnuts are grown mainly for the seeds. The seeds are favoured for their nutritional value and versality. The mature seeds are a rich source of protein (16 - 22 % DM) and carbohydrates (42 - 60 % DM) (Poulter and Caygill, 1980). In addition it contains the highest amount of lysine, one of the important amino acids, at a concentration of 400 - 430 mgg^{-1} of nitrogen (Key, 1979). The lipid content is low (5 - 6 % DM) (Poulter and Caygill, 1980; Aykroyd and Doughty, 1982). Total lipid content of seeds are inferior to other oil seed legume such as groundnut (*Arachis hypogea*) (45.3 - 47.7 % DM) (Rosario *et al.*, 1981; Aykroyd and Doughtly, 1982), but compare favourably with cowpea (1 - 1.6 % DM), pigeon pea (1.2 - 1.5 % DM) (Brough and

Azam - Ali, 1992) and soybean (Poulter, 1981). Brough and Azam – Ali (1992) reported that proximate composition of bambara groundnut is not affected by adverse growing conditions such as water stress. From nutritional point of view this property is of importance to the subsistence farmers who grow the crop in areas of low rainfall.

Bambara groundnut is eaten in a variety of ways ranging from fresh cooked pods; cooked dry grain and "coffee" drink to bam corn (e.i mixture of bambara groundnut flavour and corn) (Lartey, 1976). Large scale canning has been reported in Zimbabwe and Ghana (Johnson, 1968; Lartey, 1976). On the other hand, Duke *et al.* (1977) reported oil extraction by the Azande of Congo. The tops of bambara groundnut are used as feed for livestock (Holm and Marloth, 1940; Duke *et al.*, 1977). Furthermore, bambara groundnut have been used as protein source in pig and poultry ration (Uwaegbute, 1977).

2.4 Genetic variation in bambara groundnut

Bambara groundnut appears to have a wide range of genetic variability due to its wide geographical dispersion that could give scope for selection. This is mostly manifested by variation in seed size, seed colour and patterning of the testa. However, there are no cultivars of bambara groundnut in the strict sense, they are considered as landraces (Linnemann and Azam - Ali, 1993).

Most landraces existing today have arisen from casual selection in the cause of cultivation and people's migration (Johnson, 1968). Although there are no cultivars of bambara groundnut in the strict sense, farmers tend to differentiate cultivars basing on;

colour of the testa, seed size, eye pattern, location and growth habit (Holm and Marloth, 1940; Johnson, 1968). Basing on colour only, one of the farmer's methods of differentiating cultivars, Holm and Marloth (1940) listed five cultivars grown in South Africa while Johnson (1968) identified similar number of cultivars grown in Zimbabwe.

In Tanzania, initial selection of cultivars was also based on colour of the testa; eye colour and place of origin (Symth, 1968). Some of the cultivars grown in Tanzania as a product of initial selection include red coloured BA/48/1, the cream "red-eye" Mwanza, the Mpwapwa cream "non eyed" BA/2 and Mpwapwa cream "Black-eyed". Others include Shinyanga black coloured, Singida speckled or mottled, Mwanza cream coloured "brown eye" and Tabora cream "brown patches". (Tanzania: MOA, 1970; Elia, 1985).

In order to facilitate systematic description of germplasm accessions in collections and to facilitate the exchange of accessions between institutions, a comprehensive description list for bambara groundnut was published (IBPGR/IITA/GTZ, 1987). Accessions were characterized by recording highly heritable traits, which were visible by naked eye and expressed in all environments. Thus it is important to describe the seed accurately in terms of attributes such as testa colour, testa pattern, colour of the pattern, eye pattern and eye colour (Linnemann and Azam - Ali, 1993).

2.5 Agronomy

2.5.1 Cropping systems

In many traditional farming systems bambara groundnut is grown in association with one or more other species. These include cereals (millet, sorghum or maize), root or tuber crops (cassava), other legumes (groundnut or cowpea) or vegetables (okra, pumpkin) (Doku and Karikari, 1971a; Ezuch, 1977; Haque, 1980). The crop may also be grown as a sole crop (Stanton *et al.,* 1966).

Bambara groundnut also is used in rotation cropping system. Okigbo (1973) reported that in Nigeria the crop might be grown in rotation with maize, cowpea, cassava or yam. Although rotation of bambara groundnut with tobacco has been successful, this practice is not recommended where infestation of eelworm is likely (Valentine, 1963) cited by Linnemann and Azam - Ali (1993). The crop is favoured in crop rotation due to its ability of fixing atmospheric nitrogen and hence improving nitrogen status of the soil.

2.5.2 Land preparation

Bambara groundnut prefers deep, free draining soils, with a light, friable seedbed, which is conducive to pod burying (Johnson, 1968). If ridging equipment is available, flat-topped ridges are recommended (Johnson, 1968), especially when the soil is susceptible to water logging or the soil is shallow; otherwise, a flat seedbed is preferred.

2.5.3 Sowing

The shelled bambara groundnut seeds are reported to deteriorate at ambient temperature (Sreeramulu, 1983). Therefore, seeds to be used as planting material should be shelled as near to the planting period as possible in order to maximize viability. Depending on the ambient temperatures and on relative humidity, seed viability may persist for several months or over a year (Sreeramulu, 1983; Temu, 1994). There is a general notion that good seeds for planting should be large because they produce more vigorous seedlings. However, in terms of fractional emergence, Zulu (1989) observed that across a wide range of soil moisture levels, small seeds (less than 8mm in diameter) and medium (8 - 9.5mm diameter) sized seeds consistently had a greater final and faster emergence than the large ones.

2.5.4 Seed rates and sowing depth

In many areas, bambara groundnuts are grown in association with other crops. It is rarely grown as a sole crop. Thus, it is difficult to determine its seed rates. However, FAO (1961) reported that the average seed rate is 35 $kgha^{-1}$ for Tanzania, 25 - 45 $kgha^{-1}$ for Kenya, 50 – 60$kgha^{-1}$ for South Africa and 60 - 75 $kgha^{-1}$ for Eastern Nigeria.

Johnson (1968) recommended planting space to be either 10 or 15 cm apart in 45cm rows. These will provide densities of about 22 and 14 plants per m^{-2} respectively. Karim (1990) cited by Linnemann and Azam-Ali (1993) reported that dense populations might be required to maximize the amount of radiation intercepted by the crop. However, these high planting densities are only appropriate in conditions where there is no water stress to limit crop productivity.

Usually bambara groundnut is planted by hand, with or without hoe. Thus, sowing depth may be quite variable. Optimum sowing depth depends on soil type. On heavy soils seeds are sown about 2.5cm deep while on light soils a sowing depth of 5-7.5cm is recommended (Doku and Karikari, 1971a). Under wet conditions, shallow sowing has been reported to achieve better and early emergence (Stanton *et al.*, 1966).

2.5.5 Fertilizer use

Generally, bambara groundnut is grown as a low - input subsistence crop. Therefore, recommendations for optimal fertilizer requirement are scarce. Where farmer used fertilizer, it is reported to experience adverse results (Linnemann, 1990).

Stanton *et al.* (1966) recommended an application of 40 kgha^{-1} sulphate of ammonia three weeks after sowing. To the contrary, Nnadi *et al.* (1976) reported that application of 20 Kg of Nitrogen per hectare as a starter did not increase yield. Application of sulphate of ammonia at a rate of 112 kgha^{-1} some times depressed yield (Malawi Government, 1970) or had a marginal yield effect (Malawi Government, 1971). Soils rich in nitrogen tend to encourage vegetative growth at the expense of pod formation (Temu, 1994; Doku *et al.*, 1977). That is why responses to nitrogen are considered to be poor.

Reports on the response to phosphorus application are also contradictory. Research conducted in Malawi, Nigeria and Zambia have failed to show any response to phosphorus application at rates up to 336 kgha^{-1} and sometimes yields were depressed (Malawi Government, 1980; Nnadi *et al.*, 1981). Whereas, Tanimu and

Yayock (1990) cited by Ramolemana *et al.* (1996) reported a significantly higher yield from application of 22 Kgha^{-1} of phosphorus. Wassermann *et al.* (1983) reported an increase in total dry matter but seed yield was not increased.

2.6 Effect of moisture on seed germination, seedling emergence and Crop establishment

The desired end in crop production is high yields and of high quality. To this end, a good start is essential. A good start for plants grown from seeds implies rapid, uniform and complete germination. Achievement of these ideals depends on a suitable environment for crop establishment and growth on one hand, and on the genetic, physiological and physical nature of the seeds on the other hand (Woodstock, 1976).

A number of studies have shown that successful establishment may be limited by poor germination or poor emergence due to high temperature, moisture stress or poor seed quality (Gurmu and Naylor, 1991; Rwehumbiza, 1994). Hilel (1972) reported that, problems of seed germination and seedling establishment are more severe in arid and semi- arid regions where rainfall is less frequent and accompanied by high transpiration rates.

Emergence of bambara groundnut is hypogeal with the cotyledons remaining underground. Emergence takes seven to 15 days (Linneman and Azam-Ali, 1993). However, the duration of wild forms, which are defined by Hepper (1970) as erratic may take up to 31 days after sowing, with some seeds remaining dormant indefinitely.

Drought can be the most limiting environmental factor to seed germination and seedling emergence and crop establishment (Sharma, 1985). Bambara groundnut appears to be more sensitive to moisture stress at germination phase than groundnut (Sesay *et al.*, 1996). This sensitivity was considered to be attributed to restricted water uptake by seeds due to the hard seed coat. Thus, it is logical to speculate that prolonged germination period is the result of restricted water uptake. In the study to investigate the germination rate under drought conditions, Zulu (1989) measured germination across a range of water potentials. Severely diminished germination was observed even by small reduction in water potential. Such observation implies that, where the uptake of water is already restricted by the hard seed coat, any minor reduction in the external water potential can significantly restrict the overall uptake of water by the seed. Therefore, an adequate supply of water at the germination stage is critical for successful crop establishment, although the crop is known to be drought tolerant.

Mkandawire (1996) observed differences in emergence percentage between different types of seedbed. Seeds sown on the ridge seedbed had the lowest rate of emergence compared to the seeds sown in the furrow or on the flat. Reason given is that, a large surface area of the soil surface was exposed to evaporation which in turn affected the amount of moisture available in the top 2.5 to 4cm of the soil surface where the seeds were placed.

To the contrary, Mabika (1992) cited by Sesay *et al.* (1996) observed that scarification by scratching three small opening on the seeds did not only delay germination but also significantly reduced it. However, the reason behind was not given. It is clear that, for rapid and uniform crop establishment sowing should ideally be completed early in the rainy season (Linnemann, 1987). In practice, bambara groundnut is usually grown as secondary crop and is often planted late after staple food and cash crops (Linnemann, 1990). The periods during which the bambara groundnut are sown are often associated with relative low moisture contents in the upper soil surface layers. This may also be a major contributing factor to variability in seedling establishment often recorded.

2.7 Effect of water regimes on root growth

Maintenance of water uptake requires the development of roots into water-containing soil and their continued extraction of water in the absence of rain. Although root growth is reduced under water stress conditions (i.e. water deficit or/and water logging conditions), an absolute increase in root growth with water deficit has been observed in maize (Hsiao and Acevedo, 1974) and in cotton (Malik *et al.*, 1979).

An increase in root dry matter may indicate a greater density or a greater depth of roots. Soil and root resistance to water uptake are reduced when root length and density increases, thereby permitting higher water flow rates through the plant and delaying the onset of severe plant water deficit (Hsiao *et al.*, 1976).

Dry matter partitioning between roots, above ground vegetative growth and reproductive structures are usually modified by water stress. The responses depend upon species, when the stress occurs, its duration and its severity. Collinson *et al.* (1996) observed that under no irrigation from 35 days after sowing to maturity, the crop managed to produce 0.48 tons per hectare of root dry weight compared 0.98 tons per hectare under full irrigation. Nyamudeza (1989) observed that bambara groundnut allocated a greater fraction of its total dry weight to roots than comparable groundnut irrespective of available moisture. Thus, in relative terms, bambara groundnut appears to commit a greater supply of assimilates to roots, irrespective of soil moisture status.

Although the amount of water could affect root growth in all crop plants, there are significant variations between plant species, and within plant species at different growth stages. Meisner and Karnok (1992) using non-destructive methods in a rhizotron chambers studied groundnut root response to moisture stress by imposing thirty days drought stress beginning at 20, 50, 80, and 110 DAP in comparison to a well watered control. Root growth was reduced in the upper 40cm depth during the stress from 20 to 50 DAP compared to the control. However, at the end of the season no significant difference in overall average root growth was observed. These results imply that, root growth in groundnut may be temporarily reduced if water stress occurred in the early stage of root growth but would recover once favourable conditions are restored. Knowledge of the stage(s) at which root growth becomes more sensitive to water stress, could help plan when to grow the crop such that the most sensitive stage is synchronized with the period of adequate water supply.

Under water deficit conditions, root: shoot ratio tends to increase (Beg and Turner, 1976). This may reflect an increase in the proportion of assimilates allocated to the roots, or a change in the rate of death or turnover of roots relative to the shoot. Collinson *et al.* (1996) observed root: total DM ratio of 0.11 and 0.16 for bambara groundnut subjected to water equivalent to 300 and 125mm of rain respectively. They suggested that, the plant apparently responds to drought by partitioning more assimilate into the roots relative to the shoot so that a greater soil volume can be exploited.

Moisture stress was also observed to affect hormone production. At higher level of water stress, abscisic acid (ABA) begins to increase markedly in leaf tissues and to a lesser extent in other tissues including roots (Bradford and Hsiao, 1982). In addition, ABA inhibits shoot growth; further conserving water and root growth appears to be promoted. This would increase the water supply as transpiratory surface is reduced while the water absorption surface increases. There is also evidence that suitably low concentration of ABA increase the rate of water conductance through roots, which would reduce the water stress in the shoot (Kriedemann and Lovey, 1974).

2.8 Effect of water stress on vegetative growth, flowering and pod-filling stages.

Water is one of the most limiting factors affecting crop production in semi-arid environments. Where irrigation has supplemented rainfall for crop production, a need for better understanding of crop water requirement and yield relationships has been created (Labanauskas *et al.*, 1981). There is a general agreement that water stress at certain growth stage causes more injury than at other stages (Denmead and Shaw, 1960; Bunting and Kassam, 1988). But there are significant variations in injury level between plant species. That is, knowing at what growth stage a certain crop plant becomes more sensitive to water stress, it would be possible to plan when to grow a crop such that the most sensitive stage to water stress is synchronized with the period of adequate moisture supply to the soil. In other words, an important aspect of crop water requirement is the timing of water application.

Hilel *et al.* (1972) reported that cowpea subjected to three levels of water stress during one of the three growth stages (vegetative, flowering and pod-filling), flowering stage was the most sensitive to moisture stress. In a similar study, Turk *et al.* (1980) and Shouse *et al.* (1981) observed that moisture stress at flowering and pod-filling stages had the most serious negative influence on seed production, whereas stress at vegetative stage had the least effect on seed yield. They further reported that water use efficiency was decreased when irrigation was withheld during flowering and pod-filling stages but was increased with no irrigation during vegetative stage because there was no decrease in yield. Similarly, Wein *et al.* (1979) observed no significant effect on seed yield when cowpea was subjected to a two-week drought at vegetative stage. Summerfield *et al.* (1979) reported a contradictory observation where greenhouse-grown cowpea was sensitive to water stress only at vegetative stage.

Water stress imposed during anthesis in corn (*Zea mays*) resulted in little or no fertilisation of ovules and consequently, ear void of grain was observed (Denmead and Shaw, 1960). In barley (*Hardeum vulgare*), Denmead and Shaw 1960 on the other hand observed that water stress during the booting stage, resulted to low grain yield but grains contained high protein percentage, a condition undesirable in the malting of barley.

Working with groundnut (*Arachis hypogaea*) Nageswara Rao *et al.* (1985) reported that total biomass production was reduced when water stress was imposed from the start of flowering to the start of seed growth and from the start of seed growth to maturity. However, reduction was more severe when water stress was imposed from the start of seed growth to maturity. The report further revealed that stress from emergence until the start of peg initiation gave more favourable distribution of dry matter into reproductive components. This effect provides a significant managerial option in that stress at this stage can be allowed so as to maximize use of irrigation resource. In terms of pod and kernel yield, Nageswara Rao *et al.* (1985) observed reduction in yield when stress was imposed at the start of seed growth which is contrary to other studies, which reported greatest yield reduction when water stress was imposed at flowering stage (Pallas *et al.*, 1979). It was concluded that high damage was observed when stress was imposed at flowering because results were based on short season cultivars. For long duration cultivars, damage caused by late season drought is more severe than drought occurring at early stages of the crop growth. Thus the soil water deficit occurring during the pod-filling stage has to be considered in the light of indeterminate nature of the crop.

In another study, an experiment was conducted to compare water relations of common bean (*phaseolus vulgaris* L.) and tepary bean *(P. acutifolius)* (Markhat, 1985). After two weeks of growth water was withheld such that the *P. vulgaris* plants were left without watering throughout the night. Results indicated that plant dry weight and leaf area was reduced by water stress in both species. Total dry weight of *P. acutifolius* decreased significantly more than that of *P. vulgaris*. The decrease was observed in leaves; stem and roots with most of the differences in cultivars coming from effect on root dry weight. Although *P. acufolius* was affected more by water stress than common bean, *P. acufolius* produced more total dry matter and leaf area under both well watered and water stressed conditions.

From the available literature, it is evident that water stress affects most of the aspect of growth for most of crop species. However, the magnitude of the effect will depend on several factors including the crop species, the variety or landrace or genotype, the intensity of water stress and the time of onset of water stress in relation to the stage of growth of the crop. While some literature exist on the interaction of all the above-mentioned factors on growth and development of some crops, there is not much literature on the interactions of the factors influencing the effect of water stress on growth and development of bambara groundnut.

CHAPTER THREE

3.0 MATERIAL AND METHODS

Two experiments were conducted during the 1998 and 1999 cropping season to investigate the effects of moisture regimes on growth, development and yield of two bambara groundnut landraces. Each experiment was conducted under field and screen house conditions. The 1998 experiment aimed at studying the effects of different levels of total water supply on growth and productivity of bambara groundnut by supplying irrigation water equivalent to 500, 375, 250 and 125mm of rain during the growth period. The experiment conducted during 1999 aimed at investigating the effect of water stress at different growth stages of bambara groundnuts on its growth and productivity.

3.1 Experimental location

The experiments were conducted at the horticultural unit of the Sokoine University of Agriculture (SUA), located at 6°45"S and 37°40"E and 525 meters above the sea level (m.a.s.l).

3.2 Screen house experiments

3.2.1 Soil sampling and analysis

Soil used in the screen house experiments was collected from the horticultural unit, SUA, where the field experiments were conducted. Soil surface up to 30cm depth was collected at various points, selected randomly to form a composite sample. From the composite sample a sub-sample was drawn and analyzed at the Department of Soil Science (SUA) for physico-chemical properties. The results are summarized in Table 2.

3.2.2 Pot size and fertilization

Twenty litre pots were filled with 25 Kg of soil each, and arranged in the screen house. The soil in the pots was watered to field capacity a day before planting. Prior to sowing, NPK fertilizer (6:20:16) was applied in each pot at the rate of 30, 100 and 80 kg of N, P and K per hectare, respectively.

3.2.3 Planting materials and plant population

Seeds were obtained from a prominent farmer in Dodoma, (Central Tanzania) and were fresh seeds from the 1997/98 season. Cream and red seeded landraces were selected because they are the most common grown by farmers in Tanzania. Before planting, seeds were soaked for 24 hours to ensure that they absorb enough water through its hard coat. Ten seeds (two seeds per station) were sown in each pot at a depth of 5cm and intra-row spacing of 5cm. Emergence counts started 7 DAS and continued until 16 DAS. A seed was considered to have emerged if the plumule broke through the surface of the soil (Temu, 1994). After establishment (21 DAS), thinning was done to leave five plants per pot with an intra-row spacing of 10cm. A total of 48 pots were used in each experiment.

Table 2. Physical and chemical characteristics of the soil used in the experiments at SUA, 1999.

Soil properties	Results	Method used	Comments
pH (H_2O)	6.6	pH	Slightly acidic
Bulk density (g/cm^3)	1.4	Core	Low
Moisture content (%)	70	Volumetric	High
Textural classes (%)			Sand clay loam
Sand	70	Hydrometer	High
Silt	10	Hydrometer	Low
Clay	20	Hydrometer	Low
Organic carbon (%)	0.8	Walkley and Black	Very low
Total nitrogen (%)	0.2	Micro Kjeldahl	Low
Phosphorus (ppm)	14.7	Bray and Kurtz	Low
Exchangeable cations (Cmol/kg)		Ammonium acetate extraction	
Calcium	4.6		Medium
Magnesium	3.0		Medium
Potasium	0.1		Medium
CEC (Cmol/kg)	10	Ammonium acetate extraction	Low

3.2.4 Experimental design and treatments

The experiments were arranged as a split-plot in randomized complete block design with three replications. In each experiment the main plot (Factor A) was made up of landraces, where the cream constituted the main plot one (M_1) and red constituted the main plot two (M_2). In experiment one (effect of different levels of total water supply), the subplot treatments (Factor B) were achieved by supplying four levels of irrigation water, equivalent to 500, 375, 250 and 125 mm of rainfall during growth period, and designated as T_1, T_2, T_3 and T_4, respectively. However, from planting to full establishment (21 DAS) soil was watered to field capacity to ensure uniform establishment. Treatments (varying water levels) commenced after 21 DAS.

