CHAPTER ONE

1.0 INTRODUCTION

Bambara groundnut *(Vigna subterranea (L.) Verdc.)* is a pulse with subteranean fruit–set and is cultivated by smallholders over much of semi-arid Africa (Linnenann and Azam–Ali, 1993). The crop is a legume species of African origin (Borget, 1992) and is widespread south of the Sahara (Ocran *et al.,* 1998).

Food legumes have a major role to play in the fight against malnutrition. It is therefore necessary that their levels of consumption, which are already too low in a number of developing countries, should be increased (Borget, 1992). Legumes serve as a source of protein to a large proportion of the population in the poor countries of the world by being the least expensive and easily stored and transported non-processed protein source for rural and urban dwellers (Rachie and Silvester, 1977). The high carbohydrate (65%) and relatively high protein 18% content of bambara groundnut make it a complete food (Doku, 1995).

Bambara groundnut is probably the most drought–resistant of the grain legumes and may be found growing successfully where annual rainfall is below 500 mm and optimum between 900–1000 mm per year (Ocran *et al.,* 1998). The plant can be grown under dry climatic conditions where the rainfall during the rainy season would be adequate to enable them to accomplish their vegetative cycle (Borget, 1992). An evenly distributed rainfall in the range 600–1000 mm encourages optimum growth but satisfactory yields can be obtained in areas with a pronounced dry season since the crop is relatively drought resistant (Messiaen, 1992).

Bambara groundnut is resistant to high temperatures and can be grown on poor marginal soils not suitable for other leguminous crops (Yamaguchi, 1998). Bambara groundnut is not attacked by disease and pests in any of its production regions. However, in damp conditions, it may be susceptible to various fungal diseases (Baudoin and Mergeai, 2001). It has a very low insect pest and disease susceptibility (Tweneboah, 2000).

In West Africa bambara groundnut (*Vigna subterranea)* was for a long time at par with, or slightly ahead of cowpea (*Vigna uniguiculata)* in terms of production (market availability) and utilization. In Ghana, over 40,000 cans (various sizes) of bambara groundnut were produced annually throughout the 1960's and early 1970's. The canned product was very popular throughout West Africa and competed favourably with Heinz baked beans. The status of the nut however, started to decline from 1970's with introduction of high yielding varieties of groundnut (*Arachis hypogaea)* and pest control methods for cowpea (Doku, 1996).

The protein of bambara groundnut is of good quality and has surplus lysine which complements cereals in the diet (Ocran *et al.,* 1998). The composition of the seeds, from the point of view for human nutrition is very well balanced, as they contain 20% soluble carbohydrates and 8% fats (Messiaen, 1992). It is high in protein but unlike ordinary groundnuts contains very little oil (Tweneboah, 2000).

Bambara groundnut has been ranked as the third most important grain legume, after groundnut *(Arachis hypogaea L.)* and cowpea *(Vigna unguiculata)* in semi-arid Africa, but has not been accorded due attention in research (Rachie and Silvester, 1977). Little research has been done to date to improve bambara groundnut. The work done on the crop has been limited to mass selection of a few local varieties, followed by a purification phase for the main agronomic characteristics. International Institute of Tropical Agriculture (IITA) has recently evaluated a large collection of bambara groundnut comprising more than 1000 introductions collected from all over Africa (Baudoin and Mergeai, 2001).

Climate change and the changing weather patterns associated heat and drought stress are on the increase. Heat and drought tolerance varieties have also not been developed. Therefore identification of heat and drought tolerant landraces would ensure food security and nutritional deficiency especially among the children. This study was carried out to evaluate tolerance in the five bambara groundnut landraces to heat and drought stress and to determine growth, development and yield of the crop in the dry season in Guinea savanna and transition agro-ecological zones of Ghana.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and distribution

Bambara groundnut, (*Vigna subterranea (L) Verdc.)* is of West African origin and has been cultivated in tropical Africa for centuries (Yamaguchi, 1983). Bambara groundnut is an indigenous African leguminous crop and one of the most important pulses grown on the continent (Doku and Karikari, 1969). The crop has been widely cultivated in tropical regions since the seventeenth century. In addition to sub-Saharan Africa, it is now found in many parts of South America, Asia and Oceania (Baudoin and Mergeai, 2001).

The centre of origin of bambara groundnut is probably north – eastern Nigeria and northern Cameroon. It is found in the wild from central Nigeria eastwards to southern Sudan, and is now cultivated throughout tropical Africa and to a lesser extent in tropical parts of America, Asia and Australia (Brink *et al.,* 2006). Bambara groundnut was domesticated in the semi-arid zone of West Africa, probably around the headwaters of the Niger River, from where it spread in ancient times to Central Africa, and more recently to the Malagasy Republic, Asia and South America (Tweneboah, 2000).

The crop is indigenous to West Africa where it has a long history of cultivation although there is now limited production in parts of Asia and South and Central America (Gibbon and Pain, 1985). Bambara groundnut is a hardy plant particularly well suited to the growing conditions found in the savanna regions with a Sudanese and Sudano–Guinean climate (Baudoin and Mergaei, 2001).

The crop is found wild in West Africa. It has been cultivated throughout tropical Africa for many centuries. It was taken at an early date to Madagascar, probably by Arabs. It has reached Brazil and Surinam early in the seventeenth century and was later taken to the Philippines and Indonesia (Purseglove, 1992).

2.2 Taxonomy and botanical description

The species *Vigna subterranea* belongs to the genus *Vigna*, and subtribe Phaseolinae, the tribe Phaseoleae and the family Papilionaceae (Baudoin and Mergeai, 2001). Bambara groundnut which since 1980, has been renamed *Vigna subterranea* after having been known as *Voandzeia subterranea* for more than a century (Borget, 1992). In 1763, Linnaeus described it in *Species Plantarum,* and named it *Glycine subterranea*, in accordance with his system of nomenclature. Du Petit–Thouars (1806) found the crop in Madagascar and proposed the name *Voandzeia subterranea (L). Thouars*, which was widely used by subsequent researchers for over a century. Recently, detailed botanical studies were undertaken by Maréchal *et al.* (1978), who found great similarities between bambara groundnut and plant species of the genus *Vigna.* This confirmed studies done by Verdcourt, who seized the opportunity in 1980 to propose the current name *Vigna subterranea (L) Verdc.* (Goli, 1995).

Bambara groundnut is a small herb that grows to about 0.30–0.35 m in height, and like the groundnut has compound leaves of three leaflets. Both prostrate and erect forms occur. The much–branched stems root at the nodes to form a bunched herbaceous annual with a thick taproot which forms a profusion of lateral roots towards its tip (Tweneboah, 2000). The general appearance of the plant is bunched leaves arising from branched stems which form a crown on the soil surface. Stem branching begins very early, about one week after germination, and as many as twenty branches may be produced (Goli, 1995).

The plant has a bushy habit. It consists of about ten running stems with very short internodes. Roots grow from the nodes at each stem. The leaves with erect petioles are alternate and trifoliate.

The peduncles are auxiliary, elongating from the stem nodes, each peduncle bearing one to three flowers (usually two). The plant is considered to be autogamous (Baudoin and Mergaei, 2001). Pale yellow flowers are borne on the freely branching stems and after fertilization the stem of the flower grows down towards the soil, taking the developing seed with it. The pod (1.25–2.5 cm in diameter) is drawn into the soil and ends up lying about 1 cm beneath the surface. The pods usually contain only a single seed but sometimes there are two (Gibbon and Pain, 1985). Mean temperature during the seasons influences the time taken to achieve physiological maturity (Linnemann and Azam–Ali, 1993).

2.3 Varieties

The crop is indigenous to sub-Sahara Africa and there has been limited research into developing new varieties so all varieties are considered to be traditional. They appear in colours of black, white, cream, brown, red and mottled. Other varieties from Burkina Faso are also grown (Ocran *et al.,* 1998). Several varieties are recognized in Africa differing in the shape of the leaves and the size, hardness and the colour of the seeds. The greatest variation is found in Togo and Zambia (Purseglove, 1992).

No cultivars of bambara groundnut have been named, but genotypes are distinguished on the basis of seed attributes (colour, size, hardness) and plant form (bushy or spreading). Sometimes names are based on the location where the seed was collected (Brink *et al.,* 2006).

2.4 Production

2.4.1 Propagation and Planting

The crop is always grown from seed and is sown in either mixed cultivation with cereals (pearl millet, root crops or other legumes) or in pure stands (Gibbon and Pain, 1985). Ocran *et al*. (1998) reported that the crop may be grown either as a single stand or intercropped with groundnut, millet or sorghum. In rotations, it may be planted as an opening crop perhaps followed by cassava, or in the second year it may be intercropped with cereals, vegetables, groundnuts or other pulses. Doku (1995) stated that there is also a trend towards mixed cropping with yams, the bambara groundnut being planted on yam mounds protect the mounds from erosion, conserves moisture and creates fewer temperature fluctuations in the mound.

The crop performs best on deeply ploughed field with a fine seedbed, eventually allowing the plant to bury its developing fruits. Ridging is advisable if the soil is shallow or prone to water logging (Brink *et al.,* 2006). Baudoin and Mergeai (2001) reported that proper loosening of the soil helps pod penetration during fructification and improves the yield. Tweneboah (2000) also mentioned that a well prepared friable seed bed is required to enable the plants bury their pods after fertilization.

Tindall (1997) indicated that seeds, normally shelled are sown on beds or ridges in rows 40-50 cm apart, 20-30 cm between plants. According to Ocran *et al.* (1998), the recommended row spacing is usually 10-45 cm with an intra row spacing of 15-17 cm. One seed is sown per hole 3-5 cm deep. Seed rate varies in several location, that is 35 kg/ha in Tanzania; 25-45 kg/ha in Kenya; higher rate of 60-75 kg/ha in South Africa when rat damage is expected (FAO, 1961). Gibbon and Pain (1985) observed that the normal seed rate is 30-60 kg/ha of shelled nut giving 150,000 plants/ha.

Sowing dates vary considerably within locations. In Zambia and Botswana, for example, sowing takes place from November to February. Sometimes phased planting occurs, examples, in Skumaland, Tanzania (Brink *et al.,* 2006). In the derived savanna zone of Ghana, two crops are possible, the first crop sown in May - June and the second crop in October. In the north the main planting period is between August–September (Tweneboah, 2000). In the Guinea savanna zone, the crop is usually grown during the minor season (September-November) when the rainfall is reliable. In the Sudan Savanna zone, it is usually cultivated towards the end of the single long rainy season (Doku, 1995).

2.4.2 Growth and Development

The optimum temperature for germination of bambara groundnut is 30-35°C. Emergence takes 5-21 days. Vegetative development may continue after reproductive development has started. Flowering starts 30-55 days after sowing and may continue until the plant dies (Brink *et al.,* 2006). After fertilization the pods form and reach their maximum size about 30 days. The seeds expand and reach maturity during the following 10 days (Linneman and Azam–Ali, 1993). The duration of the crop cycle is between 100-180 days (Baudoin and Mergeai, 2001).

2.4.3 Management

Weeding of bambara groundnut takes place 1-3 times, often with a hoe. Earthing up to cover the young pods is common, and may be done by hand, with a hoe or with ox-drawn equipment. Earthing up improves yield, but is labour intensive; it is often combined with weeding (Brink *et al.,* 2006). Purseglove (1992) also reported that the rows are usually earthed up and in some areas are lightly covered with soil to promote fruit production. Tweneboah, (2000) mentioned that the plants are hand weeded when 10 cm high and mounded or earthed up at flowering time to encourage development of the pods underground.

