KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY-KUMASI- GHANA

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CROPS AND SOIL SCIENCIES

SCREENING OF MAIZE (*Zea mays* L.) INBRED LINES FOR TOLERANCE TO DROUGHT

A DISSERTATION SUBMITTED TO THE DEPARTMENT OF CROP AND SOIL SCIENCES, FACULTY OF AGRICULTURE IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MPhil. AGRONOMY (PLANT BREEDING)

BY

OBED AMPONSAH ABROKWAH

JUNE, 2015

CERTIFICATION

I hereby declare that this submission is my own work and that, to the best of my knowledge, it contains no materials previously published by another person nor materials which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

Obed Amponsah Abrokwah …….. ……..

Signature Date

(Student)

Certified by:

Prof. Richard Akromah …….. ……..

(Supervisor) Signature Date

Certified by:

Dr. Charles kwoseh …….. ……..

(Head of Department) Signature Date

ABSTRACT

An experiment was conducted in the plant house at the mechanization department of Kwame Nkrumah University of Science and Technology (KNUST) to determine the drought tolerance levels of twelve maize (*Zea mays* L) genotypes as a basis for the development of drought tolerant maize hybrids. Eight inbred lines and four varieties with different genetic backgrounds were used in a Completely Randomized Design (CRD) with four replications. Water was withdrawn at six weeks after planting and resumed at ten days interval for the water stressed maize genotypes and the non stressed maize genotypes received water throughout the experiment. Data were collected on plant height, leaf moisture content, dry matter yield, root dry mass, and grain yield. Individual means of water stressed genotypes were compared to their corresponding non-stressed in a pairwise comparison analyses (t-test) and LSD was used to determine differences in treatment means at 5% probability level. There were significant differences among the maize genotypes as regards to the water treatments and the parameters measured (plant height, leaf moisture content, dry matter yield, root dry mass, and grain yield). Water stress decreased growth and development of maize genotypes significantly. An exception was Aburohemaa which did not show any significant difference between the water stress and non-stress conditions for plant height.

Weak positive correlations were obtained between grain yield and leaf moisture content (r^2 = 0.02), grain yield and root dry mass (r^2 = 0.03), grain yield and plant height (r^2 = 0.142). However, there was a weak negative correlation between grain yield and dry matter yield (r^2 = -0.159).

With performance as regards to Drought Susceptibility Index (DSI) which is a measure of yield stability (DSI = (1- Yd / Yw) / D. Where Yd = mean yield under drought, Yw = mean yield under well-watered conditions, and D = drought intensity = 1- (mean yield of

all genotypes under drought / mean yield of all genotypes under well-watered conditions), maize genotypes Tzeei 4, Tzeei 76, Tzeei 1 and Aburohemaa could be recommended to be used as source for drought tolerance in maize breeding programme.

DEDICATION

To my mother, Madam Patricia Amponsah. This is the fruit that your labour has yielded

ACKNOWLEDGEMENTS

First and foremost, my sincere gratitude goes to the Almighty God whose loving kindness had and continues to sustain my life. It is impossible to describe adequately all of the immense contributions made to this study in terms of suggestions, guidance, time and patience of Prof. Richard Akromah (Supervisor), Rev. Fr. Prof. Mensah Bonsu and Dr. Eric Asare (of blessed memory). Not only did they offer constructive criticisms, but, they were a source of inspiration and good judgement

I would wish to acknowledge with thanks and appreciation, the total contribution of my parents and siblings; Madam Patricia Amponsah, Bright Oduro Kwarteng of Sydney-Australia, David Owusu Yeboah, Mr. Joseph Amponsah and all the Amponsah family in providing the financial support and generous assistance for the execution of this research work.

I would also wish to express my sincere gratitude to all those who in diverse ways contributed to this piece of work especially, Mr. Robert Kankam and Mr. Martin Luther of CSIR - Crops Research Institute, Dr. Roland Nuhu Issaka of Soil Research Institute, Dr. Ofori of Agricultural Engineering Department-KNUST, Mr. Anthony of Mechanization Department-KNUST,Mr. Malik Borigu, and Mr. Osei of the Plant Pathology laboratory- KNUST.

Finally, my deep appreciation goes to all my friends and loved ones especially, Christiana Offeh Gyebi of Ministry of Food and Agriculture (MOFA), Isaac Danso Ntiamoah, Augustine Antwi Boasiako, Kofi Aboagye, Benjamin Karikari, and Agyare Yaw Richard for their support and assistance towards the success of this research work

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

Maize (*Zea mays* L.) is a cereal crop that belongs to the plant family Gramineae, sub-family Panicoideae and the tribe Andropogoneae (Norman *et al*., 1995). Maize is produced on nearly 100 million hectares of land in developing countries, with almost 70% of the total maize production in the developing world coming from low and lower middle income countries (FAOSTAT, 2010). Millions of people worldwide are dependent on maize as a staple food.

Maize accounts for 15 to 56% of the total daily calories of people in about 25 developing countries particularly in Latin America and Africa (Adetiminrin *et al*., 2008). In terms of production and consumption in the world, maize is ranked third to rice and wheat. (Mboya, 2011, IITA, 2009). In Sub-Saharan Africa maize is the most important cereal crop. Rice, maize, millet and sorghum are the four main cereals produced and consumed in Ghana. In terms of production and consumption in Ghana maize is ranked first. (Breisinger *et al*., 2008). Maize can be directly consumed as food at various developmental stages from baby corn to mature grain. A high proportion of maize produced is used as stock feed, example 40% in tropical areas and up to 85% in developed countries (Farnham *et al*., 2003). It can be fed to livestock as green chop, dry forage, silage or grain. Various fraction of milling processes can also be used as animal feed. Maize can be processed for a range of uses both as ingredient in food or drink, example corn syrup in soft drinks or maize meal, or for industrial purposes (DARD, 2002) Maize is the major source of starch worldwide, and is used as a food ingredient, either in its native form or chemically modified (White, 1994). Corn starch can be fermented into alcohol, including fuel ethanol, while the paper industry is the biggest non-food user of maize starch. The oil and protein are often of commercial value as by-

products of starch production and are used in food manufacturing (McCutcheon, 2007). Maize is produced in the coastal savannah, forest, forest-savannah transition, Guinea savannah and Sudan savannah zones of Ghana. Growers in these zones need several improved maize varieties of different maturity periods. These varieties with different maturity periods have been developed and released by the Crops Research Institute (Badu-Apraku et al., 1992; Badu- Apraku and Fontem, 2010, CSIR- CRI, 2010, Sallah et al., 1997). These varieties are widely adopted by maize growers throughout the country (Dankyi et al., 1997; Morris et al., 1999, Asiedu et al., 2001).

Though several improved varieties of different maturity periods have been developed and released, maize productivity in farmers' fields is generally low, averaging 1.6 t/ha, (Bänzier and Diallo, 2001, FAOSTAT, 2010), and it could even be as low as 0.5 t/ha compared to over 5.0 t/ha in parts of northern and southern Africa (PPMED, 1992), 8.0 t/ha in Indonesia (Krisdiana and Heriyanto, 1992), 6.3 t/ha in Province of China (Qiao et al., 1996), and 7.0-8.9 t/ha in Ethiopia (Onyango and Ngeny, 1997). The cause of this low productivity is attributed to low soil fertility (low soil N) and drought stress (Bänziger et al., 2000). Water deficit affects plant growth, yield and eventually leads to a considerable crop failure. Farmers in the sub region depend on rainfed agriculture during the crop production period but one major constraint that limits maize production in Ghana is frequent drought stress (Ohemeng-Dapaah, 1994). Rainfall is unpredictable in terms of quantity and distribution during the growing season (Ohemeng-Dapaah, 1994; Kasei et al., 1995) resulting in drought stress significant yield losses. As a typical example, total maize production in Ghana declined by 30% in 1982 as a result of drought stress throughout the country (GGDP, 1983).

Drought is a major abiotic factor that limits maize production in low-income countries (Seghatoleslami et al., 2008). One strategy to reduce water stress on crop yield is to use

drought tolerant species and cultivars (Carrow et al., 1990). There is unexhausted information on the performance of maize varieties under drought stress in Ghana. Useable genetic variability for drought and gains from selection have been reported by several workers (Edmeades et al., 1992; Bolanos and Edmeades, 1993;). Therefore, it is necessary to screen maize inbred lines for tolerance to drought as it will provide the basis for the development of drought tolerant hybrids for maize producers in developing nations where plant breeding improvements will be easily adopted than high-input agronomic practices.

General objective

To identify drought tolerant inbred lines as a basis for the development of drought tolerant hybrids.

Specific objectives

1. To evaluate maize genotypes for drought tolerance.
2. To relate water stressed genotypes with a control/ non-stressed to be able to predict drought tolerance in maize using drought susceptibility index.
3. To identify useful reliable traits to identify drought resistant or susceptible varieties.

CHAPTER TWO

LITERATURE REVIEW

2.1 Evolution of the maize plant.

The evolution of maize (*Zea mays* L. ssp mays) from its probable wild progenitor teosinte (*Zea mays ssp parviglumis*) is one complex example of morphological evolutions in plants. These taxa differ extensively in both plant and inflorescence architecture. When teosinte was first discovered, taxonomists failed to recognize its close relationship to maize; they therefore placed it in a separate genus and tribe (Galinat, 1988). After several researches, it was agreed that teosinte and maize were fully interfertile, and in essence members of the same biological species, Beadle (1939) proposed that maize is simply a domesticated form of teosinte, and that as few as five major genes largely control the morphological evolution from teosinte.

2.2. Biology of maize

2.2.1. Root

Normally maize plants have three types of roots, (i) seminal roots - which develop from radical and persist for long period, (ii) adventitious roots or fibrous roots developing from the lower nodes of stem below ground level which are the effective and active roots of plant and (iii) brace or prop roots, produced by lower two nodes. The roots grow very rapidly and almost equally outwards and downwards. After tasselling, the brace roots develop into bands from the first two to three aerial nodes. Root hairs increase root surface area that is exposed to the soil. Favourable soils may allow maize root growth up to 60 cm laterally and in depth (ARC- Grain Crops Institute, 2003)

2.2.2. Stem

The stem generally attains a thickness of three to four centimeters. The inter nodes are short and fairly thick at the base of the plant; become longer and thicker higher up the stem, and then taper again. The ear bearing inter node is longitudinally grooved, to allow proper positioning of the ear head (cob). The upper leaves in corn are more responsible for light interception and are major contributors of photosynthate to grain. (Hitchcock and Chase, 1971).

2.2.3. Leaves

Maize leaves are arranged spirally on the stem alternatively in two opposite rows on the stem. The leaf consists of a sheath, ligules, auricles and a blade. The leaf is supported by a mid-rib along its entire length. There are stomata along the leaf surface. These stomata are arranged in rows. There are more stomata on the underside of the leaf than the upper surface. There are motor cells on the upper surface of the leaf that serves as an osmo-regulator. When the weather is moist, the motor cells will absorb water and become turgid resulting in the unfolding of the leaf. During a warm weather, the motor cells lose their turgor resulting in the leaves curling inwards which exposes a smaller surface of the leaf to evaporation (ARC- Grain Crops Institute, 2003).

2.2. 4. Flower

The apex of the stem ends in the tassel, an inflorescence of male flowers and the female inflorescences (cobs or ears) are borne at the apex of condensed, lateral branches known as shanks protruding from leaf axils. The male (staminate) inflorescence, a loose panicle, produces pairs of free spikelets each enclosing a fertile and a sterile floret. The female (pistillate) inflorescence, a spike, produces pairs of spikelets on the surface of a highly condensed rachis (central axis, or “cob”). The female flower is tightly covered over by several layers of leaves, and so closed in by them to the stem that they don’t show

themselves easily until emergence of the pale yellow silks from the leaf whorl at the end of the ear. The silks are the elongated stigmas that look like tufts of hair initially and later turn green or purple in color. Each of the female spikelets encloses two fertile florets, one of whose ovaries will mature into a maize kernel once sexually fertilized by wind-blown pollen. (Coe *et al*., 1988)

2.2.5. Grain

The individual maize grain is botanically a caryopsis, a dry fruit containing a single seed fused to the inner tissues of the fruit case. The seed contains two sister structures, a germ which includes the plumule and radical from which a new plant will develop, and an endosperm which will provide nutrients for that germinating seedling until the seedling establishes sufficient leaf area to become autotroph. The germ is the source of maize "vegetable oil" (total oil content of maize grain is 4% by weight). The endosperm occupies about two thirds of a maize kernel's volume and accounts for approximately 86% of its dry weight. The endosperm of maize kernels can be yellow or white. The primary component of endosperm is starch, together with 10% bound protein (gluten), and this stored starch is the basis of the maize kernel's nutritional uses. (OGTR, 2008)

2.3. Importance of maize

Maize is one of the oldest cultivated grains and one of the most productive crop species. It can be directly consumed as food at various developmental stages from baby corn to mature grain. The grain can be consumed as human food, fermented to produce a wide range of foods and beverages. It can be fed to livestock as green chop, dry forage, silage or grain. Corn starch can be fermented into alcohol including fuel ethanol, while the paper industry is the biggest non-food user of maize starch. The oil and protein are often of commercial value as by-products of starch production and are used in food manufacturing (McCutcheon, 2007). The roots can be used for mulching, incorporated

into the soil to improve the physical structure, or dried and burned as fuel (Morris, 2002). In Sub-Saharan Africa, maize is a staple food for an estimated 50% of the population (IITA, 2009). It is an important source of carbohydrate, protein, iron, vitamin B, and minerals. The importance of maize in human diet, livestock feed and as raw material for some industries has increased in the last two or three decades of the 20th century (Badu-Apraku *et al*., 2008).

2.4. World maize production

In 2012, United States of America topped the list of the world's maize producers with about 314 million tonnes, followed by China (193 million tonnes), Brazil (70 million tonnes), EU-27 (65 million tonnes), Ukraine (23 million tonnes), India (21 million tonnes), Mexico (21 million tonnes), South Africa (12 million tonnes), Canada (11 million tonnes), and the rest of the world (126 million tonnes) all from the world's total production of over 874 million tonnes (USDA, 2012). From 1989-1991, the average maize grain yield per hectare in Africa was 1.2 tonnes. This was twice the amount recorded in the 1950s when high-yielding cultivars were not available (Byerlee and Heisey, 1997). But in recent times, maize production in Africa, has assumed a pattern of steady growth, mostly due to the expansion of land area cropped with maize and partly also due to improvement in maize yields (Manyong *et al*., 2000). In Eastern, Southern, Central and Western Africa, maize accounts for about 60% of total harvested area of annual food crops and 30-70% of total calorific consumption (FAOSTAT, 2007).

In Sub-Saharan Africa, maize production has witnessed a great increase in the last 20years (Babatunde *et al*., 2008). This progress was the result of the development and adoption of high-yielding and early maturing varieties through the joint research efforts of scientists in different institutes in the region (IITA, 1997). Based on these joint efforts, maize has moved up on the scale of importance of cereal crops in the region displacing

sorghum and millet. (Smith *et al.*, 1997). Between 1980 and 2001, when the performance of maize was compared with millet and sorghum in Western and Central Africa, it came out that, there was much improvement in the performance of maize relative to the other cereal crops (Fakorede *et al*., 2003). During the period between 1980 and 2002, the total land area cultivated to maize, millet and sorghum averaged about 8.0, 10.3 and 10.9 million hectares, respectively. However, maize recorded an average annual total production of 0.43 far higher than 0.23 and 0.30 million tonnes recorded for millet and sorghum, respectively. Total grain production estimated for maize, millet and sorghum in 2001 averaged 12.1, 9.5, and 11.6 million tonnes, respectively. (Fakorede *et al*., 2003). Also, average grain yield for maize increased from 0.9 tonnes per ha in 1980 to about 1.3 tonnes per ha in 2001, a yearly increase of 0.02 tonnes per ha whereas grain yields for millet and sorghum remained unchanged during the period. The performance of maize was attributed to early maturity, high yield, better taste, high market prices, and availability during hunger period and colour (Enyong *et al*., 1999). Maize is grown in the coastal belt, the Forest savanna transition, Guinea savanna to the north east corner in Ghana (NARP, 1993). But the major agro-ecological region for maize is the forest-savanna transition zone, which has a bimodal rainfall regime and therefore two cropping seasons. The current area planted to maize in Ghana stands at approximately 1 million ha, with the yield and production averages of about 1.74 metric tons (MT) per ha and 1.65 million MT respectively. (.FAOSTAT, 2013)

It constitutes the primary staple in the areas of production (PPMED, 1992), and features predominantly in animal feed and as industrial raw material (NARP, 1993).

2.5. Ecology and growth requirements of maize

2.5.1. Temperature

Maize is a warm weather crop and is not grown in areas where the mean daily temperature is less than 19 ºC or where the mean of the summer months is less than 23 ºC. Although the minimum temperature for germination is 10 ºC, germination will be faster and less variable at soil temperatures of 16 to 18 ºC. At 20 ºC, maize should emerge within five to six days. The critical temperature detrimentally affecting yield is approximately 32 ºC. Frost can damage maize at all growth stages and a frost-free period of 120 to 140 days is required to prevent damage. While the growth point is below the soil surface, new leaves will form and frost damage will not be too serious. Leaves of mature plants are easily damaged by frost and grain filling can be adversely affected. (ARC- Grain Crops Institute, 2003)

2.5.2. Precipitation and Water requirements.

Maize needs at least 500-700 mm of well-distributed rainfall during the growing season. Even that amount of rain may not be enough, however, if the moisture cannot be stored in the soil because of runoff or shallow soil depth, or if the evaporative demand is very large due to high temperatures and low relative humidity (ARC- Grain Crops Institute, 2003). Approximately 10 to 16 kg of grain are produced for every millimeter of water used. A yield of 3152 kg/ha requires between 350 and 450 mm of rain per annum. At maturity, each plant will have used 250 litres of water in the absence of moisture stress (ARC- Grain Crops Institute, 2003).

