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EFFECTS OF DROUGHT STRESS ON MAIZE GENOTYPES (Zea mays L.) USING SOME PLANT PARAMETERS.

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A greenhouse experiment was conducted in November 2011 to January 2012 at the mechanization department of Kwame Nkrumah University of Science and Technology (KNUST) to determine the effects of drought stress on maize genotypes using some plant parameters. The soil used was sandy loam classified as *Ferric Acrisols*. Eight inbred lines and four varieties with different genetic backgrounds were used in a Completely Randomized Design (CRD) with four replications. Two sets of the genotypes were established (water stress and non-stress conditions), of which one set received water up to the end of the experiment but with the other set water was withdrawn at six weeks after planting and resumed at ten days interval. Data were collected on plant height; leaf moisture content, dry matter yield, and root dry mass. Individual means of water-stressed genotypes were compared to their corresponding nonstress genotypes in a pairwise comparison analyses (t-test) and LSD was used to determine differences in treatment means at 5% probability level. Inbred line Tzeei 50 (Tropical Zea extra early inbred 50) showed no significant difference between the two water regimes in all the four indicators used, followed by the variety Aburohemaa which recorded three out of the four indicators used. The factors used for the ranking procedure proved to be effective indicators for the selection of drought-tolerant maize.

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 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). Many 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 bowls of cereal 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 stock as green chop, dry forage, silage or grain. The various fraction of milling processes can also be used as animal feed. Maize can be processed for a range of uses both as an ingredient in food or drink, example corn syrup in soft drinks or maize meal, or for industrial purposes. 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). Cornstarch 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; Sallah et al., 1997). These varieties are widely adopted by maize growers throughout the country (Dankyi et al., 1997; Morris et al., 1999).

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 resulting in drought stress in the production zones which eventually results in significant yield losses (Ohemeng-Dapaah, 1994; Kasei et al., 1995).

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). Drought-tolerant varieties will provide a highly cost-effective means of stabilizing yields and farmers' income. There is limited information on the performance of maize varieties under drought stress in Ghana. Researchers have reported about genotypic variabilities for drought and gains that can be obtained when these genotypes are selected. (Edmeades et al., 1992; Bolanos and Edmeades, 1993). Due to long-term trends in global climate change and the expansion of maize production in drought-prone regions, the development of drought-tolerant maize varieties is of high importance, particularly for maize producers in developing nations where plant breeding improvements are more easily adopted than high-input agronomic practices.

The objective of this study was to evaluate the effects of drought stress on maize genotypes using some plant parameters.

Materials and Methods

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 topsoil used was sandy loam with a pH of 5.8 and was taken from the Horticulture Department of Kwame Nkrumah University of Science and Technology (KNUST). 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.

Experimental materials and sources

Plastic pots, each measuring 12315 cm3 (Length × Breadth × Height), were filled with 12 kg each of topsoil. 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 Tzeei1, Tzeei 4, Tzeei 8, Tzeei 21, Tzeei 35, Tzeei 50, Tzeei 63 and Tzeei 76, and the varieties were Abontem, Aburohemaa, Akposoe, and Omankwa.

Fertilizer application

Seven grams per pot of compound fertilizer (NPK -15-15-15) and five grams sulfate of ammonia were used as fertilizer source at the second and fifth week after planting.

Experimental design and treatments

Completely Randomized Design (CRD) with twelve treatments (12 genotypes) and four replications. The treatments were divided into two sets (water stress and non-stress maize genotypes). Water was withdrawn at six weeks after planting and resumed at ten days interval for the water stress maize genotypes and the non-stress maize genotypes received water throughout the experiment. A volume of 2400 cm3 of water was applied initially to the soil in each pot and their individual weights were recorded. Before irrigation, each pot was weighed and the weight differences (kg) were converted to volume (cm3). 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.

Data collection

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:

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

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 metal measuring tape. The average height of the four plants of each genotype was then determined.

Dry matter yield per plant

At harvest, the biomass of one plant of each genotype in a replication excluding the roots were 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.

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.

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 not stressed in a pairwise comparison analyses (t-test) and LSD was used to determine differences in treatment means at 5% probability level.