2.4.4 Nutritional Requirement

Farmers do not normally apply chemical fertilizer to bambara groundnut fields. The nitrogen requirement is met by natural N_2 fixation as indicated by several nodulation studies (Doku, 1996). The nodules on their roots can fix atmospheric nitrogen and therefore ensure their nitrogen nutrient supply without recourse to nitrogen in the soil. However, there are some cases where, for various reasons, assimilation is poor and the application of nitrogen fertilizer has a positive effect particularly in the early period of growth, when root development is rapid. Later application may suppress nodulation.

The dose normally ranges from 30 to 50 kg of nitrogen per hectare (Borget, 1992). According to Baudoin and Mergeai (2001), as with almost all legumes, bambara groundnut is capable of symbiosis with nitrogen–fixing bacterial belonging to the genus Rhizobium. The maximum quantity of nitrogen, which can be obtained by symbiotic fixation, is 100 kg/ha. The crop is able to meet its nitrogen requirements but it is known to respond favourably to application of about 250 kg/ha of single super phosphate applied before planting (Tweneboah, 2000). The addition of nitrogen at planting time or later at the rate of 60 kg/ha of sulphate of ammonia, approximately three weeks after sowing appears to be economic and in Malagasy, seeds are placed in holes containing cow dung (F.A.O, 1961).

2.4.5 Harvesting

Harvesting begins about four months after sowing when the pods are mature and the plant leaves are beginning to yellow. The plants are simply pulled out of the ground, with the attached nuts (Gibbon and Pain, 1985). In a dry environment, harvesting takes place when the entire foliage dries up. In humid ecosystems, however, pod-rotting or early seed germination (in the pod) may take place while the leaves are still partially green. Harvesting is then recommended before full foliage drying (Goli, 1995). According to Karikari (1998), in Botswana, immature pods are usually harvested about two months before the pods dry completely. Although a farmer may harvest a crop as immature for immediate use, bambara groundnut of commerce are available only as mature dry seeds.

2.5 Cultivation

2.5.1 Climate and Soil Requirements

The crop does better than most other bean crops in poor soils and grows best with moderate rainfall and sunshine (Williams *et al*., 1980). Under less favourable growing conditions, such as limited water supply and infertile soil, it yields better than other legumes, for example, groundnut (National Research Council, 1979). The crop will grow on soils in hot, dry regions that are marginal for groundnuts and other pulses, as for example the savanna ochrosols of Africa (Gibbon and Pain, 1985). Borget (1992) also reported that the crop is the least demanding for mineral elements and thrives in soils which are considered too marginal for groundnut.

Bambara groundnut can be grown on a range of soils, especially light loams and sandy loams but may be successfully grown on heavier soils than groundnuts. Generally it performs better on poor soils than groundnuts. Light soils make harvesting easier, soils rich in nitrogen may produce excessive vegetative growth which is undesirable for seed production (Tweneboah, 2000). Doku and Karikari (1969) also reported that the crop is the most drought resistant pulse, producing a crop under conditions of high temperature and low rainfall, where other pulses fail to thrive. According to Karikari (1969), the fertility coefficient (the pod: flower ratio) was higher during the dry than in the wet season. He therefore suggested that the dry season would be more favourable for the cultivation of the crop.

Bambara groundnut tolerance of drought and ability to yield in soils too poor to support the growth of more favoured legumes are all factors which contribute to its continued popularity with poor farmers (Azam–Ali, 1992). The crop is very drought–resistant but for good yields requires moderate rainfall of 750–1000 mm during the rainy season and a dry period for harvesting (Tweneboah, 2000). Production can occur under rainfall of 600–700 mm per annum but optimum growth occurs with 900–1200 mm per annum (Gibbon and Pain, 1985).

The crop is adapted to a wide range of soils and performs better on poor soils than groundnuts (Tweneboah, 2000). Yield of bambara groundnut on low–fertility soils are generally higher than those of groundnuts grown on similar soil. Soils with a pH of 5.0–6.5, will produce satisfactory crops (Messiaen, 1992). The cultivation of bambara groundnut is of particular importance in semi – arid areas. In such regions, the crop has been found to thrive and produce yield under adverse conditions, such as limited water supply and low soil fertility (Wassermann *et al.,* 1983).

2.5.2 Drought and heat Tolerance

Bambara groundnut is considered to be drought resistant (Doku and Karikari, 1969; Tweneboah, 2000). Farmers claim that in years when groundnut fails due to low rainfall, bambara groundnut produces good returns (Linnemann, 1990). The reasons why bambara groundnut is apparently able to withstand greater water stress than other legumes and still produce at least some yield are unclear (Collinson *et al.*, 1993). The crop will yield in unfavourable environments but there are few reports of its productivity in relation to water stress. It is generally accepted that bambara groundnut is tolerant of drought but little research has been conducted to establish what degree of stress the crop is able to tolerate (Linnemann, 1991).

The adaptations which enable the crop to tolerate drought are not well understood. Limited evidence suggests that a short growing period and deep root system are two important adaptations to a dry environment (Begemann, 1988). The well developed root system of bambara groundnut exploits the rhizosphere for moisture and the sink demand of the rather thin and much branched prostrate stem cannot offer any significant competition for assimilates relative to the developing pods (Doku, 1996).

Nyamudeza (1989) observed that bambara groundnut allocated a greater fraction of its total dry weight to roots than comparable groundnut crops irrespective of available soil moisture. This strategy has clear advantage when water is scarce enabling a greater soil volume to be exploited for available water. The crop uses the available water frugally through slow leaf area development, therefore conserving water so that there is sufficient for the crop to survive through the reproductive period and produce some yield (Muriuki, 1990).

In Africa, bambara groundnut is confined to the dry regions, between the desert and the savanna (Southern fringe of the Sahara) and adapted to growing in areas of relatively high temperatures for many leguminous crops (Tindall, 1997).

2.5.3 Response To Day Length

It is important to know at what moment in their life cycle plants are sensitive to photoperiod. In the case of a flowering response to photoperiod, usually three phases are distinguished between sowing and flowering; basic vegetative phase, in which plants are not sensitive to photoperiod; an inductive phase, in which plants are sensitive to photoperiod and a post – inductive phase, during which flower buds develop into open flowers and photoperiod does not play a role anymore (Hodges and French, 1985).

Bambara groundnut is not photoperiodic (Baudion and Mergeai, 2001) but Tweneboah (2000) reported it as a typical short–day plant and this agrees with Tindall (1997) who mentioned that most cultivars are adapted to short days. Fruit development has been reported to be influenced by photoperiod (Linnemann and Azam–Ali: 1993). Long photoperiods delay or even prevent fruit set in some cultivars. Flowering is considered day–neutral, but continuous light was shown to delay flowering by 6–11 days in a few genotypes (Nishitani *et al*., 1988).

There are considerable differences between genotypes in their response to photoperiod. In many genotypes, flowering is photoperiod–insensitive, while the onset of podding is retarded by long photoperiods. In some genotypes both flowering and the onset of podding are delayed by long photoperiods (Brink *et al.,* 2006). Many bambara groundnut landraces have a specific day length requirement for pod filling, that is, allocation to yield will only begin at a particular day length (FAO, 2001). Photoperiod usually has a stronger effect on the onset of podding than on the onset of flowering (Linnemann and Cruafurd, 1994)

2.5.4 Yield

The highest recorded seed yield under field conditions is 4 t/ha. Average yields are 300–800 kg/ha but yields of less than 100 kg/ha are not uncommon (Brink *et al.,* 2006). Average yields of dry seeds usually range between 300 and 800 kg/ha in traditional farming and may exceed 3,000 kg in intensive farming (Baudoin and Mergeai, 2001). Williams *et al*. (1980) also reported yields of 500–1000 kg of dried nuts per hectare. Gibbon and Pain (1985) observed that yields are lower than those of groundnuts, 300–800 kg/ha being the average in most areas in the northern part of Ghana.

Bambara groundnut yields are low because the production environments are characterized by various abiotic and biotic stresses. However, even under optimal conditions the yields are variable and unpredictable and this is partly due to variability in growth and development of individual plants within landraces (Squire *et al.,* 1997).

2.5.5 Pest and Diseases

The crop appears to be remarkably free from pests and diseases (Purseglove, 1992). This agrees with Doku (1995) who mentioned that the crop is relatively pest and disease–free apart from weevil attack during storage. Gibbon and Pain (1985) observed that no serious pest or diseases are reported for this crop but damage is sometimes caused by leaf hoppers *(Hilda patruelis and Empoasca facialis)*. Tanimu and Aliyu (1995) have also made similar observations that bambara groundnut is relatively free of the insect pests that plague other legumes, such as the cowpea and peanut. And on the whole, pesticides are hardly used by farmers when cultivating bambara groundnut.

Bambara groundnut is considered to be generally less affected by diseases and pests than groundnut or cowpea, but several diseases and pests can cause serious damage to the crop. The most important fungal diseases are cercospora leaf spot *(Cercospora spp.),* powdery mildew *(Erysiple polygoni)* and Fusaruim wilt (*Fusarium oxysporum*) (Brink *et al.,* 2006). According to Goli (1995) in dry weather, pod attacks by termites have been consistently observed and root knot nematode *(Meloidogyne javanica)* also attacks the roots of the plant in sandy soils.

2.6 Uses

Seeds of bambara groundnut are not sold on world markets but play an important part in the diet of people in several West African countries where they are the third most important commodity after cowpea and groundnut in the national production and consumption statistics (Baudoin and Mergeai, 2001). In Ghana, the beans used to be canned in gravy at GIHOC Cannery in Nsawam. The product was thus available throughout the year and over 40,000 cans of various sizes were produced annually (Doku and Karikari, 1971). The seeds are consumed either immature or in matured states, but dry seeds are hard and difficult to cook and may be ground before use (Tweneboah, 2000).

Bambara groundnut is eaten in various ways, depending on the region. They can also be processed into flour for use in soups, purées and flat cakes. The canning of bambara seeds in sauce has been reported in Ghana (Baudoin and Mergeai, 2001). The crop is grown mainly for its edible protein and not as an oil crop. When dried, the seeds are very hard and can only be eaten when ground into flour. Unripe seeds can be eaten fresh but mature seeds have to be soaked and boiled before eating (Gibbon and Pain, 1985). Doku and Karikari (1969) reported that in Ghana, the nuts are boiled with pepper and salt in the preparation of “Aboboi” which, when served with "gari" (grated and roasted cassava) or "tatare" (mashed fried ripe plantain), makes a very delicious meal.

In many West African countries, the fresh pods are boiled with salt and pepper, and eaten as a snack. In Côte d'Ivoire, the seed is used to make flour, which makes it more digestible. In East Africa, the beans are roasted, then pulverized, and used to make a soup with or without condiments. Bread made from bambara groundnut flour has been reported in Zambia (Linnemann, 1990). In Senegal leaf preparations are applied to abscesses and infected wounds, leaf sap is applied to the eyes to treat epilepsy, and the roots are sometimes taken as an aphrodisiac. Pounded seeds mixed with water are administered to treat cataracts. The Zybo tribe in Nigeria uses the plant to treat venereal diseases (Brink *et al.,* 2006). The leaves which are rich in protein and phosphorus are used as fodder for livestock (Drabo *et al.,* 1995).