2.5.3. Soil

The most suitable soil for maize is one with a good effective depth, favourable morphological properties, good internal drainage, an optimal moisture regime, sufficient

and balanced quantities of plant nutrients and chemical properties that are favourable specifically for maize production. (Obeng, 1971). Although large-scale maize production takes place on soils with a clay content of less than 10 % (sandy soils) or in excess of 30 % (clay and clay-loam soils), the texture classes between 10 and 30 % have air and moisture regimes that are optimal for healthy maize production.(ARC-Grain Crops Institute, 2003)

2.6. Constraints to maize production in Sub-Saharan Africa

2.6. 1. Abiotic factors

Maize shows a wide genetic base for abiotic stress tolerance, which is mirrored by its ability to grow in a variety of environments, although it is essentially a crop of warm climates with adequate moisture (Purseglove, 1972). One way that abiotic stress affects the maize plant is by moving the source-sink balance (Lee and Tollenaar, 2007). Classic symptoms of excess source capacity are purpling of leaves, sheath tissues and stalks during grain filling while symptoms of excess sink capacity are premature senescence of leaves and stalks during grain filling (Lee and Tollenaar, 2007). Some of the abiotic factors that affect maize production are nutrient deficiencies, temperature, water deficiency, and waterlogging. Maize grown commercially, whether for grains or silage, has a high demand for soil nutrients, especially nitrogen (N), phosphorus (P) and potassium (K) (Birch *et al*., 2003). The micronutrients such as zinc and molybdenum may, depending on the soil type, if not applied properly may cause deficiency symptoms. When nutrients are limiting or when they are in excess, symptoms such as leaf yellowing, stunted plants, delayed flowering and short, poorly filled ears, crop lodging and sometimes death of plants can occur (Hughes, 2006). Maize is a warm weather-growing crop which requires warm daytime temperatures of between 25˚C-30˚C and cool nights. Temperatures below 8˚C or above approximately 40˚C usually will cause

cessation of development. This is because factors such as photosynthesis, translocation, and pollen viability are affected negatively (Birch *et al*., 2003). Rainfall is a limiting factor to dryland production of commercial maize crops and irrigation is essential in areas with a winter dominant rainfall pattern or where the amount of summer dominant rain is highly variable. Maize is particularly susceptible to water stress at the flowering stage when yield potential is being set especially as this coincides with the high evapotranspiration rates of mid-summer (Farnham *et al*., 2003). Plants growing for prolonged periods in waterlogging soils show stomatal closure, reduced leaf area growth, chlorosis, reduced root growth, root death and ultimately plant mortality. (Srinivasan *et al*., 2004). Damage to roots is due mainly to the accumulation of toxic products (such as lactic acid) as a result of anaerobic respiration. Tropical and sub- tropical cultivars are most susceptible to waterlogging at the early vegetative stage and at 'knee-high' stage (prior to tasselling). (Srinivasan *et al*., 2004).

2.6.2. Biotic factors

Maize is a vigorous and tall-growing plant; it is susceptible to competition from weeds, particularly at the early stages of crop growth and particularly because the wide spacing between rows provides opportunity for weed establishment. Weeds may directly lead to yield reduction by competing with the maize plants for nutrients and water and need to be controlled within 3 weeks of crop emergence (Morris, 2008). Pests and diseases are other factors that affect maize production. Maize is most susceptible to damage by pests and diseases during the establishment phase when soil insects can cause up to 30 % losses and necessitate replanting of the crop, and from tasselling to harvest. (O'Gara, 2007). Some of the pests and diseases that cause damage to maize during germination and maturity are black field earwigs, wireworms, false wireworms, cutworms, maize

stem borer, African black beetle, soft rot, fusarium cob rot and stalk rot, head smut, downy mildew, common rust, boil smut and maize dwarf mosaic. (Beckingham, 2007)

2.7. Effects of climate change on maize production in the tropics

Maize is produced on nearly 100 million hectares in developing countries, with almost 70 % of the total maize production in the developing world coming from low and lower middle income countries (FAOSTAT, 2010). In large parts of Africa maize is the principal staple crop; accounting for an average of 32 % of consumed calories in Eastern and Southern Africa, rising to 51 % in some countries. (FAOSTAT, 2010). Heisey and Edmeades (1999) estimated that one quarter of the global maize area is affected by drought in any given year. Additional constraints causing significant yield and economic losses annually include low soil fertility, pests and disease. It is difficult to give an accurate figure on combined maize yield losses due to these stresses; however it is likely to be extensive. Maize yields remain low and highly variable between years across Sub-Saharan Africa at 1.6 tonnes per hectare, only just enough to reach self-sufficiency in many areas (Bänziger and Diallo, 2001; FAOSTAT, 2010). The world population is expected to surpass 9 billion by 2050, with population growth highest within developing countries. Harvest at current levels of productivity and population growth will fall far short of future demands. Projections of climate change will further exacerbate the ability to ensure food security and foster economic growth within many maize producing areas. Some of the factors that accounts for the decline in maize production in the tropics are both abiotic and biotic factors. Some of these factors are heat, waterlogging, plant diseases and insect pests.

2.7.1. Waterlogging

Over 18 % of the total maize production area in South and Southeast Asia is frequently affected by floods and waterlogging problems, causing production losses of 25-30 %

annually (Zaidi *et al.*, 2010). Although the area of land in Sub-Saharan Africa affected by waterlogging is lower than in Asia, it is a risk in a few areas. Waterlogging stress can be defined as the stress inhibiting plant growth and development when the water table of the soil is above field capacity. The diffusion rate of gases in the flooded soil could be 100 times lower than that in the air, leading to reduced gas exchange between root tissues and the atmosphere (Armstrong and Drew, 2002). As a result of the gradual decline in oxygen concentration within the rhizosphere, the plant roots suffer hypoxia (low oxygen), and during extended waterlogging, (more than 3 days) anoxia (no oxygen) (Zaidi *et al*., 2010). Carbon dioxide, ethylene and toxic gases (hydrogen sulphide, ammonium and methane) also accumulate within the rhizosphere during periods of waterlogging (Ponnamperuma, 1984). A secondary effect of waterlogging is a deficit of essential macronutrients (nitrogen, phosphorous and potassium) and an accumulation of toxic nutrients (iron and magnesium) resulting from decreased plant root uptake and changes in redox potential. Nutrient uptake is reduced as a result of several factors. Anaerobic conditions reduce ATP production per glucose molecules, thereby reducing energy available for nutrient uptake. Reduced transport of water further reduces internal nutrient transport. Reduced soil conditions

decrease the availability of key macro nutrients within the soil. Under waterlogging conditions nitrate is reduced to ammonium and sulfate is converted to hydrogen sulphide, and both become unavailable to most of the non-wetland crops, including maize which eventually leads to a reduction in yield.

2.7.2. Plant diseases

For a disease to occur a virulent pathogen, susceptible host and favourable environment are essential (Legrève and Duveiller, 2010). All of these components are strongly coupled with environmental conditions. Global climate changes have the potential to

modify host physiology and resistance, and alter both stages and rates of pathogen development. Environmental conditions controlling disease development include rainfall, relative humidity, temperature and sunlight. Changes in these factors under climate change are highly likely to have an effect on the prevalence of diseases and emergence of new diseases. The disease infection cycle includes inoculum survival, infection, latency period, production of new propagules and dispersal, all of which are strongly influenced by environmental conditions. The penetration or infection of a plant by infectious propagules is determined by specific environmental conditions. In general, fungi require high relative humidity or moist leaf surfaces for infection; changes in these conditions will increase infection rates. For example, *Cercospora zeae-maydis* and *Cercospora zeina* cause gray leaf spot (GLS) in maize and are highly sensitive to environmental conditions (Crous *et al*., 2006). Under dry conditions (relative humidity < 80%), the pathogen ceases to grow and infection stops (Thorson and Martinson, 1993). Therefore, changes in temperature, humidity and rainfall patterns have the potential to increase infection by many maize pathogens. Increased temperature reduces the latency period (generation time) resulting in a higher number of generations per season. Generation time determines the amplification of plant disease in two ways - accelerating and increasing inoculums load and/or affecting pathogen evolution rates and pathogen's capacity to adapt to the environment-potentially allowing the pathogen to adapt faster to the environment than the host. Climate change may also affect gene flow, the process through which particular alleles or individuals are exchanged among separate populations. This will increase pathogen population diversity leading to variation in host resistance, variation in pathogen virulence and new specific interactions. This has the potential to result in new diseases or pathogen emergence, and the introduction of pathogens into new ecological niches. Depending on the distribution of populations and

environmental conditions that are influenced by climate change, gene flow leads to an increase in population diversity or to the introduction of a new population in new ecological niches. An important example of changes in growing season conditions being linked to outbreaks of diseases, with serious human health implications, is mycotoxins and their prevalence within maize systems. Mycotoxins are toxic secondary fungal metabolites that contaminate agricultural products and threaten food safety. Different groups of mycotoxins are produced by different fungi. *A. flavus* and *A. parasiticus* produce aflatoxin, *F. verticillioides* produces fumonisin, and *F. graminierum* produces deoxynivelanol (DON) and zearalenone (Cardwell *et al*., 2001; Miller, 2008).

Mycotoxin contamination is a serious problem with long-term consequences for human and animal health. Sub-lethal exposure to mycotoxins suppress the immune system, increase the incidence and severity of infectious diseases, reduce child growth and development, and reduce the efficacy of vaccination programs (Williams *et al.,* 2004). Consumption of high doses of mycotoxins causes acute illness and can prove fatal. In 2004, more than 125 people died in Kenya from eating maize with aflatoxin B1 concentrations as high as 4,400 parts per billion - 220 times the Kenyan limit for foods (Lewis *et al.,* 2005). The maize implicated in this outbreak was harvested during unseasonable early rains and stored under wet conditions conducive to mold growth and therefore aflatoxin contamination (CDC, 2004). Previous outbreaks in Kenya and India have also been attributable to unseasonable, heavy rain during harvest (Krishnamachari *et al.,* 1975; Ngindu *et al.,* 1982). Environmental conditions conducive to mycotoxin producing fungi vary. *A. flavus* competes poorly under cool conditions and the prevalence of *A. flavus* is higher in warmer environments (above 25°C) compared to cooler environments (20 - 25 °C) (Shearer *et al.,* 1992). The environment influences not only the quantity of aflatoxin producers, but also the "type" of producer present (Horn

and Dorner, 1999). In Africa, "S" mophotypes of *A. flavus* are associated with hot and dry agro- ecological zones with latitudinal shifts in climate influencing fungal community structure (Cardwell and Cotty, 2002). For the Fusariums, *F. graminearum*, is predominate in temperate maize growing environments, whereas *F. verticillioides* and *F. proliferatum* and *fumonisins* are more widely spread in tropical and subtropical environments (Miller, 1994). The optimal temperature range for *F. graminearum* is between 24-28 °C and above this temperature range *F. verticillioides* out-competes *F. graminearum* (Miller, 2001; Reid *et al*., 1999). Increasing temperatures within maize growing regions are highly likely to change the geographical distribution and predominance of *F. verticillioides,* particularly in currently cooler regions where it will replace *F. graminerum*. This shift in Fusarium species will result in a change in mycotoxins, from deoxynivalenol and zearalenone (produced by *F. graminierum*) to fumonisin (produced by *F. verticillioides*). Increased incidence of *F. verticillioides* and subsequent fumonisin contamination has already been reported in Guatemala, Mexico, Zimbabwe and Kenya (Torres *et al*., 2007).

2.7.3. Insect-pests

The dynamics of insect-pests are also strongly coupled with environmental conditions. Insects do not use their metabolism to maintain their body temperature, and are dependent on ambient temperature to control their body temperature. Temperature is therefore the single most important environmental factor influencing insect behavior, distribution, development and survival, and reproduction. Insect life stage predictions are calculated on accumulated degree days, which is a function of both time and temperature. Increased temperature can speed up the life cycle of insects leading to a faster increase in pest populations. It has been estimated that 2 °C increase in temperature has the potential to increase the number of insect life cycles during the crop

season by one to five times (Petzoldt and Seaman, 2005, Bale *et al*., 2002; Porter *et al*., 1991). The feeding rate of many arthropod vectors increases at higher temperatures, thus increasing exposure of crops to mycotoxigenic fungi thereby increasing the spread of mycotoxins (Bale *et al*., 2002, Dowd, 1992). Insect damage has been shown to be closely related to Fusarium or Aspergillus ear rots (Miller, 2001, Munkvold and Hellmich, 2000). A field survey in Austria demonstrated that the incidence of the European maize borer increased *F. verticillioides* disease and *fumonisin* concentrations but not *F. graminierum* (Lew *et al*., 1991). Therefore, the increased global warming and drought incidences will favor insect proliferation and herbivory, which will likely increase the incidence and severity of insect related damages as well as aflatoxin and fumonisin mycotoxins in maize. Higher average temperatures have the potential to change the geographical distribution of crops. This may in turn result in an expansion of the geographical distribution of insect-pests and their associated pathogens (e.g. maize streak virus, corn stunt complex that are vectored by different species of leaf hoppers), resulting in a change in the geographical distribution of diseases.

2. 8. Drought

Drought denotes a period without appreciable precipitation, during which the water content of the soil is reduced to such an extent that plants suffer from lack of water (Larcher, 1995). It is therefore defined by Yoshida (1981) as an imbalance between water uptake and water lost through transpiration. On a large scale, drought results from the combination of low precipitation and high evapotranspiration caused by dryness of the air and high levels of radiation (Larcher, 1995). Nevertheless, plants may experience transient drought stress during noon hours of hot days even with adequate rainfall or irrigation (McKersie and Lesshem, 1994b). If plants are to survive this imbalance they

must have a range of both morphological and biochemical mechanisms that enable them to grow and reproduce despite water limitations (Turner, 1997).

Drought events can be classified according to their cause; meteorological drought occurs when precipitation is significantly below expectations for the year and location; agricultural drought is when water supplies used directly for agriculture are scarce resulting in a consistently high soil moisture deficit over the growing season. The threshold for agricultural drought may be influenced by shifting to another crop because different crops have different water requirements (Ashley, 1993).

2.8.1. Impact of drought on crop production

Drought is a major cause of food insecurity for many households. It has been estimated to cause annual maize yield loss of 24 million tonnes in the developing world. The estimated losses are about 15 per cent (about 1.2 million tonnes) annually in Indonesia (Dahlan *et al.,* 1997); 0.7 t/ha or 68 per cent in the commercial farming sector, and 1.69 t/ha or 37 per cent in the large-scale commercial sector in Zimbabwe (Machida, 1997); 10-75 per cent in Asia (Logrono and Lothrop, 1997); and 1.2 million tonnes in Argentina (Eyherabide *et al.,* 1997). Drought stress is also a major factor that limits maize productivity in Ghana (Mercer-Quashie *et al.,* 1993; Ohemeng-Dapaah, 1994; SARI, 1995; Kasei *et al.,* 1995; Obeng-Antwi *et al.,* 1999). Drought is a greater problem for the rural poor of developing countries because they mainly depend on rain-fed agriculture for their livelihood. Drought is second only to poor soil fertility in reducing yield in the developing world, leading to a 15% overall reduction in grain yield in these countries, and in a bad year can be the major constraint on yield in developed countries as well (Agrama and Moussa, 1996). There is therefore great need for staple food crops that combine higher and more stable yields than currently available, both in good growing years and when drought strikes. Drought stress affects the growth of maize at all stages

of development, directly and indirectly (Norman *et al*., 1995; Ribaut *et al*., 1996; Chen-Zong-Long, 1996).

2.8.2. Impact of drought at different stages of maize development

Drought is a multidimensional stress affecting plants at various levels of their development (Blum, 1996), and is generally accepted as the most widespread abiotic stress experienced by crop plants (Quarrie *et al*., 1999), as well as a major limiting factor to crop production in most areas of the world, especially the tropics. Even intermittent water deficit at critical stages of cereal crops may reduce yield (Ludlow and Muchow, 1990), and in high rainfall (>800mm) areas, short periods of drought can decrease yield considerably. Plants adapt to stresses using different mechanisms such as escape (which allows a plant to grow and complete its life cycle before soil moisture becomes limiting), avoidance (which enables plants to maintain positive tissue water relations even under limited soil moisture conditions), and tolerance (which stabilize and protect cellular integrity under conditions of tissue desiccation) (Ludlow and Muchow, 1990).

Maize uses about 0.1 inch per day through to a maximum of 0.35 inch per day during pollination and then drops back to about 0.05 inch per day at the black layer stage (physiological maturity). The effects of water deficiency depends on growth stage, deficiency level and environmental changes during drought. Even minor drought during physiological stages can reduce maize yields. More specifically, four days of visible wilting between the boot stage (only a week prior to tasseling) and milking stage may reduce yield by 50 percent or more. During later, reproductive stages, yield losses from drought decrease as maize nears physiological maturity. Research indicates that from tasselling (VT) through the soft dough (R4) stage, maize will require about 7 inches of water for normal growth and development. This demand for moisture at key periods of growth shows maize's vulnerability to drought. To produce optimum grain maize yields,

23 to 25 inches of water are required during the growing season. (Mc Williams and Denise, 2005)

2.9. Morphological and physiological indicators of drought response.

Drought is a complex physico - chemical process, in which many biological macro molecules and small molecules are involved, such as nucleic acids, proteins, carbohydrates, lipids, hormones, ions, free radicals, mineral elements (Moaveni., 2011) The ability of a cultivar to produce high yield over a wide range of environmental condition is very important. Response of plants to water stress depends on several factors, such as developmental stage, intensity and duration of stress and cultivar genetics (Eskandari and Kazemi, 2010). The plant response is complex because it reflects over space and time the integration of stress effects and responses at all underlying levels of organization (Yordanov *et al.*, 2003).

Morphological traits have a special role to determine the importance of each trait on increasing yield, as well as to use those traits in the breeding programs, which at least lead to improving yield and introducing commercial varieties under end - of - season drought stress condition (Mollasadeghi *et al.*, 2011). Morphological characters include root length, spike number, grain number per spike, 1000 grain weight, awn length (Plaut *et al.*, 2004). Wajid *et al*. (2002) reported that wheat crop produces highest grain yield by applying irrigation at all definable growth stages. Because irrigation is an expensive input, farmer, agronomist, economist and engineer need to know the response of yield to irrigation. Furthermore, Jahfari (2004) and Rafique (2004) reported that yield and yield components are significantly increased within different wheat cultivars. Garavandi and Kahrizi (2010) by evaluating 20 bread wheat genotypes reported that genotypes have higher genetic diversities for grain yield, spike number per square meter, number of seed per spike, spike density and awn length in comparison with other traits. Development of

cultivars with high yield is the main goal in water limited environments, but success has been modest due to the varying nature of drought and the complexity of genetic control of plant responses (Mirbahar *et al.,* 2009). In plants, a better understanding of the morpho-anatomical and physiological basis of changes in water stress resistance could be used to select or create new varieties of crops to obtain a better productivity under water stress conditions (Martinez *et al.,* 2007).