In experiment two (effect of water stress at different growth stages), the sub-plot treatments (Factor B) were made up of water stress imposed at one specific growth stage at either vegetative, flowering or pod filling stages, leaving other stages well-watered. Well-watered conditions throughout the growing season constituted the control. The treatments were as follows:

T_1 - Well watered conditions throughout the growing period (control). That is, irrigation water equivalent to 500mm of rainfall was evenly distributed throughout the growing period.

T_2 - Water withheld from full establishment (21 DAS) until 50% flowering period (46 DAS). Thereafter, water was applied normally up to maturity.

T_3 - Plants well watered until 50% flowering. Thereafter, water supply was withheld from 50% flowering (46 DAS) to pod filling (70 DAS). Thereafter plants were well watered again to maturity.

T_4 - Plants were well watered up to the start of pod filling (70 DAS). Thereafter water was withheld to 100 DAS, before resuming normal watering upto maturity.

Each experiment had a total of 24 subplots and the treatment combinations in each replication were as shown in Table 3. The treatments were assigned at random starting with factor A to main plots then subplots (Factor B) within each main plot.

3.2.5 Water management

Amount of water applied was determined using the following relationship:

$W = A \times D$

Where:

W = water applied during the growing period (m^3)

A = Plot area (m^2)

D = depth of irrigation

Amount of water applied during the growing period and its distribution for both experiments are summarized in Tables 4 and 5.

Table 3. Summary of treatment combinations in each replication.

Experiment one (Effect of different levels of total water supply).
Cream + T_1 (500mm of rain)
Cream + T_2 (375mm of rain)
Cream + T_3 (250mm of rain)
Cream + T_4 (125mm of rain)
Red + T_1 (500mm of rain)
Red + T_2 (375mm of rain)
Red + T_3 (250mm of rain)
Red + T_4 (125mm of rain)
Experiment two (Effect of water stress imposed at different growth stages)
Cream + T_1 (Well watered throughout)
Cream + T_2 (Water Stress at vegetative stage)
Cream + T_3 (Water stress at flowering)
Cream + T_4 (Water stress at pod filling stage)
Red + T_1 (Well watered throughout)
Red + T_2 (Water stress at vegetative stage)
Red + T_3 (Water stress at flowering stage)
Red + T_4 (Water stress at pod filling stage)

3.2.6 Crop Protection

In the screen house, plants showed some signs of powdery mildew attack at full flowering stage. Topsin-M 70% (Thiophanate methyl-70%) was sprayed using knapsack sprayer following manufacture recommendations.

3.2.7 Data collection

3.2.7.1 Soil data

The soil physical and chemical characteristics were analyzed in the department of Soil Science at Sokoine University of Agriculture. The results are as summarized in Table 2.

Table 4. Amount of irrigation water applied (mm of rain equivalent) and its distribution for the effect of different levels of total water supply under screen house conditions.

DAS	T_1	T_2	T_3	T_4
	(500mm)	(375mm)	(250mm)	(125mm)
21	30	30	30	25
27	22	20	20	10
31	20	15	17	
34	20	19	16	10
37	18	20		
41	20	15	15	8
45	18	14	15	
48	20	18		8
53	18	14	16	
56	18	17		8
59	16	15	15	
62	20	17		10
65	22		18	
67	18	18		8
70	20	17	15	
72	18	15		8
76	18	15	14	
79	17			
81	16	18		10
84	20	15	15	
87	16			6
89	19	18		
93	15		18	
96	16	18		8
99	18	15	14	
103	15			6
105	12	12	12	

Table 5. Amount of irrigation water applied (mm of rain equivalent) and its distribution for the effect of water stress imposed at different growth stages under screen house conditions.

DAS	No stress	Stressed at vegetative	Stressed at flowering	Stressed at podding
	(500mm)	(328mm)	(329mm)	(362mm)
21	17		17	17
24	18		18	18
27	17		17	17
30	18		18	18
33	20		20	20
36	22		22	22
39	21		21	21
42	22		22	22
45	21		21	21
48	22	22		22
51	21	21		21
54	22	22		22
57	21	21		21
60	22	22		22
63	22	22		22
66	23	23		23
69	22	22		22
72	21	21	21	
75	20	20	20	
78	21	21	21	
81	18	18	18	
84	16	16	16	
87	13	13	13	
90	11	11	11	
93	9	9	9	
96	7	7	7	
99	6	6	6	
102	4	4	4	4
105	3	3	3	3
108	2	2	2	2
112	2	2	2	2

3.2.7.2 Weather data

A thermometer was placed in the screen house so as to record the average daily temperatures. The data were also compared with the values recorded at meteorological station located within SUA main campus. Other weather data collected from SUA meteorological station are rainfall (mm) evaporation (mm), maximum and minimum temperatures (^{0}C) and maximum and minimum relative humidity (%). These data are presented in Appendix 1.

3.2.7.3 Phenological data

Phenological data were recorded as the number of days taken to reach different developmental stages of bambara groundnut landraces (cream and red), starting from planting up to physiological maturity. The data include number of days to seedling emergence, full establishment, first flower, full podding and physiological maturity.

3.2.8 Sequential growth measurements

During the growth period to maturity, the following yield and yield components were measured from single plants earmarked at 21DAS and uprooted at 46, 70, 100 and 120 DAS.

3.2.8.1 Number of leaves

This was achieved by counting all fully opened trifoliate leaves.

3.2.8.2 Number of flowers

Flowers were removed from the peduncle of plants used for growth measurements and counted.

3.2.8.3 Number of pods

Pod number was recorded on plants uprooted at 70, 100 and 120 DAS and reported as number of pods per plant.

3.2.8.4 Leaf dry matter

One plant from each treatment was uprooted at 46, 70, 100 and 120 DAS and washed clean. All leaves (including petioles) were removed from the sampled plants and oven dried to constant weight at 80°C. Thereafter, its weight was recorded.

3.2.8.5 Stem dry matter

Prostrate stems, pegs and crowns were all considered as part of stem. These parts were removed from the plants, oven dried to constant weight at 80°C and recorded.

3.2.8.6 Root dry matter

Root dry matter was determined for plant parts below the crown. Care was taken to recover as much roots as possible by sieving all soil around root zone. Recovered roots were washed clean, oven dried to constant weight at 80°C and weighed.

3.2.8.7 Pod dry matter

Pods removed from uprooted plants at 100 and 120 DAS were oven dried to constant weight at 80°C and its weight recorded as gram per plant.

3.3 Field experiments

3.3.1 Location

Two field experiments were conducted at the SUA horticultural unit during the dry season between July and November 1999.

3.3.2 Land preparation

The experimental area was disc-ploughed and hoed to prepare a fine seedbed. Sedges (*Cyperus spp*) and Berrmuda grass (*Cynodon dactylon*) were the predominant weeds at the time of land preparation.

3.3.3 Experimental design and treatments

The experimental design and treatments were similar to screen house experiments as described under section 3.2.3. The experimental layout was as shown in appendix 3.

3.3.4 Plot size and planting

Each experiment had a total of 24 subplots. The plot size was 2.8m x 1.5m (4.2m^2), consisting of 8 rows. A space of 1.5m wide was left between subplots to avoid water seepage between subplots. Seeds were sown in July 1999. Seeds were collected from an open market in Dodoma. Two seeds per station were sown at inter and intra-row spacing of 35 and 5cm, respectively, at a depth of 5cm. At 21 DAS, thinning was done for the red landrace to leave one seedling per station and 10cm intra-row spacing.

3.3.5 Water management

Procedures used to determine the amount of water applied were as described for the screen house experiment (section 3.2.4). Their distributions for the whole growing season are summarized in Table 6 and 7.

Table 6. Amount of irrigation water applied (mm of rain equivalent) and its distribution for the effect of different levels of total water supply under field conditions.

DAS	T_1	T_2	T_3	T_4
	500mm	375mm	250mm	125mm
12	17	14	6	
24	18	16	8	7
27	17	14	9	6
30	18	16		4
33	20	18	14	
36	22	19	13	7
39	21	18	14	9
42	22	19	13	
45	21	17	9	8
48	22	18		9
51	21	17	11	
54	22	18	12	7
57	21	17	11	4
60	22	18		
63	22	18	11	7
66	23		12	6
69	22	18	11	
72	21	17	12	8
75	20	16	10	4
78	21	14		7
81	18	14	12	
84	16	13	9	4
87	13		10	7
90	11	8	12	4
93	9	7	11	
96	7	4	7	6
99	6		6	4
102	4	3	4	4
105	3	2		
108	2	2	2	2
112	2		1	1

]Table 7. Amount of irrigation water applied (mm of rainfall equivalent) and its distribution for the effect of water stress imposed at different growth stages under field conditions.

DAS	No stress	Stresses at vegetative	Stressed at flowering	Stressed at podding
21	17		17	17
24	18		18	18
27	17		17	17
30	18		18	18
33	20		20	20
36	22		22	22
39	21		21	21
42	22		22	22
45	21		21	21
48	22	22		22
51	21	21		21
54	22	22		22
57	21	21		21
60	22	22		22
63	22	22		22
66	23	23		23
69	22	22		22
72	21	21	21	
75	20	20	20	
78	21	21	21	
81	18	18	18	
84	16	16	16	
87	13	13	13	
90	11	11	11	
93	9	9	9	
96	7	7	7	
99	6	6	6	
102	4	4	4	4
105	3	3	3	3
108	2	2	2	2
112	2	2	2	2
	(500mm)	(328mm)	(329mm)	(362mm)

3.3.5 Crop protection and other agronomic practices

The crop growth in the field was also attacked by powdery mildew. Topsin-M 70% WP (Thiophanate-methyl-70%) was used to control the disease according to manufacturer recommendations. Aphids (*Aphasia spp*), leafhoppers (*Impoasca spp*) and grasshopper were the serious insect pests observed during the growing season. Karate (lambda-cyhalothrin) was used to control the insect pests according to manufacturer recommendations. All plots were kept weed free through periodic hand weeding at two weeks intervals. Earthing – up was done at 57 DAS.

3.3.6 Data collection

Soil characteristics, weather records, phenological data and sequential growth measurements were done and recorded as described under the screen house experiments (section 3.2.7.1 to 3.2.8.7). However, two plants were sampled instead of one plant (for the screen house experiments) and the average was computed.

3.3.6.1 Light interception and leaf area index

Light interception was measured using a 1m long AccuPAR Ceptometer (Decagon devices, USA). Measurements were recorded on the area earmarked for final harvest in each sub plot at 70 and 100 DAS. Measurements were not taken before 70 DAS because the instrument was out of function. Measurements were made both above (I_o) and below (I) the canopy. The AccuPAR automatically computed leaf area index (LAI).

3.3.6.2 Final harvest data

All plants in the harvested area ($1m^2$) were counted and recorded. Six plants were randomly selected from the harvest area. The following agronomic yield components were measured on the six plants.

3.3.6.3 Shelling percentage

Shelling percentage was calculated from pod and kernel weight as:

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

3.3.6.4 Pod yield per hectare

All pods from the six plants in each plot were weighed separately and converted to pod yield in tons/ha.

3.4 Data analysis

The data were subjected to analysis of variance (ANOVA) using the MSTAT-C statistical package. Duncans New Multiple Range Test (DMRT) at $p \leq 0.05$ was adopted in mean separation. The data were also subjected to linear regression analysis as described by Gomez and Gomez (1984) to estimate linear correlation for the measured parameters, using the same statistical package.

Model

$Y_{ijk} = ì + â_i + aj + ì_{ij} + k + ajk + E_{ijk}$

Y_{ijk} = Response

ì = General effect

$â_i$ = Replication effect

aj = Main factor effect

$ì_{ij}$ = Main plot random effect

k = Subplot factor effect

ajk = interaction effect due j^{th} and k^{th} factor B

E_{ijk} = Subplot random effect

CHAPTER FOUR

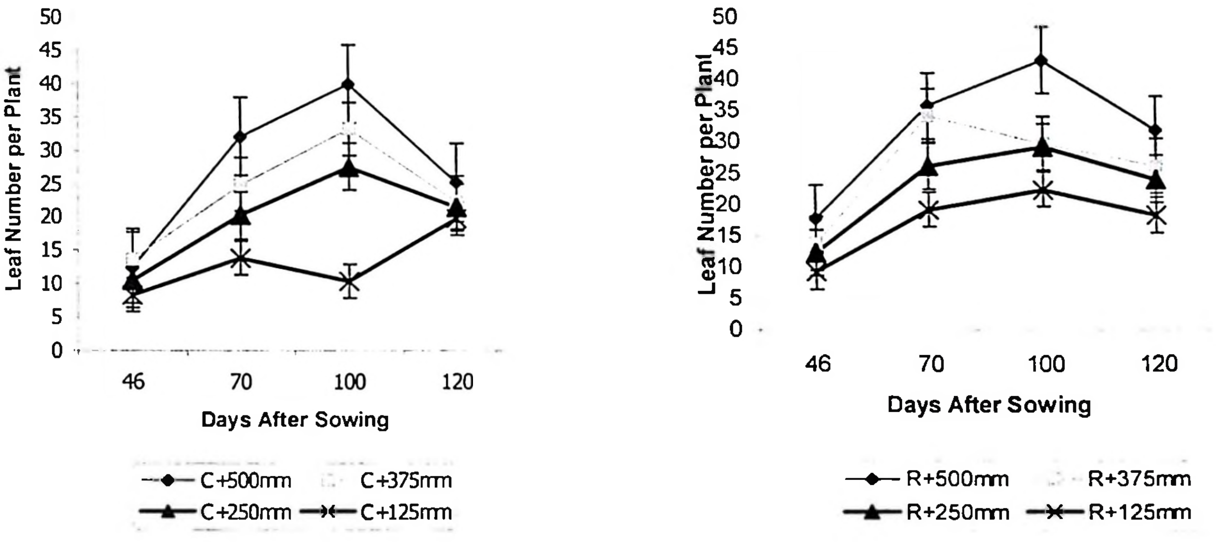
4.0 RESULTS

4.1 Effect of total water supply on growth and development of bambara groundnuts

4.1.1 Number of leaves per plant

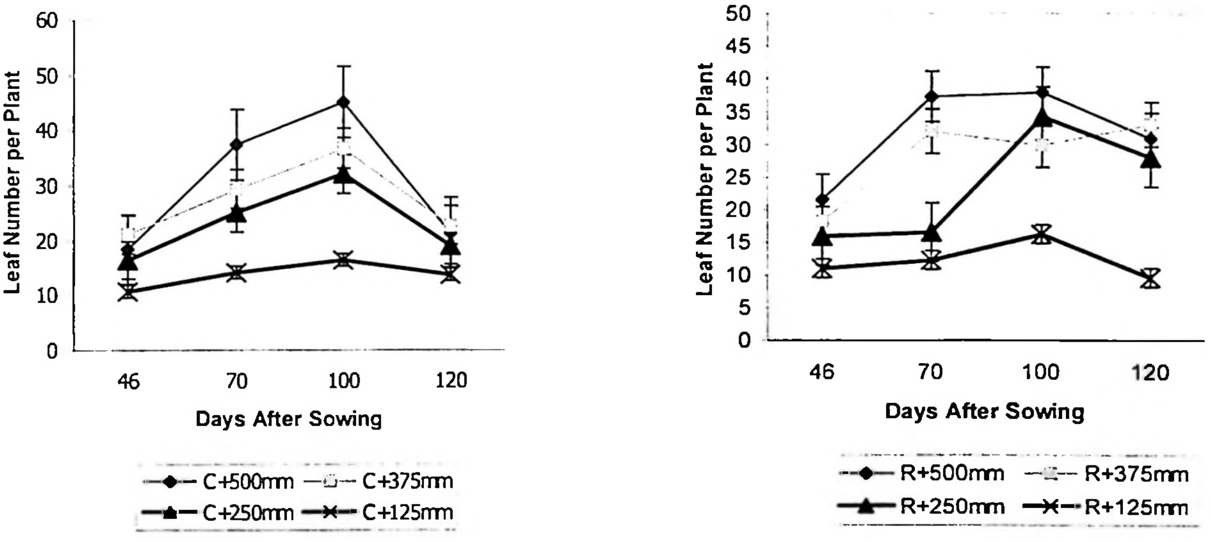
Figures 1(a) – (d) show the effect of different levels of total water supply (mm) per growing season on number of leaves per plant. Generally number of leaves increased with increased water supply. Plants grown under screen house produced higher number of leaves per plant than those grown under field conditions, except at physiological maturity where the trend was reversed. The red seeded landrace yielded more leaves than the cream.

Water level one (500mm), two (375mm) and three (250mm) significantly ($P<0.05$) produced higher number of leaves than water level four (125mm) both under field and screen house conditions. There were no significant differences on number of leaves per plant between 500, 375 and 250mm of rain equivalent except for cream landrace at 70 and 100 DAS under field conditions, where the 500mm treatment recorded significantly more leaves than 250mm. Similarly, there were no significant differences between the 250 and 125mm treatments, both in the field and screen house. The interaction between landraces (factor A) and water levels (factor B) was not significant at all sampling times, both under the field and screen house conditions



(a) (b)

Fig.1a and 1b. Number of leaves for cream (C) and red (R) seeded bambara groundnut subjected to different levels of total water supply under field conditions.



(C) (d)

Fig.1c and 1d. Number of leaves for cream (C) and red (R) seeded bambara groundnut subjected to different levels of total water supply under screen house conditions.

4.1.2 Leaf area index (LAI)

Effect of water levels on LAI measured at 70 and 100 DAS is summarized in Table 8. The red landrace produced significantly (P<0.05) more LAI than the cream landrace. The 500mm treatment recorded highest LAI while 125mm treatment recorded the lowest. Effects of 375mm and 250mm treatments were almost similar such that there were no significant differences between the two except at 70 DAS where the 375mm treatment recorded a significantly higher LAI than 250mm. The interaction between landrace and water levels was not significant.

Table 8. LAI for bambara groundnut subjected to different water levels of total water supply under field conditions.