2.7 Nutritonal value

Bambara groundnut is the only legume whose seeds are referred to and used as complete food because they contain protein, carbohydrate and fat in sufficient proportions to provide a nutritious food (Poulter and Caygill, 1980). The seed makes a complete food, as it contains sufficient quantities of protein, carbohydrate and fat (Goli, 1995). The ripe seeds contain on average 10% water, 15 - 20% protein, 4 - 9% fat, 50 - 65% carbohydrate and 3 - 5% fibre (Baudoin and Mergeai, 2001).

Brough and Azam – Ali (1992) indicated that the mature seeds are a rich source of protein (16-25 % DM) and carbohydrate (42–60% DM) but, in comparison with groundnut, the lipid content is low (5-6% DM). The gross energy value of bambara groundnut seed is greater than that of other common pulses such as cowpea, lentil and pigeon pea (FAO, 1982). Purseglove (1992) also reported that the ripe seeds contain: protein 16-21%; fat 4.5-6.5%; carbohydrate 50-60%; thus providing a completely balanced food. Brink *et al.* (2006) mentioned that dried leaves for fodder contain crude protein 15.9%, crude fibre 31.7%, ash 7.5% and fat 1.8%.

2.8 Production and international trade

Bambara groundnuts are cultivated throughout tropical Africa and in Madagascar. It is also found on the continents of America (Brazil, Paraguay and Surinam); Asia (India, Indonesia, Malaysia, the Philippines and Sri Lanka) and Oceania (Northern Australia and New Caledonia). About 45–50% of world production comes from West Africa (Baudoin and Mergeai, 2001).

Reliable production figures for the crop are difficult to obtain, because the crop is grown mainly for home consumption and sale at local markets. The major producers are Burkina Faso, Chad, Cote d'Ivoire, Ghana, Mali, Niger and Nigeria. The main exporting countries are Burkina Faso, Chad, Mali, Niger and Senegal; they supply markets in Benin, Ghana, Nigeria and Togo (Brink *et al.,* 2006). The crop does not enter world trade because they are cultivated in the drier regions of tropical Africa mainly for local consumption, but seldom on a large scale. The most extensive production is in Zambia (Purseglove, 1992). Gibbon and Pain (1985) also reported that production is on a small scale for home consumption and the largest areas are to be found in Zambia.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Sites

Field experiments were conducted at the Irrigation Company of Upper Region (ICOUR) in Navrongo (10^{0} $54^{/}$ N, 1^{0} $7^{/}$ W) Upper East Region and the Agricultural Research Station, Wenchi (7^{0} $44^{/}$ N, 2^{0} $6^{/}$ W) Brong Ahafo Region (which served as a check) from February to June, 2007.

3.2 Experimental Design and Treatment

A Randomized Complete Block Design (RCBD) with four replications for the heat experiment at ICOUR and three replications for the other two experiments at ICOUR and Wenchi were used. Plot size was 6 m x 6 m. Individual plots within a block were separated from by 1m, while the blocks were separated from each other by a distance of 2 m.

Inter-row spacing was 50 cm and intra-row spacing was 20 cm. The seeds were sown with a cutlass to a depth of about 3-5 cm. Two seeds per stand were sown and thinned to one seed per stand at 21 days after planting (DAP) given a plant population of 10plants/m^{2}. The seeds were obtained from CSIR-Crop Research Institute (CRI), Kumasi.

The treatments were five bambara groundnut landraces (Plates 1 and 2):

(i). Tom (big seed size, deep cream with black eye)

(ii) Burkina (small seed size, light cream with white eye)

(iii) Nav Red (medium seed size, reddish brown)

(iv) Nav 4 (medium seed size, cream with ash eye)

(v) Black Eye (medium seed size, cream with black eye)

3.3 Management Practices

The fields were ploughed, harrowed and ridged. 250 kg/ha of single super phosphate was applied before sowing. Drought stress experimental field was irrigated up to seedling establishment (4 weeks) after which there was no further irrigation. The heat stress and the checked experiments were, however, irrigated to maturity. The field was weeded three times by hand hoeing.

3.4 Data Collected

3.4.1 Soil Sampling

Soil samples were collected at random spots from the experimental fields from a depth 0-25 cm. The samples were thoroughly mixed and sub-samples taken. It was air-dried, crushed with a wooden roller, passed through a 2 cm mesh sieve and used for chemical and physical analysis. Appendix 1 shows the physical and chemical properties of the soils at the experimental sites. Soil test performed before the start of the experiments were as follows:

(i) Particle size analysis

This was done by the hydrometer method of Bouyoucos (Day, 1965). 50 g of soil was used and readings taken at five minutes and eight hours for silt plus clay and clay respectively. Temperatures recorded were 27.5 ^{0}C for the first reading and 29 ^{0}C for the second reading.

(ii) Soil - pH

Soil pH was measured using a Pye Unican pH meter (model 290) and a soil:water ratio of 1:2.5.

(iii) Total nitrogen

Total nitrogen was determined using the macro – Kjedahl method (Chapman and Pratt, 1961).

(iv) Available phosphorus

The determination of available P was done using Bausch and Lomb supertonic 20 spectrophotometer after extraction by the Bray P1 method (Bray and Kurtz, 1945).

(v) Organic matter

Soil organic matter content was determined using the Walkley – Black method (Jackson, 1965). The percent organic matter was calculated by multiplying carbon (%C) by the factor 1.724.

(vi) Exchangeable K, Na, Ca and Mg

1.0 N ammonium acetate solution (pH 7.0) was used in the extraction of the exchangeable based. K and Na were determined using flame photometry. Ca and Mg where determined by titration using 0.02 N EDTA solution (Moss, 1961).

(vii) Exchangeable AL and H

These were extracted with 1.0N KCl solution. Al plus H was determined by titration with 0.05N NaOH (IITA Manual Series No. 1, 1979).

3.4.2 Crop parameters

(i) Number of leaves per plant

The number of leaves of 10 tagged plants were counted at 20, 45, 60, 105 and 120 days after planting (DAP) and the average recorded.

(ii) Number of days to 50% flowering

The number of days to 50% flowering was taken as the number of days that elapsed, after sowing when 50% of the plants began to produce inflorescences.

(iii) Plant height at harvest (120 DAP)

The height from the ground level to the highest point of the 10 tagged plants was measured at harvest with a meter rule and the average calculated.

(iv) Plant canopy width at harvest (120 DAP)

The horizontal distance from one end of the canopies of the 10 tagged plants to the other ends were measured with meter rule and average calculated for the plant canopy width.

(v) Leaf, Stem, Root and Total plant dry weights

The leaves, stems and roots of 10 sampled plants were separated, oven-dried at 80^oC for 48 hours to a constant weight to obtain their weights. The leaf, stem and root dry weights were added to obtain the total plant dry weight. Sampling was done at 20, 45, 60, 105 and 120 DAP.

(vi) Leaf area

Leaves from 10 sampled plants were detached and their leaf areas measured using a leaf area meter (C1-202). Sampling was done at 20, 45, 60, 105 120 DAP.

(vii) Pod dry weight

Pods from 10 plants sampled at 120 days after planting were cleaned, dried at 80^oC for 48 hours to a constant weight in an oven to obtain their dry weights.

(viii) Seed dry weight

The dried pods of various landraces were shelled and weighed to obtain their weights.

3.4.3 Climatological data

The following climatic information at the experimental sites was obtained from the Meteorological Department at Navrongo and Wenchi (Appendices 2-11).

(i) Daily maximum temperatures

(ii) Daily minimum temperatures

(iii) Daily rainfall

(iv) Daily relative humidity

(v) Daily sunshine hours

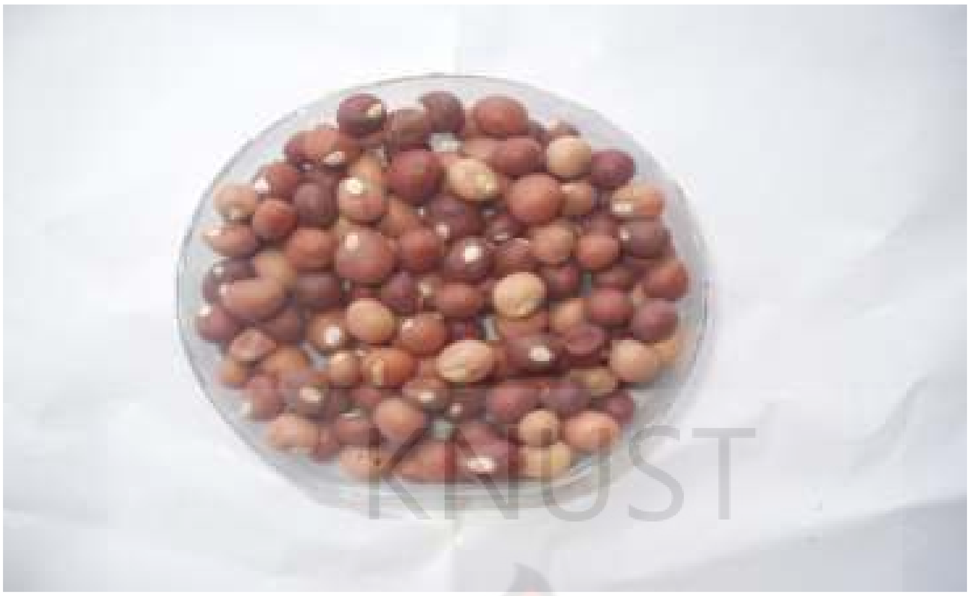
3.5 Data analysis

The data was analysed using Analysis of Variance (ANOVA). Differences between treatment means were determined using the Least Significant Difference method. The computer package used for the analysis was Gen Stat.

Plate 1.1:

Black Eye

Nav 4



Nav Red

Plate 1. 2:

Burkina

Tom

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Leaf Dry Weight

Leaf dry weight results of the heat experiment are presented in Table 4.1. At vegetative and flowering stages, treatment effects were not significantly different ($P > 0.05$). At the podding stage, however, leaf dry weight of Tom was significantly higher ($P < 0.05$) than that of the Nav Red. All other treatment differences were not significant. At the maturity stage, the greatest leaf dry weight was recorded in the Tom landrace, and this was significantly higher than the effect on Nav 4 landrace only. Tom is a faster growing landrace than Nav Red.

Leaf dry weight increased across sampling dates until 105 DAPS, after which it declined. The largest increase (20-40%) was between podding and maturity stages. Tom landrace still produced the highest leaf dry weight at harvest stage and this effect was significantly greater than that of Nav Red and Burkina. Other treatment effects were not significant at 5%.

The results show that Tom has large vegetative growth from photosynthesis as was reported by Brown (1984) that for many crops, the importance of the vegetative growth is simply to produce a large enough photosynthetic factory to obtain maximum yields. The leaf dry weight increased across sampling occasions to maturity and declined and this may be attributed to the setting in of senescence as was reported by Webster and Wilson (1986) that as plants become older, a large portion of the plant structures becomes inactive and leaves may fall from the plant representing loss of dry weight due to senescence.