Results

Leaf relative water content (LRWC)

With this index, highly significant differences ($p < 0.001$) existed among the inbred lines as well as the varieties of both water stressed and nonstress conditions. For the water-stressed genotypes, inbred lines Tzeei 50 and Tzeei 21 recorded the highest percentages of 58 % and 55% respectively. (Table 1)

Table 1. Leaf relative water content (LRWC) for the genotypes used for the study

Genotypes	LRWC (%)
Tzeei 1	36
Tzeei 4	44
Tzeei 8	45
Tzeei 21	55
Tzeei 35	46
Tzeei 50	58
Tzeei 63	49
Tzeei 76	46
Abontem	41
Aburohemaa	50
Akposoe	49
Omankwa	53
GM	**47.7**
Lsd	**1.49**
CV	**6.13**

GM = Grand Mean, Lsd = Least significant difference, C.V = Coefficient of Variation

Pairwise comparison of means for 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 using the pairwise comparison of means, plant height at harvest for these three water-stressed inbred lines and their control did not show any significant difference at 0.05 probability level (Figure 1).

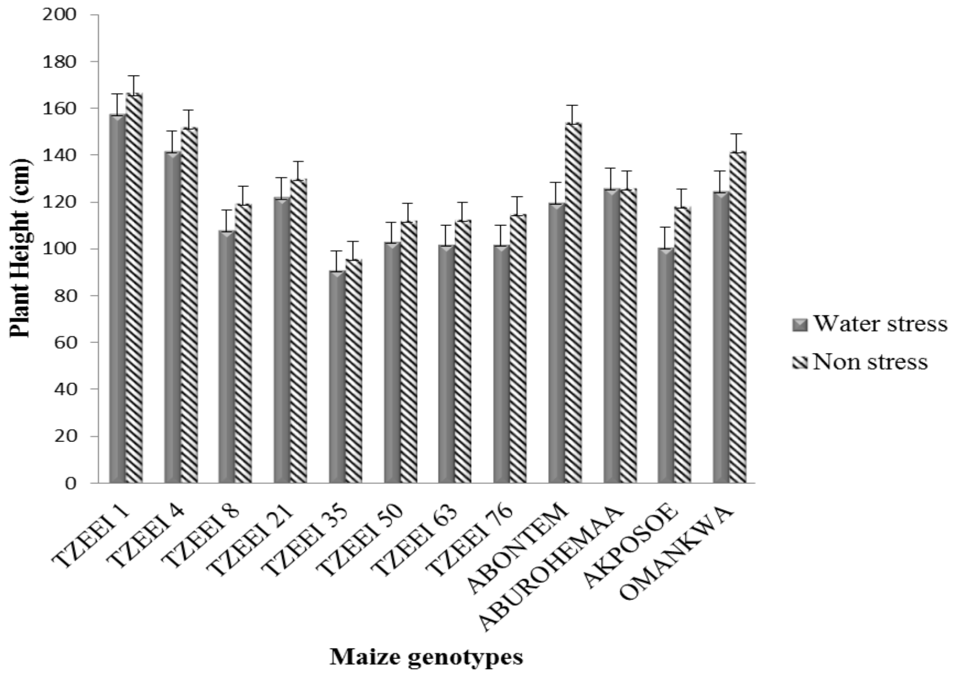

Figure 1. Plant height for the genotypes at 34 days of water stress.

Pairwise comparison of means for root dry matter yield

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 (water stress and nonstress 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.

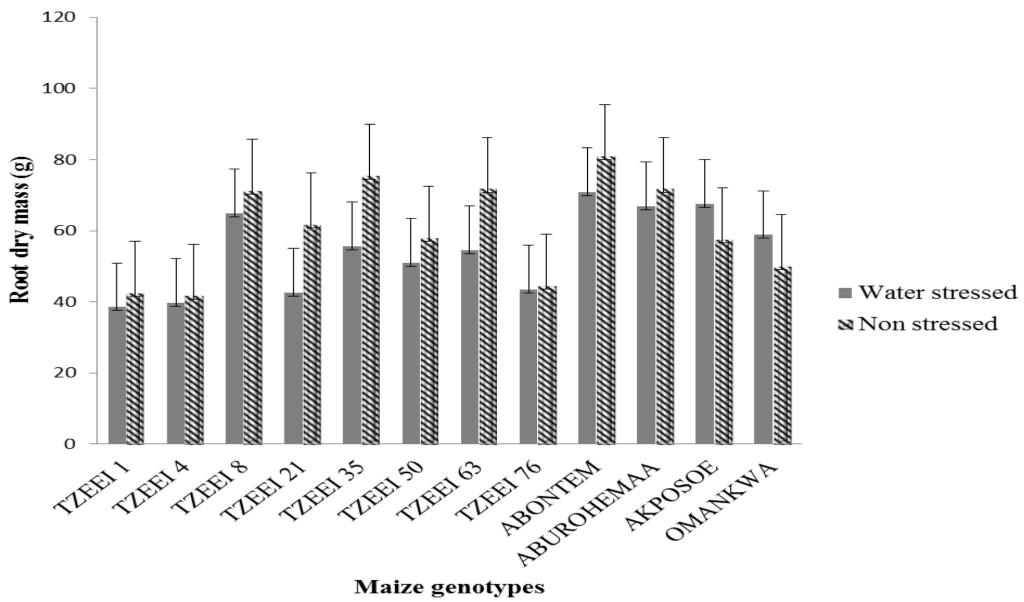

Figure 2. Root dry matter for the genotypes at 36 days of water stress.