Treatments	70 DAS	100 DAS
*C + 500mm	0.85a	0.62a
C + 375mm	0.60b	0.48b
C + 500mm	0.45c	0.35bc
C + 125mm	0.34d	0.33c
**R + 500mm	0.90a	0.72a
R + 375mm	0.75b	0.53b
R + 250mm	0.60c	0.47b
R + 125mm	0.49d	0.45b
Mean	0.69	0.54
SE±	0.10	0.05
CV(%)	9.17	15.94

*C = Cream

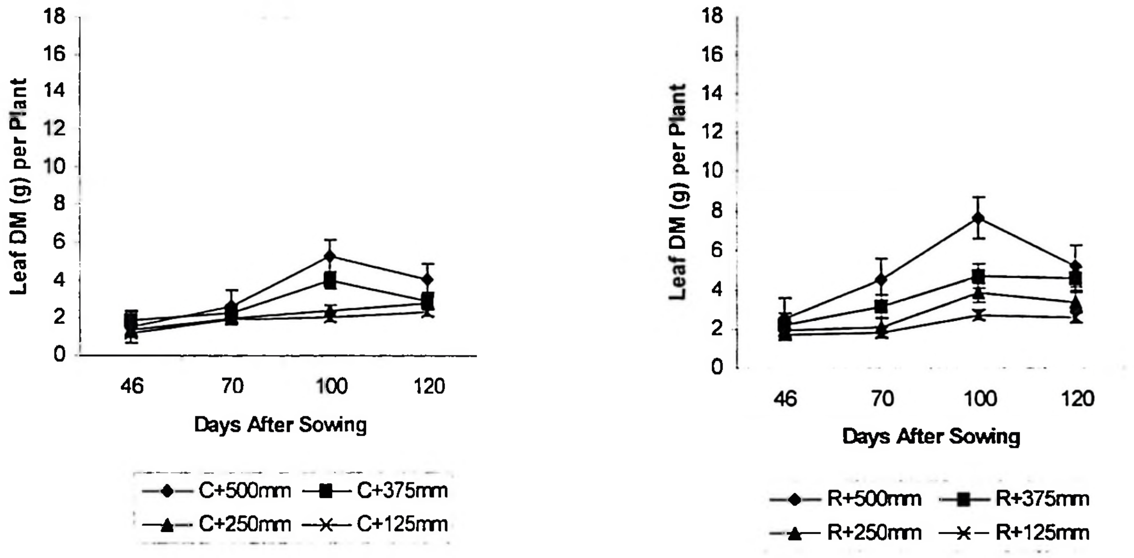
**R = Red

Means in the same column followed by the same letter are not statistically different (P<0.05) following means separation by Duncan's Multiple Range Test (DMRT)

4.1.3 Leaf dry matter

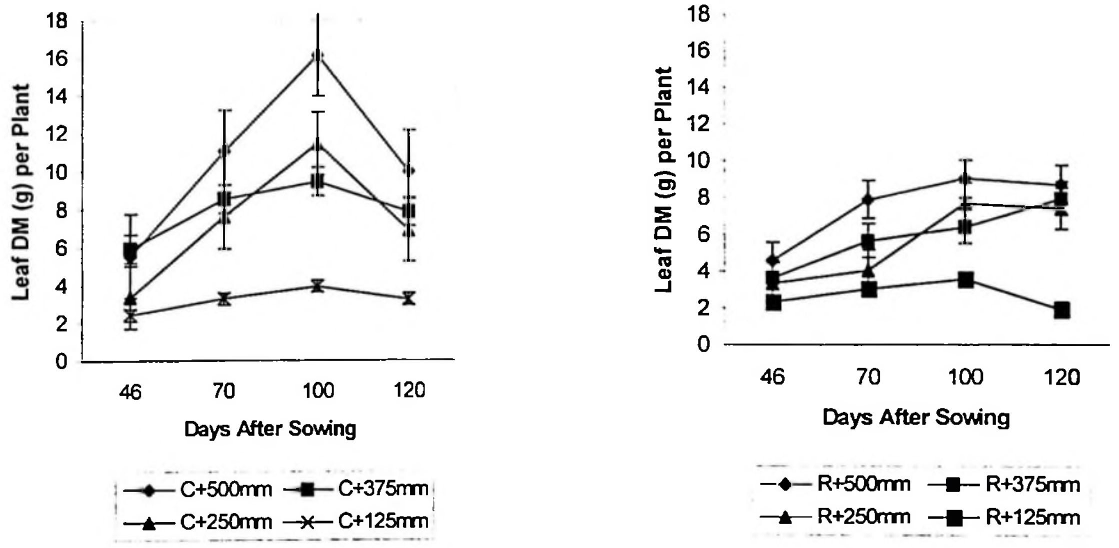
Effect of water levels on leaf dry matter (DM) accumulation is presented in Figures 2(a) - (d). Leaf dry matter accumulation followed the leaf number trends such that it increased with increasing water levels. Similarly, leaf DM accumulation under screen house conditions was higher than under field conditions. Under field conditions, red seeded landrace accumulated more leaf DM than cream landrace while under screen house condition, the reverse was true. Significant ($p<0.05$) effect of leaf DM due to landrace was apparent at 100 and 120 DAS under field conditions and only at 70 DAS under screen house conditions.

The 500mm treatment recorded the highest leaf dry matter per plant while the 125mm treatment recorded the lowest. The difference between the 500mm and 375mm treatments was not significant ($p>0.05$) except at 100 DAS where the 500mm treatment yielded significantly higher leaf DM than the 375mm treatment; similarly, between 250mm and 125mm treatments, except at 100 DAS where the 250mm treatment produced more leaf DM than the 125mm treatment. The 375mm and 250mm treatments did not differat all sampling periods except at 100 DAS for the cream landrace, under field conditions where the 375mm significantly increased leaf DM than the 250mm treatment. The interaction between landrace and water levels was not significant under both growing conditions.



(a) (b)

Fig. 2a and 2b. Leaf DM for cream (C) and red (R) seeded bambara groundnut subjected to different levels of total water supply grown under field conditions.



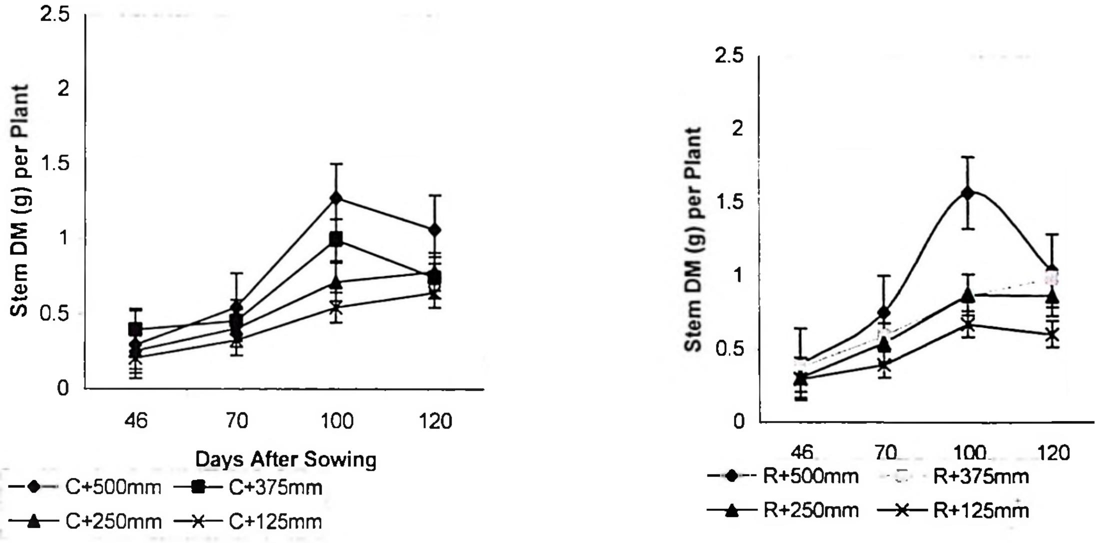
(c) (d)

Fig. 2c and 2d. Leaf DM for cream (C) and red (R) seeded bambara groundnut subjected to different levels of total water supply grown under screen house conditions.

4.1.4 Stem dry matter

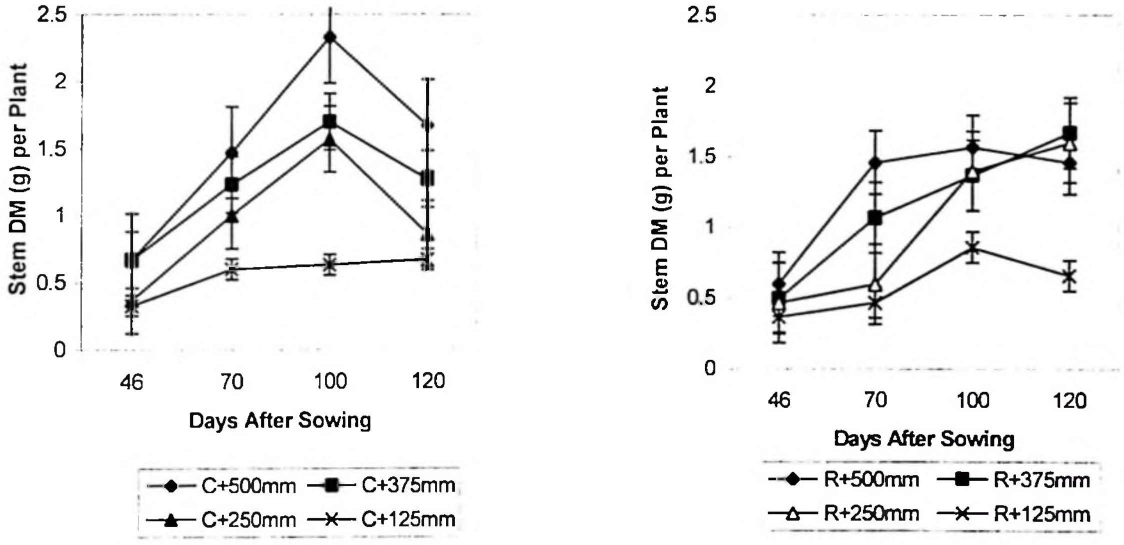
Stem DM production for the two bambara groundnut landraces grown under screen house and field conditions is presented in Figures 3 (a) – (d). Generally, declining water levels reduced stem DM accumulation, both in the screen house and field conditions. Irrespective of water treatment and landraces, stem DM accumulation under screen house conditions was much higher than those under field conditions. Under field conditions, the red landrace accumulated more stem DM than the cream landrace. On the other hand, the cream landrace under screen house conditions accumulated more stem DM than the red landrace except at 46 DAS for 250mm and 125mm treatments and at 120 DAS for 375mm and 250mm treatments where the red landrace accumulated more stem DM than the cream landrace. However, the landrace effect was not significant (P>0.05) except at 100 DAS, under field conditions where the red landrace significantly yielded higher stem DM than the cream landrace.

Under field condition, there were no significant (P>0.05) differences in stem DM accumulation among water levels, except at 100 DAS when the 500mm treatment significantly accumulated higher stem DM than other water levels. The 125mm treatment accumulated the lowest stem DM. It was only at 100 DAS when the 375mm treatment accumulated significantly more stem DM than the 250mm and 125mm treatments for cream landrace. At 70 DAS, the 500mm treatment significantly increased



(a) (b)

Fig. 3a and 3b. Stem DM for cream (C) and red (R) seeded bambara groundnut subjected to different levels of total water supply grown under field conditions.



(c) (d)

Fig. 3c and 3d. Stem DM f for cream (C) and red (R) seeded bambara groundnut subjected to different water levels of total water supply grown under screen house conditions

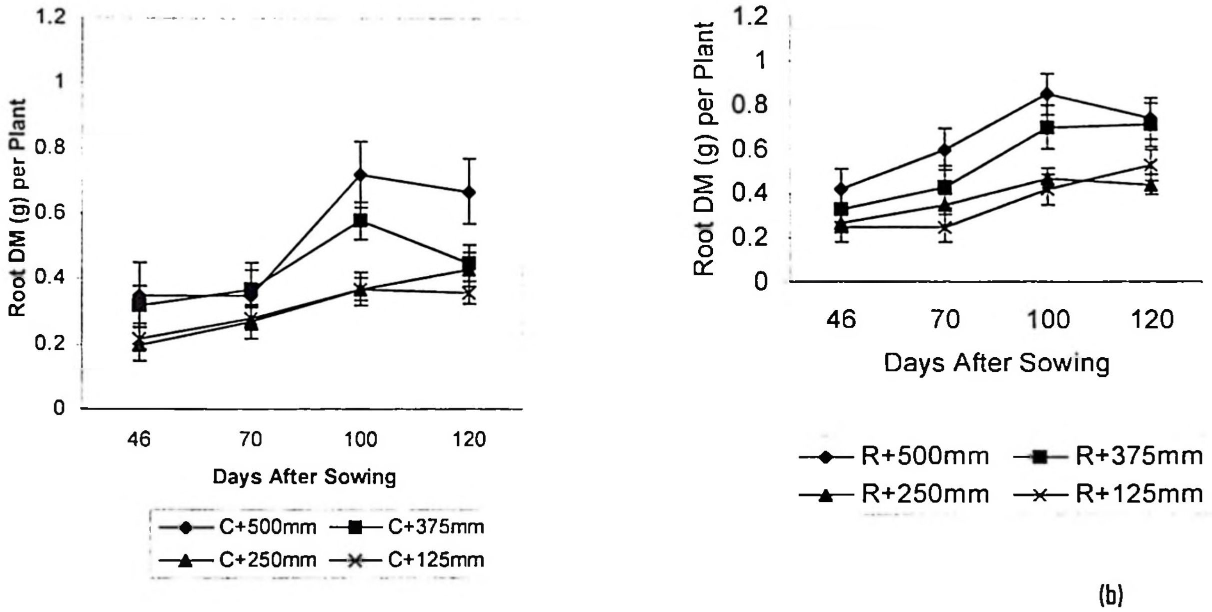
✓

stem DM over the 125mm treatment for both landraces, while the 250mm treatment did so for only the red landrace. At 100 and 120 DAS the 500mm treatment produced significantly higher stem DM than 125mm treatment for the red landrace only. The general trend was that, the 500mm treatment produced the highest stem DM while the 125mm treatment produced the lowest stem DM. The 375 and 250mm treatments were similar in terms of stem DM accumulation.

4.1.5 Root dry matter

Root DM production generally increased with increasing water levels (Figures 4(a) - (d)). The cream landrace produced more root DM under screen house than field conditions. Root DM accumulation for the red landrace was almost similar under field and screen house conditions. The landrace effect was significant ($P<0.05$) only under the field condition at 70, 100 and 120 DAS where the red seeded landrace accumulated more root DM than cream.

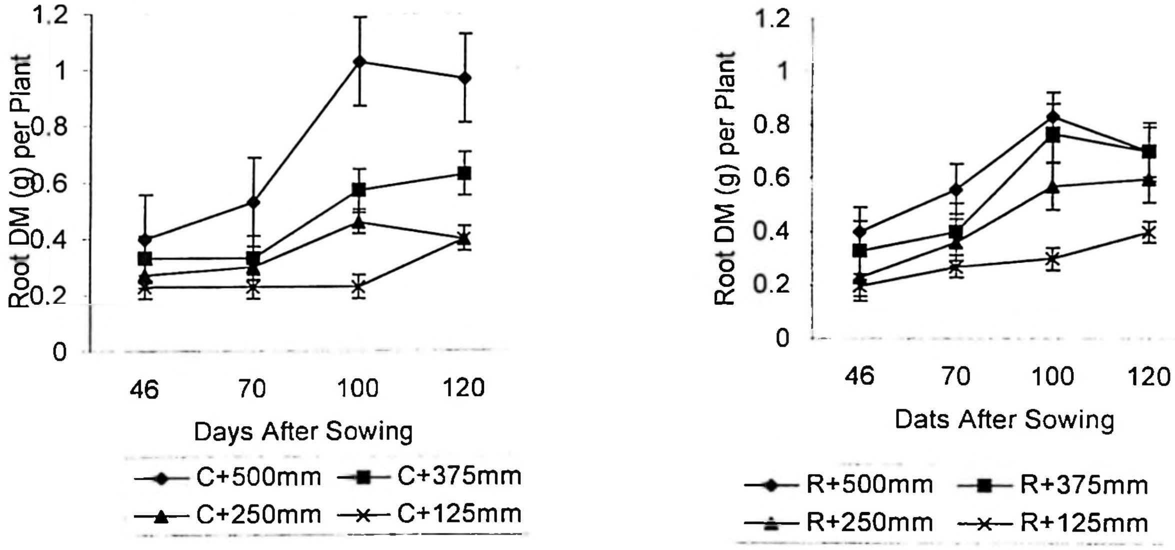
The 500mm treatment produced significantly ($p<0.05$) higher root DM than the 250 and 125mm treatments at all sampling periods in the field and screen house conditions. The 125mm treatment significantly produced the lowest root DM. There were no significant differences between 500 and 375mm treatments except at 100 and 120 DAS, both under the field and screen house conditions. Likewise, there were no significant differences between 250 and 125mm treatments except at 70 DAS for red landrace and 100 DAS



(b)

(a)

Fig. 4a and 4b. Root DM for cream (C) and red (R) seeded bambara groundnut subjected to different levels of total water supply grown under field conditions



(c) (d)

Fig. 4c and 4d. Root DM for cream (C) and red (R) seeded bambara groundnut subjected to different levels of total water supply grown under screen house conditions under field and screen house conditions, respectively. For both landraces, the 375mm treatment recorded significantly more root DM than 250mm treatment at 70 and 100 DAS, under field conditions. The interactions between landraces and water levels were not significant except at 70 DAS under field conditions.

4.1.6 Number of flowers

Declining water levels from 500mm to 125mm did not significantly affect days to flowering. As such, onset of flowering started at 36 DAS for 500 and 250mm treatments and 37 DAS for 375 and 125mm treatments under screen house conditions. Under field conditions, flowering was delayed to 40 and 41 DAS for 500mm and other levels, respectively.

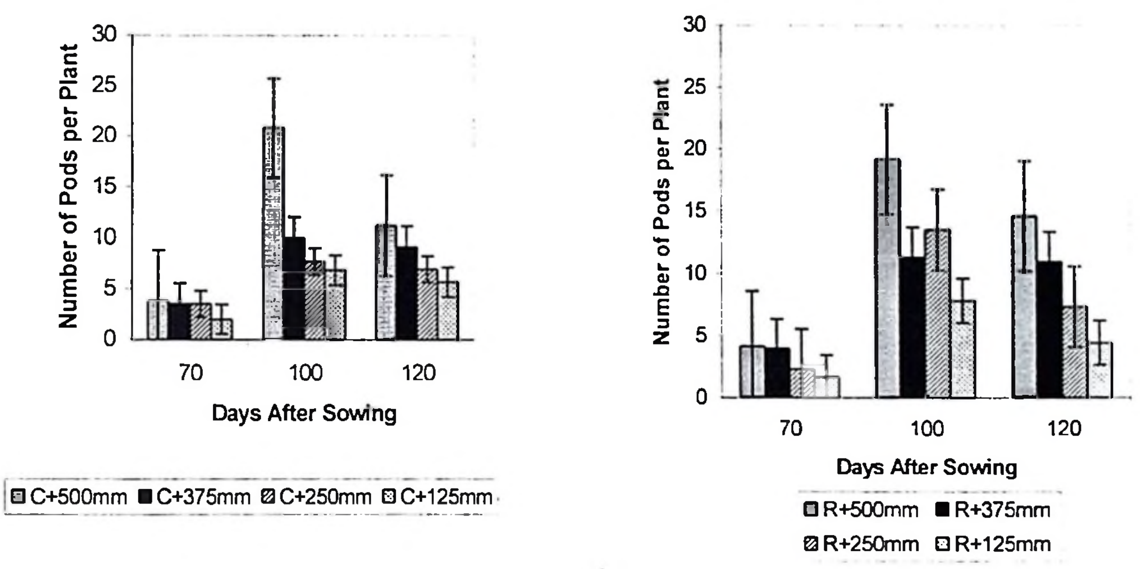
Upto 70 DAS, number of flowers per plant increased with increasing water levels. Late in the season, the most stressed treatments (250 & 125mm) produced more flowers than well - watered treatments (500 & 375mm). Irrespective of treatments, plants grown in screen house conditions produced more flowers than those grown in the field. There was no significant landrace effect on number of flowers per plant.

There were no significant ($P>0.05$) differences in number of flowers per plant between water levels up to 70 DAS, both in the field and in screen house for both landraces. At 100 and 120 DAS, the 250 and 125mm treatments significantly produced more flowers per plant than 500 and 375mm rain equivalent treatments. At these periods, there were no significant differences between 500 and 375mm treatments, neither between 250 and 125mm treatments. The interaction effect between landraces and water levels throughout the growth period were not significant.

4.1.7 Number of pods

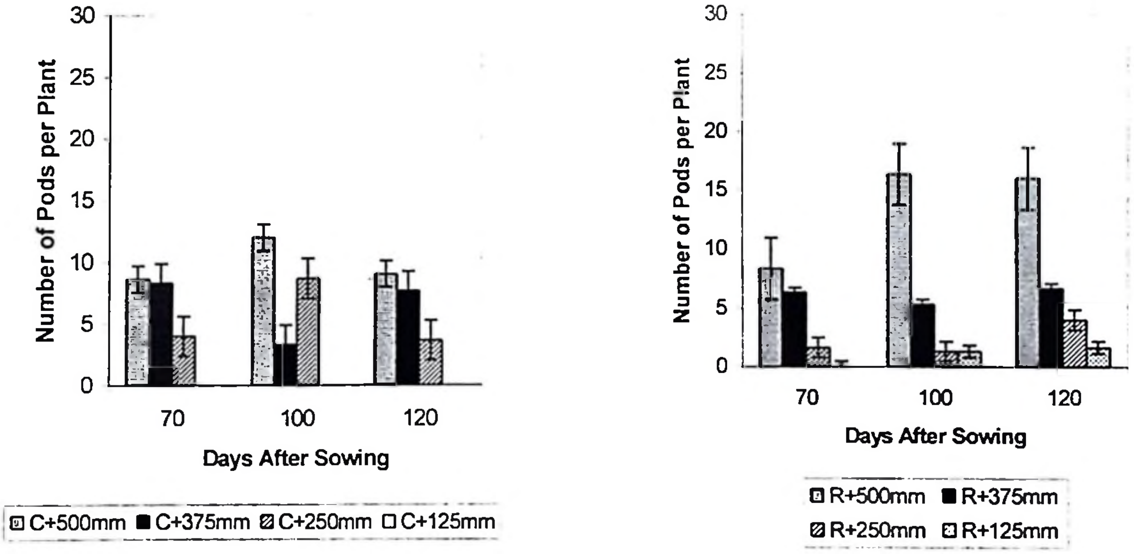
Podding began at 62 DAS for bambara groundnut subjected to 500, 375 and 250mm rain equivalent but was delayed to 72 DAS in the lowest (125mm) treatment under field conditions. Under screen house conditions, pod appearance began earlier (59 DAS) for 500, 375 and 250mm treatments while for 125 mm treatment, podding started at 86 DAS for the red seeded landrace. No single pod was recorded for the cream landrace given water equivalent to 125mm of rain.