The reactions of plants to water stress depend on the intensity and duration of stress as well as plant species and its stage of growth (Jaleel *et al.,* 2008). Some of the indicators of plants respond to drought stress are as follows: production of oxidative stress and antioxidant defense systems, roots and root systems, changes in the ratio of chlorophyll content, the role of phytohormones and relative water content. (Ashraf *et al*., 1994)

2.9.1. Oxidative stress and antioxidant defense systems

When plants are subjected to various abiotic stresses, some reactive oxygen species (ROS) such as super-oxide (O^{2-}), hydrogen peroxide (H_2O_2), hydroxyl radicals (OH^-) and singlet oxygen are produced. These (ROS) may initiate destructive oxidative processes such as lipid peroxidation, chlorophyll bleaching, protein oxidation and damage to nucleic acids (Terzi and Kadioglu, 2006). The antioxidant defenses appear to provide crucial protection against oxidative damages in cellular membranes and organelles in plants grown under un-favorable conditions (AL-Ghamdi, 2009.). Active oxygen species are considered to be important damaging factors in plants which are exposed to stressful environmental conditions such as drought (Upadhyaya *et al.,* 2007.). The antioxidant defense system in the plant cell includes both enzymatic (antioxidants), such as superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX) (Ahmadizadeh *et al.,* 2011) and non-enzymatic antioxidants including- carotenes, ascorbic acid (AA) (Pignocchi and Foyer, 2003), -tocopherol (-toc) (Muller *et al.,* 2006),

reduced glutathione (GSH) (Xu *et al.*, 2008). Carotenes form a key part of the plant antioxidant defense system, but they are very susceptible to oxidative destruction. β - carotene, present in the chloroplasts of all green plants is exclusively bound to the core complexes of Photo System1 (PSI) and Photo System11 (PSII). Protection against damaging effects of ROS at this site is essential for chloroplast functioning. A major protective role of β-carotene in photosynthetic tissue may be through direct quenching of triplet chlorophyll, which prevents the generation of singlet oxygen and protects from oxidative damage (Farooq *et al.*, 2009).

Acclimation of plants to drought is considered to promote antioxidants defense systems to face the increased levels of activated oxygen species (AOS), which in turn, cause membrane damage by lipid peroxidation and indicated by malondialdehyde (MDA) content, which is one of the main parameters for evaluating membrane oxidation extent and are toxic for cells (Shao *et al.*, 2005). The decline in catalase (CAT) activity is regarded as a general response to many stresses (Gunes *et al.*, 2008). Ahmadizadeh *et al.*, (2011) reported that the activity of superoxide dismutase (SOD) and catalase (CAT) decreased in susceptible landraces, where as in resistant landraces dismutase (SOD) and catalase (CAT) remained unchanged and in some cases they showed an increase under stress condition.

2.9.2. Roots and root systems

Root distribution and root system structure, which are both affected by soil moisture, play an important role in the plant's ability to survive drought situations. Plants having the ability to increase root growth into regions with more available soil water have better chances of survival under drought situations (Mambani and Lal, 1983), since increased root growth re-establishes the soil-root contact and facilitates water uptake (Yambao *et al.*, 1992). Plants having the ability to develop deep and thick roots are better adapted to

growth in drought prone areas than thin rooted plants with a shallow root system. Thick (fibrous) roots reach deeper soil layers and have less axial resistance to water flow because of a larger meta-xylem, and thereby facilitate and increase water uptake. Irrespective of root axial resistance, a few long roots can theoretically sustain the transpirational demand and maintain adequately high leaf water potential in the shoot (Yambao *et al.,* 1992), and thick roots have also been confirmed to have a better ability to penetrate compact soil. They persist longer, produce more and larger branch roots and thereby increase water uptake capacity (Ingram *et al.,* 1994). When drought develops, the root/shoot dry matter ratio may increase and in the roots both morphology and distribution changes. These changes may have a genetic basis and they are an integrated expression of various adaptive processes taking place in the roots in response to plant water deficit (Nguyen *et al.,* 1997).

2.9.3. Chlorophyll content

Drought stress produce changes in the ratio of chlorophyll 'a' and 'b' and carotenoids (Farooq *et al.,* 2009). Chlorophyll content is positively associated with photosynthetic rate which increases biomass production and grain yield. Photosystem II (PS II) is highly sensitive to environmental inhibiting factors and water stress will damage its reaction centers severely. The chemical reaction of Photosystem II (PS II) is also affected strictly by water stress (Shamsi, 2010). Chlorophyll concentration has been known as an index for evaluation of source, therefore decrease of this can be considered as a non-stomata limiting factor in the drought stress conditions. There are reports about decrease of chlorophyll content in drought stress conditions (Kuroda *et al.,* 1990). Also, it is reported that chlorophyll content of resistant and sensitive cultivars to drought and thermal stress can be reduced. But resistant cultivar to drought and thermal stress conditions had high chlorophyll content (Shamsi, 2010). Some study has demonstrated that chlorophyll

content is positively correlated with photosynthetic rate (Thomas *et al.*, 2005). Increasing the chlorophyll content in crops may be an effective way to increase biomass production and grain yield. Ashraf *et al*. (1994) also reported that drought stress reduces concentration of chlorophyll 'b' more than chlorophyll 'a'.

2.9.4. The role of Phytohormones

Phytohormones are a group of naturally occurring organic substances that influence physiological processes and have certain biochemical trends in common. They are mostly small molecules synthesized from ubiquitous precursors, sometimes via multi-stepped pathways, in a wide range of tissues or cells within tissues and are deactivated by either oxidation or conjugation. They may act either in the cell or tissue in which they are synthesized or may be transported through a distance to bring about specific physiological responses (Davies, 1995). Phytohormones are active in very small quantities, and some of them have both promoting and inhibitory influences. Hormones are not only stimulators, but are also chemical regulators that communicate information about both the developmental or physiological state of cells and tissues, and conditions in the surrounding environment both beneath and above the soil surface (Turner, 1997). Cells are thought to recognize phytohormones using receptor proteins, but to date, only ethylene receptors have been identified (Kende and Zeevart, 1997, Rock, 2000). Receptor proteins contain binding sites for specific hormones. Binding of a hormone to its receptor might allow the receptor to interact either with other components in the cell or directly with regulatory sequences of DNA in order to activate or repress the transcription of specific genes (Davies, 1995). The concept of phytohormone action can be divided into changes in concentration, sensitivity and transport. Changes in hormone concentration can be brought about by changes in environmental conditions, or by changes in levels of substances that enhance or inhibit the response to the hormone (Firn,

1986). At the same time sensitivity to the hormone might change as a result of a change in the number of receptors (receptivity), a change in receptor affinity (affinity), or a change in the subsequent chain of events (response capacity) (Firn, 1986). In addition, hormone movement or transport may be enhanced or inhibited by a change in sap flow, membrane permeability or pH in and along the pathway (Hartung and Davies, 1991). Abscisic acid (ABA) is a phytohormone known to synergistically or antagonistically with other hormones coordinate and control plant growth and development in response to external factors, including water deficit. Within the context of drought stress, ABA is probably the most intensively investigated phytohormone, and is widely thought to influence plant growth and development (Beardsell and Cohen, 1975; Bunce, 1999). ABA appears to be the promoting agent in some physiological processes and the inhibitory agent in others, and its action, in most situations, is determined by a balance between its roles of an inhibitor and a promoter (Hoffmann-Benning and Kende, 1992). ABA can inhibit both shoot and root growth. As a response to drought it may have less effect on root growth, and thereby cause root-shoot ratio to change. Cytokinins (CK) that are generally considered to be antagonists of ABA have opposing effects in the developmental processes including stomatal opening (Blackman and Davies, 1984). Giberellic acid (GA) promotes shoot growth but is not known to be involved in any of the other processes (Davies, 1995). While ABA production is increased during drought, the production of Cytokinins (CK) that have been suggested to affect guard cell sensitivity to ABA is decreased (Schurr *et al.*, 1992). Ethylene promotes the growth of root hairs and its production is stimulated by ABA. This might explain the lesser inhibition of root growth than shoot growth by ABA (Reid, 1995). In addition to phytohormones salicylic acid, jasmonic acid, secondary messengers such as calcium ions

(Ca^{+}), and shifts in pH are considered to play important roles in the phytohormone-mediated control of plant growth and development (Atkinson *et al.,* 1990).

2.9.5. Relative Water content

Drought stress affects water status in plants. Relative water content is useful means for determining the physiological water status of plants (Makbul *et al*., 2011). Relative water content is the indicators of degree of drought stress. Relative water content (RWC) of leaves is higher in the initial stages of leaf development and declines as the dry matter accumulates and leaf matures. Obviously, stressed plants have lower RWC than non-stressed plants. Relative water content (RWC) of non-stressed plants range from 85 to 90%, while in drought stressed plants; it may be as low as 30% (Reddy *et al.,* 2003). In studies that were performed on 4 cultivars of bread wheat, Relative water content (RWC) reduced to 43 percent (from 88% to 45%) by moisture stress (Siddique *et al.,* 2000). Mationn *et al.* (1989) presented a similar report as regards a drop in the amount of Relative water content (RWC) in tolerant and sensitive cultivars of barley. Significant differences in leaf water potential and Relative water content (RWC) were recorded among the tolerant and intolerant cultivars of wheat. It is reported that high relative water content is a resistant mechanism to drought (Shamsi, 2010). Overall decrease in Relative water content (RWC) under drought stress is highly significant in all the cultivars used, in accordance with Allahmoradi *et al.* 2011 in Mungbean. Gonzalez *et al.* (2008) recorded significant decrease in Leaf volumetric water content and Relative water content (RWC) in barley under drought stress.

Shamsi (2010) reported that with an increase in the intensity of drought stress on wheat cultivars, there was a decrease in relative water content. The RWC expresses the water content per centimeters at a given time as related to the water content at full turgidity.

This study sought to determine the genotypic differences among twelve genotypes when subjected to periodic water stresses during late growth stage.

CHAPTER THREE

MATERIALS AND METHODS

This study was conducted in a plant house to assess the sensitivity of eight inbred lines and four varieties of maize to drought and the effects of the drought on the yield and yield components of these inbred lines and the varieties.

3.1. Evaluation of maize genotypes for their response to drought.

3.1.1. Site of plant house study

The potted experiment was conducted in a plant house at the mechanization department of Kwame Nkrumah University of Science and Technology (KNUST). The top soil used was sandy loam and was taken from the Horticulture Department of Kwame Nkrumah University of Science and Technology (KNUST). Geographically, the site lies between latitudes 01^0; 36^0 and 01^0; 43^0 West of the Greenwich meridian. The soil used was sandy loam classified as Ferric Acrisols according to FAO (1990) equivalent to Typic Haplustult in the USDA (1998) soil classification system.

3.1.2. Experimental materials and sources

Plastic pots, each measuring 12315 cm^3 (Length × Breadth × Height), were filled with 12 kg each of top soil. Eight maize inbred lines developed by the International Maize and Wheat Improvement Center (CIMMYT) were supplied by the CSIR-Crops Research Institute (CRI) and four improved varieties developed by CRI were used in the study. The inbred lines were Tzeei-1, Tzeei- 4, Tzeei- 8, Tzeei- 21, Tzeei- 35, Tzeei- 50, Tzeei-63 and Tzeei- 76, and the varieties were Abontem, Aburohemaa, Akposoe and Omankwa. Seven grams per pot of compound fertilizer (NPK -15-15-15) and five grams

sulphate of ammonia were used as fertilizer source at the second and fifth week after planting.

3.1.3. Characteristics of the genotypes used for the study

Table 3.1: Characteristics of the genotypes used for the study.

Name of Inbred line	Grain Colour/Texture	Plant Height (cm)	50% Tassel Days	50% Silk Days	Maturity Days
Tzeei 1	White	168	48	51	80-85
Tzeei 4	White	152	47	49	80-85
Tzeei 8	White	116	50	56	80-85
Tzeei 21	White	130	51	53	80-85
Tzeei 35	White	100	53	55	80-85
Tzeei 50	White	119	47	49	80-85
Tzeei 63	Yellow	123	48	50	80-85
Tzee1 76	Yellow	121	47	50	80-85

Table 3.2: Characteristics of the varieties used for the study

Name of variety	Type of variety	Grain Colour Texture	Plant Height (cm)	50% Tassel Days	50% Silk Days	Maturity Days
Abontem	QPM/OPV	Yellow/Dent	170	46	48	80-85
Aburohemaa	QPM/OPV	White/Dent	157	44	47	90-95
Akposoe	QPM/OPV	White/Dent	130	46	48	80-85
Omankwa	QPM/OPV	White/Dent	165	51	55	90-95

QPM = Quality protein maize, OPV= Open Pollinated Variety

Source: CSIR-Crops Research Institute Kumasi, Ghana.

3.1.4 Experimental design and treatments

The experimental design used was Completely Randomized Design (CRD) with twelve treatments (12 genotypes) and four replications. A total of ninety- six potted plants were used. The treatments were divided into two groups (water stressed and non stressed maize genotypes). Water was withdrawn at six weeks after planting and resumed at ten days interval for the water stressed maize genotypes and the non stressed maize genotypes received water throughout the experiment.

3.1.5. Soil sampling and analyses

3.1.5.1 Soil sampling

Soil samples were collected from the Horticultural Department of KNUST (Kwame Nkrumah University of Science and Technology) which is in the semi-deciduous forest zone of the Agro-ecological zones in Ghana from a depth of 0- 15 cm in August, 2013. The bulk sample was air-dried, ground and passed through a 2mm sieve. A sample was taken and stored in polythene bag for later analysis.

3.1.5.2 Soil chemical analysis

The sample stored was analysed by standard laboratory procedures.

1. **Soil pH**

   Soil pH was determined using MK2 pH meter (with a glass electrode) with soil to water ratio of 1: 2.5. A 30 g soil sample was weighed into plastic pH tube to which 75 ml water was added from a measuring cylinder. The suspension was stirred frequently for 30 minutes. After calibrating the pH meter with buffer solutions at pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension. This was done according to the method described by Landen (1991).

2. **Organic carbon**

The wet combustion method described by Walkley and Black (1934) was used to determine the amount of organic carbon in the soil. Percentage carbon in the soil sample was calculated as follows:

$$\% \text{ carbon} = \frac{10.5 - (XN) \times 0.3 \times f}{W}$$

Where

W= Weight of the soil sample that was used

X= Volume of ferrous sulphate that is needed for titration

N= Normality of ferrous sulphate solution

f= Correlation factor

3. **Percent organic matter (O. M)**

The organic carbon value that was obtained was multiplied by the correlation factor (1.72) to convert it to percent organic matter as described by Landen (1991).

4. **Total Nitrogen**

Total nitrogen was determined by using the Macro- Kjeldahl method (Jones, 1991). This was done in accordance with the method described by Bremmer and Mulvaney (1982). A 0.5 g soil sample was weighed into a Kjeldahl digestion flask. To this 5 ml distilled water was added. After 30 minutes, concentrated sulphuric acid (5 ml) and selenium mixture were added and mixed carefully. The sample was then digested for 3 hours until a clear digest was obtained. The digest was diluted with 50 ml distilled water and mixed well until no more sediment dissolved and allowed to cool. The volume of the solution was made to 100 ml with distilled water and mixed thoroughly. A 25 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of 40 % NaOH solution added

followed by distillation. The distillate was collected in 2.0 % boric acid and was titrated with 0.02 N HCl using bromocresol green as indicator. A blank distillation and titration was also carried out to take care of the traces of nitrogen in the reagents as well as the water used. This was done on the basis that 14 bg of nitrogen is contained in one equivalent weight of NH_3, the percentage of nitrogen in the soil was calculated as:

$$\% \text{ nitrogen} = \frac{14 \times (A-B) \times N \times 100}{1000}$$

Where:

A= Volume of standard acid used in the sample titration.

B= Volume of standard acid in the blank titration.

N = Normality of standard acid.

5. Exchangeable bases (K, Ca, Mg, and Na)

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 M ammonium acetate extract (Black, 1986) and the exchangeable acidity (hydrogen and aluminium) was determined in 1.0 M KCl extract (Page *et al*., 1982). A 5 g soil sample was weighed into a leaching tube and leached with 100 ml buffered 1.0 M ammonium acetate solution at pH 7. To analyze calcium and magnesium, a 25 ml aliquot of the extract was transferred into an Erlenmeyer flask. To this were added 1 ml portion of hydroxylamine hydrochloride, 1 ml of 2.0 % potassium cyanide, 1 ml of 2.0 % potassium ferrocyanide, 10 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution. The solution was titrated with 0.01 M EDTA (ethylene diamine tetra acetic acid) to a pure turquoise blue colour.

A 25 ml aliquot of the extract was transferred into a 250 ml Erlenmeyer flask and the volume made up to 50 ml with distilled water. Following this, were added 1 ml hydroxylamine, 1 ml of 2.0 % potassium cyanide and 1 ml of 2.0 % potassium ferrocyanide solution. After a few minutes, 5 ml of 8.0 M potassium hydroxide solution and a spatula of murexide indicator were added. The resultant solution was titrated with 0.01 M EDTA solution to a pure blue colour.

Calculation:

The concentrations of calcium + magnesium or calcium were calculated using the equation:

$$\text{Ca + Mg (or Ca) (cmol/kg soil)} = \frac{0.01 \times (Va - Vb) \times 1000}{w}$$

Where

w = weight (g) of air – dried soil used

Va = ml of 0.01 M EDTA used in sample titration

Vb = ml of 0.01 M EDTA used in blank titration

0.01= concentration of EDTA

Potassium (K) and sodium (Na) in the leachate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg/l K and Na solutions to 100 mg/l. In doing this, 25 ml portion of each solution was taken into 250 ml volumetric flask and made up to the volume with distilled water. Portions of 0, 5, 10, 15, 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks. One hundred milliliters of 1.0 M NH4OAc solution was added to each flask and made to the volume with distilled water. This resulted in standard series of 0, 2.5, 5.0, 7.5, 10 mg/l for K

and Na. Potassium and sodium were measured directly in the leachate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively

Calculation:

$$\text{Exchangeable K (cmol/kg soil)} = \frac{(a-b) \times 250 \times mcf}{10 \times 39.1 \times w}$$

$$\text{Exchangeable Na (cmol/kg soil)} = \frac{(a-b) \times 250 \times mcf}{10 \times 23 \times w}$$

Where

a = mg/l K or Na in the diluted sample percolate

b = mg/l K or Na in the diluted blank percolate

w = weight (g) of air- dried sample

mcf = moisture correcting factor

The soil sample was extracted with unbuffered 1.0 M KCl solution for the determination of exchangeable acidity (Al^{3+} and H^{+}). Ten grams of soil sample was weighed into a 200 ml plastic bottle and 50 ml of 1.0 M KCl solution added. The mixture was shaken on a reciprocating shaker for 2 hours and filtered. An aliquot of 25 ml of the extract was pipetted into a 250 ml Erlenmeyer flask and 4 - 5 drops of phenolphthalein indicator solution added. The solution was titrated with 0.025 N NaOH until the colour just turned permanently pink. A blank was also included in the titration.