Table 4.1: Effect of heat stress on leaf dry weight of bambara landraces at Navrongo in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	7.0	8.5	60.7	206.0	123.0
Nav Red	9.4	12.5	49.2	163.0	104.0
Nav 4	9.7	12.9	62.5	158.0	138.0
Burkina	10.3	13.2	61.7	204.0	110.0
Tom	11.0	14.9	67.7	246.0	190.0
Grand Mean	9.5	12.4	60.4	196.0	113.0
CV (%)	26.1	41.1	23.8	12.1	10.5
LSD (0.05)	NS	NS	16.3	84.8	72.1

The leaf dry weight of the drought experiment were not significantly different among the landraces on all sampling dates, except at harvest stage where Burkina landrace recorded the highest leaf dry weight, which effect was significantly higher than the effects of all others, except Nav Red landrace. Other treatment differences were statistically similar (Table 4.2). Leaf dry weight increased across all sampling occasions as reported by Brink *et al*. (2006), that vegetative development may continue after reproductive development has started.

The inability of the landraces to produce pods might have also led to continuous vegetative growth even up to the harvest period. Brown (1984) stated that if fruiting is prevented in peanut and cotton by removing flowers, vegetative growth proceeds rapidly, but if a heavy fruit load is formed, vegetative growth is greatly reduced.

Table 4.2: Effect of drought stress on leaf dry weight of bambara landraces at Navrongo in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	6.0	10.6	33.5	51.3	113.9
Nav Red	6.5	10.9	30.7	44.7	132.7
Nav 4	6.4	10.9	35.4	46.7	106.4
Burkina	7.7	11.8	33.2	59.3	196.3
Tom	8.1	12.0	39.7	62.0	117.0
Grand Mean	6.9	11.5	34.5	52.8	133.3
CV (%)	15.2	24.6	21.3	24.3	14.8
LSD (0.05)	NS	NS	NS	NS	68.1

Results of leaf dry weight of the Wenchi experiment are presented in Table 4.3. At the vegetative stage, Tom landrace recorded 90.0g per plant and its effect was significantly greater than all other landraces, except that of Nav Red which recorded 86.2g per plant. At flowering stage, effects of the Black Eye, Nav 4 and Burkina landraces were similar and were all significantly lower than the effects of Tom and Nav Red landraces. The greatest leaf dry weight 158.7g per plant was recorded in the Tom landrace, which effect was also significantly higher than that of the Nav Red landrace. Leaf dry weight increased between flowering and podding stages more than 200%.

At podding stage, leaf dry weight recorded in Tom was significantly higher than that of Burkina only. All other treatments effects were similar. At maturity stage, leaf dry weight of Tom landrace was the highest (618.0g), which was significantly higher than that of Nav 4 only. All other treatment differences were not statistically significant. Tom still produced the greatest leaf dry weight at harvest stage and the effect was significantly higher than that of all others, except that of Nav Red landrace. Effect of Nav Red was also higher than that of Nav 4.

Leaf dry weight increased across sampling occasions until maturity stage, after which it declined. This observation is similar to an earlier one made by Martin *et al*. (2006). They observed that decline in amount of leaf is due to the death and abscissions of leaves at a faster rate than new leaves are formed during the reproductive portion of the growth cycle. The vegetative nature of Tom may be important in weed control as was reported by Hay and Walker (1994) that extensive vegetative growth can aid in weed control by competing for sunlight and other factors.

Table 4.3: Leaf dry weight of bambara landraces of the check experiment at Wenchi in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	75.0	119.0	326.3	538.0	490.0
Nav Red	86.2	136.0	323.0	544.0	502.3
Nav 4	74.8	119.0	323.0	487.0	415.6
Burkina	75.2	119.0	317.3	491.0	440.1
Tom	90.0	158.7	368.3	618.0	578.0
Grand Mean	80.2	130.3	331.6	536.0	485.2
CV (%)	2.6	1.5	7.6	6.2	6.7
LSD (0.05)	11.7	8.3	45.2	75.1	80.4

4.2 Stem Dry Weight

Results of stem dry weight of the heat experiment did not show significant difference on all sampling dates (Table 4.4). Allocation of assimilates to bambara stem may be small as was found out by Doku (1996) that sink demand of the thin and much branched prostrate stems cannot offer any significant competition for assimilates vis-à-vis the developing pods.

Table 4.4: Effect of heat stress on stem dry weight of bambara landraces at Navrongo in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	6.3	9.1	50.0	190.0	131.0

Nav Red	11.1	15.3	50.0	211.0	115.0
Nav 4	13.2	17.3	54.9	210.0	127.0
Burkina	18.0	22.3	54.4	280.0	155.0
Tom	15.2	19.1	45.9	235.0	110.0
Grand Mean	12.8	16.6	51.0	225.0	128.0
CV (%)	21.5	49.4	14.4	4.6	19.8
LSD (0.05)	NS	NS	NS	NS	NS

Results of the stem dry weight of the drought experiment did not show significant differences on all sampling dates, except at maturity stage where Burkina landrace recorded the highest effect which was significantly higher than that of Tom and Black Eye landraces. All other treatment effects were not significantly different (Table 4.5).

Allocation of assimilates to bambara stem may be small as was found out by Doku (1996) that sink demand of the thin and much branched prostrate stems cannot offer any significant competition for assimilates relative to the developing pods. The stem dry weight also increased with stages of plant development from vegetative stage till harvest stage probably because the plants could not produce pods and assimilates continued to be partitioned into the vegetative parts instead of the pods.

Table 4.5: Effect of drought stress on stem dry weight of bambara landraces at Navrongo in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	5.0	7.6	19.8	59.3	116.7
Nav Red	6.8	9.3	19.2	72.0	123.2
Nav 4	7.9	10.3	22.1	65.3	107.8
Burkina	8.5	10.7	21.1	84.0	150.3
Tom	6.6	9.7	22.0	61.3	123.2

Grand Mean	7.0	9.5	20.8	68.4	124.2
CV (%)	14.3	21.4	20.1	19.8	17.8
LSD (0.05)	NS	NS	NS	21.5	NS

Stem dry weight results of the Wenchi experiment are presented in Table 4.6. Treatment differences were only significant at podding stage. At podding stage, the greatest effect was recorded in the Tom landrace, but this was significantly higher than that of the Nav 4 landrace only. All other treatment differences were not significant. In all the landraces, stem dry weight increased across the sampling periods to maturity stage and declined indicating that assimilates were being translocated to the developing pods as was reported by Evans and Wardlaw (1976) that assimilates are partitioned among the various sinks in a coordinated way according to their requirements.

Table 4.6: Stem dry weight of bambara landraces of the check experiment at Wenchi in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	11.5	16.7	68.0	158.7	174.3
Nav Red	12.1	17.0	79.3	113.3	131.4
Nav 4	12.4	17.0	62.3	107.7	120.1
Burkina	12.0	17.0	68.0	113.3	136.0
Tom	16.6	22.7	90.7	153.0	169.2
Grand Mean	12.9	18.1	73.7	129.2	146.2
CV (%)	27.1	11.2	33.4	17.3	20.5

LSD (0.05)	NS	NS	25.5	NS	NS

4.3 Root Dry Weight

Results of the root dry weight of the heat experiment are presented in Table 4.7. Treatment differences at 20, 45 and 105 DAP stages were not significant. At podding stage, however, the root dry weight in the Black Eye landrace was significantly higher than that of Nav Red only. All other treatment differences were not significant. Also at harvest stage, root dry weight of the Nav Red landrace was significantly higher than those of the Burkina and Tom landraces. All other treatment differences were not significant.

The root dry weight increased from vegetative to maturity stage and declined. This observation confirms that of Ezedinma (1995) that all plants mature and cease growth because of completion of the life cycle or the onset of dormancy.

Table 4.7: Effect of heat stress on root dry weight of bambara landraces at Navrongo in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	0.1	0.2	2.6	3.1	2.4
Nav Red	0.4	0.5	1.6	3.7	3.0
Nav 4	0.3	0.4	2.3	2.7	2.1
Burkina	0.5	0.6	2.2	2.2	1.8
Tom	0.4	0.5	1.8	2.2	1.3
Grand Mean	0.3	0.4	2.1	2.8	2.1
CV (%)	25.9	55.8	14.4	14.8	8.0
LSD (0.05)	NS	NS	0.9	NS	1.1

Root dry weight results of the drought experiment are presented in Table 4.8. No significant differences were observed at vegetative, flowering and podding stages, but at maturity and harvest stages, significant differences were observed. At maturity stage, the treatment effect of Burkina landrace was highest and this was significantly higher than that of all other landraces. Differences in the effects of the other landraces were not significant. Burkina still produced the highest root dry weight at harvest stage and the effect was significantly greater than that of other landraces. Other treatment effects were not significantly different.

The root dry weight of Black Eye, Nav Red and Burkina increased from vegetative stage to maturity stage and declined but that of Nav 4 and Tom increased till harvest stage. The highest root dry weight recorded by Burkina landrace shows the well developed nature of the root system and this may be an adaptation of the crop to drought stress as was observed by Doku (1996) that the well developed root system of bambara exploits the rhizosphere for moisture. If high root dry weight corresponds to extensive root system then it might serve as an attribute which help to extract more water under drought stress created by the high temperature. Begemann (1988) expressed a similar view that length of the root system evidently has important relevance to the drought tolerance of bambara groundnut.

Table 4.8: Effect of drought stress on root dry weight of bambara landraces at Navrongo in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	0.1	0.3	0.9	2.1	1.9
Nav Red	0.2	0.4	1.1	2.3	1.8
Nav 4	0.2	0.4	0.7	1.9	2.3
Burkina	0.3	0.5	0.6	3.8	3.7
Tom	0.2	0.4	1.0	2.1	2.6
Grand Mean	0.2	0.4	0.8	2.4	2.5
CV (%)	16.3	24.6	17.2	12.4	14.3
LSD (0.05)	NS	NS	NS	1.1	0.9

Differences in root dry weight of the Wenchi experiment were not significant at vegetative and flowering stages, but at podding, maturity and harvest stages differences occurred. At podding stage, the greatest effect was recorded in Tom, which effect was significantly higher than those of Nav 4 and Burkina landraces. Root dry weight of Nav Red was significantly higher than that of Nav 4, which recorded the lowest effect. At maturity stage, root dry weight was still greatest in Tom landrace and this effect was significantly higher than all other treatment effects, except that of the Black Eye landrace. All other treatment differences were not significant at 5% level of significance. Nav 4 produced the lowest root dry weight at the harvest stage and this was significantly lower than that of Tom only. Other effects were statistically similar (Table 4.9).

The root dry weight increased from the vegetative stage and declined at harvest stage. This tread may be due to senescence. Norman *et al*. (1995) reported that the function of roots is more important than their weight. Therefore the extent of the root system is important as the root system must grow to exploit larger volumes of soil for nutrients and water.