Pod number per plant decreased with decreasing water levels. Irrespective of water levels, number of pods increased with age up to 100 DAS and thereafter declined upto harvest maturity (Fig. 5(a) – (d)). Regardless of landrace, bambara groundnut grown under field conditions yielded more pods per plant than those grown under screen house conditions (Fig. 5a & 5b Vs 5c & 5d). There was no significant (P>0.05) in landrace effect but the red landrace produced relatively more pods than the cream.



(a) (b)

Fig. 5a and 5b. Number of pods per plant for cream (C) and red (R) bambara groundnut subjected to different levels of total water supply under field conditions.



(c) (d)

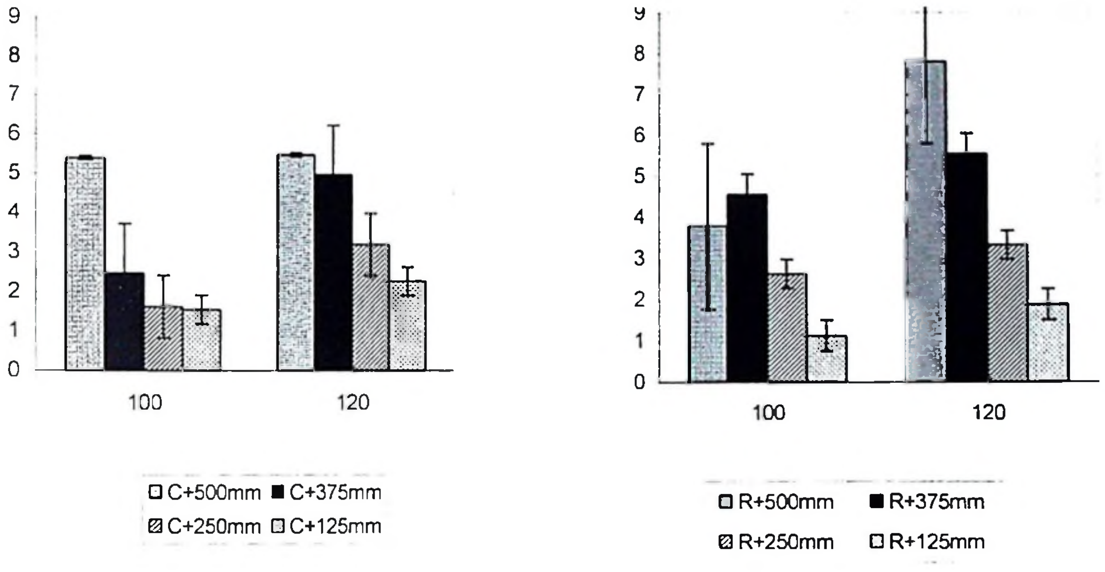
Fig. 5c and 5d. Number of pods per plant for cream (C) and red (R) bambara groundnut subjected to different levels of total water supply under screen house conditions.

The 500mm treatment recorded significantly (P<0.05) higher number of pods per plant than 250 and 125mm treatments. The 125mm treatment recorded the lowest number of pods per plant. There were no significant differences in number of pods between the 500 and 375mm treatments except at 100 DAS where 500mm treatment yielded more pods per plant than the 375mm treatment. On the other hand, there were no significant differences between 250 and 125mm rain equivalent treatments except at 100 DAS for cream and red landraces, under screen house and field conditions respectively where 250mm treatment significantly produced more number of pods than 125mm treatment. The 375 and 250mm treatments did not differ significantly except at 70 DAS for both landraces and 100 DAS for cream landrace under screen house conditions. There were no significant interaction effect between landraces and water levels throughout the growth period.

4.1.8 Pod dry matter

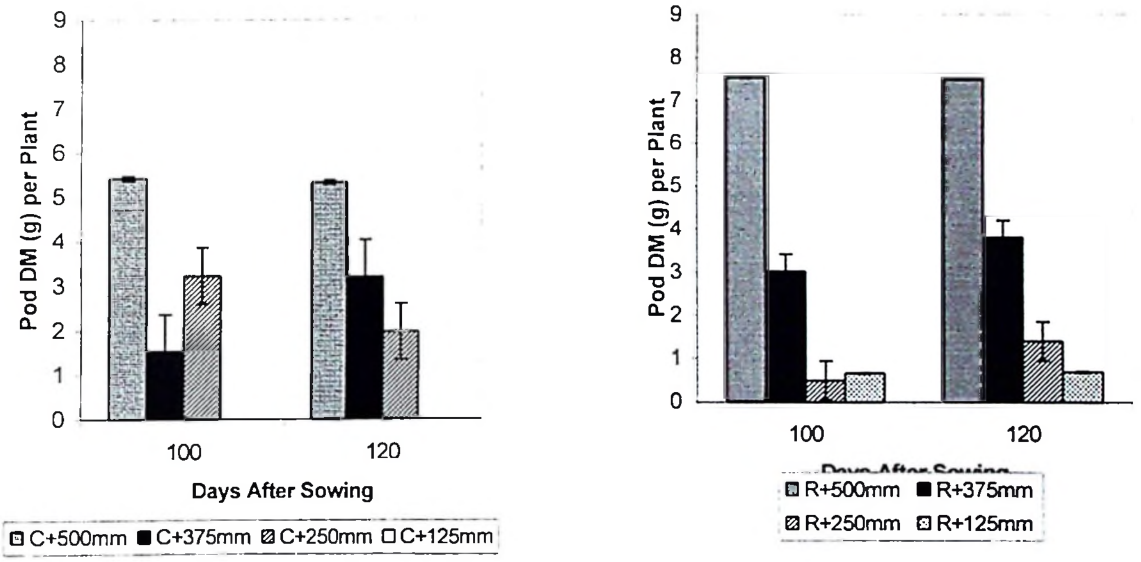
Pod dry matter per plant decreased with decreasing water levels (Figures 6(a) - (d)). Generally, plants grown under field conditions recorded higher pod dry matter per plant than those grown under screen house conditions.

Pod dry matter for 500mm treatment was significantly (P<0.05) higher than that of 250 and 125mm treatments. The 125mm treatment significantly recorded the lowest pod dry



(a) (b)

Fig. 6a and 6b. Pod DM per plant for cream (C) and red (R) bambara groundnut subjected to different levels of total water supply under field conditions.



(c) (d)

Fig. 6c and 6d. Pod DM per plant for cream (C) and red (R) bambara groundnut subjected to different levels of total water supply under screen house conditions.

matter. There were no significant differences in pod dry matter between the 250 and 125mm treatments. At final sampling there was no significant difference in pod dry matter between the 500 and 375mm treatments except for red landrace. The interaction between water levels and landraces was significant only at 100 DAS. where the red seede landrace recorded significantly higher pod dry matter than the cream.

4.1.9 Kernel dry matter

Effect of water levels on kernel dry matter per plant is summarized in Table 9. The trend for kernel dry matter resembled that of pod dry matter. Kernel dry matter increased with increasing water levels. Generally, the red landrace produced more kernel dry matter than cream landrace, although the difference was not significant ($P>0.05$).

Under field conditions the 500 and 375mm treatments produced significantly ($P<0.05$) more kernel dry matter than the 250 and 125mm treatments. There were no significant differences between 500 and 375mm treatments except for the red landrace. Similarly, there were no significant differences between the 250 and 125mm treatments. The interaction between landraces and water levels was not significant.

4.1.10 Shoot dry matter

Figures 7(a) – (d) show the effect of water levels on shoot DM accumulation per plant. Shoot DM accumulation increased with increasing water levels. Plants grown under screen house conditions produced more shoot DM than those grown under field conditions. Red landrace produced more shoot dry matter than cream landrace under field conditions, while under screen house conditions red landrace produced less shoot DM than cream landrace. However, landrace effect was significant only at 70 DAS under screen house conditions and at 100 and 120 DAS under field conditions.

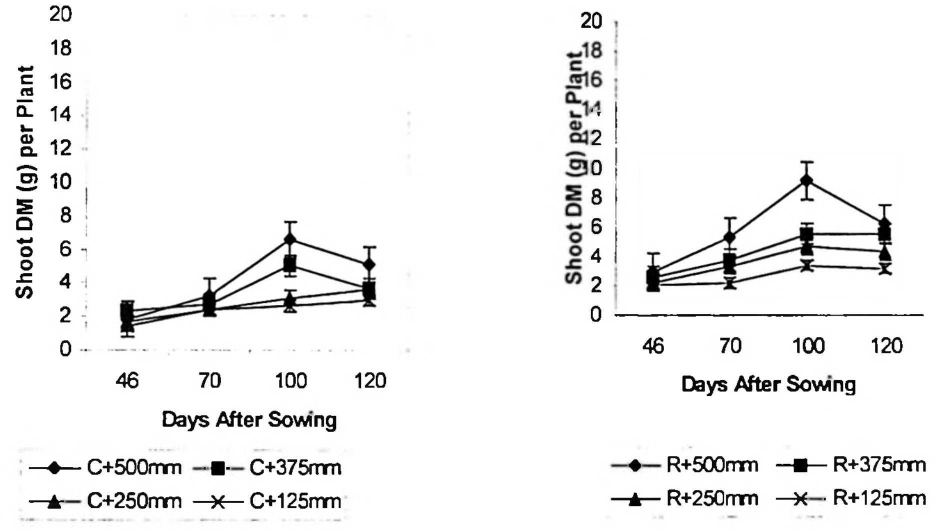
Table 9. Kernel dry matter (g) per plant for bambara groundnut subjected to different levels of total water supply under the field conditions at 120 DAS.

Treatments	Kernel DM***
*C + 500mm	4.42a
C + 375mm	4.05a
C + 250mm	2.52b
C + 125mm	1.91b
**R + 500mm	6.10a
R + 375mm	4.37b
R + 250mm	2.68c
R + 125mm	1.50c
Mean	3.44
SE±	2.53
CV(%)	21.21

* = Cream

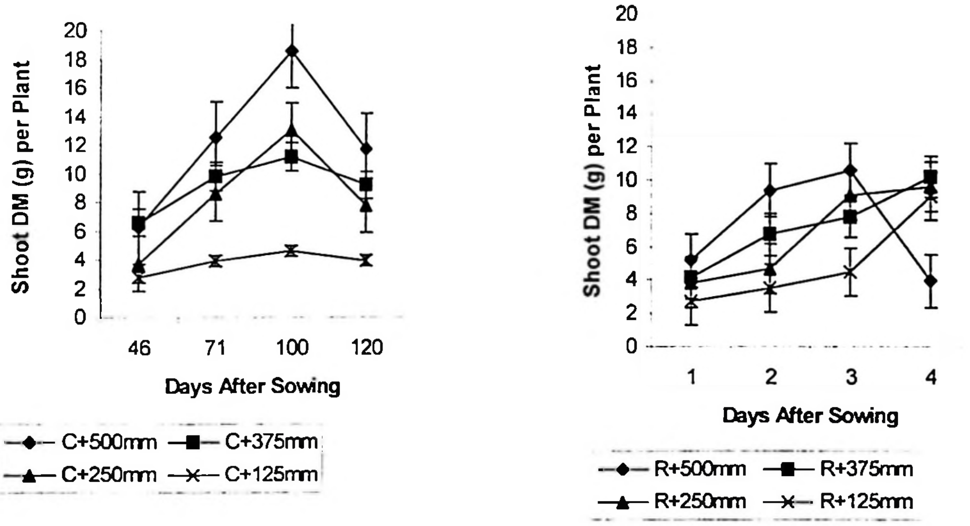
** =Red

***Means in the same column followed by the same latter are not statistically different (P<0.05) following means separation test by Duncan's Multiple Range Test (DMRT).



(a) (b)

Fig. 7a and 7b. Shoot DM for cream (C) and red (R) seeded bambara groundnut subjectec to different levels of total water supply grown under field conditions.



(c) (d)

Fig.7c and 7d. Sh DM for cream (C) and red (R) seeded bambara groundnut subjected to different levels of total water supply grown under screen house conditions.

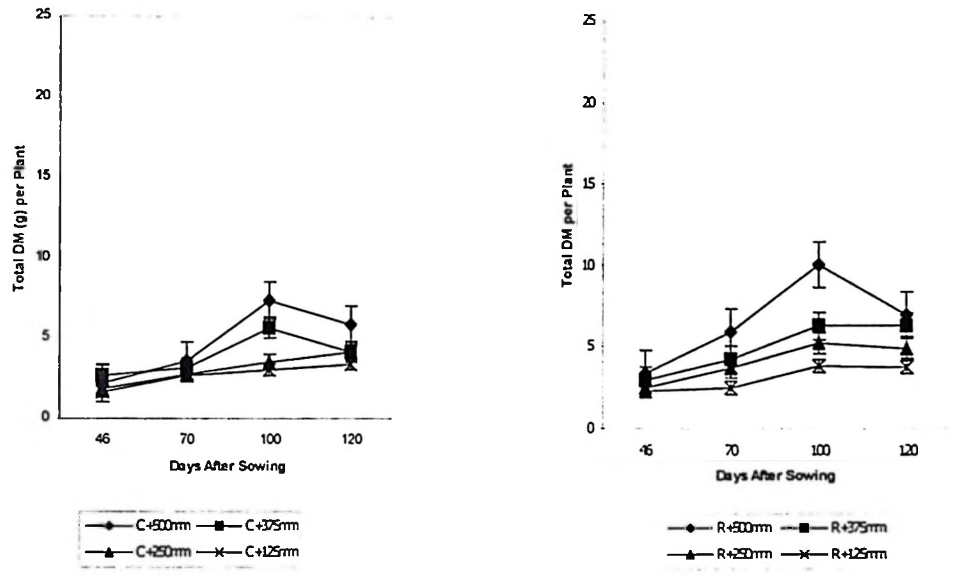
For the plants grown under field conditions, there were no significant (P>0.05) differences in shoot DM upto 70 DAS, except for the red landrace at 70 DAS where the 500mm treatment produced significantly higher shoot DM than the 250 and 125mm treatments. Differences due to the water levels were revealed at 100 DAS. During this time the 500mm treatment produced significantly the highest shoot DM while the 125mm treatment recorded the lowest. There were no significant differences between the 375 and 250mm treatments and between the 250 and 125mm treatments for cream and red landraces, respectively. At final harvest, there were no significant differences between water levels except for the 500mm treatment, which significantly produced more shoot DM than the 125mm treatment.

For the crop grown under screen house conditions three patterns of shoot DM accumulation were vivid. The 500mm treatment significantly (P<0.05) produced the highest shoot DM except at 46 and 120 DAS where its difference with the 375mm treatment was not significant. The 125mm treatment yielded significantly the lowest shoot DM of all other water levels. There were no significant differences between the 375 and 250mm treatments and shoot DM produced by the two water levels lied between that of 500 and 125mm treatments.

4.1.11 Total plant dry matter.

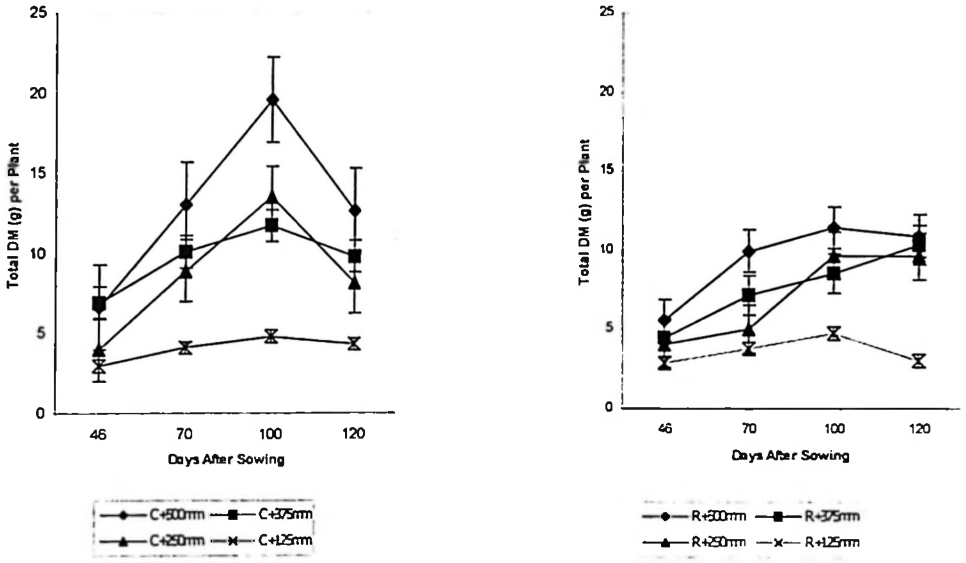
The trend for total dry matter per plant was similar to that of shoot DM accumulation. Plant DM increased with increased water levels (Fig. 8a – d). Total plant DM produced by plants under screen house conditions was higher than those under field conditions. Under field conditions the red seeded landrace produced significantly higher total plant DM than the cream seeded landrace while under the screen house the vice versa was observed. However, landrace effect was not significant ($p<0.05$) at 70 DAS under screen house and at 100 and 120 DAS under field conditions.

Effect of water levels on total plant DM accumulation for bambara groundnut raised under field conditions was not significantly ($P>0.05$) different before 70 DAS. At 70 DAS, the 500mm treatment accumulated significantly higher total plant DM for the red seeded landrace than the 250 or 125mm treatments. The 375mm treatment produced higher total plant DM than the 125mm treatment at 70 DAS. At 100 DAS the 500mm treatment DM accumulation was significantly highest while lowest was recorded with the 125mm treatment. The 375mm treatment recorded significantly more total plant DM than the 250 and 125mm treatments. There were no significant differences between the 250 and 125mm treatments. At harvest (120 DAS), the 500mm produced significantly higher total plant DM than other water levels. There were no significant differences in total plant DM between other water levels except for red landrace where the 375mm treatment significantly produced higher total plant DM than the 250 and 125mm treatments.



(a) (b)

Fig.8a and 8b. Total plant DM for cream ((seeded bambara groundnut subjected to different levels of total water supply grown under field conditions.



(c) (d)

Fig. 8c and 8d. Total plant DM for cream (C) and red (R) seeded bambara groundnut subjected to different levels of total water supply grown under screen house condition

Total plant DM produced by plantsgrown under screen house conditions generally fell under three main groups. The 500mm treatment accumulated significantly ($P<0.05$) highest total plant DM except at 46 DAS for the cream landrace, and at 120 DAS for the red landrace where there were no significant differences with the 375mm treatment, and the 375 and 250mm treatments, respectively. The 125mm treatment recorded the lowest total plant DM except at 46 DAS where the 250 and 125mm treatments did not differ significantly. The 375 and 250mm treatments produced significantly more total plant DM than the 125mm treatment except at 46 DAS for cream landrace, where the 250 and 125mm treatments did not differ significantly. There were no significant differences between the 375 and 250mm treatments except at 46 DAS for cream landrace, where the 375mm treatment recorded significantly more total plant DM than the 250mm treatment. The interaction between landraces and water levels was not significant throughout the experimental period.

4.1.12 Pod yield

The effect of water levels on pod yield at final harvest (tons per hectare) indicated that pod yield increased with an increase in water levels (Table 10). The red seeded landrace yielded more pods than the cream landrace at all water levels, except for 125mm. However, there was no significant ($P>0.05$) landrace effect.

Pod yield for the 500 and 375mm treatments were significantly ($P<0.05$) higher than those of the 250 and 125mm treatments. The 125mm treatment recorded the lowest pod yield, which was not significantly different from that of the 250mm treatment. Similarly, there were no significant differences between the 500 and 375mm treatments, except for red landrace under screen house conditions. The interaction between landraces and water levels were not significant throughout the growth period.

Table 10. Pod yield (Tons/Ha) and shelling percentages for bambara groundnut subjected to different water levels under field conditions.

Treatments	Pod yield (t/ha)*	Shelling percentage*
**C + 500mm	1.83a	80.25a
C + 375mm	1.66a	81.49a
C + 250mm	1.07b	78.61a
C + 125mm	0.76b	82.94a
***R + 500mm	2.60a	78.24a
R + 375mm	1.85b	79.14a
R + 250mm	1.11c	80.38a
R + 125mm	0.63c	75.77a
Mean	1.55	78.38
SE±	0.18	3.46
CV(%)	22.12	7.54

*Means in the same column followed by the same latter are not statistically different (P<0.05) following mean separation test by Duncan's Multiple Range Test (DMRT).

**C = Cream landrace

***R = Red landrace

4.1.13 Shelling percentage

Effect of different levels of total water supply on shelling percentage is shown in Table 10. No consistence pattern of shelling percentage due to growing conditions was observed in this study. There was neither significant (P>0.05) difference due to landrace effect neither amount of water supplied.