Calculation:

$$\frac{(a-b) \times M \times 2 \times 100 \times mcf}{w}$$

Where

a = ml NaOH used to titrate with sample

b = ml NaOH used to titrate with blank

M = molarity of NaOH solution

w = weight (g) of air-dried sample

2 = 50/25 (filtate/ pipetted volume)

mcf = moisture correcting factor (100 + % moisture)/100

6. Effective Cation Exchange Capacity (ECEC)

This was determined by adding all the exchangeable cations namely Na^{+}, K^{+}, Ca^{2+}, Mg^{+2}, Al^{3+}

and H^{+}

7. Percentage base saturation

The percentage base saturation was obtained by dividing the total exchangeable bases (T. E. B) by the Effective Cation Exchange Capacity (ECEC), and the result was multiplied by 100.

$$\frac{Total\ Exchangeable\ Bases}{Effective\ Cation\ Exchange\ Capacity} \times 100$$

8. Available Phosphorus

The Bray P method (Bray and Kurtz, 1945) was used to determine the available phosphorus content in the soil. The phosphorus content was determined by using the Bausch and Lamb Spectrophotometer. A 5 g soil sample was weighed into a shaking bottle (50 ml) and 35 ml of extracting solution of Bray's Nº 1 added. The mixture was shaken for 10 minutes on a reciprocating shaker and filtered through a Whatman No. 42 filter paper. An aliquot of 5 ml of the blank, the extract, and 10 ml of the colouring reagent (ammonium molybdate and tartarate solution) were pipetted into a test tube and uniformly mixed. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21D spectrophotometer at a wavelength of 660 nm at medium sensitivity.

A standard series of 0, 1, 2, 3, 4 and 5 mgP/L was prepared from 20 mg/L phosphorus stock solution.

Calculation

$$\text{P (mg/kg)} = \frac{(a-b) \times 35 \times 15 \times mcf}{w}$$

Where

a = mg/L P in sample extract

b = mg/L P in blank

mcf = moisture correcting factor

35 = ml extracting solution

15 = ml final sample solution

w = sample weight in gram

3.1.5.3 Soil physical analysis

The hydrometer method which was described by Day, (1953) was used to analyse the soil particle size. A 50 g of air-dried soil was weighed into a measuring cylinder and 50 ml of calgon (sodium hexamethaphosphate) added. The suspension was shaken and allowed to stand. Corrected hydrometer readings at 40 seconds and 3 hours were taken.

Calculation:

$$\% \text{ sand} = 100 - [(A / W) \times 100]$$

$$\% \text{ clay} = 100 \times (B / W)$$

$$\% \text{ silt} = 100 - (\% \text{ sand} + \% \text{ clay})$$

Where

A= corrected hydrometer reading at 40 seconds

B = corrected hydrometer reading at 3 hours

W = weight of dry soil

The textural class was then determined from the textural triangle.

3.1.6. Amount of water applied

Moisture per day

Available moisture per day = $\frac{1500 \text{ mm}}{150 \text{ mm}}$

= 10 mm/day ≈ 1 cm/day

Depth of water (Θz) 1 cm = Volumetric water content (Θv) x depth of soil

Depth of water (Θz) 1 cm = $\frac{\text{Volumetric water} \times \text{depth of soil}}{\text{Volume of soil (volume of container)}}$

Volume of water per day = $\frac{\text{Depth of water (Θz)} \times \text{Volume of soil (Volume of container)}}{\text{Depth of soil}}$

But:

Depth of water (Θz) = 1 cm

Volume of soil (volume of container) = Л r^2 h

= $\frac{22}{7}$ x 14^2 x 20

$= 12315\ cm^3$

Depth of soil (depth of container) = 20cm

Therefore:

Volume of water per day $= 1 \frac{cm \times 12315cm^3}{20cm}$

$= 615.75\ cm^3 \approx 600cm^3$

But, to initially saturate the air dried soil to field capacity, a four day volume of water was considered. Thus:

Volume of water applied initially $= 600\ cm^3 \times 4$

$= 2400\ cm^3$

A volume of 2400 cm^3 of water was applied initially to the soil in each pot and their individual weights were recorded. The pots were left for two days for the soil to settle before planting was done.

3.1.7. Planting

Three seeds each of the 12 genotypes were planted per pot in the ninety- six plastic pots and seedlings were later thinned to two per pot. A total of 192 plants were obtained. Sowing was done on October 11, 2013.

3.1.8. Irrigation schedule

All the ninety-six potted plants received water at four (4) days interval until the sixth week. After the sixth week, water was withdrawn from one group (48 pots) for ten days and after the tenth day, watering was resumed for two weeks then water was withdrawn again till the next tenth day. The remaining 48 potted plants received water throughout the experiment and this served as the control. Before irrigation, each pot was weighed and the weight differences (kg) were converted to volume (cm^3). The values obtained for

each pot represented the volume of water applied to that particular pot at that period. The idea was to regain the initial soil moisture content at 4 days interval

3.1.9. Fertilizer application

Seven grams of NPK (15-15-15) was applied per pot two weeks after planting (2 WAP) and this was followed with top dressing with five grams of sulphate of ammonia per pot at five weeks after planting (5 WAP). These fertilizer applications were done a day before irrigation so that nutrients could be available to plant roots. Furadan 3G insecticides were used to control stem borers and other insect pests.

3.1.10. Data collection

1. Leaf Moisture Content (LMC) (%)

During the period of moisture stress, two leaves of each genotype excluding the flag leaf were taken with a pair of scissors. The fresh weight was quickly measured, and was subsequently oven-dried to a constant weight at about 50° C. LMC was then calculated as follows:

$$\% \text{ MC} = \frac{FW - DW}{FW} \times 100$$

Where FW = Fresh weight

DW = Dry weight.

2. Plant height

The first measurement was taken at forty- two days after planting (42 DAP) and at each sampling date, the height of four plants of each genotype was taken. Plant heights were measured from the base of the plant to the tip of the longest leaf using a metallic measuring tape. The average height of the four plants of each genotype was then determined.

3. Dry matter yield per plant

At harvest, the biomass of one plant of each genotype in a replication excluding the roots was taken and oven-dried at 72°C to a constant mass and their masses were taken with an electronic balance.

The mean dry masses were then calculated.

4. Root dry mass

At harvest, roots were separated from the shoots and were gently removed from the soil mass. The roots were gently washed to remove all soil. They were then dried at 72°C to constant mass. The average dry mass of roots of each genotype was thus measured.

5. Grain yield

At harvest (physiological maturity), ears with at least one fully developed grain were harvested. All ears harvested from each genotype were weighed and representative ear samples were shelled to determine percent moisture. Grain yield was computed from ear weight (EWT) adjusted to 15 % moisture content (MOIST) and 80 % shelling percentage (SHELL), using the following formula by Salami *et al.*, (2003).

Grain yield (kg/ha):

$$\text{EWT} \times \frac{[(100-\text{MOIST})]}{85} \times 10000 \times \text{SHELL}$$

EWT = Ear Weight, MOIST = Moisture content, SHELL = Shelling percentage.

6. Drought intensity and drought susceptibility index estimation

The drought intensity as well as the drought susceptibility indices were determined for both the water stressed genotypes as well as the non-stressed genotypes. From the estimation, drought index based on relative grain yield of the water stressed genotypes were estimated. The relation used was the one proposed by Fischer and Maurer (1978)

Drought Susceptibility index (DSI)

$$DSI = 1 - \frac{Ys}{Yw} \div D \quad \text{..... (Equation 3.1)}$$

$$D = 1 - \frac{Xs}{Xw} \quad \text{..... (Equation 3.2)}$$

Where

D = drought intensity

Xs = respective average yield of all genotypes under water stressed condition.

Xw = respective average yield of all genotypes under well-watered condition

Ys = individual yield under water stressed condition.

Yw = individual yield under well-watered condition.

Genotypes with average susceptibility to drought have a DSI (Drought Susceptibility Index) value of 1.0.

Values of DSI (Drought Susceptibility Index) less than 1.0 indicates less susceptibility and greater tolerance to drought.

Values of DSI (Drought Susceptibility Index) equal to 0.0 indicates maximum possible drought tolerance (no effect of drought on yield)

3.1.11. Data Analysis

Calculation of drought intensities based on the average yields between the two water regimes

The drought intensity (D) was calculated for dry matter yield, leaf moisture content, plant height; root dry matter and grain yield by using equation 3.2.

$$\text{Drought Intensity} = 1 - \frac{\text{Mean yield of all genotypes under stress condition}}{\text{Mean yield of all genotypes under watered condition}}$$

From table 4.4: Dry Matter Yield (DMY) = $1 - \frac{54.5}{60.6}$

= 0.10

Leaf Moisture Content = $1 - \frac{147.7}{71.5}$

= 0.33

Plant Height = $1 - \frac{116.7}{128.7}$

= 0.09

Root Dry Matter = $1 - \frac{5.46}{6.04}$

= 0.10

Grain Yield = $1 - \frac{704.1}{1819}$

= 0.61

Data were subjected to ANOVA (Analysis of Variance) using GenStats statistical package 11th edition. Individual means of water stressed genotypes were compared to their corresponding non stressed in a pairwise comparison analyses (t-test) and LSD was used to determine differences in treatment means at 5% probability level.

CHAPTER FOUR

RESULTS

4.1 Physical and chemical properties of soils used

The physical properties of the soil used in the plant house showed that the soil was sandy loam. The pH of the soil used at the plant house was 5.8 which suggested a slightly acidic soil condition. The soil recorded a lower value for potassium (1.42 cmol/kg) but had a moderate value for the other properties such as percentage organic matter (3.80%), percentage carbon (2.21%), total nitrogen (0.24), and phosphorus (9.73 cmol/kg). The properties of the soil used is shown in table (4.1)

Table 4.1: Physical and chemical properties of soils at the start of plant house experiment

Soil property	
Soil depth (cm)	0 – 15
Particle size (%)	
Sand	26.69
Silt	62.87
Clay	10.35
pH (1:1 soil: H_20)	5.8
Organic carbon (%)	2.21
Organic matter (%)	3.80
Total N (%)	0.24
Exchangeable cations (cmol/kg)	
Ca	3.95
Mg	2.03
K	1.42
Na	0.3
Total exchangeable bases	7.80
Exchangeable acidity (Al^+, H^+)	0.50
Effective cation exchange capacity (mol/kg)	8.29
Base saturation (%)	93.84
Available P (cmol/kg)	9.73
Available K (cmol/kg)	100.44

4.2. Results of the plant house experiment

4.2.1. Effects of moisture stress on leaf water content

With this index, highly significant differences ($p < 0.001$) existed among the inbred lines as well as the varieties under both water stressed and non stressed conditions. For the water stressed genotypes, inbred lines Tzeei 50 and Tzeei 21 recorded the highest percentages of 58 % and 55% respectively. For the non stressed genotypes, inbred line Tzeei 21 and variety Akposoe recorded the highest percentages of 88 % and 86 % respectively.

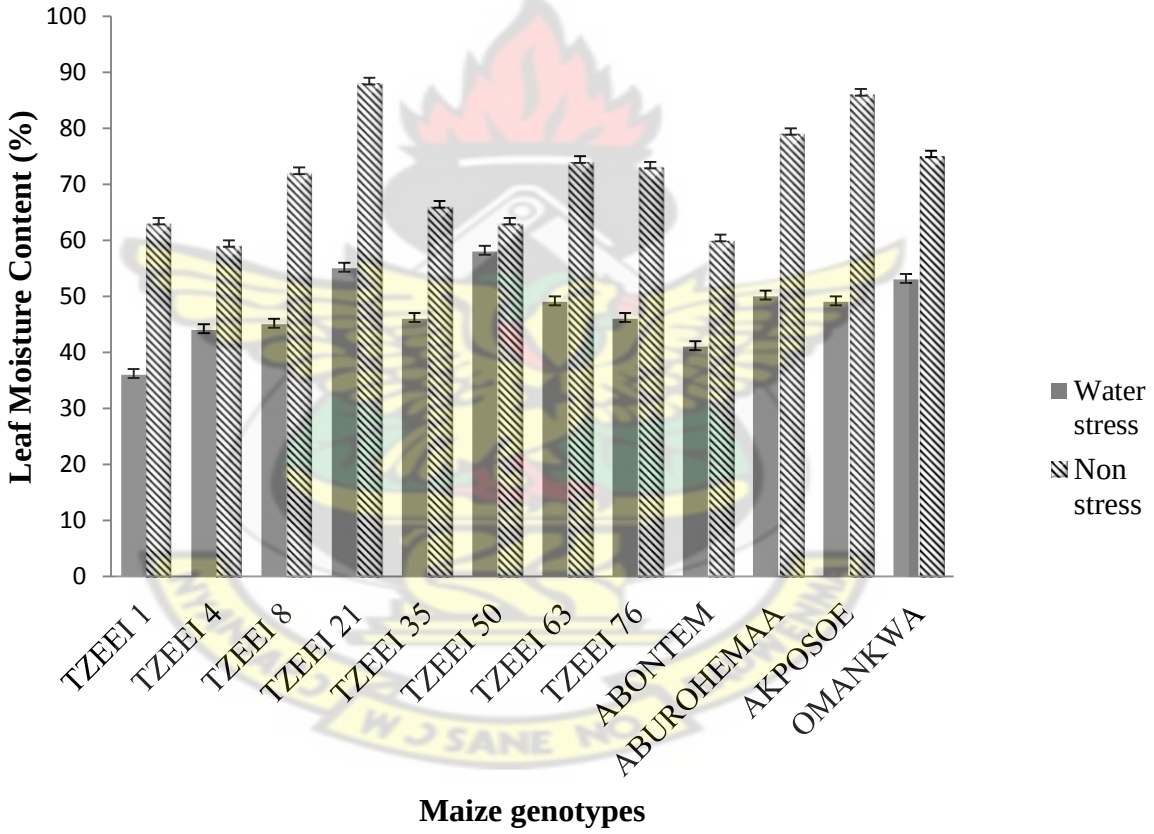

Figure 4.1: Effect of water stress on leaf water content

4.2.2. Effect of water stress on plant height

With the exception of inbred lines Tzeei 21, Tzeei 35 and the variety Aburohemaa which showed no significant differences in the two water regimes, significant differences were recorded by the other genotypes. Average height for the non stressed genotypes ranged from 96 cm to 166.5 cm and for the water stress genotypes the average height ranged from 91 cm to 157.8 cm. Tzeei 1 recorded the highest plant height (157.8 cm) for the water stress genotypes followed by Tzeei 4 (142 cm). For the non stressed genotypes Tzeei 1 again recorded the highest plant height (166.5 cm) followed by Abontem (154 cm)

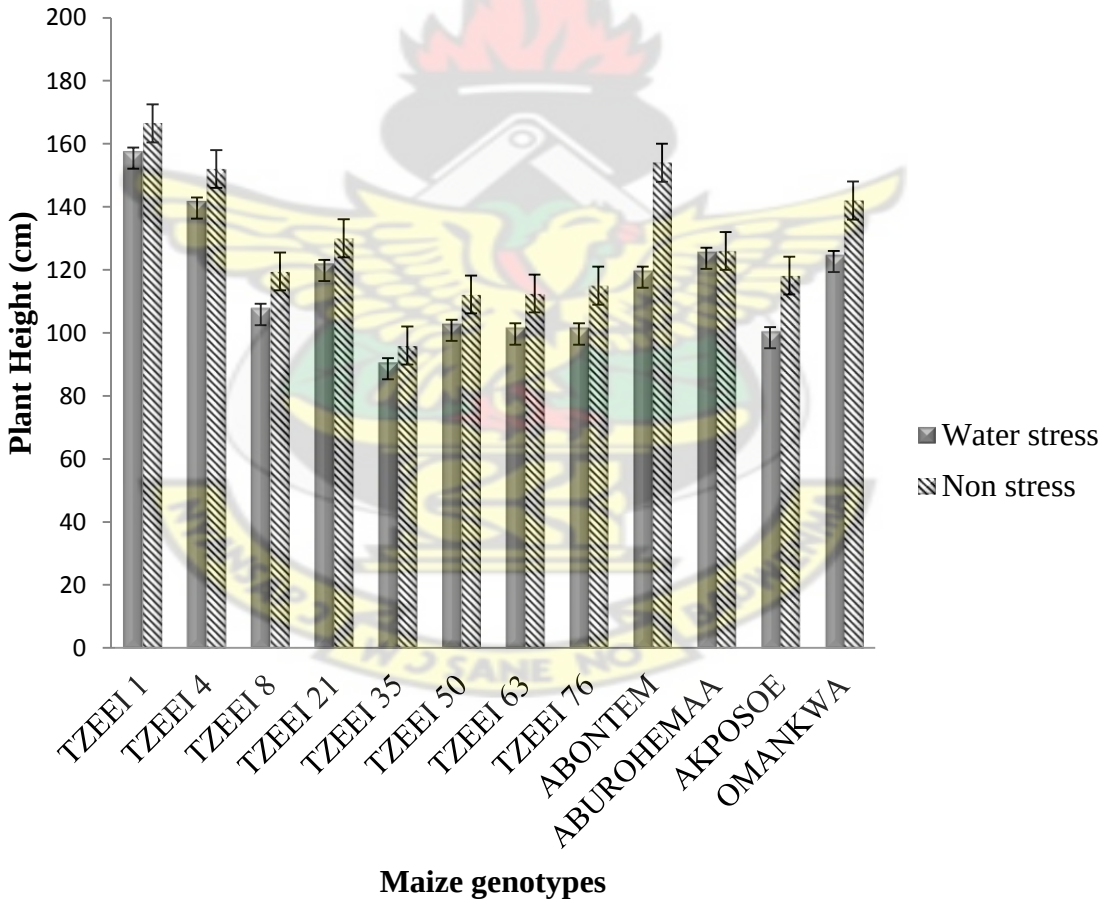

Figure 4.2: Effect of water stress on plant height.