Table 4.9: Root dry weight of bambara landraces of the check experiment at Wenchi in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	10.2	16.7	34.0	85.0	78.2
Nav Red	11.0	17.0	39.7	79.3	64.3
Nav 4	10.9	17.0	22.7	68.0	49.5
Burkina	11.2	17.0	28.3	73.7	60.1
Tom	17.1	22.7	45.3	102.0	92.4
Grand Mean	12.1	18.1	34.0	81.6	68.9
CV (%)	16.3	11.2	43.6	26.0	19.1

LSD (0.05)	NS	NS	11.7	21.9	39.3

4.4 Total Plant Dry Weight

Total plant dry weight results of the heat experiment are presented in Table 4.10. At vegetative stage, the greatest total plant dry weight was recorded in the Tom landrace, and this was significantly higher than the effects of only the Black Eye and Nav Red landraces. The Burkina also recorded greater effect than the Black Eye landrace. At flowering stage, Tom still produced the highest total plant dry weight which effect was significantly higher than that of all other landraces. All other treatment differences were not significant. No significant differences were observed at podding and maturity stages. At harvest stage, Burkina landrace recorded the highest and this effect was higher than that of Tom landrace only. Other treatment differences were not significant.

The total plant dry weight increased across the sampling occasions and declined at maturity stage. The total plant dry weight is not very important as the pod yield because the final yield of an economically important product is of most concern to the producer (Brown, 1984). In bambara groundnut, this economically important product is the pod and the seed.

Table 4.10: Effect of heat stress on total plant dry weight of bambara landraces at Navrongo in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	11.4	23.1	113.3	399	305
Nav Red	14.5	28.4	100.8	378	274
Nav 4	20.3	33.6	119.7	371	321
Burkina	25.9	36.1	118.3	487	368
Tom	30.2	57.2	115.4	484	201
Grand Mean	18.9	35.7	113.5	424	297
CV (%)	9.3	12.8	19.1	4.4	8.1
LSD (0.05)	12.4	14.0	NS	NS	156.8

Results of total plant dry weight of the drought experiment did not show significant differences at all developmental stages, except at harvest stage. At harvest stage, Burkina landrace produced the highest and the effect was significantly greater than that of Nav 4 landrace only. The effects of other treatments were statistically similar (Table 4.11).

No pod was produced by any of the landraces and this may be due to the severe water stress as has been reported by Brink *et al*. (2006) that podding may be delayed or hindered by drought. However, the highest total plant dry weight recorded in Burkina indicates its superior attributes that could translate into greater seed yield if moisture was to be available. Generally, the total plant dry weight increased across the sampling periods because vegetative growth was still going on during the theoretical harvest stage since the plants were unable to form pods.

Table 4.11: Effect of drought stress on total plant dry weight of bambara landraces at Navrongo in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	10.6	18.5	54.1	112.8	233
Nav Red	13.4	20.6	51.0	119.0	258
Nav 4	14.6	22.6	58.1	113.9	216
Burkina	15.5	22.9	54.9	147.1	351
Tom	15.0	22.1	62.6	125.4	243
Grand Mean	13.8	21.4	56.2	123.6	260
CV (%)	16.7	23.4	20.6	20.9	15.9

LSD (0.05)	NS	NS	NS	NS	125.7

Results of total dry weight of the Wenchi experiment showed significant differences (Table 4.12). At the vegetative stage, Tom recorded the highest which effect was significantly greater than that of the other landraces. Treatment differences between other landraces were not significant. At the flowering stage, the treatment effects of Black Eye, Nav Red, Nav 4 and Burkina landraces were statistically similar and were lower than that of Tom landrace. Tom produced the highest total plant dry weight at podding stage and this effect was significantly greater than that of all other landraces. All other treatment effects were statistically similar.

Difference in treatment effect was significant at the maturity stage with Tom producing the highest total plant dry weight and this effect was significantly greater than that of the other landraces. At harvest stage, Tom recorded the greatest effect and this was significantly higher than that of all other landraces. Treatment effect of the Nav 4 landrace was also significantly lower than that of the other landraces. The highest total plant dry weight or the vegetative cover of Tom could not reflect in the pod yield as Evans (1995) reported that it is only in crops like forage, where producers are interested principally in the vegetative growth.

Table 4.12: Total plant dry weight of bambara landraces of the check experiment at Wenchi in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP (g)	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	102.5	152.3	428.3	600.7	1257.0
Nav Red	119.6	170.0	442.0	624.0	1268.0
Nav 4	105.1	153.0	408.0	555.3	1106.0
Burkina	104.0	153.0	413.0	583.7	1244.0
Tom	155.3	204.0	504.0	719.7	1938.0
Grand Mean	117.3	166.5	441.7	616.7	1362.6
CV (%)	7.2	3.6	6.6	5.1	1.7

LSD (0.05)	46.4	24.7	57.9	44.3	125.8

4.5 Leaf Area Index (LAI)

The leaf area index of the heat experiment at all sampling occasions except at 105 DAP, showed significant differences ($p < 0.05$). At vegetative stage the greatest leaf area index was recorded in the Tom landrace and this was significantly higher than the effect of all other landraces. All other treatment differences were not significant. Treatment differences at flowering stage were significant with Tom producing the greatest leaf area index whose effect was also greater than the effects of the other landraces. Other treatment differences were not significant. At podding stage the effect of Tom was significantly higher than that of Burkina landrace only. The greatest treatment effect at harvest stage was still recorded in Tom and this was also significantly higher than that of Burkina and Nav 4 landraces only. All other treatment differences were not significant.

The leaf area index of the landraces increased across the sampling occasion to maturity stage and declined indicating the onset of senescence (Table 4.13). The pattern of leaf growth recorded here is consistent with plant growth pattern that shows initial slow growth, then rapid linear growth up to near maturity when growth declines because of the on set of senescence (Salisbury and Ross, 1985). Leaf area index declined between maturity and harvest stages.

Table 4.13: Effect of heat stress on leaf area index of bambara landraces at Navrongo in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	0.72	0.95	4.84	6.09	4.64
Nav Red	0.61	0.86	4.80	5.61	4.16
Nav 4	0.73	0.96	5.14	6.25	3.43
Burkina	0.82	1.03	3.81	4.58	3.32
Tom	1.20	1.42	6.51	8.22	5.99
Grand Mean	0.81	1.04	5.02	6.15	4.31
CV (%)	0.01	0.01	0.01	0.02	0.02
LSD (0.05)	0.34	0.23	1.60	NS	1.93

Differences in leaf area index of the drought experiment were not significant on all sampling occasions except at vegetative stage. At the vegetative stage, Tom recorded the highest and this effect was significantly greater than that of Nav Red landrace only (Table 4.14). Tom was the fastest plant to expand its leaf area index, therefore had greater source area to absorb solar radiation for greater growth (Brown, 1984). This however, did not transform into pod yield because it continuously grew vegetatively.

Table 4.14: Effect of drought stress on leaf area index of bambara landraces at Navrongo in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	0.32	0.53	1.50	4.09	3.69
Nav Red	0.21	0.42	1.44	3.24	2.84
Nav 4	0.22	0.44	1.51	2.06	2.27
Burkina	0.29	0.48	1.56	2.74	2.40
Tom	0.35	0.53	2.39	4.55	2.76
Grand Mean	0.28	0.48	1.68	3.34	2.79

CV (%)	0.01	0.01	0.01	0.02	0.02
LSD (0.05)	0.13	NS	NS	NS	NS

4.6 Plant Height and Canopy Width at Harvest

Plant height and canopy width at harvest (120 DAP) of the heat experiment showed significant differences ($p < 0.05$) with Tom producing the tallest plants (25.3cm), which effect was significantly higher than that of all other landraces (Table 4.15). Other treatment differences were not significant. The Tom and Nav 4 landraces recorded the greatest canopy widths and these were significantly higher than the Burkina treatment (Table 4.15). The canopy width of Black Eye landrace was also greater than that Burkina landrace.

Tall and broad canopy plants have advantage when intercropped with others in that tall plants have advantage in competing with other plants in a community (Evans, 1995). However, this shows the different plant forms of the crop as has been indicated by Doku (1996) that different growth forms exist (bunch, spreading and intermediate).

Plant height at harvest of the drought experiment showed significant differences with Tom recording the greatest effect which was significantly higher than that of Burkina only (Table 4.15). Treatment effects among other landraces were statistically similar. The height of the plants ranged from 17.7 cm to 21.2 cm and this confirms an earlier report made by Gibbon and Pain (1985) that bambara grows to a height of not more than 25 cm. No significant difference was observed in plant canopy width (Table 4.15).

Table 4.15: Plant height and canopy width at harvest as affected by heat and drought at Navrongo in 2007

Landrace	Plant height (cm)	Canopy Width (cm)

	Heat experiment	**Drought experiment**	**Heat experiment**	**Drought experiment**
Black Eye	20.8	18.9	38.2	35.7
Nav Red	22.5	19.8	36.6	36.5
Nav 4	21.3	19.4	40.0	32.9
Burkina	20.5	17.7	30.9	31.3
Tom	25.3	21.2	40.2	37.7
Grand Mean	22.1	19.4	37.1	34.8
CV (%)	7.0	6.8	11.3	12.9
LSD (0.05)	2.5	3.4	6.1	7.1

4.7 Number of Leaves Per Plant

Results on the number of leaves per plant of the heat experiment are presented in Table 4.16. From vegetative to podding stage, there were significant differences ($p < 0.05$) in the leaf number per plant but not at maturity and harvest stages. At 20 DAP, the Burkina and Black Eye landraces had significantly higher number of leaves per plant than the other landraces. At flowering stage, however, Burkina recorded the highest leaf number which was significantly higher than that of Tom and Nav Red. All other treatment differences were not statistically significant. At podding stage, the highest effect was recorded in Nav 4 and this was significantly greater than that of the Tom landrace only. Other treatment differences were not statistically significant.

The number of leaves per plant increased across the sampling occasions. Crop with more leaves could have the capability of capturing and utilizing more solar energy (Martin *et al*., 2006), which can enhance photosynthetic capacity. However, where the arrangement of such large number of leaves is not done well, there could be mutual shading among the leaves, which can also retard photosynthetic capacity (Salisbury and Ross, 1985). To avoid this, Plant Breeders are now selecting plants architecture that has small leaves on top and broader leaves below to enhance solar radiation interception.

Table 4.16: Effect of heat stress on number of leaves per plant of bambara landraces at Navrongo in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	4.5	50.8	160.7	227.1	270.0
Nav Red	4.1	47.0	160.2	226.0	263.0
Nav 4	4.2	49.2	185.4	235.8	280.0
Burkina	4.5	53.3	170.5	211.0	236.0
Tom	4.2	43.4	151.6	218.5	275.0
Grand Mean	4.3	48.7	165.6	223.7	265.0
CV (%)	2.8	9.1	9.0	14.1	19.8
LSD (0.05)	0.3	4.9	32.2	NS	NS

There were significant differences in the number of leaves per plant of the landraces of the drought experiment only at vegetative and harvest stages. No significant differences of treatment effects were seen in the landraces at flowering, podding and maturity stages. At vegetative stage, Black Eye landrace recorded the highest number of leaves per plant and this was significantly higher than those of Nav Red and Nav 4 (Table 4.17). Other treatment differences were not significant. Black Eye still produced the greatest effect at harvest stage and the effect was significantly higher than those of Nav 4 and Tom (Table 4.17).

The greater number of leaves per plant recorded by Black Eye at vegetative and harvest stages, Burkina at maturity stage might have produced enough photosynthate but could not be translocated into the sink as was reported by Lockhart and Wiseman (1988) that water stress affects translocation.