4.1.14 Correlation coefficients

This study showed (Table11) that pod yield for both landraces was positively correlated with leaf number, pod number, leaf weight, stem weight and root weight at 70, 100 and 120 DAS. On the other hand flower number was negatively correlated with pod yield for all landraces and at all sampling times.

Table 11. Correlation coefficients between pod yield and different parameters for bambara groundnut grown at different water levels of total water supply under field conditions.

	Cream Landrace			Red Landrace		
	70 DAS	100 DAS	120 DAS	70 DAS	100 DAS	120 DAS
Leaf No.	0.45^{NS}	0.37^{NS}	0.31^{NS}	0.80**	0.50^{NS}	0.64*
Flower No.	-0.15^{NS}	-0.69*	-0.59*	-0.54^{NS}	-0.53^{NS}	-0.18^{NS}
Pod No.	0.74**	0.45^{NS}	0.94**	0.65*	0.69*	0.96**
Leaf Wt.	0.60*	0.57^{NS}	0.61*	0.80**	0.35^{NS}	0.73**
Stem Wt.	0.63*	0.61*	0.85**	0.83**	0.22^{NS}	0.41^{NS}
Root Wt.	0.55^{NS}	0.69*	0.85**	0.76*	0.55^{NS}	0.70**

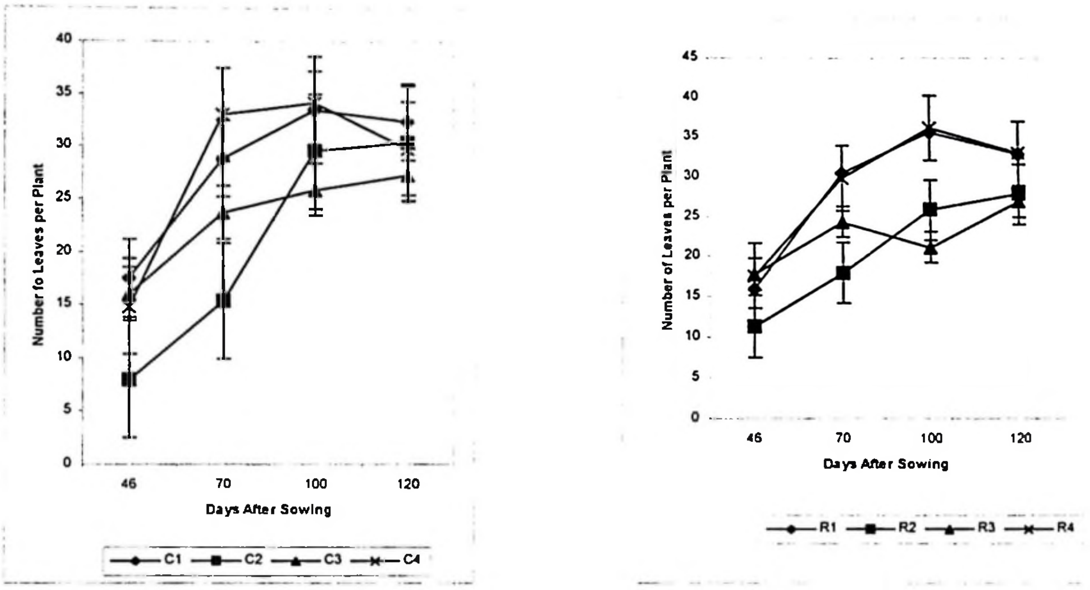
NS = Non significant ** = Significant ($P<0.1$) * = Significant ($P<0.05$)

4.2 Effect of water stress imposed at different growth stages on growth and development of bambara groundnuts.

4.2.1 Number of leaves

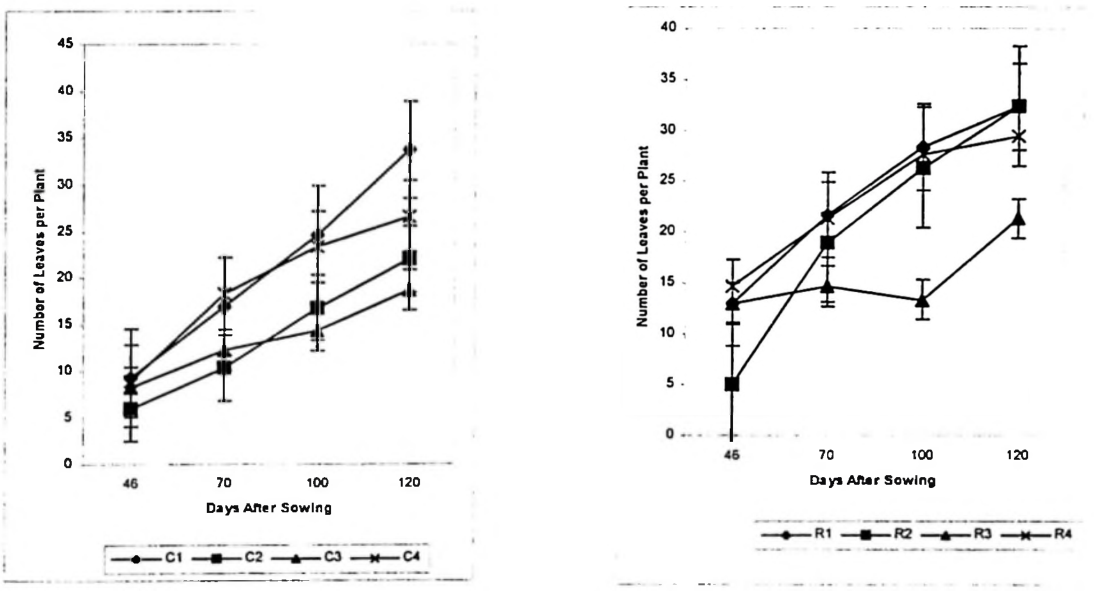
Water stress imposed at vegetative, flowering and pod-filling stages reduced number of leaves per plant as compared to the control unstressed treatment (Fig. 9(a) - 9(d). The responses were similar in the field and screen house conditions and for both landraces. Both the landraces and the interaction between landrace and water stress were not significantly different ($P>0.05$) under field conditions (fig. 9a & 9b). However, under screen house conditions the red seeded landrace recorded a significantly large number of leaves per plant than cream seeded landrace at 70 DAS. The interaction between landrace and water stress was significant only at 46 DAS.

Water stress imposed at vegetative (21 – 46 DAS) and flowering (46 – 70 DAS) stages significantly ($P<0.05$) reduced the number of leaves per plant as compared to unstressed. Number of leaves produced during the treatment period was higher for plants stressed at vegetative than those stressed at flowering stage. There were no significant differences in terms of number of leaves produced by plants stressed during pod filling stage (70 – 100 DAS) and the control during the treatment period. At physiological maturity stage (120 DAS) there were no significant differences among the stressed treatments. On the other hand, the difference between the stressed treatments and the control was not significant except for cream landrace under screen house conditions. In this case water stress



(a) (b)

Fig. 9a and 9b. The effect of water stress imposed at different growth stages on leaf number for cream (C) and red (R) seeded bambara gruondnut grown under field conditions



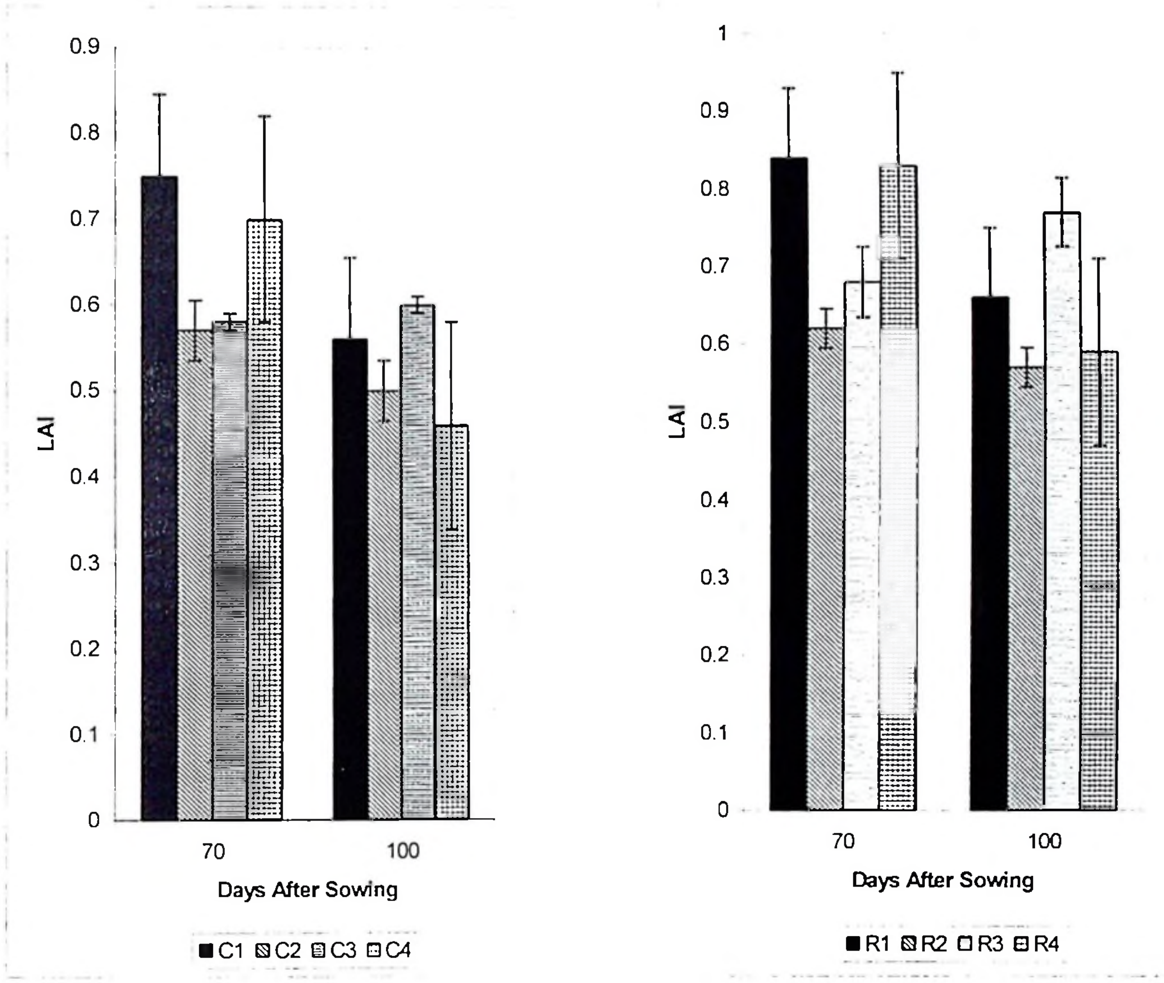
(c) (d)

Fig 9c and 9d. The eefect of water stress imposed at different growth stages on number of leaves for cream (C) and red (R) seeded bambara groundnut grown under screen house conditios.

imposed at pod filling stage significantly reduced number of leaves as compared to the control. After relieving water stress (when watering resumed normally), leaf initiation for the previously stressed treatments was significantly higher for plants stressed at vegetative stage, followed by those stressed at flowering stage. Water stress imposed at pod filling stage recorded the lowest leaf initiation rate.

4.2.2 Leaf area index (LAI)

Figures 10a and 10b summarize the effect of water stress imposed at vegetative, flowering and pod filling stages on LAI at 70 and 100 DAS. Generally, water stress imposed at any of the three growth stages decreased LAI at different magnitudes. There was no significant ($P>0.05$) difference due to landrace effect, or the interaction of landrace and water stress throughout the growth period. However, the red landrace produced relatively higher LAI than the cream landrace. during the treatment periods, LAI were significantly ($p<0.05$) lower than those of unstressed treatments. After resuming normal watering, LAI increased sharply between 70 to 100 DAS for water stress imposed at flowering stage (Fig. 10a and 10b). During the period between 70 and 100 DAS there was a decline in LAI for both the stressed and unstressed treatments except for plants stressed at flowering stage. The highest LAI value for plants stressed at vegetative and pod-filling stages was attained at 70 DAS while for those stressed at flowering, the highest value was attained at 100 DAS.



(a) (b)

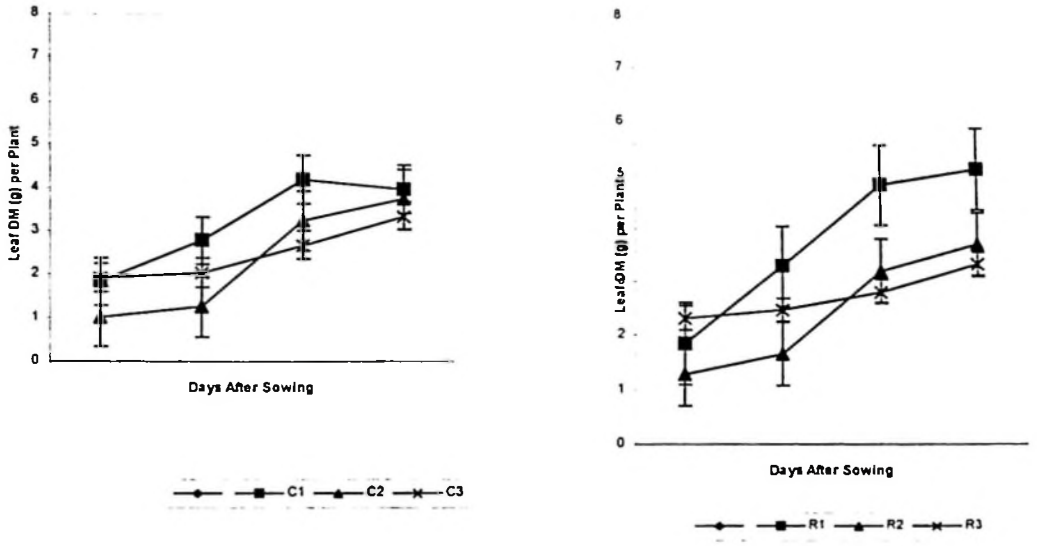
Fig. 10a and 10b. The effect of water stress imposed at different growth stages on LAI for Cream (C) and red (R) seeded bambara groundnut grown under field conditions

4.2.3 Leaf dry matter

The effect of water stress imposed at vegetative, flowering and pod filling stages on leaf dry matter accumulation per plant is presented in Figures 11a - 11d. Water stress imposed at any of the three growth stages reduced leaf dry matter per plant. There was no significance ($P>0.05$) effect due to landrace at all sampling periods. Similarly, the interaction between landrace and water stress was not significant.

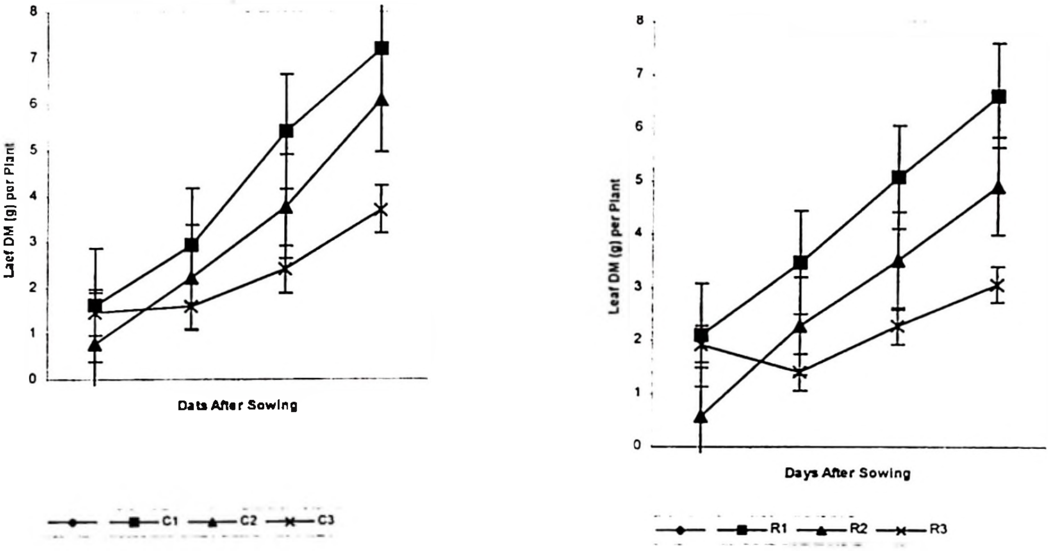
During the treatment period, water stress at vegetative and flowering stages significantly ($P<0.05$) reduced leaf dry matter as compared to the well-watered (control) treatment. Water stress at pod filling stage did not reduce leaf dry matter significantly as compared to the well-watered control. The responses were similar both in the field and screen house for both landraces.

Leaf DM at physiological maturity stage revealed no significant differences among the water treatments and also between water treatments and unstressed treatment under field conditions. Under screen house conditions, water stressed treatments recorded significantly less leaf DM as compared to the control. There were no significant differences among the stressed treatments. Generally, water stress imposed at flowering resulted to lowest leaf DM per plant, followed by water stress at vegetative stage. Water stress imposed at pod filling stage produced the least effect on leaf DM accumulation.



(a) (b)

Fig. 11a and 11b. The effect of water stress imposed at different growth stages on leaf DM for cream (C) and red (R) seeded bambara groundnut grown under field conditions.



(c) (d)

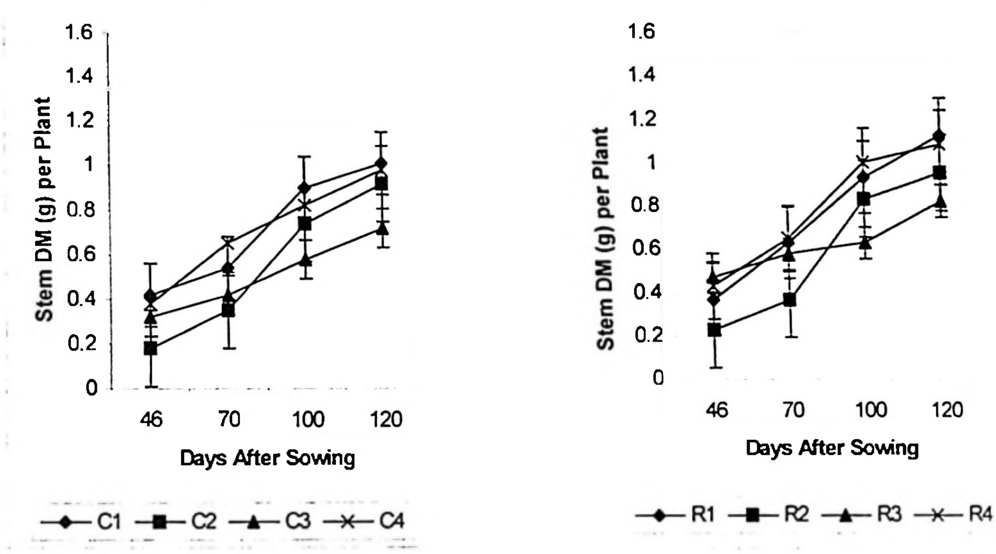
Fig. 11c and 11d. The effect of water stress imposed at different growth stages on leaf DM for cream (C) and red (R) seeded bambara groundnut grown under screen house conditions.

The rate of DM matter production after resuming normal watering (recovery) was rapid for plants stressed at vegetative stage, under screen house conditions (Fig. 11c and 11d). The rate was relatively lower under field conditions (Fig.11a and 11b). Water stress imposed at pod filling stage recorded the lowest recovering rate, while those plants water stressed at flowering was between the two. Although the rate was lower for plants stressed at pod filling stage, this treatment maintained more leaf DM matter than other treatments, followed by those stressed at vegetative.

4.2.4 Stem dry matter

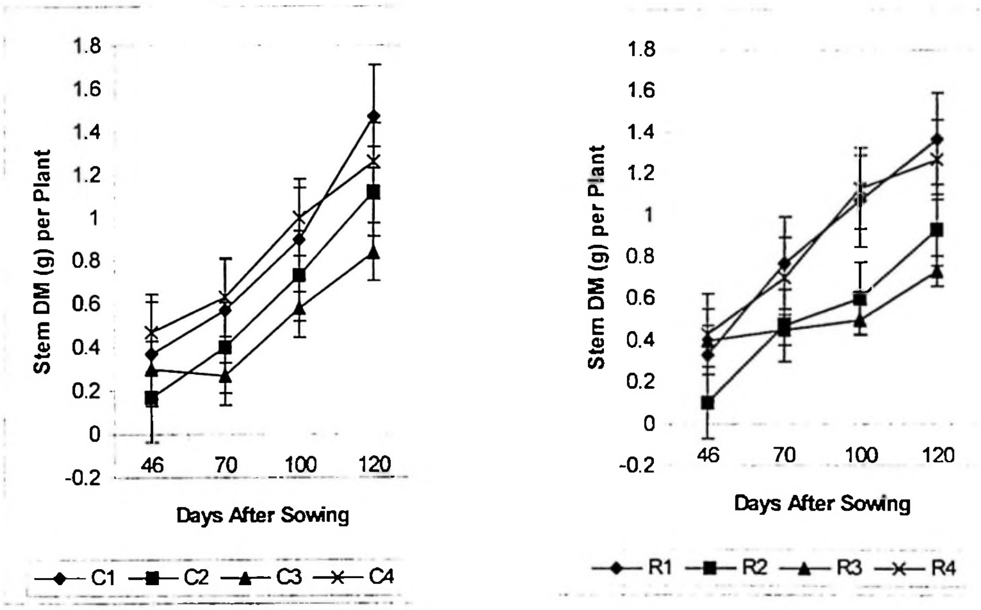
Effects of water stress imposed at vegetative, flowering and pod filling stages on stem DM are presented in Figures 12a – 12d. Water stress imposed at any of the studied stages generally reduced stem DM per plant compared to the control. The exception was for plants stressed at pod filling stage, which in most cases had stem DM similar to the control. Under field conditions, the cream seeded landrace accumulated more stem DM per plant than the red seeded landrace, while under screen house conditions red seeded landrace accumulated more stem DM than the cream seeded landrace.