4.2.3: Effect of water stress on root dry matter

With reference to root dry matter, it was observed that only inbred lines Tzeei 21, Tzeei 35 and Tzeei 63 showed significant differences between the two water regimes (stressed and non stressed conditions), the other genotypes failed to record any significant any significant figures in the two water regimes. This implies that apart from inbred lines Tzeei 21, Tzeei 35 and Tzeei 63, the other maize genotypes may be tolerant to water stress.

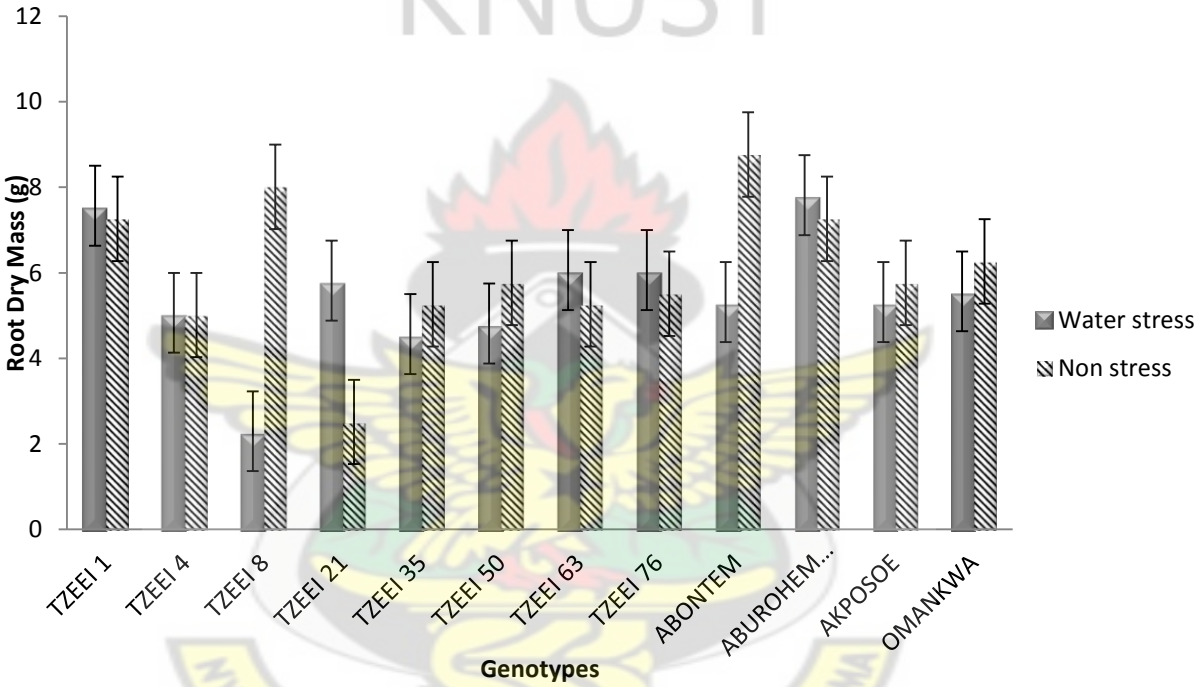

Figure 4.3: Effect of water stress on root dry matter.

4.2.4: Effect of water stress on dry matter yield

The result indicated that dry matter yield of the other genotypes apart from inbred lined Tzeei 21, Tzeei 35 and Tzeei 63 were not significantly different in the two water regimes (stressed condition and non stressed conditions). This may also implies that the nine

genotypes apart from maize genotypes Tzeei 21, Tzeei 35 and Tzeei 63 may also be tolerant to water stress

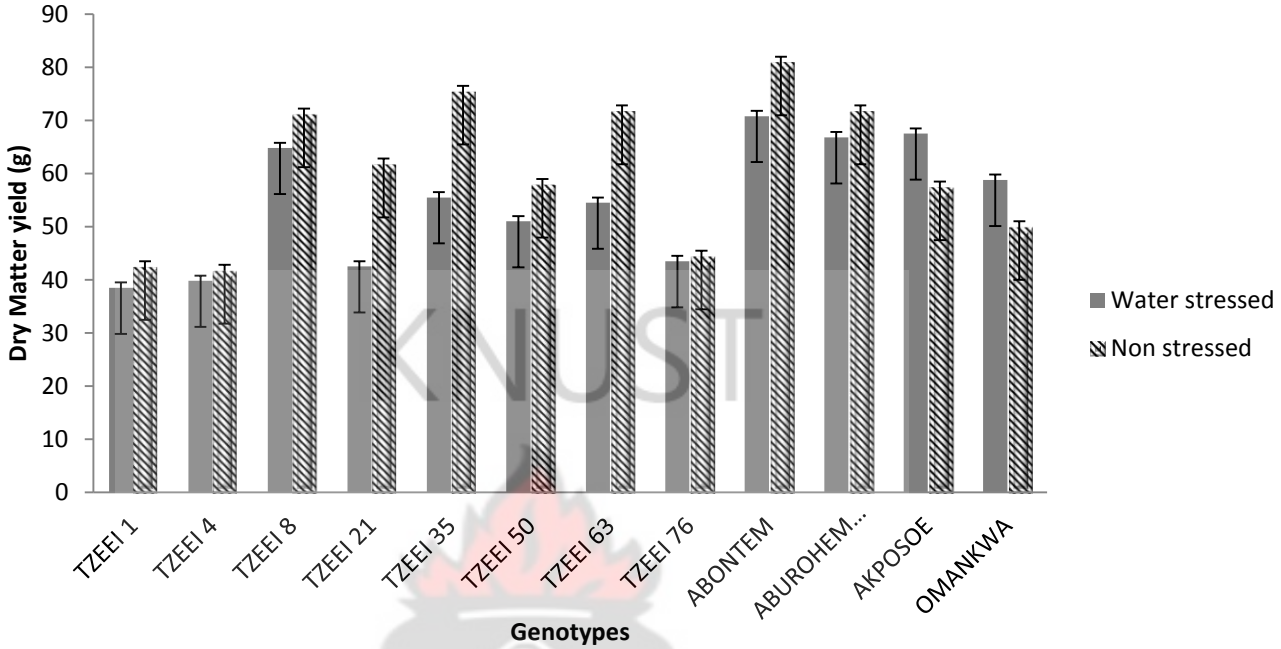

Figure 4.4: effect of water stress on dry matter yield

4.2.5 Effect of water stress on grain yield

Highly significant ($p < 0.001$) variability existed for grain yield in both water stressed and non stressed conditions. Grain yields ranged from 625 kg/ha to 865kg/ha for the water stressed genotypes and 1639 kg/ha to 1999 kg/ha for the non-stressed. Tzeei 50 recorded the highest value of 1999 kg/ha for the non-stressed genotypes and Tzeei 4 recorded the lowest value of 1639 kg/ha. For the stressed genotypes Tzeei 1 recorded the highest value (865 kg/ha) and Tzeei 4 recorded the lowest (625 kg/ha). Inbred line Tzeei 50 had the highest grain yield of 1999kg/ha which was 18 % higher than inbred line Tzeei 4 in the non stressed condition, however, in the water stressed condition, inbred line Tzeei 1 had 27.7 % higher yield than inbred line Tzeei 4. Reductions in grain yields of all the stressed genotypes were highly significant from non stressed plants at 0.05 probability level when their mean performances were compared in both conditions. The

yields of all the maize genotypes under non stressed condition far exceeded those of the maize genotypes under stressed condition.

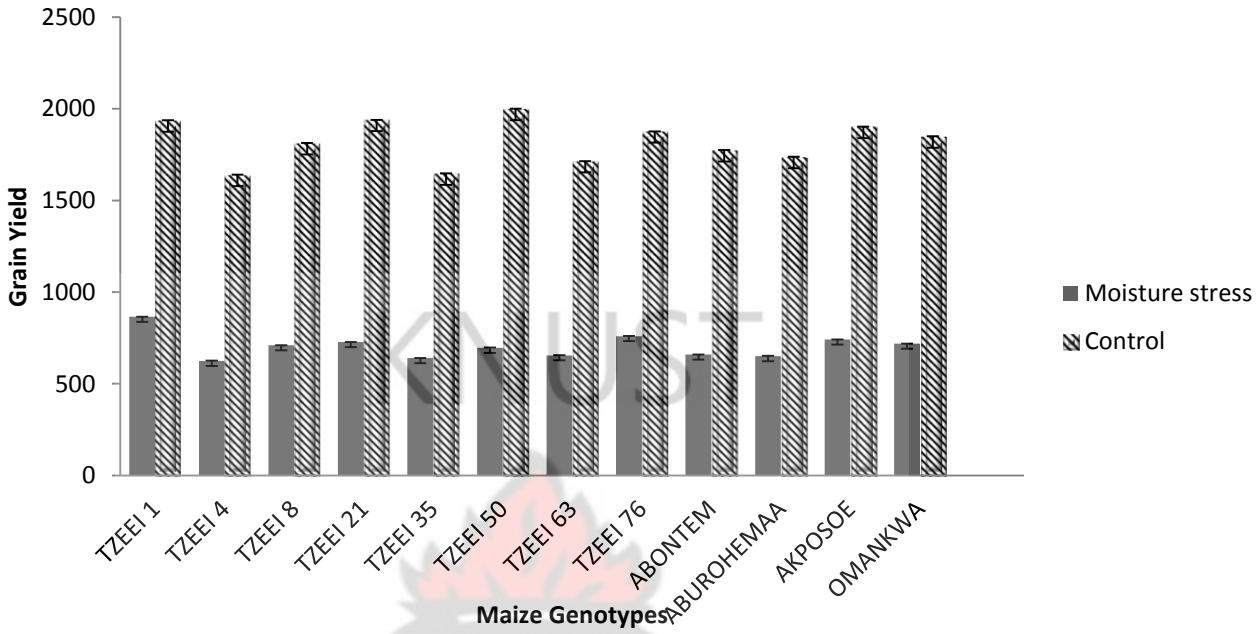

Figure 4.5: effect of water stress on grain yield.

4.3: Correlation between dry matter and grain yield, leaf moisture content and grain yield, root dry matter and grain yield, and plant height and grain yield.

Table 4.2: The relationship between dry matter yield, leaf moisture content, root dry matter, plant height and Grain yield

Parameters	Yield Correlation(r)	Coefficient Of determination/ Common variance(r^2)	probability
Dry matter yield	-0.399	0.159	16 %
Leaf moisture content	0.159	0.02	2 %
Root dry matter	0.169	0.03	3 %
Plant height	0.377	0.142	14 %

4.3.1: Relationship between grain yield and dry matter yield

Grain yield had a weak negative correlation (-0.399) with dry matter yield**.** A co-efficient of determination (r^2) of 0.159 was obtained for the genotypes under water stress. This suggests that about 16 % of the variation in grain yield increase could be attributed to a decrease in dry matter production and vice-versa.

4.3.2: Relationship between grain yield and leaf moisture content.

There was a weak positive correlation (0.159) between grain yield and leaf moisture content as recorded in table 4.2. A co-efficient of determination (r^2) of 0.02 was obtained for the genotypes under water stress. This suggests that about 2 % of the variation in grain yield increase could be attributed to increasing leaf moisture content and vice-versa.

4.3.3 Relationship between grain yield and root dry matter

There was also a weak positive correlation (0.169) between grain yield and root dry mass. A co-efficient of determination (r^2) of 0.03 was obtained for the genotypes under water stress. This suggests that about 3 % of the variation in grain yield increase could be attributed to increasing root dry mass and vice-versa.

4.3.4: Relationship between grain yield and plant height

There was again a weak positive correlation (0.37) between grain yield and plant height**.** A co-efficient of determination (r^2) of 0.142 was obtained for the genotypes under water stress. This suggests that about 14 % of the variation in grain yield increase could be attributed to increase in plant height vice-versa.

4.4: Drought intensity (D) and Drought Susceptibility Index (DSI)

Table 4.3: Drought intensities.

parameter	**DMY**	**LMC**	**PHT**	**RDM**	**GY**
Drought intensity	0.10	0.33	0.09	0.10	0.61

DMY: Dry Matter Yield, LMC: Leaf Moisture Content, PHT: Plant Height, RDM: Root Dry Matter, GY: Grain Yield.

Drought intensity based on the five parameters (dry matter yield, leaf moisture content, plant height, root dry matter and grain yield) in the water stressed and non stressed conditions evaluated in the plant house.

Table 4.4: Individual yield under water stressed condition and non-stressed conditions

Number	Genotypes	DMY (g)		DSI	LMC (%)		DSI	PHT (cm)		DSI
		WS	NS		WS	NS		WS	NS	
1	Tzeei 1	38.5	42.5	0.94	36	63	1.30	157.8	166.5	0.58
2	Tzeei 4	39.8	41.8	0.48	44	59	0.77	142	152	0.73
3	Tzeei 8	64.8	71.2	0.90	45	72	1.14	108.2	119.5	1.05
4	Tzeei 21	42.5	61.8	3.12	55	88	1.14	122.2	130	0.67
5	Tzeei 35	55.5	75.5	2.65	46	66	0.92	91	96	0.58
6	Tzeei 50	51	58	1.21	58	63	0.24	103.2	112.2	0.89
7	Tzeei 63	54.5	71.8	2.41	49	74	1.02	102	112.5	1.04
8	Tzeei 76	43.5	44.5	0.22	46	73	1.12	102	115	1.26
9	Abontem	70.8	81	1.26	41	60	0.96	120	154	2.45
10	Aburohema	66.8	71.8	0.70	50	79	1.11	126	126	0
11	Akposoe	67.5	57.5	-1.74	49	86	1.30	86	100.8	1.63
12	Omankwa	58.8	50	-1.76	53	75	0.89	75	142	5.24
GM		**54.5**	**60.6**	**0.87**	**47.7**	**71.5**	**0.99**	**116.7**	**128.7**	**1.34**
Lsd(5%)		24.9	28.9		1.49	2.24		16.50	14.35	
C.V (%)		31.8	33.1		6.13	9.20		9.80	7.80	

DMY: Dry Matter Yield, LMC: Leaf Moisture Content, PHT: Plant Height, RDM: Root Dry Matter, GY: Grain Yield. WS: Water Stress, NS: Non Stress, GM: Grand Mean, C.V (Co-efficient of Variation), DSI (Drought Susceptibility Index).

A drought index based on dry matter yield, leaf moisture content and plant height under the water stressed and non stressed conditions for the twelve maize genotypes evaluated in the plant house. Drought index ranged from -1.76 to 3.12 for dry matter yield, 0.24 to 1.30 for leaf moisture content, and from 0 to 5.24 for plant height.

Table 4.5: Individual yield under water stressed condition and non-stressed conditions

Number	Genotype	RDM (g)		DSI	GY (kg/ha)		DSI
		WS	NS		WS	NS	
1	Tzeei 1	7.50	7.25	-0.36	865	1939	0.91
2	Tzeei 4	5.00	5.00	0.00	625	1639	1.01
3	Tzeei 8	2.23	8.00	7.51	710	1812	1.00
4	Tzeei 21	5.75	2.50	-13.54	727.5	1939	1.02
5	Tzeei 35	4.50	5.25	1.49	640	1647	1.00
6	Tzeei 50	4.75	5.75	1.81	696.2	1999	1.01
7	Tzeei 63	6.00	5.25	-1.49	655	1714	1.01
8	Tzeei 76	6.00	5.50	-0.95	760	1876	0.98
9	Abontem	5.25	8.75	4.17	658.8	1774	1.03
10	Aburohema	7.75	7.25	-0.72	651.2	1737	1.02
11	Akposoe	5.25	5.75	0.91	741.2	1902	1.00
12	Omankwa	5.50	6.25	1.25	718.8	1849	1.00
G M		**5.46**	**6.04**	**0.006**	**704.1**	**1819**	**0.99**
Lsd (5%)		2.81	2.50		78.62	176.70	
C. V (%)		35.70	28.80		7.80	6.80	

DMY: Dry Matter Yield, LMC: Leaf Moisture Content, PHT: Plant Height, RDM: Root Dry Matter, GY: Grain Yield. WS: Water Stress, NS: Non Stress, GM: Grand Mean, C.V (Co-efficient of Variation), DSI (Drought Susceptibility Index).

A drought index based on dry matter yield, leaf moisture content and plant height under the water stressed and non stressed conditions for the twelve maize genotypes evaluated in the plant house. Drought index ranged from -13.54 to 7.51 for root dry matter and 0.91 to 1.03 for grain yield

Table 4.6: Drought Susceptibility Index (DSI)

Genotype	DMY	LMC	PHT	RDM	GY
Tzeei 1	**0.94**	**1.30**	**0.58**	**-0.36**	**0.91**
Tzeei 4	**0.48**	**0.77**	**0.73**	**0**	**1.01**
Tzeei 8	**0.90**	**1.14**	**1.05**	**7.51**	**1.00**
Tzeei 21	**3.12**	**1.14**	**0.67**	**-13.54**	**1.02**
Tzeei 35	**2.65**	**0.92**	**0.58**	**1.49**	**1.00**
Tzeei 50	**1.21**	**0.24**	**0.89**	**1.81**	**1.01**
Tzeei 63	**2.41**	**1.02**	**1.04**	**-1.49**	**1.01**
Tzeei 76	**0.22**	**1.12**	**1.26**	**-0.95**	**0.98**
Abontem	**1.26**	**0.96**	**2.45**	**4.17**	**1.03**
Aburohemaa	**0.70**	**1.11**	**0**	**-0.72**	**1.02**
Akposoe	**-1.74**	**1.30**	**1.63**	**0.91**	**1.00**
Omankwa	**-1.76**	**0.89**	**5.24**	**1.25**	**1.00**

DMY: Dry Matter Yield, LMC: Leaf Moisture Content, PHT: Plant Height, RDM: Root Dry Matter, GY: Grain Yield.

From the drought susceptibility index in table 4.6, the smaller the susceptibility index, the more tolerant is that genotype and such a genotype could be select for drought tolerance. For dry matter yield, Omankwa had the least susceptibility index of -1.76, for leaf moisture content inbred line Tzeei 50 had the least susceptibility index of 0.24, for plant height Aburohemaa recorded the least susceptibility index of 0, for root dry matter inbred line Tzeei 21 recorded the least susceptibility index of -13.54 and for grain yield inbred line Tzeei 1 recorded the least susceptibility index of 0.91.

Table 4.7: Correlation between dry matter yield, root dry matter, leaf moisture content, grain yield, plant height and their respective drought indices.