Pairwise comparison of means for 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 (stress condition and stress conditions). This may also imply that the nine genotypes apart from maize genotypes Tzeei 21, Tzeei 35 and Tzeei 63 may also be tolerant to water stress.

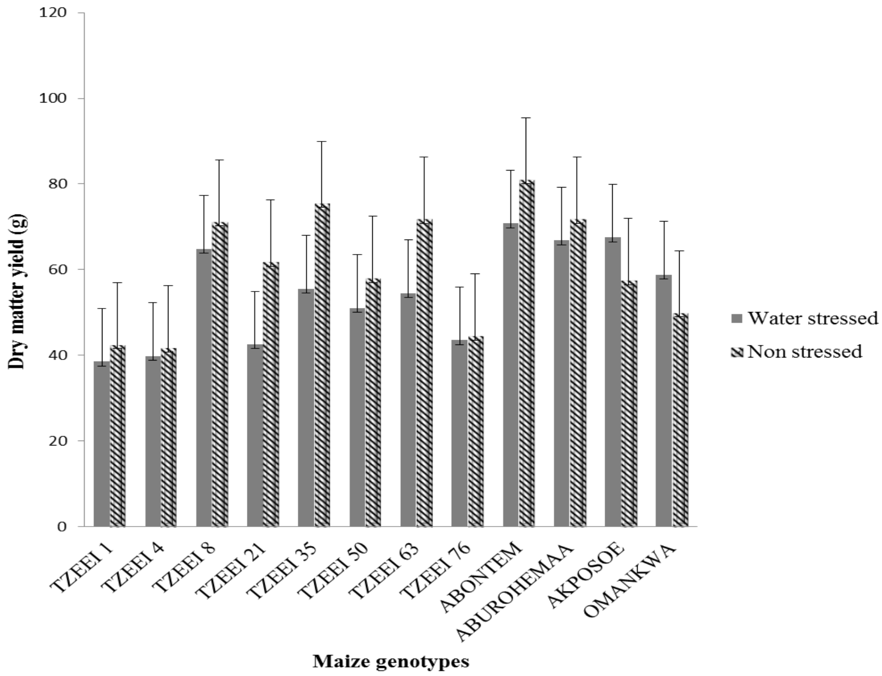

Figure 3. Dry matter for the genotypes at 36 days of water stress.

Indicators used for the study

The number of indicators scored by the twelve genotypes out of a total of four indicators used ranged from zero (0) to four (4). The genotypes were ranked according to their tolerance levels to water stress as shown in Table 2.

Genotype indicators	Number of indicators used	Number of positive
Tzeei 1	4	2
Tzeei 4	4	2
Tzeei 8	4	2
Tzeei 21	4	1
Tzeei 35	4	1
Tzeei 50	4	4
Tzeei 63	4	1
Tzeei 76	4	2
Abontem	4	2
Aburohemaa	4	3
Akposoe	4	1
Omankwa	4	2

Discussion

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.

Plant heights observed for the genotypes in the plant house were higher for the nonstress maize genotypes than the water stressed. The significant differences observed among the maize genotypes under the 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.

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).

Significant lower dry matter yield was 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, the 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).

The genotypes were ranked such that any genotype that had ≥ 3 out of the 4 indicators used was considered to be tolerant to drought. The following ranking was therefore obtained for the inbred lines and the varieties in decreasing order of drought tolerance; Tzeei 50 > Aburohemaa > Tzeei 1 = Tzeei 4 = Tzeei 8 = Tzeei 76 = Abontem = Omankwa > Tzeei 21 = Tzeei 35 = Tzeei 63.

Conclusion

The genotypes, Tzeei 50 and Aburohemaa are recommended for use in developing drought tolerance in maize breeding programmes based on their higher performances. The crop physiological parameters used; leaf relative water content, dry matter yield, root dry mass and plant height have all proved to be useful in identifying and selecting drought-tolerant maize genotypes.

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