Water stress imposed at vegetative and flowering stages significantly ($P<0.05$) reduced stem DM accumulation during the treatment periods. On the other hand, there were no significant differences between the plant water stressed at pod filling stage and those well watered during the treatment period. At physiological maturity, there were no



(a) (b)

Fig. 12a and 12b. The effect of water stress imposed at different growth stages on stem DM for cream (C) and red (R) seeded bambara groundnut grown under field conditions.



(c) (d)

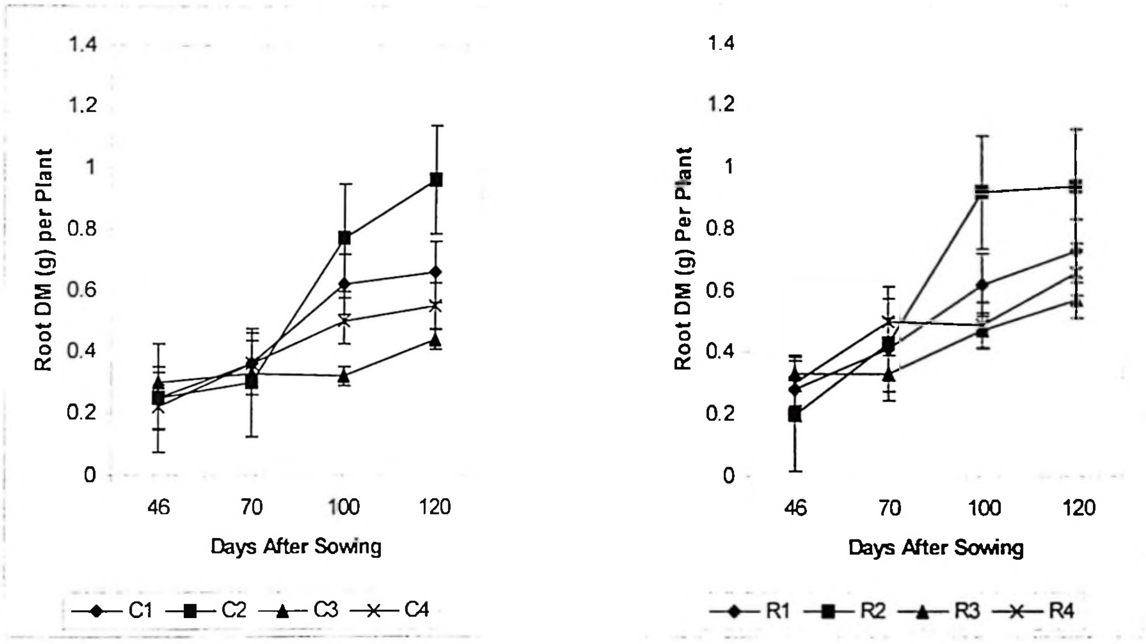
Fig. 12c and 12d. The effect of water stress imposed at different growth stages on stem DM for cream (C) and red (R) seeded bambara groundnut grown under screen house conditions.

significant differences in stem DM among the stressed treatments and also between tressed treatments and the control for the cream landrace (Fig.12a and 12c). For red landrace, water stress imposed at vegetative and flowering stages significantly reduced stem DM accumulation as compared to the control and those plants water stressed at pod filling stage (Fig.12b and 12d). However, there were no significant differences on stem DM accumulation between plants water stressed at pod filling stage and the control, or between those water stressed at vegetative and at flowering stage.

Generally, water stress at flowering stage resulted in the lowest stem DM followed by water stress at vegetative and lastly water stress at pod filling stage. Stem DM production after relieving water stress followed the trend of leaf number and leaf DM, but the rate was relatively slower for stem DM accumulation. This effect was more distinct for plants water stressed at vegetative and flowering stages, such that DM accumulation 30 days after relieving water stress was still significantly lower than the control.

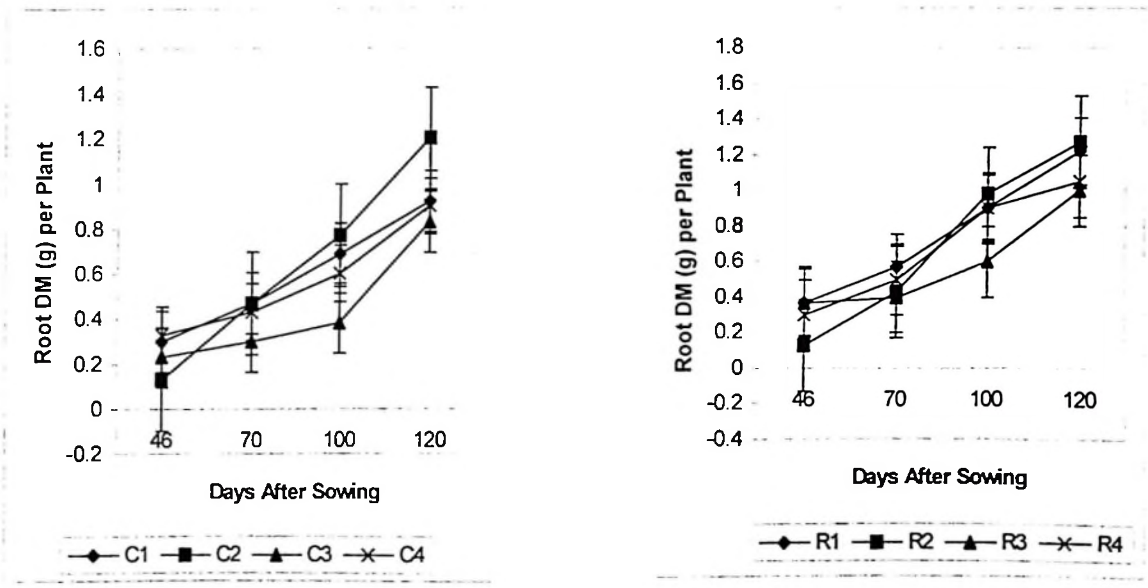
4.2.5 Root dry matter

Effect of water stress imposed at vegetative, flowering and pod filling stage on root DM accumulation is presented in Figures 13a – 13d. There were no significant (P>0.05) differences in root dry matter accumulation between the landraces both in the field and screen house conditions. However the, red seeded landrace accumulate more root DM



(a) (b)

Fig. 13a. The effect of water stress imposed at different growth stages on root DM for cream (C) and red (R) seeded bambara groundnut grown under field conditions.



(c) (d)

Fig. 13c and 13d. The effect of water stress imposed at different growth stages on root DM for cream (C) and red (R) seeded bambara groundnut grown under screan house conditions.

than cream (Fig. 13b, 13d, 13a, 13c). The interaction effect between landrace and water stress was observed only at 70 DAS under screen house conditions. Generally, root DM was higher under screen house than under field conditions (Fig.13c,13d, 13a, 13b). During the treatment periods, water stress imposed at vegetative and flowering stages significantly ($P<0.05$) reduced root dry matter as compared to the control. Water stress imposed at pod filling stage did not significantly affect root dry matter per plant during the treatment period. After relieving water stress (watering normally) a revamped root dry matter accumulation was observed and this was more conspicuous for the plants water stressed during the vegetative stage. For plants water stressed at other stages, root recovery rate was relatively slow. Generally, water stress imposed at vegetative stage resulted in highest root dry matter production. In most cases root dry matter accumulation was higher for this treatment than the control, followed by water stress at pod filling stage. Water stress imposed at flowering stage gave the lowest root DM.

4.2.6 Days to flowering

Water stress imposed at vegetative stage (21 – 46 DAS) did not significantly affect the number of days to flowering. As such flowering started at 39 DAS in all treatments. Neither the landrace effect nor its interaction with water stress were significant ($P>0.05$) in terms of number of days to flowering.

4.2.7 Number of flowers

Generally, water stress imposed at any of the three growth stages reduced number of flowers per plant. There were no significant differences on number of flowers per plant due to landrace effect or the interaction of landrace and water stress. The red landrace, however, produced relatively more flowers than cream landrace. The crop grown under field conditions produced more flowers than those grown under screen house conditions.

The number of flowers per plant was significantly ($P<0.05$) reduced by water stress imposed at vegetative and flowering stages during the treatment periods under screen house conditions for both landraces. Water stress imposed at pod filling stage did not significantly affect the number of flowers per plant. Under field conditions, on the other hand, the number of flowers per plant was significantly reduced by water stress imposed only at vegetative stage during the treatment period.

After relieving water stress, new flushes of flowers were observed in all treatments. Plants water stressed at vegetative stage produced more flowers, followed by those water stressed at flowering stage and finally by those water stressed at pod filling stage. Irrespective of when water stress was imposed, the crop continued to flower up to physiological maturity (120 DAS). At this stage, plants water stressed at vegetative and flowering stages recorded a significantly higher number of flowers per plant than those stressed at pod filling stage.

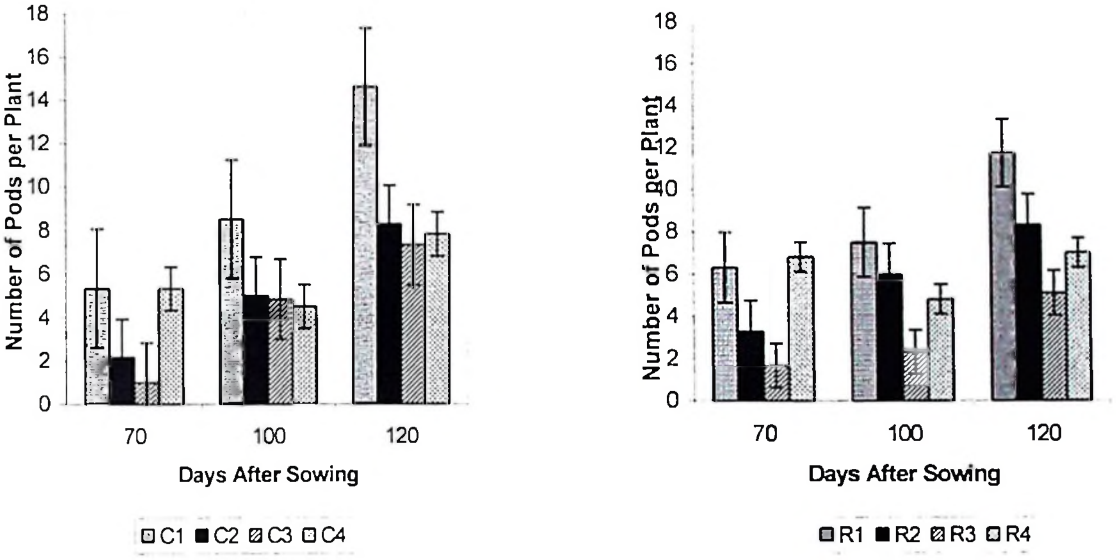
4.2.8 Number of pods

Results on the effect of water stress imposed at vegetative, flowering and pod filling stages are summarized in Figures 14a – 14d. Water stress imposed at any of the three growth stages reduced the number of pods per plant. Neither the landrace nor the interaction effects of landrace and water stress were significant (P>0.05). However, the red seeded landrace produced relatively more pods per plant than the cream under screen house conditions (Fig.14c and 14d) while the cream produced more pods under field conditions (Fig. 14a and 14b).

At physiological maturity, all water-stressed plants recorded significantly fewer number of pods per plant than the unstressed control. Among the treatments, stress imposed at flowering stage resulted in the lowest number of pods, except with the cream landrace under field conditions where the reduction had no significant effect (P>0.05) (Fig. 14a). Water stress imposed at vegetative stage produced the least effect compared with water stress at pod filling stage. However, the differences between plants stressed at vegetative and pod filling stages was not significant.

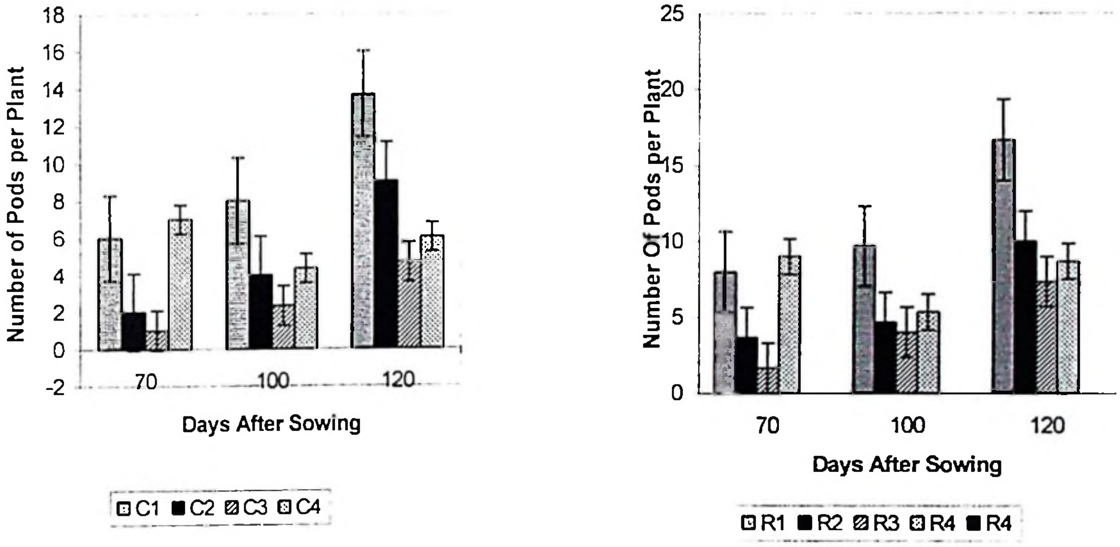
4.2.9 Pod dry matter

Effect of water stress imposed at vegetative, flowering and pod filling growth stages on pod DM per plant are summarized in Figures 15(a) – 15(d). Pod DM accumulation per plant at any of the three growth stages followed a trend similar to that observed for the number of pods per plant.



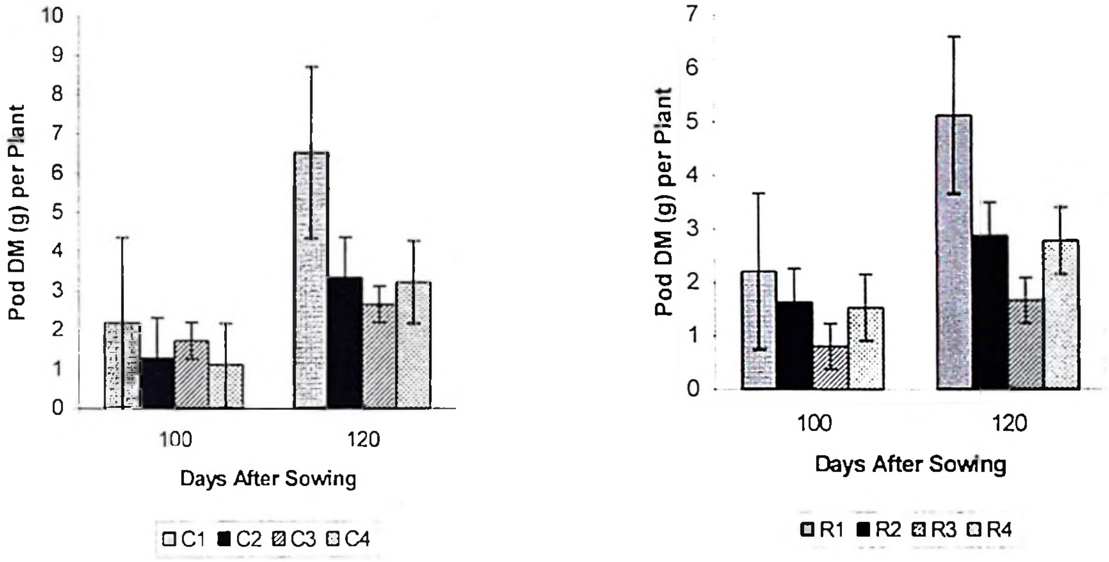
(a) (b)

Fig. 14a and 14b. The effect of water stress imposed at different growth stages on number of pods for cream (C) and red (R) seeded bambara groundnut grown under field conditions



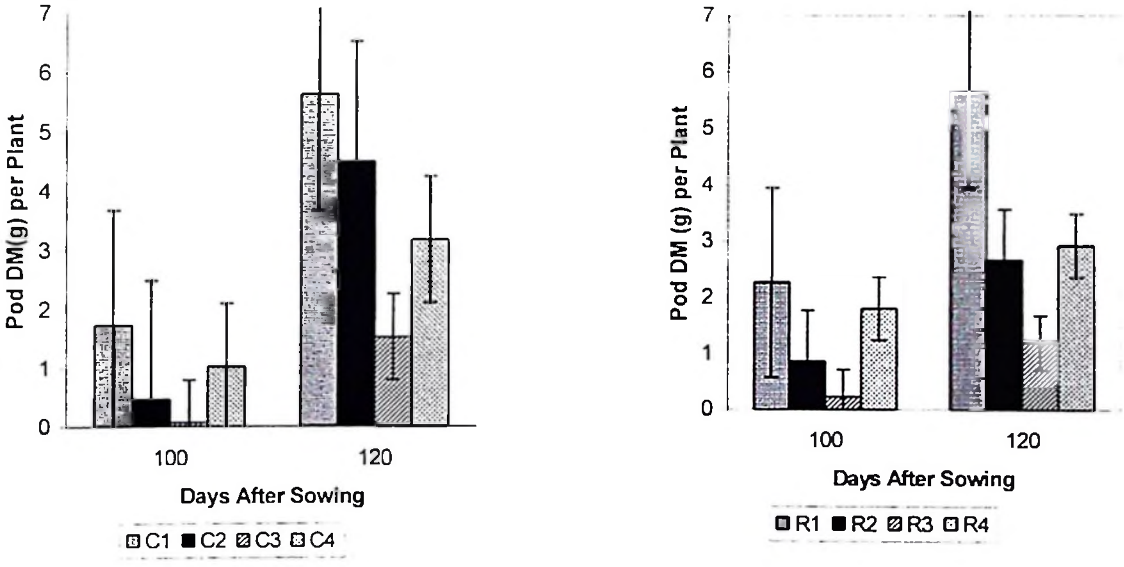
(c) (d)

Fig. 14c and 14d. The effect of water stress imposed at different growth stages on number of pods for cream (C) and red (R) seeded bambara groundnut grown under screen house conditions



(a) (b)

Fig. 15a and 15b. The effect of water stress imposed at different growth stages on pod DM for cream (C) and red (R) seeded bambara groundnut grown under field conditions



(c) (d)

Fig. 15c and 15d. The effect of water stress imposed at different growth stages on pod DM

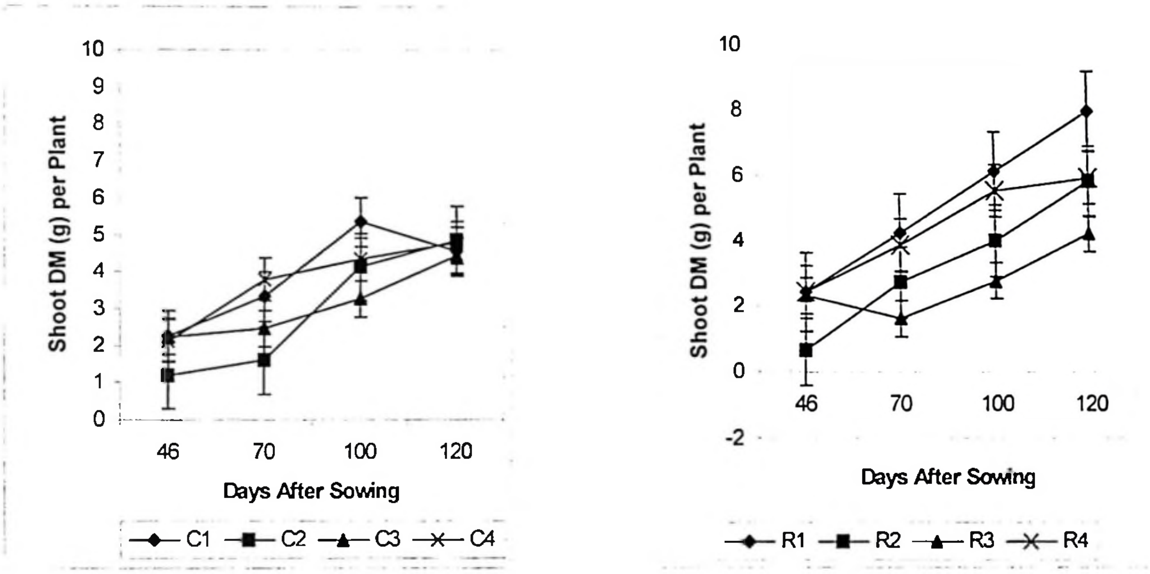
4.2.10 Shoot dry matter

Shoot DM for plants subjected to water stress at vegetative, flowering and pod filling stages is presented in Figures 16(a) – 16(d). Shoot DM production under screen house conditions was relatively higher than that under field conditions (Fig. 16a, 16b, 16c, 16d). There were neither significant ($P>0.05$) differences due to landrace effect nor due to the interaction between landrace and water stress. However, the red seeded landrace produced relatively higher shoot DM than cream under screen house conditions (Fig.16c and 16d). Under field conditions shoot DM accumulation by the two landraces was similar (Fig. 16a and 16b).