Parameter	Drought index Correlation (r)	Co-efficient of determination(r^2)
Dry matter yield	0.01	0.0001
Root dry mass	-0.708	0.50
Leaf moisture content	-0.629	0.40
Grain yield	0.106	0.011
Plant height	-0.212	0.05

The result in table 4.7 shows three (3) negative relationship out of five (5) between parameters and drought indices for the twelve genotypes under water-stressed condition. This implies that the drought susceptibility indices for these parameters could be a good tool for selecting drought tolerant maize genotypes.

4.5: Scoring and ranking of genotypes

TABLE 4.8: Scoring and ranking of genotypes based on drought susceptibility indices

Genotypes	DMY	LMC	PHT	RDM	GY	Rank sum.	Rank
Tzeei 1	7	11	2	5	1	26	3rd
Tzeei 4	4	2	5	6	7	24	1st
Tzeei 8	6	9	8	12	3	38	11th
Tzeei 21	12	9	4	1	10	36	10th
Tzeei 35	11	4	2	9	3	29	6th
Tzeei 50	8	1	6	10	7	32	7th
Tzeei 63	10	6	7	2	7	32	7th
Tzeei 76	3	8	9	3	2	25	2nd
Abontem	9	5	11	11	12	48	12th
Aburohemaa	5	7	1	4	10	27	4th
Akposoe	2	11	10	7	3	33	9th
Omankwa	1	3	12	8	3	27	4th

DMY: Dry Matter Yield, LMC: Leaf Moisture Content, PHT: Plant Height, RDM: Root Dry Matter, GY: Grain Yield.

Values of DSI (Drought Susceptibility Index) less than 1.0 indicates less susceptibility and greater tolerance to drought. Values of DSI (Drought Susceptibility Index) equal to 0.0 indicates maximum possible drought tolerance (no effect of drought on yield)

The twelve genotypes were ranked according to their tolerance level to water stress as recorded in Table 4.6. The scoring was done such that genotype with the least susceptibility index (greater tolerant) was scored 1. The next genotype was scored 2, and then the genotype with highest index which was scored 12. The less the susceptibility index, the greater the level of tolerance to drought and vice-versa. The following ranking was therefore obtained for the twelve genotypes in decreasing order of drought tolerance

Tzeei 4 > Tzeei 76 > Tzeei 1 > Tzeei> Aburohemaa = Omankwa > Tzeei 35 > Tzeei 50= Tzee1 63 >Akposoe > Tzeei 21> Tzeei 8 >Abontem

Plate 4.1 Maize varieties under the stressed (left) (ten days after flowering) and non-stressed (right) conditions in the plant house

CHAPTER FIVE

DISCUSSION

5.1. Physical and chemical properties of the soil.

The pH of the soil used at the plant house was 5.8 which suggested a slightly acidic soil condition. The physical properties of the soil used in the plant house showed that the soil was sandy loam. The chemical properties of the soil used in the plant house was relatively good according to the soil manual given by Landen (1991). The soil recorded a lower value for potassium (1.42 cmol/kg) but had a moderate value for the other properties such as percentage organic matter (3.80%), percentage carbon (2.21%), total nitrogen (0.24), and phosphorus (9.73 cmol/kg). The inherent capacity of the soil used in the plant house as regards maize production can be said to be higher and this might have a strong bearing on the conditions to which these soils were subjected to prior to their use for the experiment. The soil was taken from an area that had been left fallow for at least three years. The dark colour of the soil implied that there was adequate time for organic matter decomposition and hence availability of other important nutrients such as N, P and K.

5.2 Leaf moisture content

With this indicator, highly significant variations ($p > 0.001$) were observed among the genotypes in both the stressed and non-stressed condition. Higher percentages of 58 % and 55 % recorded by inbred lines Tzeei 50 and Tzeei 21 give an indication that these two genotypes were relatively able to maintain better plant water status within the water stressed period during which measurement was taken. This shows that inbred lines Tzeei 50 and Tzeei 21 might not have only tolerated the drought but also might have avoided the drought as defined by Fisher and Sanchez (1979) and also Otoole and Chang (1979)

that avoidance of drought is the ability of a plant to maintain relatively high water status despite the low moisture condition within the entire plant environment. According to González and González-Vilar (2001), the subjective value accepted for LRWC is ≥ 80%. From the findings of González and González-Vilar (2001), it can be deduced that all the other genotypes were apparently susceptible to drought when leaf relative water content was used as an indicator.

5.3. Plant height

Plant heights observed for the genotypes in the plant house were higher for the non stressed maize genotypes than the water stressed. The significant differences observed among the maize genotypes under non stressed condition as well as the stressed condition for the other genotypes apart from inbred lines Tzeei 21, Tzeei 35 and variety Aburohemaa was in accordance with the findings of Olaoye (2009) who observed that, plant height of maize hybrid increased up to 45.38 cm at 100% field capacity 24 DAS (Days After Sowing), while it decreased up to 24.69 cm with decreasing field capacity. It was also reported by Abo-El-Kheir and Mekki, (2007) that the plant height of single cross maize hybrid was affected when deficit water was applied at different growth stages.

5.4. Root dry matter

Significant variations were observed among the maize genotypes Tzeei 21, Tzeei 35 and Tzeei 63 for root dry matter under both stressed and non stressed conditions. Inbred line Tzeei 35 proved significantly higher than the rest of the maize genotypes and it was 23.4 % higher than inbred line Tzeei 21 under water stress and 18.1 % higher than Tzeei 21 under non stressed conditions. With the exception of maize genotypes Tzeei 21, Tzeei 35 and Tzeei 63, all the other genotypes showed apparent susceptibility to water stress when root dry matter was used as an indicator. The better performance of maize genotypes

Tzeei 35 and Tzeei 63 with respect to root dry matter indicates their efficiency in resource acquisition particularly, water. Maize genotypes Tzeei 35 and Tzeei 63 can be seen as having greater tendency to produce higher root dry matter under field conditions as concluded by Hurd (1974) that measurement of roots in boxes of soil in the greenhouse gives a fair approximation of root growth in the field. Therefore, root growth at the seedling stage may therefore be useful in predicting root growth under drought stress at later growth stages. Camacho and Caraballo (1994) also concluded that root dry mass was identified as the major criterion for selection of maize genotypes under drought conditions and this report again supports the higher drought tolerance level in inbred lines Tzeei 35 and Tzeei 63. Water and nutrient acquisition could therefore be greatly improved by selection of genotypes with efficient soil exploration by the root system as reported by Lynch, (1995).

5.5. Dry matter yield

Significant variations were observed among the maize genotypes Tzeei 21, Tzeei 35 and Tzeei 63 for root dry matter under both stressed and non-stressed conditions. Significant lower dry matter yield were recorded by maize genotypes Tzeei 21, Tzeei 35 and Tzeei 63. The significant lower dry matter yields recorded by theses maize genotypes under water stressed condition portends that the effect of the drought was severe to reduce leaf and stem growth as the crops intercepted less solar radiation. This observation agrees with the findings of Prabhu and Shivaji (2000) who reported that the main effect of drought in the vegetative period is to reduce leaf and stem growth, so the crop intercepts less sunlight. It also supports a report by Vianello and Sobrado (1991) that drought stress during vegetative stage provides diminution of the growth in maize crop leaves and stems. The result also confirms the findings of Lu *et al.* (1999) while identifying the specific physiological mechanisms at the whole-plant and cellular levels responsible for

drought resistance in barley. The authors reported that when subjected to -0.4 MPa root water deficit, the shoot growth in water- stressed wheat cultivars (on the basis of dry weight) decreased by 85.2 %, as compared with the control plants; while the shoot growth in the non- stressed was significantly less inhibited (74.8 %) by the same root water deficit. The results of this study suggested that the effect of drought was severe to reduce leaf area and stem growth reducing ability of the crops to intercept solar radiation. In some cultivated cereals, osmotic adjustment has been found to be one of the most effective physiological mechanisms underlying plant tolerance to water deficit (Turner and Jones, 1980; Morgan, 1984; Blum, 1988; Zhu *et al.*, 1997). Osmotic adjustment, as a process of active accumulation of compatible osmolytes in plant cells exposed to water deficit, may enable a continuation of leaf elongation, though at reduced rates (Turner, 1986).

5.6. Grain yield

Highly significant ($p < 0.001$) variability existed for grain yield in both water stressed and non stressed conditions. Inbred line Tzeei 50 had the highest grain yield which was 18 % higher than inbred line Tzeei 4 in the non stressed condition, however, in the water stressed condition, inbred line Tzeei 1 had 27.7 % higher yield than inbred line Tzeei 4. Reductions in grain yields of all the stressed genotypes were highly significant from non stressed plants when their mean performances were compared in both conditions. The significant differences among the genotypes under the two water regimes agrees with reports by Prabhu and Shivaji (2000), Grant *et al*. (1989) and Bänziger *et al*. (2000) that, around flowering (from two weeks before tasseling and two weeks after silking) maize is very sensitive to moisture stress and grain yield could be seriously reduced on a single cob.

5.7. Drought index and yield relationship.

The result indicated three (3) negative relationship out of five (5) between parameters and drought indices for the twelve genotypes under water-stressed condition. This means that the parameters show 60 % negative correlation with grain yield. This observation indicated that grain yield increased with decreased drought index and vice-versa for the twelve genotypes. The implication again is that genotypes with low drought indices may have high grain yield potentials or otherwise, in drought conditions. There were genotypic differences between the materials used for the study. Hence there is the potential for selection for improvement towards drought.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The three inbred lines, Tzeei 4, Tzeei 76 and Tzeei 1 were among the genotypes which were identified to be drought tolerant based on their lower drought susceptibility index in the plant house experiment. Similarly, among the four varieties used, Aburohemaa is recommended for maize growers in potentially drought prone areas specifically, in the Guinea savanna, Sudan savanna and Forest-savanna transition zones of Ghana.

There was weak correlation between the parameters used and their respective drought indices. This means that the association was weak and cannot be used to predict drought tolerance.

6.2. Recommendations

Tzeei 4, Tzeei 76, and Tzeei 1 and Aburohemaa were among the genotypes which were identified to be drought tolerant but were prone to lodging. Further improvement in their traits to overcome lodging is needed.

Future studies should include biochemical analysis in addition to morpho-physiological evaluation and at molecular level, in order to get a better understanding of mechanisms responsible for drought tolerance in maize genotypes.

Future studies should also include large number of genotypes to increase genetic variation to the greatest extent possible.

REFERENCES

Abo-El-Kheir, M.S.A. and B.B. Mekki, (2007). Response of maize single cross to water deficits during silking and grain filling stages. *World J. Agric. Sci*., 3: 269–272.

Adetiminrin, V. O., Vroh-Bi, I., Menkir, A., Mitchell, S. E., and Kresovich, S. (2008). Diversity analysis of elite maize inbred lines adapted to West and Central Africa using SSR markers. *Maydica* 53: 199-207

Agrama, H.S.A. and Moussa, M.E. (1996). Mapping QTLS in maize breeding for drought tolerance in maize. *Euphytica* 91, 89-97.

Ahmadizadeh, Valizadeh M, Zaefizadeh M, and Shahbazi H,(2011). Antioxidative protection and electrolyte leakage in durum wheat under drought stress condition. J. Appl. Sci. Res., 7(3): 236-246.

AL-Ghamdi, A.A., (2009). Evaluation of oxidative stress tolerance in two wheat (*Triticum aestivum*) cultivars in response to drought. International J. Agric. and Biol., 11: 7-12.

Allahmoradi, P., Ghobadi M. Taherabadi S and Taherabadi S, (2011). Physiological aspects of mungbean (*Vigna radiata* L.) in response to drought stress. International Conference on Food Engineering and Biotechnology. 9: 272-275.

ARC Grain Crops Institute. (2003). Maize production guide. Directorate Agriculture Information Service, Department of Agriculture. Pretoria- South Africa. pp. 2-4

Armstrong, W., and Drew, M. C., (2002). Root growth and metabolism under oxygen deficiency. *In "plant root:* hidden half (third edition)". Y. Waisel, A. Eshel and U. Kafkafi, Eds), pp. 729-761, Marcel Dekker, New York

Aseidu, E. A., Sallah, P. Y.K. Twumasi-Afriyie, S.,Obeng- Antwi, K., Ahenkora, K. and

Adusei Akowuah, P. (2001). Agronomic and Post – harvest characterization of three quality protein maize (QPM) hybrids development in Ghana. *Ghana Journal of Agricultural Science* 34: 57-62.

Ashley, J, (1993). Drought and crop adaptation. In: Dryland farming in Africa. Ed. Rowland JTRJ. MacMillan Education LTD. London. pp 46-67.

Ashraf, M.Y., A.R. Azmi, A.H. Khan and S.A. Ala, (1994). Effect of water stress on total phenols, Peroxidase activity and chlorophyll content in wheat. Acta Physiologiae Plantarum, 16(3): 185-191.

Atkinson C.J., Mansfield TA and Davies W.J., (1990). Does calcium in xylem sap regulate stomatal conduction. New Phytol. 116:19-27.

Babatunde, R.O., Fakayode, S.B. and Obafemi, A.A. (2008). Fadama maize production in Nigeria: case study from Kwara State. *Research Journal of Agriculture and Biological Sciences*, 4(5):340-345.

Badu-Apraku B. and Fontem A. L., (2010). The pattern of grain yield response of normal and quality protein maize cultivars in stress and non-stress environments. *Agronomy Journal*

Badu-Apraku, B., Fontem Lum, A., Fakorede, M.A.B., Menkir, A., Chabi, T., Abdulai, C., Jacob, S. and Agbaje, S. (2008). Performance of early maize cultivars derived from recurrent selection for grain yield and *Striga* resistance. *Crop Sci*. 48:99-112.

Badu-Apraku, B., Twumasi-Afriyie, S., Sallah, P.Y.K., Asiedu, E.A., Marfo, K.A., Dapaah, S. and Dzah, B.D. (1992). The development and release of an early maturing streak resistant maize variety, Dorke SR. Crops Research Institute, Kumasi, Ghana. *Monograph* pp. 21

Badu-Apraku, B., M.A.B. Fakorede, M. Ouedraogo, R.J. Carsky, and A. Menkir (Eds). Maize Revolution in West and Central Africa. *Proceedings for a Regional Maize Workshop*, IITA-Cotonou, Benin Republic, 14-18 May, 2001. WECAMAN /IITA.

Bale, J. S., Masters, G. J., Hodkinson, I. D., Awmack, C., Bezemer, T. M., Brown, V. K., Butterfield, J., Buse, A., Coulson, J. C., Farrar, J., Good, J. E. G., Harrington, R., Hartley, S., Jones, T. H., Lindroth, R. L., Press, M. C., Symrnioudis, I., Watt, A. D., and Whittaker, J. B. ,(2002). Herbivory in global climate change research: direct effects of rising temperatures on insect herbivores. *Global Change Biol.* 8, 1-16.

Bänziger, M., and Diallo, A. O. (2001). Progress in developing drought and stress tolerant maize cultivars in eastern and southern Africa. In "Seventh Eastern and Southern Africa Regional Maize Conference, 11th-15th Feb", pp. 189-194

Bänziger, M., Edmeades, G.O., Beck, D. and Bellon, M. (2000). Breeding for drought and nitrogen stress tolerance in maize. From theory to practice. CIMMYT, Mexico.

Beadle, G.W. (1939). Teosinte and the Origin of Maize. J. Hered. 30:245 – 247.

Beardsell M.F and Cohen D, (1975). Relationships between leaf water status, abscisic acid levels, and stomatal resistance in maize and sorghum. Plant Physiol. 56:207-212.

Beckingham, C. (2007). Commodity growing guides- Sweet corn. NSW Department of PrimaryIndustries, available online at http://www.dpi.nsw.gov.au/agriculture/horticulture/vegetables/commodity/sweet-cornNSW, Australia.

Birch, C. J., Robertson, M. J., Humphreys, E., Hutchins, N., (2003). Agronomy of maize in Australia- in revive and prospect. In: CJ Birch, SR Wilson, eds. *Versatile Maize- Golden Opportunities*: *5th Australian Maize Conference, City Golf Club Toowoomba, 18-20 February, 2003.* Available online at http://www.dpi.nsw.gov.au/agriculture/horticulture/vegetables/commodity/sweet-corn. NSW, Australia.

Black, C.A. (1986). (Eds.). Methods of soil analysis, Part I. Physical and mineralogical properties, including statistics of measurement and sampling. Part II. Chemical and microbiological properties. *Agronomy series, ASA, Madison.* Wis. USA.

Blackman PG and Davies Wi. (1984). Modification of the CO_2 responses of maize stomata by abscisic acid and by naturally occurring and synthetic cytokinins. *J. Exp. Bot*. 35:174-179.

Blum A, (1996). Crop responses of drought and the interpretation of adaptation. *Plant Growth Regulation*. 20:135-148.

Blum, A. (1988). Plant Breeding for Stress Environments. *CRC Press, Inc., Boca Raton*, Florida, pp. 223

Bolanos, J. and Edmeades, G.O. (1996). The importance of the anthesis - silking interval in breeding for drought tolerance in tropical maize. In: *Developing Drought and Low N-Tolerant Maize.* Edmeades, G. O., Banziger, M., Mickelson, H. R. and Peña-Valdivia, C.B. (Eds.). Proceedings of a Symposium, March 25-29, CIMMYT, EL Batan, Mexico D. F. Mexico.

Bolanos, J. and Edmeades, G.O. (1993). Eight cycles of selection drought tolerance in lowland tropical maize. I. Responses in yield, biomass and radiation utilization. *Field Crops Res*. 31:233-252

Bray R.H. and Kurtz, L.T. (1945). Determination of Total organic and Available forms of Phosphorus in Soils. Soil Sci. 95:39-45.

Breisinger, C., Diao, X., Thurlow, J. and Al. Hassan R. (2008). Agriculture for Development in Ghana. International Food Policy Research Institute and University of Ghana, Paper presented at the PEGNet Conference. Assessing Development Impact- Learning from Experience. Accra 11-12 September 2008 Page 2.

Bremner, J.M. and Mulvaney, C.S. (1982). Total Nitrogen. AsA and SSA. Madison. pp 593-624.

Bunce JA, (1999). Leaf and root control of stomatal closure during drying in soybean. *Physiologia Plantarum* 106:190-195.

Byerlee, D. and Heisey, P.W. (1997). Evolution of the African maize economy. Chapter 2. In *Africa's emerging maize revolution*, Byerlee, D., and C.K. Eicher (eds). Lynne Rienner Publishers, London, UK.