Table 4.17: Effect of drought stress on number of leaves per plant of bambara landraces at Navrongo in 2007

Landrace	**Vegetative stage 20 DAP**	**Flowering stage 45 DAP**	**Podding stage 60 DAP**	**Maturity stage 105 DAP**	**Harvest stage 120 DAP**
Black Eye	4.3	31.1	100.0	117.0	188.0
Nav Red	3.7	30.3	90.9	107.4	161.0
Nav 4	3.7	30.7	85.7	104.3	80.0
Burkina	3.8	32.5	100.7	130.7	183.0
Tom	3.8	28.1	91.5	114.7	90.0
Grand Mean	3.9	30.6	93.8	114.8	141.0
CV (%)	8.9	8.6	11.5	11.7	31.9
LSD (0.05)	0.5	NS	NS	NS	89.7

Differences in leaf numbers were highly significant ($p < 0.001$) on all sampling dates at the Wenchi experiment, with Tom recording the highest and Burkina the lowest. At vegetative stage, Tom recorded the highest and the effect was significantly greater than that of all other landraces. Other treatment effects were also significant at 5%. Burkina recorded the lowest treatment effect at flowering stage and this effect was significantly lower than that of all other landraces but not Black Eye. At the podding stage, the lowest leaf number was recorded in Burkina, whose effect was significantly different than those of the other landraces.

Tom still produced the greatest effect at maturity stage, which was significantly higher than the effects of the other landraces. Other treatment differences were also significant at 5%. At harvest stage, significant differences were observed in the number of leaves per plant with Tom and Burkina recording the highest and lowest respectively. The treatment effect of Burkina was significantly lower than those of other landraces (Table 4.18). More number of leaves per plant could not result in more economic yield as was reported by Tweneboah (2000) that excessive production of vegetative growth is undesirable for seed production.

Table 4.18: Number of leaves per plant of bambara landraces of the check experiment at Wenchi in 2007

Landrace	Vegetative stage 20 DAP	Flowering stage 45 DAP	Podding stage 60 DAP	Maturity stage 105 DAP	Harvest stage 120 DAP
Black Eye	15.0	42.0	114.0	146.0	179.3
Nav Red	20.7	102.7	224.0	288.0	352.3
Nav 4	16.7	56.7	114.0	167.3	197.3
Burkina	12.7	41.0	98.0	132.0	157.7
Tom	25.3	130.0	245.7	324.0	389.7
Grand Mean	18.1	74.5	159.1	211.5	255.3
CV (%)	4.2	1.9	2.3	1.3	1.6
LSD (0.05)	0.6	2.5	10.4	6.9	19.7

4.8 Days to 50% Flowering.

The days to 50% flowering of the heat experiment were highest in Nav Red, and this was significantly higher than that of the Burkina landrace only (Table 4.19). The days to 50% flowering of the landraces were between 44 and 47 days. Earlier report by Brink *et al*. (2006) indicated that flowering in bambara occurs within 30-55 days after sowing. Differences of treatment effects among landraces of the drought experiment on days to 50% flowering were not significant.

Results on days to 50% flowering of the Wenchi experiment are presented in Table 4.19. Burkina was the earliest to flower, at 37 days after planting. This effect was significantly different from that of Black Eye which took 40 days to obtain 50% flowering. All other treatment effects were not significant. This observation was different from earlier one made by Ocran *et al*. (1998) that the plant flowers within 43 days.

Table 4.19: Days to 50% flowering as affected by heat and drought at Navrongo and the check experiment at Wenchi in 2007

Landrace	Heat experiment	Drought experiment	Wenchi experiment
Black Eye	46.0	47.0	40.0
Nav Red	47.0	45.0	39.0
Nav 4	46.0	46.0	39.0
Burkina	44.0	46.0	37.0
Tom	46.0	45.0	39.0
Grand Mean	46.0	46.0	39.0
CV (%)	2.1	1.6	0.8
LSD (0.05)	2.3	NS	2.1

4.9 Pod and Seed Dry Weight

Pod dry weight and seed dry weight results of the heat experiment are presented in Table 4.20. The greatest effect of 1185 kg/ha was recorded in the Burkina landrace and this was significantly higher than all other treatment effects. The Tom landrace did not produce pods. Seed dry weight was greatest in the Burkina landrace, which was significantly higher than all other treatment effects. All other treatment differences, except Tom which produced no seeds were not significant at 5% level of probability. Partitioning of dry matter to pods in Tom however, did not correspond with high vegetative phase developed by Tom as was reported by Brown (1984).

Burkina landrace is normally grown in Burkina Faso, a country with dry environment therefore, it is not surprising for it to give the highest seed yield of 830 kg/ha. The yield was in line with the observation made by Gibbon and Pain (1985) that yields of dried nuts range from 550-1100 kg/ha. The failure of Tom to produce pod may be due to its sensitivity to high temperature or photoperiod as was reported by Brink *et al*. (2006) that there are considerable differences between genotypes in their response to temperature and photoperiod. This means while some genotypes are insensitive to photoperiod, others are. Higher temperatures during the conduct of the experiment might have prevented seed set in the Tom landrace.

Pod dry weight of the check experiment at Wenchi was highest in the Burkina landrace and this was significantly higher than that of the Tom landrace only. Other treatment differences were not significant (Table 4.20). It should be noted that Burkina landrace is from a Sahelian country and it is possible it is more resistant to harsh conditions than the other landraces.

Seed dry weight of the check experiment at Wenchi was lowest in Tom landrace. Indeed seed dry weight in the Tom landrace was very low compared to the other landraces (Table 4.20). The high vegetative growth in Tom could have accounted for the low seed yield. The crop developed vegetatively at the expense of final seed yield. The yield recorded by Burkina (3870 kg/ha) is comparable to that reported by Brink *et al*. (2006), that the highest recorded seed yield under field conditions is 4000 kg/ha.

Table 4.20: Pod and seed dry weight as affected by heat at Navrongo and the check experiment at Wenchi in 2007

Landrace	Pod Dry Weight (kg/ha)		Seed Dry Weight (kg/ha)	
	Heat experiment	Check experiment	Heat experiment	Check experiment
Black Eye	488	5140	345	3600
Nav Red	525	5310	375	3720
Nav 4	540	4430	382	3100
Burkina	1185	5530	830	3870
Tom	0.0	660	0.0	460
Grand Mean	548	4220	386	2950.0

CV (%)	10.3	12.1	9.4	12.1
LSD (0.05	17.3	174.2	11.83	122.0

CHAPTER FIVE

5.0 GENERAL DISCUSSION

Grain yield is considered as the most important parameter in cereal and legume production (Purseglove, 1992). This is because it is the grains that are harvested for food or for sale by farmers. To this end, every legume or cereal crop grown, notwithstanding the luxuriant vegetative growth it may exhibit, becomes less useful if it fails to produce acceptable seed yield. Grain yield production is the result of interaction between the genetic potential of the crop and the conditions of the environment the crop is growing. For maximum grain yield, the genetic potential of the crop must be high and the environmental factors must be conducive (Gardner *et* *al*., 1985; Evans, 1993). Yield can be poor when environmental factors are limiting despite the genetic potential of the crop, and vice versa.

In the present study, this was evident with all the landraces, especially in the drought stress experiment at Navrongo when all the landraces did not produce pods and seeds. Brink *et al.,* (2006) noted that podding may be delayed or hindered by drought. The present study confirms this observation. Additionally, the Tom landrace did not produce pods under heat stress at Novrongo (Table 4.8). However, the same landrace, as well as all the other landraces produced pods and seeds in the control experiment at Wenchi (Table 4.21). Despite the fact that Tom produced the least amount of pods and seeds at Wenchi, its inability to do so under heat stress was a direct response to an unfavourable environment. Failure of this landrace to produce pods and seeds under heat stress may be due to its sensitiveness to photoperiod or high temperature under such conditions or to both (Brink *et al.,* 2006). Tanimu and Aliyu (1995) have suggested that under such conditions, it is advisable to grow day–neutral types with irrigation for acceptable grain yield.

In spite of the inability of the Tom landrace to produce pods under heat stress, it is not an indication to write it off completely. This landrace compared very favorably, with others in vegetative growth as shown by stem and leaf dry weights, leaf production and total plant dry matter. Indeed on some sampling occasions, its treatment effect was greater than the others. Although the large vegetative growth shown by the landrace could not be translated into pod and seed production, this landrace can still fit into the agricultural system in places of heat stress as forage for livestock in heat stress environments (Evans, 1993), as cover crop for weed control (Brown, 1984; Hay and Walker, 1994) or as a green manure crop (Gardner *et al.,* 1985).

Seed yield reported in the present study, especially at Wenchi, compared with results of other workers. The Burkina landrace produced the greatest pod dry weight of 1185 kg/ha under heat stress and 5530 kg/ha in the control experiment at Wenchi (Table 4.8 and 4.21). Seed yield produced by this landrace were 830 and 3870 kg/ha, respectively in the two studies mentioned above. Brink *et al.* (2006) have noted that the greatest recorded seed yield under field conditions was 4000 kg/ha. As a landrace cultivated in the Sahelian regions where drought and heat stress are frequent, it is an indication that the Burkina landrace is very adaptable to such conditions and could be recommended to farmers in the hot and dry conditions of the Upper East and West Regions of Ghana.

Another trait of the Burkina landrace is that the pod and seed yields produced at Wenchi were far higher than those under heat stress. This indicates that, though heat tolerant, given a more conducive environment it can produce greater seed yield. Seed yields recorded by the Black Eye, Nav Red and Nav 4 under more conducive environment at Wenchi were far higher than their performance under heat stress. This shows that these other landraces were more sensitive to heat stress, and as such these should be cultivated under more conducive growth conditions for greater returns-to-investment.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

In the heat experiment, Tom landrace recorded the greatest leaf dry weight and leaf area on all sampling dates, but the high vegetative cover could not result in high seed yield. The same landrace recorded the highest plant height and canopy width at harvest. The Burkina landrace recorded the greatest pod and seed dry weight under heat stress, showing it is more tolerant than other landraces.

In the drought experiment, Burkina landrace recorded the greatest root dry weight which could be an adaptation for greater water absorption. The highest total plant dry weight was recorded by Burkina, but this was not translated into production of seeds as no pod was produced. This might have been attributed to harsh condition due to combination of water and heat stress. In the Wenchi experiment, Tom recorded highest leaf dry weight confirming its leafy nature. The greatest pod yield was recorded in the Burkina landrace.

These results indicate that among the landraces studied, the Burkina landrace showed the highest tolerance to both heat and drought stress. Under the conditions of this study, this landrace can be recommended to bambara farmers for cultivation, but for seed yield to be enhanced, cultivation must be done with irrigation. Further studies can be undertaken to confirm these recommendations by looking at yield components (number of pods per plant, number of seeds per pod and mean seed weight).