Water stress imposed at early growth stages (i.e. at vegetative and flowering) significantly ($P<0.05$) reduced shoot DM both in the field and screen house conditions. Water stress imposed at pod filling stage did not significantly reduce shoot DM per plant.

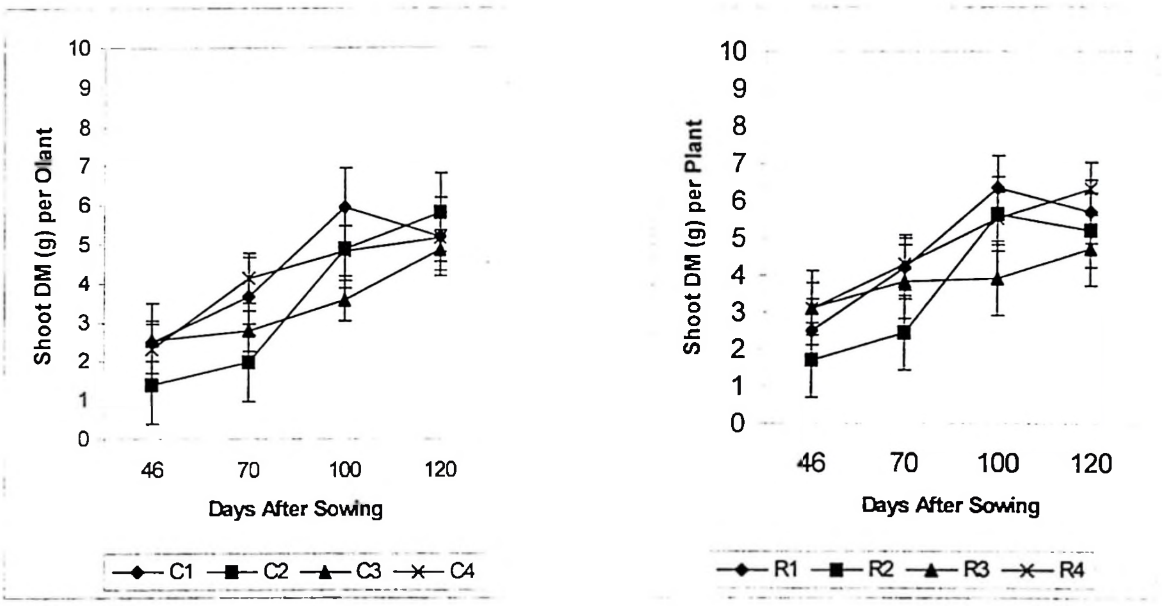
After resuming normal watering for the previously water stressed treatments, rapid shoot DM accumulation was observed. The rate of shoot DM production was highest for plants water stressed at vegetative stage and lowest for plants water stressed at flowering stage.

At physiological maturity, water stress significantly ($P<0.05$) reduced shoot DM production under screen house conditions as compared to the control (Fig.16c and 16d).



(a) (b)

Fig. 16a and 16b. The effect of water stress imposed at different growth stages on shoot DM for cream (C) and red (R) seeded bambara groundnut grown under field conditions.



(c) (d)

Fig. 16c and 16d. The effect of water stress imposed at different growth stages on shoot DM for cream (C) and red (R) seeded bambara groundnut grown under screen house conditions

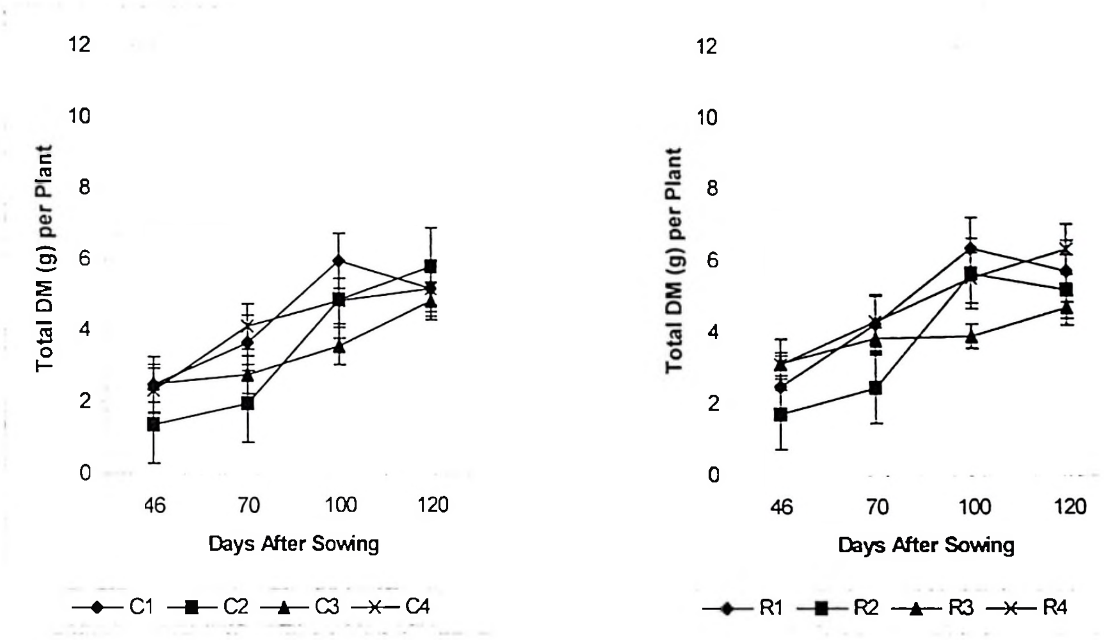
Among the water stressed treatments, there were no significant differences under both growing conditions and landraces. Irrespective of growing conditions, water stress imposed at flowering recorded the lowest shoot DM per plant while stress at pod filling stage resulted to the least effect.

4.2.11 Total plant dry matter.

Figures 17a – 17d summarizes the effect of water stress imposed at vegetative, flowering and pod filling stages on total plant DM of bambara groundnut plants. Effect of water stress imposed at any of the three growth stages on total plant DM accumulation, followed a similar trend observed in the shoot dry matter accumulation per plant.

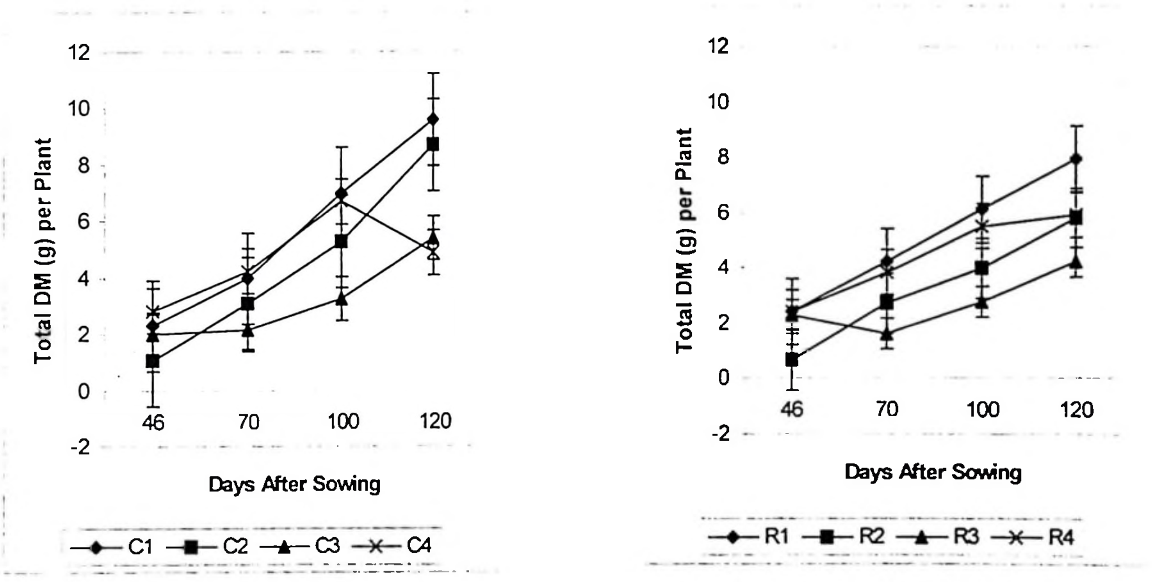
4.2.12 Pod yield.

The effect of water stress imposed at vegetative, flowering and pod filling stages on pod yield, at final harvest in tons per hectare and shelling percentage is shown in Table 12. Water stress imposed at any of the three growth stages significantly ($P<0.05$) reduced pod yield per unit area. There was no significant landrace effect, but the cream landrace yielded relatively higher than the red landrace. Similarly, there was no significant interaction effect between landrace and water stress throughout the growth period. Among the stressed treatments, water stress imposed at flowering stage recorded the lowest pod yield followed by water stress at pod filling stage. Water stress at vegetative resulted to the least effect on pod yield per hectare.



(a) (b)

Fig. 17a and 17b. The effect of water stress imposed at different growth stages on total plant DM for cream (C) and red (R) seeded bambara groundnut grown under field conditions.



(c) (d)

Fig.17c and 17d. The effect of water stress imposed at different growth stages on total plant DM for cream (C) and red (R) seeded bambara groundnut grown under screen house conditions.

4.1.13 Correlation coefficients

Correlation coefficients of leaf number, leaf weight, stem weight, root weight, flower number and pod number to pod yield for bambara groundnut subjected to water stress at vegetative, flowering and pod filling growth stages are summarized in Table 13. These variables correlated positively to pod yield, except flower number, which was negatively correlated at 100 DAS for cream landrace and at 120 DAS for both landraces.

Table 12. Pod Yield (tons/ha) and shelling percentage bambara groundnut subjected to water stress at different growth stages under field conditions.

Treatment	Pod yield (t/ha)*	Shelling percentage*
**C1 + NS	2.18a	81.32a
C 2 + SV	1.11b	76.09a
C 3 + SF	0.89b	76.59a
C 4 + SP	1.07b	82.08a
***R1 + NS	1.71a	78.73ab
R2 + SV	0.96b	74.22b
R3 + SF	0.55c	76.94ab
R4 + SP	0.93b	80.62a
Mean	1.21	78.32
SE±	0.11	1.92
CV(%)	15.44	4.23

*Means in the same column followed by the same letter are not statistically different (P<0.05) following mean separation test by Dancun's Multiple Range Test (DMRT)

** C = Cream seeded Landrace

***R = Red seeded Landrace

Table 13. Correlation coefficients of different parameters and yield of bambara groundnut plants water stressed at different growth stages as grown under field conditions.

	Cream Landrace			Red Landrace		
	70 DAS	100 DAS	120 DAS	70 DAS	100 DAS	120 DAS
Leaf No.	0.61*	0.74*	0.53^{NS}	0.70*	0.67*	0.59*
Flower No.	0.66*	-0.19^{NS}	-0.16^{NS}	0.16^{NS}	0.09^{NS}	-0.80**
Pod No.	0.33^{NS}	0.78*	0.94**	0.63*	0.86**	0.87**
Leaf Wt.	0.56^{NS}	0.56^{NS}	0.68*	0.81**	0.74*	0.81**
Stem Wt.	0.57^{NS}	0.62*	0.62*	0.69*	0.46^{NS}	0.76**
Root Wt.	0.53^{NS}	0.57*	0.75**	0.35*	0.72**	0.72**

NS = Non significant * = Significant ($P<0.01$) ** = Significant ($P<0.05$)

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5.0 DISCUSSION

5.1 Vegetative growth

Although not statistically different, the fact that cream landrace had lower emergence percentage than red landrace suggests that the cream landrace might have absorbed less water than the red landrace during the 24-hour soaking period. The red landrace might have imbibed enough water to soften the normally hard seed coat within the period of 24 hours. Alternatively, the red landrace could be having a relatively softer seed coat than the cream landrace, which allowed greater rates of imbibition, and thus a faster emergence rate than the cream landrace.

The decrease in the number of leaves per plant with decreasing water levels and water stress at any of the three growth stages revealed the fact that adequate soil moisture is one of the prerequisite conditions for optimum leaf initiation during bambara groundnut growth. In many bambara groundnut-growing areas the crop is grown as the second crop, usually as an intercrop component. As a result, in most cases the crop succumbs water deficit, leading to not only poor crop establishment but also to reduced plant growth.

Although bambara groundnut is known to thrive well under water deficit conditions, it attain optimum growth when water supply is adequate. Chavula (1991), Mwandemele

(1996) and Collinson *et al.* (1996) reported that high soil moisture content might restrict leaf production due to anaerobic conditions. It is worthwhile to note that soil properties play a major role for normal plant growth. Good soil permeability allows water to penetrate deep in the profile, thereby preventing waterlogging conditions, which may result to anaerobic conditions. In this study, the highest number of leaves obtained under high water levels suggests that rainfall up to 500mm per growing season could allow fair growth of bambara groundnut, provided that the soil is permeable enough to prevent waterlogging conditions.

Higher leaf number for the red landrace than thecream landrace may suggest genetic superiority of the red landrace over the cream landrace. On the other hand, more leaves per plant for well-watered plants grown under screen house than field conditions might be due to the fact that water availability to the plants was more favourably controlled in the screen house than in the field. Differences in air temperatures might have also contributed to the observed differences. If other factors are maintained constant, low temperatures tend to reduce leaf initiation rate. During the study period, high temperature was experienced under screen house conditions compared to field conditions (Appendix 1 and 2). Consequently, leaf initiation rate was high under screen house conditions, resulting to greater leaf number per plant than under field conditions.

Higher number of leaves for plants stressed at vegetative than at flowering stage could be associated with the fact that before imposing water stress, both the pots in the screen house and field plots were fully charged with water upto 20 DAS. Therefore, the actual water deficit lasted for relatively fewer days towards the end of the vegetative stage. Another reason is that, at this stage the plants were relatively younger and smaller, such that major part of assimilates produced were allocated to vegetative growth.

The fact that LAI followed a similar trend observed for the number of leaves, suggest that appropriate water supply was important not only for leaf initiation, but also for leaf expansion. Total LAI and its ability to intercept light depend on, among other factors, the number of leaves produced per plant and size of individual leaves.

Differences in air temperature between screen house and field conditions could have led to differences in leaf expansion rate during the growing periods. Throughout the months of February to May, when the screen house experiment was conducted, the mean ambient temperature was about 34.8 ^{0}C while during the months of July and November, 1999, when the field experiment was conducted average temperature was 29.4 ^{0}C. Bull (1968) while working with field beans and Littleton *et al.* (1973) working with cowpea reported that the relative rate of increase in leaf area was closely related to daily maximum ambient temperatures. They concluded that leaves expanded more during the warmer than during the cooler periods. In this study therefore, lower values of LAI for the field experiment suggest that the low ambient temperatures were not conducive for optimum leaf expansion and thus optimum LAI.

Leaf area index (leaf initiation & expansion), the usual measure of canopy development, is very sensitive to water deficit. Water deficit leads to a decrease in leaf initiation and expansion rates and increase leaf shedding. Boyer (1970) reported that leaf expansion is more sensitive to water deficits than the stomatal closure or photosynthesis and leaf senescence does not appear to be as sensitive as leaf expansion. However, sensitivity to water deficits depend largely on growth conditions, leaf expansion in the field being less sensitive than in the screen house if other factors were equal.

In this study, LAI followed the sequence of applied water despite low values reported. Adequate soil moisture with associated turgor forces in plant cell is required for cell expansion. Reducing water levels reduced leaf turgor forces and thereby reducing cell expansion.

Maximum LAI in this study was attained at 70 DAS after which there was a decline. Factors accounted for the decline include the onset of leaf senescence and the death of leaves due to an infestation of powdery mildew, aphids and grasshopper.

The recovery in leaf production, leaf DM and total DM when the stress was relieved at the start of flowering was remarkable. However, this recovery was less in the case where water stress was imposed at flowering and at pod filling growth stages. As a result, at final harvest (120 DAS), there were little differences in total DM between stressed and unstressed treatments, thereby emphasizing the importance of the rate of recovery after relieving water stress. Although there was a rapid leaf production after relieving water stress for plants stressed at vegetative stage as compared to other water stressed treatments, this did not result into significantly higher LAI for that treatment. The maximum LAI in the fully irrigated control was 0.94 while for the plants stressed at vegetative, flowering and pod- filling stage was 0.62, 0.77 and 0.84, respectively. Such results suggest that irrespective of the ability to recover after drought has been relieved, leaf area production is greatly reduced by drought at any stage of growth leading to reduced total DM and thus grain yield production in bambara groundnuts. Sivakumar and Sarma (1986) also reported reduced LAI, total DM and final yield in groundnut for water stress imposed at different growth stages.

Reduced LAI by water stress observed in this study suggests a physiological response to conserve water by reducing water loss through the leaf canopy. The reduction in leaf area development in response to water deficits arose from reduced rates of leaf initiation and leaf expansion. Leong and Ong (1983) found out that in groundnut, leaf initiation is more sensitive to mild water deficits than flower, peg or pod initiation. Producing few leaves with small area will result to reduced transpiration and consequently more water will be conserved to maintain plant survival. Leaf expansion and stem elongation is determined by number of cells and the degree of turgidity of the cells. Thus, the reduced leaf size and stem elongation as a result of water stress in this study could be associated with reduced soil moisture content, which led to reduction in leaf relative water content.

A study of the anatomy of groundnut leaves under water stress by Sivakumar and Sarma (1986) revealed that leaves formed under water stress had small cells than others. This further suggests that reduced leaf expansion might be a result of small cells produced during the water stress periods.

Although reduced leaf initiation and expansion is an adaptive response to water stress, the mechanism has a negative effect on plant growth and yield performance. Photosynthesis and dry matter synthesis takes place in leaves. Reduced number of leaves and leaf area led to reduced dry matter production because of reduced photosynthetic area and thus negatively affected plant growth performance. Ong (1984) and Ong *et al.* (1985) observed that in the absence of temperature limitation, the rate of leaf extension (and hence expansion) was linearly related to photosynthesis and the variation in the water content of leaves was the main factor contributing to photosynthesis.

The rate at which a stand produces DM and the amount produced at harvest, both depend on many environmental factors such as available soil moisture, solar radiation intercepted and air temperature. Several studies have demonstrated that, DM accumulation is proportional to the water lost through transpiration (Tanner and Sinclair, 1983). Under the current study, all other environmental factors were kept constant and only amount of water was varied. Generally, above ground DM production correlated with LAI, which is a function of leaf number and its expansion. It is therefore speculated that number of leaves produced, its expansion and thus the resultant LAI as influenced by available soil moisture, determined the amount of solar radiation intercepted, canopy photosynthesis and hence the amount of dry matter produced. Reports by Babiker (1989) and Chavula (1991), indicated that in bambara groundnut, just like in other crop species, LAI and total crop dry matter are closely related. Large leaf area allows for increased rates of transpiration and also facilitate more CO_2 uptake and interception of solar radiation. These processes are directly related to DM accumulation in the plant.

Net photosynthesis is reduced by water stress through the effect of water stress on radiation conversion efficiency, as a result of reduced CO_2 exchange caused by closed stomata and probably higher respiration. Water deficit in the soil leads to leaf water deficit that eventually leads to stomatal closure in most species and this reduces the rate of CO_2 uptake, at the same time reducing water loss. In order to acquire CO_2, plants must transpire, since these gases diffuse along the same pathway through stomates. The degree of water deficit will determine the extent of stomatal closure. Results from this study suggest that with reduced water levels, stomatal closure followed a similar trend and consequently DM production followed the same pattern of applied water.