Camacho, R.G. and Caraballo, D.F. (1994). Evaluation of Morphological Characteristics in Venezuelan Maize *(Zea mays* L.) genotypes under drought Stress. Sci. Agric . (Piracicaba, Braz.). 51(3): 453-458

Cardwell, K. F., and Cotty, P. J. (2002). Distribution of Aspergillus section flavi among field soils from the four agro ecological zones of the Republic of Benin, West Africa. *Plant Disease* 86**,** 434-439.

Cardwell, K. F., Desjardins, A., Henry, S. H., Munkvold, G. and Robens. J. (2001) Mycotoxins: the cost of achieving food security and food quality. www.apsnet.org/online/feature/mycotoxin/top.html.

Carrow, R.N., Shearman, R.C. and Watson, J.R. (1990). Turfgrass. In irrigation of agricultural crops Agon. Monogr. 30, ASA, CSSA and ASSA (ed. Stewart, B.A and Nielson, D.R.), 889-919. Madison. WI. Centre for Climate Change Research, School of Environmental Sciences, University of *Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report*, Tyndall.

CDC (Centers for Disease Control and Prevention). (2004). Outbreak of aflatoxin poisoning- eastern and central provinces, Kenya, January-July, 2004. MMWR Morb Mortal Wkly Rep 53:790-792. Available: http://www.cdc.gov/mmwr/ preview/ mmwrhtml/mm5334a4.htm.

Chen-Zong-Long. (1996). Influence of drought in maize fields in South China: Strategies to overcome these constraints. *In Developing drought and low N- tolerant maize.* (Ed). G. O. Edmesades, M. Banzinger, H. R. Michelson and C. B. Pena-Valdivia). Mexico, DF (Mexico). CIMMYT, 1997.

Coe, E.H.Jr., Nueffer, M.G. and D.A. Hoisington. (1988). The genetics of maize. In G.F Sprague and J.W. Dudley, Eds. Corn and corn improvement. Agronomy Monographs No.18; pp. 81-236. American Society of Agronomy: Madison, Wisconsin.

Crous, P. W., Groenewald, J. Z., Groenewald, M., Caldwell, P. Braun, U., and Harrington, T. C. (2006). Species of *Cerceospora* associated with grey leaf spot of maize. *Stud. Mycol.* 55, 189-197.

CSIR- CRI Council for Scientific and Industrial Research-Crops Research Insitute, Ghana, (2010). Ghana releases four new DT (Drought Tolerant) maize varieties

Dahlan, M. Mejaya, M.J. and Slamet, S. (1997). Maize losses due to drought in Indonesia and sources of drought tolerance and escape. *In Developing drought - and low N-tolerant maize* (Ed). Edmeades, G.O., Banziger, M., Mickelson, H.R. and Pena-Veldivia, C.B.). Mexico, DF (Mexico). CIMMYT, 1997.

Dankyi, A.A., Anchirinah, V.M. and Apau, A.O. (1997). Maize technology adoption in Ghana. *NARP Maize Technical Report, May 1996-August 1997*. National Agricultural Research Project, Crops Research Institute, Kumasi. P. 100-103.

Davies P.J., (1995). The plant hormone concept: Concentration, sensitivity and transport. In: Plant Hormones. Physiol., Biochem. and Mol. Biol. Pp 13-38. Kluwer Academic.

Day, R.P. (1953). Experimental Confirmation of Hydrometer Theory. Soil Sci. 75: 181-186.

DARD (Directorate Agriculture and Rural Development, European Commission (EU). (2002). Structure of the world starch, Evaluation of Community Policy for Starch and Starch Products, Final report page 3.

Dowd, P. F. (1992). Insect interactions with mycotoxin- producing fungi and their hosts. *In* "insect interactions with mycotoxin- producing fungi and their host" (D. Bhatnagar, E.B. Lillehoj and D.K. Arora, Eds.) pp. 137-155, Marcel Dekker, New York.

Edmeades, G.O. and Gallaher, N. (1992). Breeding tropical corn for drought tolerance. Department of Agronomy. University of Florida, Gainesville, FL32611. Page 5-7

Enyong, L., Coulibaly, O., Adesina, A., Youri, A. and Raman, A. (1999). Dynamics of maize production, adoption of improved varieties and food security in the northern region of Cameroon. In: *Strategy for sustainable maize production in*

West and Central Africa, Badu-Apraku, B., Fakorede, M.A.B., Ouedraogo, M. and Quin, F.M. (eds). *Proceedings of a Regional Maize Workshop*. 21-25 April, 1997, WECAMAN/IITA-Cotonou, Benin Republic, pp. 365-376.

Eskandari, H. and K. Kazemi, (2010). Response of different bread wheat (*Triticum aestivum* L.) genotypes to post-anthesis water deficit. *Notulae Sci. Biol*., 2(4): 49-52.

Eyherabide, G.H., Guevara, E. and Totis-de-Zeljkovich, L. (1997). Effect of the hydrostress in maize production in Argentina. *In Developing drought- and low N-tolerant maize* (G.O. Edmeades, M. Banzinger, H. R. Mickelson and C. B. Pena-Valdivia). Mexico DF (Mexico). CIMMYT, 1997.

Fakorede, M.A.B., Badu-Apraku, B., Kamara, A.Y., Menkir, A. and Ajala, S.O. (2003). Maize revolution in West and Central Africa: an overview. In: *Maize revolution in West and Central Africa*,

FAO (Food and Agricultural Organization). (1990). Soil Map of the World- Revised Legend. 4th Draft FAO. Rome.

FAOSTAT, (2013). Food and Agriculture Organization of the United Nations, Food Statistics, Maize trends in Ghana.

FAOSTAT, (2010). Food and Agricultural Organization of the United Nations (FAO), FAO Statistical Database.

FAOSTAT. (2007). Food and Agriculture Organization of the United Nations, Food Security Statistics, 2007.

Farooq, M., A. Wahid, N. Kobayashi, D. Fujita and S.M.A. Basra, (2009). Plant drought stress: effects, mechanisms and management. Agron. Sustain. Dev., 29: 185-212.

Farnham, D. E., Benson, G. O, Pearce, R. B. (2003). Corn perspective and culture. Chapter 1. In: P J White, LA Johnson, eds. Corn, chemistry and technology,

Edition 2nd. American Association of Cerial chemicals, Inc. St Paul, Minesota, USA pp 1-33.

Firn, R.B, (1986). Growth substance sensitivity: The need for clearer ideas, precise terms and purposeful experiments. Plant Physiol. 67:267-272.

Fischer, R.A. and Sanchez, M. (1979). Drought resistance in spring wheat cultivars. Effects on plant water relation. *Aust. J. Agric. Res. 30:801-814*.

Fisher, R. A and R. Maurer. (1978). Drought resistance in spring wheat cultivars. I. Grain yield responses. *Austr. J. Agric. Res.* 29: 897-912.

Galinat, W.C. (1988). The origin of corn. In G.F Sprague and J.W. Dudley, Eds. Corn and corn improvement. Agronomy Monographs No.18; pp. 1-31. American Society of Agronomy: Madison, Wisconsin.

Garavandi, M. and D. Kahrizi, (2010). Evaluation of genetic diversity of bread wheat genotypes for phonologic and morphologic traits. The 11th Crop Science and Plant Breeding Congress Iran, pp.: 537-541.

GGDP. 1983 Maize improvement. (1983). *Annual Report. Ghana Grains Development Project*. Crops Research Institute, Kumasi, Ghana.

Gonzalez, A., I. Martín and L. Ayerbe, (2008). Yield and osmotic adjustment capacity of barley under terminal water stress conditions. J. Agron. Crop Sci., 194(2): 81-91.

González, L. and González-Vilar M. (2001). Determination of relative water content. Depto Bioloxía Vexetal e Ciencia do Solo, Universidade de Vigo, Spain.

Grant, R.F., Jackson, B.S., Kiniry, J.R. and Arkin, G.F. (1989). Water deficit timing effects on yield components in maize. *Agronomy Journal* 81:61-65.

Gunes, A., D. Pilbeam, A. Inal and S. Coban, (2008). Influence of silicon on sunflower cultivars under drought stress, I: Growth, antioxidant mechanisms and lipid peroxidation. Commun. Soil Science and Plant Nutrition, 39: 1885-1903.

Hartung ,W. and Davies W.J., (1991). Drought-induced changes in physiology and ABA. In: Abscisic acid: Physiology and biochemistry. Environmental plant biology series. Bios Scientific publishers. Eds. Davies WJ & Jones HG. Pp 63-80.

Heisey, P. W., and Edmeades, G.O. (1999). Maize Production in Drought - Stressed Environments: Technical Options and Research Resource Allocation. Part 1 of CIMMYT 1997/1998 World Facts and Trends; Maize Production in Drought - Stressed

Hitchcock, A.S. and A. Chase. (1971). Manual of the grasses of the United States Volume 2. P. 790-796. Dover Publications: N.Y.

Hoeft, R. G, Nafzieger, E.D, Johnson, R. R. and AIdrich, S. A., (2000). Modern Corn and Soybean Production. MCSP publications, Champaign, Illinois, USA.

Hoffmann-Benning, S and Kende, H., (1992). On the role of abscisic acid and gibberellin in the regulation of growth in rice. Plant Physiol. 99:1156-1161.

Horn, B. W., and Dorner, J. W. (1999). Regional differences in production of Aflatoxin B, and cyclopiazonic acid by soil isolates of *Aspergillus flavus* along a transect within the United States. *Appl. Environ. Microbiol.* 65, 1444-1449.

Hughes, M. (2006). Maize- nutrition and irrigation. The State of Queensland Department of Industries and Fisheries, available online at http://www.dpi.gld.gov .au/cps/rde/dpi/hs.xsl/26- 3720- ENA-HTML.htm.

Hurd, E. (1974). Phenotype and drought tolerance in wheat. Agriculture Meteorology, Amsterdam, v.14, p.39-55.

IITA (International Institute of Tropical Agriculture). (2009). Cereals and Legumes Systems.

IITA. (1997). "Phenomenal increase in maize production in West and Central Africa", IITA, Ibadan, Nigeria.

Ingram, J., Bueno, F.D., Namuco, O.S, Yambao, E.B, and Beyrouty, C.A, (1994). Rice root traits for drought resistance and their genetic variation. In: Rice roots: Nutrients and water use. Selected papers from the International Rice Research Conference. Ed Kirk GJD. Pp 67-78.

Intergovernmental Panel on Climate Change (IPCC). (2001a). Climate Change (2001): The Scientific Basis. Working Group 1 Contribution to the IPCC Third Assessment Report. Online at http://www.ipcc.ch, November 2001.

Intergovernmental Panel on Climate Change (IPCC). (2001b). The Regional Impacts of Climate Change: An Assessment of Vulnerability. Online at http://www.ipcc.ch, November 2001.

Intergovernmental Panel on Climate Change (IPCC). (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. Summary for policy makers, online at http://www.ipcc.cg/SPM13apr07.pdf.

Jahfari, H.A., (2004). Modeling the growth, radiation use efficiency and yield of new wheat cultivars under varying nitrogen rates. M.Sc. Thesis, Dept. Agron. Univ. Agri. Faisalabad, Pakistan.

Jaleel, C.A., R. Gopi, B. Sankar, M. Gomathinayagam and R. Panneerselvam, (2008). Differential responses in water use efficiency in two varieties of *Catharanthus roseus* under drought stress. Comp. Rend. Biol., 331: 42-47.

Jones, J. Benton. *Kjeldahl Method for Nitrogen Determination.* Athens, GA: Micro-Macro Publishing, 1991.

Kasei, C.N., Mercer-Quashie, H. and Sallah, P. Y. K. (1995). Identifying probable dry periods in maize production under a monomodal rainfall regime in Northern Ghana. pp 255-263. *In Contributing to food self-sufficiency: maize research and*

development in West and Central Africa. Proceedings of a regional maize workshop, May 29-June 2, 1995, IITA. Cotonou, Benin.

Kende, H and Zeevaart, J.A.D., (1997). The five "classical" plant hormones. The Plant Cell 9:1197-1210.

Khan, A. S., S. UL-Allah and Sadique S., (2010). Genetic variability and orrelation among seeding traits of Wheat (*Triticum aestivum)* under water stress. Inter. J. Agric. Biol., 2 : 247-250.

Krisdiana, R. and Heriyanto, D. (1992). Analysis of the hybrid and Arjuna maize production system in Kediri. *In Balai Penelitian Tanaman Pangan, Malang (Indonesia). [Report of research results of Malang Research Institute for Food Crops during 1991]. Risalah hasil penelitan Tanaman Pangan tahun 1991* (ed. A. Kasno, K. H. Hendroatmodjo, M. Dahlan, Sunardi and A. Winarto), pp. 70-78. Malang (Indonesia) BPTP. 1992.

Krishnamachari, K. A., Nagarajan, V., Ramesh, V. B., and Tilak, T. B. G. (1975). Hepatitis due to aflatoxicosis: an outbreak in western India. *Lancet* 305, 1061-1063. Landen, J.R. 1991. Booker Tropical soil Manual. Addison Wesley Longman Limited, England. pp 113-129.

Kuroda, M., T. Qzawa and Imagawa H., (1990). Changes in chloroplast peroxidase activities in relation to chlorophyll loss in barley leaf segments. Physiologia Plantarum, 80: 555-560

Landen, J.R. (1991). Booker Tropical soil Manual. Addison Wesley Longman Limited, England. pp 113-129.

Larcher, W., (1995). Physiological Plant Ecology. Springer-Verlag, Berlin

Lee, E. A., Tollenaar, M. (2007). Physiological bases of successful breeding strategies for maize grain yield. *Crop Science* 47(S3): S202-S215.

Legrève, A. and Duveiller, E. (2010). Prevailing potential disease and pest epidemics under a changing climate. *In:* "climate change and crop production" (M.P. Reynlods) ed., pp. 263 - 283, CABI press.

Lew, H., Adler, A. and Edinger, W. (1991) Moniliformin and the European corn borer (Ostrinia nubilalis). *Mycotox Res*. **7**, 71-76.

Lewis, L., Onsong, M., Njapau, H., Schurz- Rogers, H., Luber, G., Kieszak, S., Nyamongo, J., Backer, L., Dahiye, A. M., Misore, A., DeCock, K., Rubin, C., (2006). Aflatoxicosis Investigation Group. Aflatoxin contamination of commercial maize products during an outbreak of acute aflatoxicosis in Eastern and Central Kenya. *Environ. Health Perspect. 113*, 1763 - 1767.

Liu, W.J., Yuan S, Zhang N.H., Lei T., Duan H., Liang H.G., and Lin H.H (2006). Effect of water stress on photosystem 2 in two wheat cultivars. Biological Plantarum, 50(4): 597-602.

Logrono, M.L. and Lothrop, J.E. (1997). Impact of drought and low nitrogen on maize production in Asia. *In Developing drought and low N-tolerant maize* (ed. G.O. Edmeades, M. Banziger, H.R Mickelson and C. B. Pena-Veldivia). Mexico, DF (Mexico). CIMMYT, 1997.

Lu, Z., Tamar, K., Neumann, P.M., Nevo, E. (1999). Physiological characterization of drought tolerance in wild barley (*Hordeum spontaneum*) from the Judean Desert. *BGN*-29- 36.

Ludlow, M.M., Muchow, R.C., (1990). A critical evaluation of traits for improving crop yields in water limited environments. Adv. Agron. 43:107-153.

Lynch, J. (1995). Root Architecture and Plant Productivity. Department of Horticulture, Pennsylvania State University, University Park, Pennsylvania, 16802-420. Plant Physiol. 109: 7-13.

Machida, L. (1997). Estimate of yield losses in maize production due drought in Zimbabwe. *In Developing drought - and low N-tolerant maize* (ed. G. O. Edmeaades, M. Banziger, H. R. Mickelson and C. B. Pena-Valdivia). Mexico, DF (Mexico). CIMMYT, 1997.

Makbul, S., N., Saruhan-guler, Durmus N., and Guven S, (2011). Changes in anatomical and physiological parameters of soybean under drought stress. Turk. J. Bot., 35: 369-377

Mambani B and Lal R, (1983). Responses of upland rice cultivars to drought stress. III. Screening rice varieties by means of variable moisture along a toposequence. Plant and Soil 73:73 - 94.

Manyong, V.M., Kling, J.G., Makinde, K.O., Ajala, S.O.and Menkir, A. (2000). Impact of IITA-improved germplasm on maize production in West and Central Africa. *Impact Document*. IITA, Ibadan, Nigeria.

Martinez, J.P., H. Silva, J.F. Ledent and M. Pinto, (2007). Effect of drought stress on the osmotic adjustment, cell wall elasticity and cell volume of six cultivars of common beans (*Phaseolus vulgaris* L.). European J. Agron., 26: 30 - 38.

Mationn, M.A., J.H. Brown and H. Ferguon, (1989). Leaf water potential, relative water content and diffusive resistance as screening techniques for drought resistance in barley. Agron. J., 81: 100-105.

Mboya, K, Nkongolo, K.K., Kalonji-Mbuyi, A. (2011). Nutritional Analysis of Quality Protein Maize Varieties selected for Agronomic Characteristics in a Breeding Program Int. J. Plant Breed. Genet, 5: 317-327.

McCutcheon, A. (2007). Victoria, Australia, Agriculture Notes - Bioethanol in Victoria AG 1314, 1-3. State of Victoria, Department of primary Industries.

McKersie BD and Leshem Y.Y., (1994b). Water and drought stress. In: Stress and stress

coping in cultivated plants. Kiuwer Academic Publishers, Dordrecht, Netherlands. pp 148-180.

Mc Williams, Denise. (2005). Drought strategies for corn and grain Sorghum. Extension agronomist, Department of Extension Plant Sciences, New Mexico State University, Las Cruces, New Mexico

Mercer-Quarshie, H., Amankwatia, Y.O., Twumasi-Afriyie, S. and Marfo, K.O. (1993). Crops Research Institute Medium Term Plan 1993-1997. Crops Research Institute, Kumasi.

Miller, J.D. (1994). Epidemiology of Fusarim, *Fusarium graminierum* disease of wheat and corn. *In* "Mycotoxins in grain: compounds other than Aflatoxin" (J.D. Miller and H.L. Trenholm HL, Eds.), pp. 19 - 36, Eagan Press.