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APPENDICES

APPENDIX 1

Physical and chemical properties of the soil at the experimental sites

Property	**Navrongo**	**Wenchi**
Sand (%)	63	82
Silt (%)	25	6
Clay (%)	12	12
pH (1:2.5 H_2O)	5.97	5.30
Organic matter (%)	0.54	6.72
Texture	Sandy Loam	Sandy Loam
Total Nitrogen (%)	0.11	0.12
Available P (ppm)	22.69	15.0
Exchangeable Cations (me/100g)		
K	0.46	0.05
Ca	5.87	0.40
Mg	1.67	0.11
Al + H	0.18	1.00
Na	0.55	0.01

APPENDIX 2

Daily Climatological Data for Navrongo in February, 2007

Date	Rainfall (mm)	Temperature (^{o}C)		Sunshine Duration Hours	Relative Humidity (%)	
		Min.	Max.		06.00	15.00
1	0.0	23.7	39.1	7.6	23.0	16.0
2	0.0	22.5	40.2	9.6	31.0	13.0
3	0.0	22.0	40.2	9.1	37.0	13.0
4	0.0	21.0	39.7	10.4	38.0	15.0
5	0.0	21.4	39.5	10.3	35.0	19.0
6	0.0	21.0	40.5	10.5	38.0	17.0
7	0.0	20.5	40.5	10.3	47.0	19.0
8	0.0	23.6	39.0	10.1	44.0	20.0
9	0.0	21.5	39.5	10.3	39.0	10.0
10	0.0	19.1	39.7	10.5	33.0	11.0
11	0.0	23.0	38.1	8.6	26.0	14.0
12	0.0	22.9	37.8	9.5	24.0	13.0
13	0.0	23.6	37.0	9.5	21.0	14.0
14	0.0	22.4	36.1	10.4	24.0	18.0
15	0.0	21.5	36.5	9.8	29.0	17.0
16	0.0	22.0	37.2	9.2	26.0	10.0
17	0.0	21.1	37.6	8.9	21.0	11.0
18	0.0	22.4	39.0	9.6	26.0	12.0
19	0.0	21.9	40.5	10.1	24.0	14.0
20	0.0	21.9	40.5	9.7	26.0	12.0
21	0.0	22.5	39.7	6.8	31.0	13.0
22	0.0	24.1	37.0	7.6	15.0	14.0
23	0.0	23.2	36.0	9.3	24.0	17.0
24	0.0	21.8	36.6	9.9	32.0	20.0
25	0.0	22.2	38.3	9.8	27.0	18.0
26	0.0	24.2	38.5	8.7	29.0	17.0
27	0.0	24.3	38.9	9.6	29.0	19.0
28	0.0	23.4	39.0	9.9	29.0	25.0
Mean	-	22.5	38.7	9.5	30.0	15.0

Source: Ghana Meteorological Agency (Navrongo)

APPENDIX 3

Daily Climatological Data for Navrongo in March, 2007

Date	Rainfall (mm)	Temperature (°C)		Sunshine Duration Hours	Relative Humidity (%)	
		Min.	Max.		06.00	15.00
1	0.0	24.0	37.8	9.3	32.0	24.0
2	0.0	24.3	38.3	9.0	35.0	24.0
3	0.0	24.8	38.1	3.7	16.0	12.0
4	0.0	24.6	39.1	7.3	20.0	12.0
5	0.0	21.5	39.5	10.3	24.0	11.0
6	0.0	21.3	40.0	10.0	27.0	12.0
7	0.0	23.0	40.0	10.1	21.0	15.0
8	0.0	22.0	39.7	10.4	30.0	8.0
9	0.0	23.0	40.2	10.9	21.0	8.0
10	0.0	23.4	37.8	7.8	22.0	13.0
11	0.0	24.0	37.5	7.4	25.0	15.0
12	0.0	24.0	38.7	8.6	26.0	17.0
13	0.0	25.2	39.6	7.6	25.0	12.0
14	0.0	25.3	40.2	8.7	28.0	19.0
15	0.0	24.2	40.8	9.0	38.0	21.0
16	0.0	25.8	37.7	1.9	31.0	30.0
17	0.0	24.0	41.1	6.6	42.0	23.0
18	0.0	26.6	40.5	1.1	35.0	18.0
19	0.0	26.8	40.1	7.6	48.0	25.0
20	0.0	27.5	40.9	9.2	55.0	25.0
21	0.0	27.9	41.6	9.4	49.0	27.0
22	0.0	28.4	40.0	4.5	53.0	32.0
23	0.0	26.6	41.6	6.8	63.0	18.0
24	0.0	27.0	42.8	9.1	57.0	15.0
25	0.0	28.0	42.0	9.6	60.0	21.0
26	0.0	26.7	41.7	7.8	33.0	21.0
27	0.0	26.7	40.5	8.3	69.0	27.0
28	Trace	29.4	42.6	9.5	50.0	23.0
29	0.0	26.8	40.0	5.3	64.0	23.0
30	0.0	26.4	41.5	9.3	67.0	21.0
31	0.0	28.5	42.8	8.0	53.0	20.0
Mean	-	25.4	40.2	7.9	39.0	19.0

Source: Ghana Meteorological Agency (Navrongo)

APPENDIX 4

Daily Climatological Data for Navrongo in April, 2007

Date	Rainfall (mm)	Temperature (^oC) Min.	Max.	Sunshine Duration Hours	Relative Humidity (%) 06.00	15.00
1	Trace	26.3	40.5	20.0	63.0	27.0
2	0.0	25.6	39.4	5.5	73.0	32.0
3	0.0	27.9	41.0	4.8	68.0	19.0
4	0.0	30.2	40.6	16.0	60.0	31.0
5	Trace	30.5	32.5	0.2	60.0	51.0
6	0.0	25.0	38.3	1.5	77.0	32.0
7	0.0	27.9	36.7	2.6	64.0	39.0
8	0.0	26.0	26.0	6.0	72.0	27.0
9	0.0	27.6	27.6	9.3	59.0	21.0
10	0.0	27.4	27.4	9.7	58.0	25.0
11	16.9	28.6	28.6	8.0	69.0	30.0
12	11.3	21.6	21.6	6.6	83.0	43.0
13	0.0	23.0	23.0	0.2	80.0	56.0
14	0.0	25.6	25.6	9.6	84.0	33.0
15	0.0	27.5	27.5	9.2	80.0	32.0
16	12.5	28.6	28.6	7.7	72.0	38.0
17	29.0	24.4	24.4	9.9	79.0	40.0
18	0.0	22.1	22.1	1.4	96.0	65.0
19	0.0	24.6	24.6	11.0	92.0	44.0
20	0.0	27.7	27.7	5.1	78.0	60.0
21	0.0	26.5	26.5	10.7	88.0	41.0
22	46.1	26.8	26.8	1.0	71.0	74.0
23	0.0	21.8	21.8	2.4	93.0	64.0
24	0.0	24.8	24.8	9.6	91.0	46.0
25	0.0	26.2	26.2	9.3	74.0	40.0
26	0.0	27.5	27.5	9.5	77.0	53.0
27	2.1	26.6	26.6	5.1	75.0	45.0
28	0.0	23.5	23.5	7.9	83.0	45.0
29	15.8	26.0	26.0	10.8	84.0	43.0
30	21.3	23.0	23.0	5.5	88.0	64.0
Mean	5.2	26.0	37.6	6.3	71.0	42.0

Source: Ghana Meteorological Agency (Navrongo)

APPENDIX 5

Daily Climatological Data for Navrongo in May, 2007

Date	Rainfall (mm)	Temperature (^{o}C)		Sunshine Duration Hours	Relative Humidity (%)	
		Min.	Max.		06.00	15.00
1	42.2	22.4	34.5	9.9	95.0	55.0
2	0.0	21.8	33.9	0.0	99.0	74.0
3	0.0	21.5	35.0	10.5	92.0	54.0
4	0.0	26.4	34.4	9.9	86.0	59.0
5	0.0	26.9	34.5	6.1	88.0	53.0
6	0.0	26.2	35.4	11.1	89.0	54.0
7	0.2	25.6	35.0	8.8	81.0	58.0
8	0.0	24.5	38.0	11.3	91.0	48.0
9	Trace	27.0	36.0	7.2	78.0	54.0
10	0.0	26.0	37.8	7.3	80.0	42.0
11	0.0	26.2	35.2	6.0	71.0	46.0
12	0.0	26.5	35.4	3.8	80.0	51.0
13	32.4	27.8	37.2	9.0	83.0	48.0
14	0.0	21.6	27.6	0.2	95.0	72.0
15	0.0	22.4	31.0	4.3	91.0	64.0
16	27.1	25.8	32.7	6.9	92.0	60.0
17	0.0	25.6	34.9	10.1	92.0	54.0
18	1.1	25.8	35.6	10.1	84.0	52.0
19	0.0	23.4	33.4	6.7	90.0	53.0
20	0.0	25.0	36.0	10.8	92.0	50.0
21	0.8	27.1	33.0	8.6	90.0	61.0
22	21.7	24.8	35.5	10.5	90.0	54.0
23	0.0	27.0	35.0	5.3	78.0	51.0
24	0.0	24.0	35.6	10.1	92.0	52.0
25	Trace	26.2	34.5	10.0	88.0	52.0
26	0.0	24.0	34.0	5.2	86.0	52.0
27	0.0	23.6	32.1	10.8	85.0	43.0
28	0.0	26.7	34.5	5.4	80.0	52.0
29	10.7	24.8	33.3	11.1	83.0	42.0
30	5.4	21.0	33.1	3.6	81.0	69.0
31	0.0	20.1	33.7	10.9	92.0	57.0
Mean	11.7	24.8	34.7	7.8	87.0	54.0

Source: Ghana Meteorological Agency (Navrongo)

APPENDIX 6

Daily Climatological Data for Navrongo in June, 2007

Date	Rainfall (mm)	Temperature (^oC) Min.	Max.	Sunshine Duration Hours	Relative Humidity (%) 06.00	15.00
1	0.0	25.8	35.6	11.2	86.0	53.0
2	0.0	27.1	28.3	0.0	80.0	69.0
3	0.0	21.2	32.0	10.7	95.0	56.0
4	0.0	24.0	33.0	11.1	91.0	56.0
5	0.0	24.5	34.6	11.1	90.0	50.0
6	40.6	25.8	29.4	0.4	84.0	93.0
7	0.0	20.5	29.0	1.5	96.0	75.0
8	0.0	22.8	31.0	7.3	90.0	67.0
9	0.0	24.5	33.1	10.2	89.0	59.0
10	0.0	25.2	34.0	7.3	89.0	56.0
11	0.0	24.6	33.6	11.0	92.0	54.0
12	0.0	25.0	33.3	10.8	89.0	54.0
13	0.0	24.7	34.1	11.2	91.0	53.0
14	0.0	26.8	34.5	5.8	81.0	52.0
15	0.0	25.6	35.6	10.9	81.0	49.0
16	27.1	26.3	36.7	11.1	78.0	46.0
17	0.0	19.8	31.5	5.1	92.0	70.0
18	0.0	23.7	33.6	11.2	92.0	55.0
19	0.0	25.5	35.2	10.7	93.0	51.0
20	0.0	25.8	33.2	7.0	87.0	58.0
21	0.8	24.8	31.6	4.5	86.0	77.0
22	21.7	23.4	34.4	9.4	90.0	48.0
23	0.0	20.5	31.0	7.8	81.0	59.0
24	0.0	22.0	33.0	8.8	90.0	61.0
25	0.0	23.4	34.0	11.2	85.0	52.0
26	0.0	25.0	34.5	11.5	89.0	53.0
27	0.0	25.6	34.0	8.8	87.0	48.0
28	0.0	25.1	32.1	4.5	89.0	62.0
29	0.7	25.0	34.5	8.0	81.0	52.0
30	47.6	25.5	33.3	8.3	88.0	55.0
Mean	4.6	24.3	33.1	8.3	88.0	58.0

Source: Ghana Meteorological Agency (Navrongo)