Above ground DM increased with age up to a threshold value, at 100 DAS and declined thereafter. Decline in DM production was due to leaf senescence or translocation of DM produced to fill the developing pods or both. It was noted that, the rate of decline was higher for the well watered than the most water stressed treatments. Such results suggest that water stressed plants maintained leaves for a longer period than well-watered plants.

Alternatively, the water-stressed plants translocated less above ground DM to the reproductive structures, because they had fewer organs to feed. Lawn (1982) reported similar results for a range of grain legumes grown on stored moisture, where water stressed plants produced fewer and smaller leaves which did not senescence until near maturity, as compared to crops that were well watered for the first half of vegetative growth. The later showed a reduction in leaf production and expansion and marked leaf senescence as soon as water was withheld.

Higher total DM produced during the treatment period for plants stressed at pod filling stage than plants stressed at vegetative or flowering growth stages was attributed to more and well-developed leaves produced earlier before imposing water stress. It implies that, photosynthetic area was much developed such that more DM was produced compared to other treatments. During flowering period, plants become more active such that any water stress at this stage tremendously affected plant growth, leading to the lowest dry matter. Thus, in terms of DM production, flowering stage was considered to be the most sensitive stage to water stress in bambara groundnut growth than the other developmental stages.

Rapid leaf production and DM accumulation observed after relieving water stress, especially for water stress imposed at vegetative stage is associated with the adaptive response of indeterminate plants which remain in a quiescent vegetative growth, but have ability to grow vegetatively if the water stress is removed, as long as lethal deficits are not reached. This can be termed as compensatory adaptive mechanism. However it was noted that the compensatory adaptive mechanism decreased with age. Similar compensatory adaptive response was earlier observed by Tark *et al.* (1980) while working with cowpea, a botanically closely related crop to bambara groundnut.

Lack of significant differences in flower number per plant between the most water stressed (250 and 125mm) treatments was due to the fact that number of flowers reported were those recorded during the sampling periods only. Between sampling periods there were a good number of flowers produced, which either withered or developed to pegs but were not counted. Thus, the number of flowers reported did not exactly represent the actual flowers produced but gives the general picture. These results suggest that if enough water is available, then bambara groundnut tends to produce large number of flowers during the early growth stages. When water supply is inadequate the crop tend to produce relatively fewer flowers per plant but the flowering period becomes longer (is extended). The behaviour of producing flowers up to harvesting period and the observed production of new flush of flowers after relieving water stress imposed at any of the three growth stages again suggests that bambara groundnut has an indeterminate growth habit which makes it tolerant to water stress than the closely related legumes. On the other hand, producing more flowers towards the end of the growing season in the most water stressed plants indicated a physiological mechanism to postpone the reproductive stage so as to sustain production whenever environmental conditions becomes favourable. Turk and Hall (1980) observed that under moderate levels of water deficits, cowpeas flower and mature earlier, but severe water deficits delay reproductive activities. Therefore large number of flowers produced by the most stressed treatment late in the season is likely to be delayed reproductive activities by water stress. It might be an adaptive response such that with early water deficits the crop delayed the reproductive phase since the environment was not conducive. However the plants had the ability to continue with reproductive growth after the water deficit was reversed, as long as lethal deficits has not been reached. The same reason is considered for the highest number of flowers observed after relieving water stress imposed at vegetative stage.

One could expect more flowers to be produced after relieving water stress imposed at flowering because the stress was imposed during the reproductive phase. However, this was not the case because the actual effect of water stress came to effect a bit later when the plants had already produced a good number of flowers. Furthermore, water stress was imposed on plants that were already approaching maturity compared to those stressed at vegetative stage. Generally, indeterminate plants tend to reduce number of flowers with age. This phenomenon was more obvious for the water stress imposed at pod filling stage. In this treatment, no water stress was imposed between sowing and start of pod filling phase, so much of the flowers were produced in early growth stages. Therefore, few flowers produced after relieving water stress was due to the fact that plants were close to maturity. The fact that after relieving water stress bambara groundnut produced new flowers and these flowers were more than those produced by well-watered control treatment suggests that, in bambara groundnut, relieving water stress tends to trigger more flower production.

Dry matter partitioning between roots, above ground shoot and reproductive structures is usually modified by water deficits. Response depends upon the species, the time of onset of stress, its duration and its severity. Increased root DM production with increased water supply indicated a greater root density, greater rooting depth or accumulation of heavy roots or both. Although root DM increased with increasing water levels in this study, the percentage of total DM partitioned to roots increased with decreasing water supply. The result suggests that bambara groundnut allocates more of its total DM to roots under water stress conditions than under well-watered conditions. This phenomenon is considered to be one of the possible drought tolerance mechanisms in bambara groundnut to ensure more water absorptive system is available when water supply is likely to limit growth. Similar results were earlier observed in maize (Hsiao and Acevedo, 1974). Soil and root resistance to water uptake are reduced when root length density increases, thereby permitting higher water flow rates through the plant and delaying the onset of severe plant water deficits. Whilst partitioning more DM to roots may enhance water uptake, it represents a loss to the above ground DM produced as the same DM could have been used to produce grain seeds. However, investment in extensive root growth will not be wasteful if significant mobilization of root DM to the grain occurs during grain filling or additional water extracted overcomes water deficits at critical growth stage. In this study, well-watered treatments gave higher root DM up to 100 DAS after which it declined. This decline reflected mobilization of photosynthates to the developing pods as there was an increase in DM partitioned to the structures. For the most water stressed plants, continued increase in root DM up to harvesting period was associated with either the indeterminate nature of bambara groundnut or less mobilization of the photosynthates to the grain, since this treatment produced fewer pods per plant. The highest root DM of the red landrace suggested greater genetic adaptability to water stress than the cream landrace.

5.2 Yield and yield components.

In bambara groundnut, the flower is borne above the ground and thereafter it withers. The flower stalk elongates bends down and forces the ovaries underground. The seeds develop and mature below the soil surface. Hence, both the quantity and quality of the seeds is intimately related to conditions that favour the growth processes preceding and during the development of the seed. Proper functioning of these growth processes requires a favourable balance controlled by the relative rates of soil moisture uptake by the roots and the water loss by transpiration. Water deficits that are a consequence of imbalance between water uptake and transpiration affect bambara groundnut growth differently depending on the stage of growth of the crop and the degree or intensity of the water stress.

Decreased number of pods for the crop grown under screen house condition irrespective of landrace and treatment effects is associated with differences in available soil moisture. Under field conditions, there is a large volume of soil, thus the crop might have had a chance to get more moisture deeper in the profile and also through both horizontal and vertical seepage. Under the screen house conditions, plants depended only on water supplied as treatment. Water is one of the most important row materials for dry matter synthesis. Therefore, with reduced water supply, less dry matter was produced and consequently little dry matter was available for the growing vegetative parts and for reproductive structures. Furthermore, air temperature was relatively higher under screen house than field conditions. This increased evaporative demand and as a consequence soil moisture was further reduced under screen house as compared to the field conditions.

Higher number of pods per plant for the red than the cream landrace revealed the genotypic differences between the two landraces. Such influences were also noted in the number of leaves and LAI, which are the major physiological determinants of dry matter production and thus grain yield. Such results suggest that, genetically the red landrace has greater ability to synthesize dry matter and translocate it to reproductive organ (pods) than the cream landrace.

The effect of water deficits on crop yield is determined primarily by the degree and timing of such deficits. Increased pod yield with increasing water levels revealed the potential of bambara groundnut production at high soil moisture content than low moisture conditions during the cropping season. Findings reported by Ameyaw and

Doku (1983) and Collinson *et al.* (1996) indicated that under high moisture content, pod yield is usually suppressed. They argued that suppressed pod yield at high soil moisture content was due to susceptibility of legumes to waterlogging as a result of sensitivity of rhizobia within the root nodules to anaerobic conditions. However it is important to note that waterlogging results when poor soil permeability exists. During the study period, no waterlogging condition was observed indicating that the soil was permeable enough. These observations suggest that for optimum production, bambara groundnut requires high amount of water with well drained soil. Temu (1994) suggested the optimum rainfall for optimum growth and production of bambara groundnut to lie between 900 and 1000mm while Johnson (1968) reported that maximum yield in Madagascar was obtained at 1200mm. These findings confirm that bambara groundnut withstand not only water deficits but also high rainfall condition.

A reduction in soil water content has a dual effect on peg and pod development owing to the subterranean fruiting habit of bambara groundnut. On one hand, root water content directly affects plant water status, photosynthesis and hence assimilates supply to developing pegs and pods. Stirling *et al.* (1989b) working with groundnut observed that, the rate at which new assimilates are allocated to pegs declines before there is a detectable fall in the turgor potential of pegs. Results from the current study therefore suggest that reduced number of pods due to water stress was partly due to reduced CO_2 assimilation. On the other hand, water content in the pegging and podding zones affect reproductive growth independently of root zone moisture content. The severe reduction in pod number, pod yield per hectare and kernel dry matter per plant could be associated, mainly with soil surface moisture content. Soil surface moisture content is considered critical to peg penetration into the soil. Taylor and Ratliff (1969) reported that as soil dries its mechanical resistance increases. For fruiting to occur the genophores must enter the soil. Hence the soil physical conditions is of critical importance since genophores are to exert pressure to enter the soil to overcome soil penetration resistance. As soil dries, the soil penetration resistance increases. The implication of increased soil penetration resistance on bambara groundnut yield is reduced peg penetration into the soil and reduced peg developed into pods. If numbers of pegs developed into pods are few, consequently, pod dry weight per plant, pod yield per unit area and kernel dry weight per plant will automatically be reduced. After imposing drought stress, it takes some time for the stress to become effective. This implies that more of the pegs developed into pods are the ones produced before the stress came into real effect. Most of those produced after the stress came into real effect failed to develop into pods. As a result water stress imposed at pod filling stage decreased yield primarily by reducing number of pods than kernel weight.

One could expect the number of pods per plant produced for the water stress imposed at pod filling stage not to differ from that of the control treatment because water stress was imposed while most of the pods had been produced. In this study,however, that was not the case. The implication is that, after imposing water stress either pod abortion took place or some pods did not fill effectively. Water stress is known to reduce photosynthesis and thus little assimilate is available to fill the developing pods. Probably pod abortion took place so as to remain with few pods the plant could fill properly. This phenomenon is further suggested by the fact that shelling percentage was not significantly different among the stressed treatments and even between the stressed and unstressed treatments. These results further suggest that bambara groundnut tends to maintain the pods which can be filled fully by the available vegetative structures. Reduction of pod number, pod dry matter, kernel dry matter and pod yield per hectare by water stress imposed at the vegetative stage as compared to the fully irrigated control suggests that during early growth, plants remained relatively small, and thus after relieving the stress more of the assimilates produced per unit available photosynthetic machinery were used to build more biomass.

Differences in pod yield due to landrace effect suggest that the red landrace had higher yielding potential than the cream landrace, irrespective of the amount of water applied. Temu (1994) and Sibuga *et al.* (1996) reported similar results. The general manifestation noted in the red landrace that influenced more pod yield than the cream landrace include high ability to produce large number of leaves, leaf area index and root dry matter. All these variables influenced production of more photosynthetic materials required for higher total DM translocation to pods, and thus higher grain yield.

Pod yield is a function of many environmental and physiological factors, among the most important being available soil moisture and air temperatures. Optimum soil moisture tends to enhance vegetative growth (i.e. well developed canopy). A well-developed canopy intercepts more solar radiation and produce more dry matter. which is later translocated to economic yield. This is one of the possible reasons for increased pod yield with increasing water levels.

Branching in bambara groundnut leads to production of prostrate stems. Prostrate stems provide flowering nodes. Prostrate stems decreased with decreasing water levels. With decreasing prostrate stems flowering nodes also decreased and consequently few flowers were produced. With few flowers, few pods also developed. It is considered that, to a greater extent, pod yield was reduced under water stressed treatments due to few flowers produced as a result of few flowering nodes during the study period. These results are in agreement with Mwandemele (1996) who reported that bambara groundnut raised in furrow during the short rain season enhanced flowering, pod and grain yield. The reason given is that furrows acted as microwatersheds in which runoff water from the ridges and other parts of the field concentrated. It is therefore important to realize that adequate water supply is very crucial for optimum bambara groundnut growth and production, although the plant is frequently considered to be tolerant to drought than other related legumes.

Values of pod yield reported from this study were low compared to those reported by Ameyaw and Doku (1983), Collinson *et al.* (1996) and Mwandemele (1996). The low yields might be associated with infestation of powdery mildew, aphid and grasshoppers.

These diseases and insect pests considerably reduced photosynthetic area of the plants, calminating into production of small fruits and finally low yield. These results confirm that various insect pests attack bambara groundnut irrespective of general pest and disease free attitude towards the crop, especially under humid and relatively warm conditions similar to those of Morogoro.

Low pod yield especially under field conditions was also associated with low temperatures. Under screen house conditions where temperatures were relatively higher, the crop recorded relatively higher yield. Although it has been reported that bambara groundnut can thrive well upto altitude of 1,520m above sea level, indicating that the crop can tolerate low temperatures, higher pod yield obtained under screen house, where temperatures were relatively higher, suggests that low temperatures are not conducive for optimum growth and production of bambara groundnut. In most cases high temperatures are accompanied by increased evaporative demand. Therefore, bambara groundnut production under high temperatures will require adequate water supply, so as to strike the balance.

The reduced harvest indices in the drier treatments were perhaps a consequence of reduced availability of assimilates for translocation to the pods for effective kernel development. It would appear that, little dry weight accumulated by the droughted treatments was reserved for plant survival and very few assimilates were thus available for translocation to pods.

*The shelling percentages observed in this study (between 70 and 85.7%) were slightly higher than those reported by Johnson (1968) and Linneman (1992) (which ranged between 70 and 77%). High shelling percentages are an indication of effective pod filling (Tarimo and Mkesele, 1986). The non-significant effect on shelling percentages due to water levels and water stress at different growth stages observed in this study suggests that bambara groundnut have physiological mechanism to maintain pods that is able to fill. In other words, the amount of dry matter accumulated by the plant dictate the number of pods to be maintained by the plant upto physiological maturity.

There was a significant ($P<0.05$) positive correlation between pod yield and various yield components. The fact that yield was positively correlated with number of leaves, leaf weight, stem weight, root weight and number of pods in both landraces indicate that yield can be appreciably increased by creating appropriate conditions that would increase values of these variables. Furthermore, these components could be used as indicators of sources of yield variation in bambara groundnut landraces. Bambara groundnut improvement through breeding could also be achieved through improvement of traits associated with increasing pod production per plant. The other components including number of flowers did not show consistent relationship with yield variation, hence are of little predictive value for yield.

CHAPTER SIX

6.0 CONCLUSIONS

This study has revealed that, the growth and yield of bambara groundnut can be seriously affected by reduced water supply. Water stress at any of the three growth stages (vegetative, flowering and pod filling) can result in to large in bambara groundnut yield. Genotypic variation was an important factor in the differences observed in growth and yield, such that the two landraces yielded differently among treatments. On the basis of these results, the following conclusions were drawn.

1. Water supply equivalent to as low as 125mm of rain per growing season, if evenly distributed during the cropping season, would not affect the onset of flowering and maturity of bambara groundnut. Such a low amount of water, however, significantly reduced the number of flowers per plant, although the flowering period for the most water stressed plants was lengthened when compared to the well-watered plants.

2. The percentage of total dry matter partitioned to the leaves increased with increasing total water supply, while the percentage of total dry matter partitioned to stem and roots increased with decreasing amount of total water supplied. It was thus concluded that, bambara groundnuts tends to diverge more dry matter to roots and stems under water stress, a mechanism considered to be responsible for drought tolerance of the crop.

3. Areas receiving rainfall below 375mm per growing season are not recommended for optimum bambara groundnut production. The reduced pod yield with decreasing total water supply is considered to be associated with reduced vegetative growth which determines the amount of assimilate production which are later translocated to pods. Therefore, for optimum bambara groundnut production, adequate water supply should be achieved during growth.

4. Among the three growth stages studied, water stress at flowering was the most detrimental, followed by water stress at pod filling and lastly at vegetative stage. Water stress at flowering severely reduced shoot growth and pod yield. It is thus concluded that the period of high moisture demand for shoot growth and pod yield was between the onset of flowering and podding (46 and 70 DAS). Therefore, moisture stress should be avoided during this period.

5. The fact that relieving water stress at any of the three growth stages resulted to vegetative and flower re-growths. The rate of such re-growth decreased with increasing plant age. Bambara groundnut is thus considered to possess a mechanism to postpone both vegetative and reproductive growth when conditions are unfavorable and to compensate for losses due to water stress after relieving the stress provided that so long as the lethal deficits were not reached.

6. Between the two landraces, the red landrace yielded higher, both in terms of biological and economic yields than the cream landrace, indicating a genetic superiority of the red landrace over the cream one, both in terms of drought tolerance and production potential when optimum growing conditions are available. Such evidence suggests an existence of unexploited genetic diversity among the bambara groundnut landraces that could be used in the future for breeding programmes in the crop.

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APPENDICES

Appendix 1. Summarized weather data during the study period, 1999.

Month	Week	Temperature (°C)		Evaporation (mm)	Rainfall (mm)	Relative Humidity (%)	
		Maximum	Minimum			Max.	Mi
February	1	33.6	22.6	61	0.0	81.3	39.6
	2	34.7	22.6	42	0.0	85.3	36.1
	3	32.5	21.5	47.6	2.9	89.4	51.7
	4	34.2	22.2	51	0.0	90.6	41.1
March	1	33.2	22.6	45.1	7.7	92.9	56.7
	2	30.4	21.4	28.7	4.7	96.1	66.1
	3	30.4	22.1	38.7	58.2	92.3	61.3
	4	29.7	21.5	37.1	71.3	97.4	73.3
April	1	28.5	21.4	21.9	42.7	98.6	76.3
	2	30.6	20.6	27.3	48.1	97.3	64.9
	3	30.1	20.1	24.0	54.6	97.9	66.7
	4	28.9	20.2	27.5	48.8	98.0	69.0
May	1	29.5	20.3	24.9	65.5	99.0	67.6
	2	28.2	20.0	17.7	25.3	98.0	70.1
	3	28.0	19.3	19.5	2.8	97.9	64.9
	4	29.5	18.4	35.6	11.7	97.3	59.2
June	1	26.5	18.6	21.0	26.4	97.6	65.1
	2	28	16.6	23.2	0	96.7	59.4
	3	28.8	18.7	38.0	1.2	97.9	56.4
	4	27.3	14.0	30.1	0	94.2	51.4
July	1	25.9	17.4	17.0	17.6	97.7	60.4
	2	26.6	15.8	19.6	16.8	94.4	57.0
	3	27.2	17.3	21.4	4.4	95.4	53.0
	4	25.8	15.7	27.9	0.3	95.0	58.4
August	1	26.3	26.3	15.6	2.9	97.4	60.1
	2	27.6	27.6	20.8	0.0	96.4	56.6
	3	26.1	26.1	24.0	15.5	96.4	54.1
	4	27.1	27.1	26.4	1.2	96.2	60.2
September	1	28.5	28.5	32.4	2.3	93.3	45.9
	2	28.9	28.9	23.4	0.0	93.4	49.6
	3	29.9	29.9	35.1	0.0	97.4	45.7
	4	30.9	30.9	49.7	0.7	96.1	43.6
October	1	31.1	31.1		9.7	94.0	45.6
	2	29.0	29		0.0	94.1	52.0
	3	32.1	31.1		0.0	95.4	37.6
	4	32.8	32.8		0.2	93.1	38.8
November	1	33.6	33.6	38.2	0.0	92.6	34.3
	2	33.6	33.6	33.1	0.0	93.3	39.7
	3	33.3	33.3	44.5	6.8	92.3	51.4
	4	31.6	31.6	66.7	24.5	96.0	48.4

Appendix 2. Summarised temperature data recorded in the screen house during the study period.

Month	Week	Temperature ^{0}C	
		Maximum	Minimu
February	3	38.4	24.4
	4	37.8	25.3
March	1	36.9	25.9
	2	35.6	26.8
	3	37.4	24.5
	4	35.5	25.2
April	1	31.2	25.9
	2	34.7	26.4
	3	32.5	25.9
	4	32.0	24.2
May	1	31.9	23.8
	2	32.3	23.2
	3	32.4	24.9
	4	34.0	22.9
June	1	31.0	21.5
	2	31.8	21.8

Appendix 3. Experimental layout for experiment 1 (Different levels of total water supply)

T3	T4		T4	T1		T1	T1
T4	T2		T1	T3		T4	T2
T1	T3		T3	T2		T3	T3
T2	T1		T2	T4		T2	T4

Appendix 4. Experimental layout for 2 (Water stress at different growth stages)

T4	T3		T2	T1		T4	T2
T2	T4		T4	T3		T1	T4
T1	T2		T3	T2		T3	T1
T3	T1		T1	T4		T2	T3