Miller, J. D. (2001). Factors that affect the occurrence of fumonisin. *Environ. Health Perspect.* 109, 321--324

Miller, J. D. (2008). Mycotoxins in small grains and maize. *Food Additives Contam.* 25, 219-230.

Mirbahar, A.A., G.S. Markhand, A.R. Mahar, S.A. Abro and N.A. Kanhar, (2009). Effect of water stress on yield and yield components of wheat (*Triticum aestivum* L.) varieties. Pak. J. Bot., 41(3): 1303-1310.

Moaveni, P., (2011). Effect of water deficit stress on some physiological traits of wheat (*Triticum aestivum*). Agric. Sci. Res. J., 1(1): 64-68.

Mollasadeghi, V., A.A. Imani, R. Shahryari and M. Khayatnezhad, (2011). Classifying bread wheat genotypes by multivariable statistical analysis to achieve high yield under anthesis drought. Middle-East J. Sci. Res., 7(2): 217-220.

Morgan J.M. (1984). Osmoregulation and water stress in higher plants. *Ann. Rev. Plant Physiol*.35: 299-319.

Morris, R. (2008). Flood irrigated maize in the South West of Western Australia. Daily Note 20, Government of Western Australia Department of Agriculture, available online at http://www.agric.wa.gov.au/content/FCP/CER/DN20.PDF

Morris, M.L. (2002). Impacts of International Maize Breeding Research in Developing Countries, 1966-98. Mexico, D.F.: CIMMYT.

Morris, M.L., Tripp, R. and Dankyi, A.A. (1999). Adoption and impacts of improved maize production technology: A case study of the Ghana Grains Development Project. Economics Program Paper 99-101. Mexico, D.F.: CIMMYT.

Muller, M., I. Hernandez, L. Alegre and S. Munne-Bosch, (2006). Enhanced a-tocopherol quinine levels and xanthophyll cycle de-epoxidation in rosemary plants exposed to water deficit during a Mediterranean winter. J. Plant Physiol., 163: 601-606.

Munkvold, G.P., and Hellmich, R.L. (2000). Genetically modified insect resistant maize: implications for management of ear and stalk diseases. APS*net* Features. Online. Doi: 10.1094/PHP-2000-0912-01-RV.

NARP. (1993). National Agricultural Research Project, pp 1-18. In: Annual Report on cereals by the commodity committee, Accra, Ghana.

Ngindu, A., Johnson, B.K., Kenya, P.R., Ngira, J.A., Ocheng, D.M., Nandwa, H., Omondi, T.N., Jansen, A.J., Ngare, W., Kaviti, J.N., Gatei, D., and Siongok, T.A (1982). Outbreak of acute hepatitis caused by aflatoxin poisoning in Kenya. *Lancet* 8285, 1346-134

Nguyen HT, Babu RC and Blum A, (1997). Breeding for drought resistance in rice: Physiology and molecular genetic considerations. Crop Sci. 37:1426-1434.

Norman, M.J.T., Pearson, C.J. and Searle, P.G.E. (1995). *The ecology of Tropical food crops*, 2nd ed. Cambridge University Press, New York. NY.USA. pp 127-140.98

O'Gara, F. (2007). Irrigated Maize Production in the Top End of the Northern Territory: Production Guidelines and Research Results. Northern Territory Government, Department of Primary Industry, Fisheries and Mines.

Obeng-Antwi, K., Sallah, P.Y.K., and Frimpong-Manso, P.P. (1999). Performance of some maize genotypes in drought stress and non-stress environments. Ghana J. Agric. Sci.35:49-57

Obeng, H.B., (1971). (2) The Major Soils of Ghana and Their Potentialities for Agricultural Development. J. of the AAASA 1(No1): L 19-27, Addis Ababa Ethiopia.

OGTR. (2008). The Biology of *Zea mays* L ssp *mays* (maize or corn). Australian Government of the Gene Technology Regulator. Version 1: September 2008.

Ohemeng-Dapaah, S. (1994). Analysis of daily rainfall data and its application to maize production in the transitional zone of Ghana. pp 173-179. In *Progress in food grain research and production in semi-arid Africa* (Eds). Proceedings, SAFGRAD Inter-works Conference, Niamey, Niger, 7-14 March, 1991.

Olaoye, G.L., (2009). Screening for moisture deficit tolerance in four maize (*Zea mays* L.) populations derived from drought tolerant inbred x adapted cultivar crosses. *Tropic. Subtropi. Agroecol.*, 10: 237–251

Onyango, R.M.A. and Ngeny, J.M.A. (1997). Verification of recommended maize production package on farmers' field in Tran-Nzoia District. *In maize productivity gains through research and technology dissemination* (ed J.K.

Ransom, A.F.E. Palmer, B.T. Zambezi, Z.O. Mduruma, S.R. Waddington, K.V. Pixley and D.C. Jewell). Addis Ababa (Ethiopia). CIMMYT, 1997.

Otoole, J.C. and Chang, T.T. (1979). Drought resistance in cereals: Rice. a case study. Pp. 373-405 in Mussell H. and Staples R.C, eds. Stress physiology in crop plants. Wiley inter science. New York.

Page, A.L., R.H. Miller and D.R. Keeney (Eds.). (1982). Methods of soil analysis. Part 2.Chemical and microbiological properties. 2nd Edition. Agronomy series 9, ASA, SSSA, Madison, Wis. USA.

Pardey, P.G. and Beintema, N.M. (2001). Slow magic: agricultural Research and Development, a century after Mendel. Food Policy Report, International Food Policy Research Institute, Washington, DC.

Petzoldt, C., and Seaman, A. (2005). Climate change effects on insects and pathogens. Climate Change and agriculture: promoting practical and profitable responses.http://www.climateandfarming.org/pdfs/FactSheets/III.2Insects.Pathogens.pdf

Ponnamperuma, F.N. (1984). Effects of flooding on soils. *In* : Flooding and plant growth" (T.T Kozlowski. Ed.,), pp. 9-45, Academic Press, London.

Porter, J. H., Parry, M. L. and Carter, T. R. (1991). The potential effects of climatic change on agricultural insect pests. *Agricult. Forest Meteor.* 57**,** 221 - 240.

Pignocchi, C. and C.H. Foyer, (2003). Apoplastic ascorbate metabolism and its role in the regulation of cell signaling. Curr. Opin. Plant Biol., 6: 379-389.

Plaut, Z., B.J. Butow, C.S. Blumenthal and C.W. Wrigley, (2004). Transport of dry matter into developing wheat kernels. Field Crops Res., 96: 185-198.

PPMED. (1992). Agriculture in Ghana: Facts and figures. Policy Planning, Monitoring and Evaluation Department, Ministry of Food and Agriculture, Accra. pp 74-75.99

Prabhu, L. P. and Shivaji, P. (2000). Meeting world maize needs: Technological opportunities and priorities for the public sector. CIMMYT World Maize Facts and Trends.

Purgeslove, J.W. (1972). *Tropical Crops: Monocotyledons*. Longman Scientific and Technical New York.

Qiao, C.G., Wang, J.Y., Gua, H.A., Cheng, X.J., Lui, J.Y. and Li, S.Q. (1996). A review in the advances in maize production in Julin Province during 1974 -1993. Fd Crop. Res. 47 (1), 65-75.

Quarrie SA, Stojanovic J and Pekic S, (1999). Improving Drought Resistance in Small-grained Cereals: A Case Study, Progress and Prospects. Plant Growth Regulation 29:1-21.

Rafique, M., (2004). Effect of different levels of irrigation on growth, water use efficiency and yield of different wheat cultivars. Ph.D. Thesis Department of Agronomy, University of Agriculture Faisalabad, Pakistan.

Reddy, T.Y., V.R. Reddy and V. Anbumozhi, (2003). Physiological responses of groundnut (*Arachis hypogea* L.) to drought stress and its amelioration: a critical review. Plant Growth Regulation, 41: 75-88.

Reid, L. M., Nicol, R. W., Ouellet, T., Savard, M., Miller, J. D., Young, J. C., Stewart, D. W., and Schaafsma, A. W. (1999). Interaction of *Fusarium graminearum* and *F. moniliforme* in maize ears: Disease progress, fungal biomass, and mycotoxin accumulation. Phytopathol. 89, 1028-1037.

Reid MS, (1995). Ethylene on plant growth, development and senescence. In: Plant Hormones. Physiology, Biochemistry and Molecular Biology, second edition, pp 486-508. Davies PJ (Ed)

Ribaut, J.M., Hoinsington, D.A., Deustch, J.A., Jiang, C. and Gonzalez-de-Leon, D. (1996). Identification of quantitative trait loci under drought conditions in tropical maize. I. Flowering parameters and anthesis silking interval. *Theoret. Appl.Gen. 92 (7), 905-914*.

Rock CD, (2000). Pathways to abscisic acid-regulated gene expression. New Phytol.148:357-396.

Sallah, P.Y.K., Twumasi-Afriyie, S., Asiedu, E.A., Obeng-Antwi, K., Boa-Amponsem, K., Ahenkora, K., Agyemang, A. and Lampoh, E.K. (1997). Development and release of Dodzi, an extra-early maturing maize variety in Ghana. Crops Research Institute, Kumasi, Ghana. Mimeograph. pp. 28

SARI. 1995. Report of the (1995) workshop and planning session for the Upper West Region. Savanna Agriculture Research Institute.

Schurr U, Gollan T and Schulze E-D, (1992). Stomatal response to drying soil in relation to changes in the xylem sap composition of *Heliantus annuus* L. II. Stomatal sensitivity to abscisic acid imported from xylem sap. Plant, Cell Environ. 15:561-5 67

Seghatoleslami, M. J., M. Kafi and E. Majid, (2008). Effects of drought stress at different growth stage on yield and water use efficiency of five proso millet (*panicum milliaceum* L.) genotypes. Pakistan J. Bot, 40: 1427-1432.

Shamsi, K., (2010). The effects of drought stress on yield, relative water content, proline, soluble carbohydrates and chlorophyll of bread wheat cultivars. J. Animal and

Plant Sci., 8(3): 1051-1060.

Shao, H.B., Z.S. Liang and M.A. Shao, (2005). Changes of some anti-oxidative enzymes under soil water deficits among 10 wheat genotypes at maturation stage. Colloids Surf. B: Biointerfaces, 45: 7-13.

Shearer, J. F., Sweets, L. E., Baker, N. K., and Tiffany, L.H. (1992). A study of *Aspergillus flavus, Aspergillus parasiticus* in Iowa crop fields – 1988- 1990. *Plant Disease* 76, 19-22.

Siddique, M.R.B., A. Hamid and M.S. Islam, (2000). Drought stress effects on water relations of wheat. Bot. Bull. Acad. Sin., 41: 35-39.

Srinivasan, G., Zaidi, P. H., Singh, N.N., Sanchez, C. (2004). Increasing productivity through genetic improvement for tolerance to drought and excess-moisture stress in Maize (*Zea mays* L.). Seng, V., Crasweii, E., Fukai, S., and Fischer, K. Eds, Australian Centre for International Agricultural Research Canberra. Pp. 227-239

Smith, J., Weber, G., Manyong, V.M. and Fakorede, M.A.B. (1997). Fostering sustainable increases in maize productivity in Nigeria. Chapter 8. In *Africa's emerging maize revolution*, Byerlee, D., and C.K. Eicher (eds). Lynne Rienner Publishers, London, UK.

Terzi, R. and A. Kadioglu, (2006). Drought stress tolerance and the antioxidant enzyme system in *ctenanthe setosa*. Acta Biologica Cracoviensia Series Botanica, 48(2): 89-96.

Thomas, J., A. Jeffrey, C. Atsuko and M.K. David, (2005). Reguling the proton budget of higher plant photosynthesis. Proc. Natl. Acade. Sci. USA., 102(27): 9709-9713.

Thorson, P. R. and Martinson, C. A. (1993) Development and survival of *Cercospora zeae maydis* germlings in different relative humidity environments. *Phytopathol.* 83, 153---157.

Torres, O. A., Palencia, E., Lopez de Pratdesaba, L., Grajeda, R., Fuentes, M., Speer, M. C., Merrill Jr, A. H., O'nnell, K., Bacon, C. W., Glenn, A. E., and Riley, R. T. (2007). Estimated fumonisin exposure in Guatemala is greatest in consumers of lowland maize. *J. Nutr.* 137, 2723-2729.

Turner N.C. (1986). Crop water deficits: a decade of progress. *Adv. Agron*. 39, 1-51.

Turner N.C and Jones M.M. (1980). Turgor maintenance by osmotic adjustment: A review and evaluation. In: Turner N.C. & P.J. Kramer. eds. Adaptation of Plants to Water and High Temperature Stress. *John Wiley & Sons*, New York, USA. pp. 87-103.

Turner NC. (1997). Further progress in crop water relations. *Adv. in Agron.* 58:293-338.

Upadhyaya, H., M.H. Khan and S.K. Panda, (2007). Hydrogen peroxide induces oxidative stress in detached leaves of *Oryza Sativa* L. Gen. Appl. Plant Physiol., 33(1-2): 83-95.

USDA. United States Department of Agriculture. (1998). Year Book of Agriculture, Washington.

USDA. (2012). Earthly Institute from U. S Department of Agriculture Production, supply and Distribution.

Vianello, I. and Sobrado, M. (1991). Respuestas contrastantes del maíz tropical ante la sequía en el período vegetativo o reproductivo. Turrialba, San Jose, v. 41, pp.403-411.

Wajid, A., A. Hussain, M. Maqsood, A. Ahmad and M. Awais, (2002). Influence of sowing date and irrigation levels on growth and grain yield of wheat. Pak. J. Agri. Sci., 39(1): 22-24.

Walklley, A. and Black, J.A. (1934). An Examination of the Degtijaveff Method for Determining Soil Organic Matter and proposed Modification of the Acid Titration Method. Soil Sci. 37: 27 – 38.

Williams, J. H., Phillips, T. D., Jolly, P. E., Stiles, J. K, Jolly, C. M. and Aggarwal, D. (2004). Human aflatoxicosis in developing countries: a review of toxicology, exposure, potential health consequences, and interventions .*Am. J. Clin. Nutr*. 80, 1106 - 1122

White P. J. (1994). Properties of corn starch, chapter 2. In: AR Hallauer, ed. Specialty corns. CRC Press Inc. Boca Raton, USA. Pp 29-54.

White R.G, Kirkegaard J.A. (2010). The distribution and abundance of wheat roots in a dense, structured subsoil - implications for water uptake. *Plant Cell and Environment* 33, 133-148.

Xu, P.L., Y.K. Guo, J.G. Bai, L. Shang and X.J. Wang, (2008). Effects of long-term chilling on ultrastructure and antioxidant activity in leaves of two cucumber cultivars under low light. Physiologia Plantarum, 132: 467-478.

Yambao EB, Ingram KT and Real J.G. (1992). Root xylem influence on the water relations and drought resistance of rice. J. Exp. Bot. 43(252):925-932.

Yoshida S, (1981). Fundamentals of rice crop Science. The International Rice ResearchInstitute. Manilla, Phillipines.

Yordanov, I., V. Velikova and T. Tsonev, (2003). Plant responses to drought and stress tolerance, Bulg. J. Plant Physiol., Special Issue, 187-206.

Zaidi, P. H., and Singh N. N. (2010). Effect of waterlogging on growth, biochemical compositions and reproduction in maize. *J. Plant Biol.* 28, 61 - 69.

Zhu, J.K., Hasegawa P.M., Bressan R.A. (1997). Molecular aspects of osmotic stress in plants, Critical Rev. in *Plant Sci.* 16, 253-277.

APPENDICES

Appendix 1: ANOVA for dry matter yield. (non -stressed)

Variate: dry_matter_non_stress

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications stratum	3	1353.7	451.2	1.12	
replications.*Units* stratum					
Treatments	11	8289.7	753.6	1.87	0.081
Residual	33	13284.0	402.5		
Total	47	22927.5			

Appendix 2: ANOVA for dry matter yield. (Stressed)

Variate: dry_matter_stressed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications stratum	3	212.6	70.9	0.24	
replications.*Units* stratum					
Treatments	11	5832.2	530.2	1.77	0.101
Residual	33	9901.2	300.0		
Total	47	15946.0			

Appendix 3: ANOVA leaf moisture content. (non -stressed)

Variate: leaf_moisture_content_non_stress

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications stratum	3	0.3066	0.1022	0.72	
replications.*Units* stratum					
Treatments	11	226.1478	20.5589	143.97	<.001
Residual	33	4.7123	0.1428		
Total	47	231.1667			

Appendix 4: ANOVA for leaf moisture content. (Stressed)

Variate: leaf_moisture_content_stressed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications stratum	3	29.714	9.905	6.77	
replications.*Units* stratum					
Treatments	11	91.591	8.326	5.69	<.001
Residual	33	48.305	1.464		
Total	47	169.610			

Appendix 4: ANOVA for plant height (non- stressed)

Variate: plant_height_non_stressed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications stratum	3	750.17	250.06	2.51	
replications.*Units* stratum					
Treatments	11	19126.17	1738.74	17.47	<.001
Residual	33	3284.33	99.53		
Total	47	23160.67			

Appendix 5: ANOVA for plant height (stressed)

Variate: plant_height_stressed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications stratum	3	1257.7	419.2	3.19	
replications.*Units* stratum					
Treatments	11	16486.6	1498.8	11.40	<.001
Residual	33	4340.0	131.5		
Total	47	22084.3			

Appendix 6: ANOVA for root dry matter. (non -stressed)

Variate: root_dry_mass_non_stressed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications stratum	3	8.417	2.806	0.93	
replications.*Units* stratum					
Treatments	11	117.917	10.720	3.55	0.002
Residual	33	99.583	3.018		
Total	47	225.917			

Appendix 7: ANOVA for root dry matter (stressed)

Variate: root_dry_mass_stress

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications stratum	3	13.786	4.595	1.21	
replications.*Units* stratum					
Treatments	11	88.806	8.073	2.12	0.048
Residual	32	121.747	3.805		
Total	46	211.702			

Appendix 8: ANOVA for grain yield (non- stressed)

Variate: yield non stressed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
replications stratum	3	22969.	7656.	0.51	
replications.*Units* stratum					
treatments	11	612994.	55727.	3.69	0.002
Residual	33	498019.	15091.		
Total	47	1133981.			

Appendix 9: ANOVA for grain yield (stressed)

Variate: grain yield-stressed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
replications stratum	3	4956.	1652.	0.55	
replications.*Units* stratum					
treatments	11	195514.	17774.	5.95	<.001
Residual	33	98563.	2987.		
Total	47	299033.			