APPENDIX 7

Daily Climatological Data for Wenchi in February, 2007

Date	Rainfall (mm)	Temperature (^{o}C)		Sunshine Duration Hours	Relative Humidity (%)	
		Min.	Max.		06.00	15.00
1	0.0	22.7	34.4	6.7	88.0	47.0
2	0.0	23.0	36.7	9.4	84.0	32.0
3	0.0	23.4	35.5	8.0	85.0	40.0
4	0.0	24.0	34.5	6.5	93.0	42.0
5	12.1	23.7	35.0	8.2	92.0	44.0
6	0.0	24.0	31.7	1.6	88.0	69.0
7	0.0	23.4	35.3	7.3	92.0	43.0
8	7.7	24.0	33.8	5.4	90.0	51.0
9	4.6	23.4	32.6	4.2	91.0	92.0
10	0.0	16.3	35.5	7.2	89.0	35.0
11	0.0	19.5	34.5	10.1	92.0	45.0
12	0.0	23.6	35.6	8.6	90.0	25.0
13	0.0	21.1	35.0	8.6	93.0	25.0
14	0.0	23.1	34.6	9.3	19.0	11.0
15	0.0	23.0	35.0	9.7	67.0	15.0
16	0.0	22.0	34.3	8.6	82.0	24.0
17	0.0	22.3	34.9	9.0	85.0	37.0
18	0.0	23.0	35.0	7.3	90.0	32.0
19	0.0	23.2	34.3	6.9	86.0	36.0
20	0.0	23.1	35.5	9.0	89.0	37.0
21	0.0	23.6	35.4	8.4	86.0	39.0
22	0.0	23.9	35.3	8.6	88.0	32.0
23	0.0	22.3	34.0	6.0	90.0	13.0
24	0.0	23.0	35.0	9.1	53.0	13.0
25	0.0	21.0	35.5	8.1	47.0	10.0
26	0.0	22.2	35.8	8.3	83.0	21.0
27	0.0	23.3	35.6	7.8	84.0	29.0
28	0.0	23.2	37.5	8.9	84.0	13.0
Mean	2.0	22.6	34.9	7.7	82.0	34.0

Source: Ghana Meteorological Agency (Wenchi)

APPENDIX 8

Daily Climatological Data for Wenchi in March, 2007

Date	Rainfall (mm)	Temperature (^oC)		Sunshine Duration Hours	Relative Humidity (%)	
		Min.	Max.		06.00	15.00
1	0.0	24.0	34.8	5.9	89.0	38.0
2	0.0	24.0	36.0	8.9	76.0	25.0
3	0.0	23.0	36.8	7.6	79.0	12.0
4	0.0	24.1	36.2	2.3	78.0	24.0
5	0.0	24.0	37.5	6.9	66.0	19.0
6	0.0	24.5	37.7	8.5	83.0	14.0
7	0.0	24.5	38.0	7.5	85.0	13.0
8	0.0	23.5	37.2	8.1	82.0	6.0
9	0.0	24.3	37.0	9.1	84.0	22.0
10	0.0	23.5	35.5	8.5	84.0	35.0
11	0.0	23.0	36.0	8.5	81.0	20.0
12	0.0	23.6	36.5	8.1	87.0	20.0
13	0.0	24.0	36.6	8.3	78.0	16.0
14	0.0	23.3	36.0	7.2	86.0	32.0
15	0.2	24.0	36.7	7.6	88.0	41.0
16	0.0	24.0	33.6	3.5	90.0	46.0
17	0.0	22.9	36.0	4.6	86.0	41.0
18	0.0	23.5	34.6	6.3	89.0	44.0
19	0.0	23.5	34.5	7.4	83.0	46.0
20	0.0	23.9	37.0	9.4	86.0	36.0
21	0.0	24.5	36.7	8.5	87.0	40.0
22	10.7	24.9	36.0	6.1	86.0	43.0
23	0.0	21.5	33.0	4.0	85.0	51.0
24	0.0	22.6	33.5	2.6	88.0	49.0
25	0.0	23.0	35.5	9.1	89.0	43.0
26	0.0	24.3	31.6	5.6	88.0	57.0
27	0.0	20.1	35.5	10.0	87.0	38.0
28	0.0	24.5	37.1	9.5	85.0	39.0
29	51.9	25.5	35.5	7.0	82.0	44.0
30	0.0	20.0	34.7	6.5	95.0	49.0
31	0.0	22.4	36.2	6.3	91.0	45.0
Mean	5.2	23.5	35.8	7.1	85.0	34.0

Source: Ghana Meteorological Agency (Wenchi)

APPENDIX 9

Daily Climatological Data for Wenchi in April, 2007

Date	Rainfall (mm)	Temperature (^oC)		Sunshine Duration Hours	Relative Humidity (%)	
		Min.	Max.		06.00	15.00
1	37.1	24.3	35.0	9.8	92.0	46.0
2	0.0	22.0	30.5	2.6	97.0	63.0
3	0.0	22.5	35.0	7.6	92.0	45.0
4	0.0	24.4	32.5	6.8	92.0	57.0
5	0.0	25.2	33.0	7.2	86.0	48.0
6	0.0	22.5	36.0	8.9	88.0	38.0
7	30.9	24.5	32.6	3.9	86.0	76.0
8	0.0	21.0	30.1	2.3	95.0	66.0
9	4.6	22.5	34.5	10.2	94.0	54.0
10	Trace	24.2	33.2	8.0	92.0	60.0
11	8.3	23.6	33.5	7.8	93.0	56.0
12	48.0	22.0	32.2	6.4	93.0	64.0
13	0.0	20.8	31.0	4.8	97.0	63.0
14	0.0	22.0	32.0	6.9	95.0	65.0
15	0.0	24.1	31.7	6.4	92.0	62.0
16	0.0	22.4	32.2	8.4	90.0	60.0
17	3.7	23.5	32.9	8.4	93.0	59.0
18	0.0	21.0	31.3	7.2	93.0	60.0
19	0.0	23.0	32.5	10.9	93.0	58.0
20	0.0	23.9	33.5	9.6	94.0	55.0
21	Trace	24.6	33.0	7.7	92.0	62.0
22	2.7	21.5	32.5	10.0	88.0	58.0
23	1.2	22.0	28.6	4.8	93.0	71.0
24	0.0	22.0	33.5	10.5	95.0	57.0
25	0.0	23.8	32.5	8.7	94.0	59.0
26	Trace	23.8	31.5	7.2	88.0	61.0
27	0.0	23.5	32.1	5.0	89.0	54.0
28	0.0	22.8	35.0	10.2	90.0	42.0
29	Trace	24.0	33.3	10.0	92.0	56.0
30	Trace	24.5	33.4	6.1	92.0	52.0
Mean	11.0	23.1	32.7	7.5	92.0	58.0

Source: Ghana Meteorological Agency (Wenchi)

APPENDIX 10

Daily Climatological Data for Wenchi in May, 2007

Date	Rainfall (mm)	Temperature (^{o}C)		Sunshine Duration Hours	Relative Humidity (%)	
		Min.	Max.		06.00	15.00
1	35.5	23.0	35.5	8.1	87.0	54.0
2	1.0	22.0	27.9	1.1	91.0	80.0
3	15.0	22.5	32.2	10.3	10.0	61.0
4	0.0	21.5	31.7	6.8	96.0	62.0
5	Trace	24.0	31.4	7.5	93.0	63.0
6	0.0	21.5	30.2	5.7	94.0	65.0
7	0.0	23.5	33.2	10.0	94.0	61.0
8	Trace	24.5	33.5	9.8	90.0	68.0
9	0.0	22.5	33.3	7.0	93.0	60.0
10	13.1	24.9	33.5	4.8	92.0	69.0
11	0.1	22.2	31.2	3.2	96.0	69.0
12	0.0	22.5	31.5	7.5	92.0	67.0
13	21.0	24.8	31.2	3.3	92.0	66.0
14	0.6	20.5	25.9	0.0	90.0	77.0
15	0.0	20.7	31.1	11.4	95.0	60.0
16	0.0	23.0	30.5	3.2	90.0	63.0
17	0.0	22.4	31.5	9.8	96.0	64.0
18	0.0	24.5	33.1	9.4	88.0	58.0
19	0.0	23.0	32.5	6.6	91.0	64.0
20	29.3	24.2	34.0	9.3	94.0	58.0
21	0.0	21.5	30.6	3.3	77.0	60.0
22	0.0	23.0	31.8	10.8	92.0	59.0
23	0.0	22.8	30.8	4.6	92.0	65.0
24	0.0	22.9	31.7	10.3	92.0	62.0
25	0.0	23.9	32.0	7.4	96.0	58.0
26	0.2	23.5	33.5	7.8	92.0	56.0
27	21.7	24.0	33.2	8.6	92.0	55.0
28	Trace	21.2	28.7	3.9	96.0	77.0
29	0.0	23.0	32.0	9.2	93.0	61.0
30	28.7	23.4	28.5	1.4	94.0	88.0
31	0.0	20.9	31.5	11.6	95.0	64.0
Mean	13.9	22.8	31.5	6.9	92.0	64.0

Source: Ghana Meteorological Agency (Wenchi)

APPENDIX 11

Daily Climatological Data for Wenchi in June, 2007

Date	Rainfall (mm)	Temperature (^{o}C)		Sunshine Duration Hours	Relative Humidity (%)	
		Min.	Max.		06.00	15.00
1	0.0	23.0	32.6	11.0	92.0	61.0
2	8.5	23.9	26.7	0.2	95.0	91.0
3	14.8	19.3	28.5	3.8	95.0	74.0
4	28.5	21.5	28.1	1.4	97.0	79.0
5	0.0	20.0	30.0	8.4	98.0	70.0
6	1.9	22.5	29.6	1.4	92.0	72.0
7	9.6	20.7	27.5	0.9	95.0	77.0
8	0.0	21.0	28.6	3.5	96.0	74.0
9	1.2	22.6	30.5	9.6	94.0	67.0
10	0.4	22.9	29.0	5.5	96.0	81.0
11	0.0	22.5	29.4	3.2	92.0	70.0
12	0.0	22.0	30.1	6.3	95.0	66.0
13	7.8	22.5	30.3	7.4	94.0	71.0
14	0.0	20.8	29.7	7.8	99.0	68.0
15	Trace	22.4	30.5	7.5	93.0	65.0
16	1.3	23.0	30.4	8.7	96.0	67.0
17	0.8	21.5	29.5	6.2	96.0	66.0
18	4.8	22.5	30.7	7.4	94.0	65.0
19	0.0	22.8	31.9	8.7	96.0	59.0
20	31.5	23.1	31.0	7.1	92.0	68.0
21	0.0	20.0	29.6	6.7	92.0	66.0
22	0.0	22.5	30.3	10.3	92.0	62.0
23	2.5	22.0	28.0	4.0	93.0	87.0
24	29.3	22.4	30.0	7.4	93.0	64.0
25	0.0	20.2	30.0	9.9	96.0	67.0
26	0.0	22.0	29.6	6.2	96.0	68.0
27	0.0	22.2	30.1	8.7	92.0	68.0
28	0.0	22.5	30.0	5.8	96.0	65.0
29	1.9	22.6	31.0	7.8	94.0	67.0
30	2.4	22.3	31.0	9.3	96.0	66.0
Mean	12.3	22.0	29.8	6.4	95.0	70.0

Source: Ghana Meteorological Agency (Wenchi)