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Full Length Research Paper

Establishing the basis for drought tolerance in maize (*zea mays* L.) using some secondary traits in the field

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A field experiment was carried out from October, 2009 to February 2010, to determine the drought tolerance levels of ten maize (*Zea mays* L.) genotypes and to establish a basis for the development of drought tolerant hybrids. The soil used belongs to the *Asuansi* series (*Ferric Acrisol*). Six inbred lines and four varieties with different genetic backgrounds were used. A total of 80 plots were prepared in the field, from which 50% constituted the water stressed site where water was withdrawn 6 weeks after planting (6 WAP) and the remaining 50% formed the non water stressed site where the crops received water until end of grain filling. Data were collected on leaf relative water content, leaf rolling, leaf senescence, anthesis-silking interval, ears per plant and grain yield. Pairwise comparison of means of water stressed and non stressed genotypes was done, drought intensity and indices were also formulated based on grain yield. Entries 24 and 5 were identified as apparently tolerant among the inbred lines while Mamaba, among the varieties appeared as relatively tolerant. The five secondary traits mentioned above for the ranking procedure proved to be effective indicators for the selection of drought tolerant maize genotypes.

Key words: *Zea mays*, genotype, drought tolerance, water stress, non water stress.

INTRODUCTION

Maize (*Zea mays* L.) is the most important cereal in terms of production and consumption in Ghana (Breisinger et al., 2008). In view of this, several improved varieties of different maturity periods have been developed and released by the CSIR-Crops Research Institute (Twumasi- Afriyie et al., 1997). This achievement is still challenged by low productivity in farmers' fields throughout the country, averaging 1.5 t/ha (Sallah et al., 2002), and 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). This low productivity has been attributed principally to low soil fertility (low soil N) and drought stress in farmers' fields (Banziger et al., 2000). Frequent drought stress in the largely rain-fed agricultural system is a major constraint that limits maize productivity in Ghana (Obeng-Antwi et al., 1999). Observed variation in susceptibility to water stress among genotypes suggests that the trait can be improved (Fischer et al., 1989). Assessment of crop physiological parameters of maize inbred lines for their tolerance to drought stress could be considered as part of the holistic approaches of stabilizing farmer's yields and income (Campos et al., 2004). Falconer (1981) suggested selection for drought tolerance in low-yielding conditions while Daday et al. (1973) indicated that selection for yield is more effective under favourable conditions because of greater genetic variance and heritability. The objectives of this study were: (1) to validate indicators for assessing drought tolerance in ten maize genotypes and (2) to relate water stressed maize with their corresponding non water stressed as a way of predicting drought tolerance from drought intensity and index based on grain yield.

MATERIALS AND METHODS

The field experiment was carried out at the Crops Research

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Table 1. Leaf relative water content (LRWC), leaf rolling and leaf senescence for the water stressed inbred lines.

Inbred lines	L RWC	Leaf rolling	Leaf senescence
Entry 5	86.8	1.62	2.25
Entry 6	71.8	2.50	3.50
P 23	76.3	3.38	4.00
Entry 24	80.6	1.62	4.12
Entry 27	79.5	2.38	5.00
Entry 70	82.8	2.75	4.50
Grand mean	79.60	2.38	3.90
Lsd	9.44NS	0.98*	1.39*
C.V%	7.90	34.8	23.7

* =Significant at the 0.05 level, NS = Non Significant.

Table 2. Leaf relative water content (LRWC), leaf rolling and leaf senescence for the water stressed varieties.

Variety	L RWC (%)	Leaf rolling	Leaf senescence
Obatanpa	83.70	3.25	2.88
Mamaba	85.40	1.88	2.12
Okomasa	74.60	3.00	4.12
Dorke-SR	81.70	3.00	4.12
Grand mean	81.30	2.78	3.31
Lsd	14.16NS	0.91*	0.95*
C.V%	10.90	24.80	18.00

* =Significant at the 0.05 level, NS =Non significant.

Institute (CRI), Fumesua (N 06◦ 43'; W 01° 36', 286 m above sea level), during the minor rainfall season between October, 2009 and February, 2010. The site is in the semi-deciduous forest zone with bimodal rainfall distribution pattern. Mean annual rainfall for the area is 1500 mm, and the mean minimum and maximum temperatures are 21 and 31°C, respectively. Mean annual relative humidity is about 60% at noon and 95% in the morning. The soil at the experimental site is sandy loam located on the *Asuansi* series, a *Ferric Acrisol* (FAO/ISRIC/ISSS, 1998). A randomized complete block design (RCBD) with ten treatments and four replications was used. Each treatment had a control making a total of 80 plots with each plot measuring 5 m × 1.5 m. The replications were separated by a 2 m alley. There were 2 rows of each genotype per plot. Fifty percent of the plots were irrigated at four days interval until two weeks before flowering after which water was withdrawn, and the remaining 50% received water throughout the experiment (control). The two sites were separated by a 5 m alley to prevent spill-over at the water stressed site during the period of imposed drought. Continuous irrigations prior to the stress period were carried out uniformly. Six maize inbred lines developed by the international maize and wheat improvement center (CIMMYT) and obtained from the crops research institute (CRI) and four improved varieties developed by CRI were used in the study. The inbred lines included Entry 5, 6, P 23, Entry 24, 27 and Entry 70, while the improved varieties were Obatanpa, Mamaba, Okomasa and Dorke-SR. Data were collected on leaf relative water content, leaf rolling, leaf senescence, anthesis-silking interval, ears per plant and grain yield. Pairwise comparison of means (t-test) for the water stressed site and the non stressed site was done for the parameters used. Drought intensity and drought index based on grain yield were formulated to aid the identification and selection of drought tolerant maize genotypes as follows;

Drought intensity = 1- (X**/**Xp)
Drought index = [1- (Y**/**Yp)]**/** [1- (X**/**Xp)]

Where:
X= respective average yield under water stress
Xp= respective average yield under non stress
Y= Individual yield under water stress
Yp= Individual yield under non stress

RESULTS

Leaf relative water content, leaf rolling and senescence

These three parameters were only measured in the water stressed site. There were no significant differences for leaf relative water content among the ten genotypes. However, significant differences ($p < 0.05$) were observed for leaf rolling and leaf senescence in both inbred lines and varieties (Tables 1 and 2). With the exception of Entry 5 which showed the best scores for both leaf rolling and senescence, the inbred lines had a trend in leaf

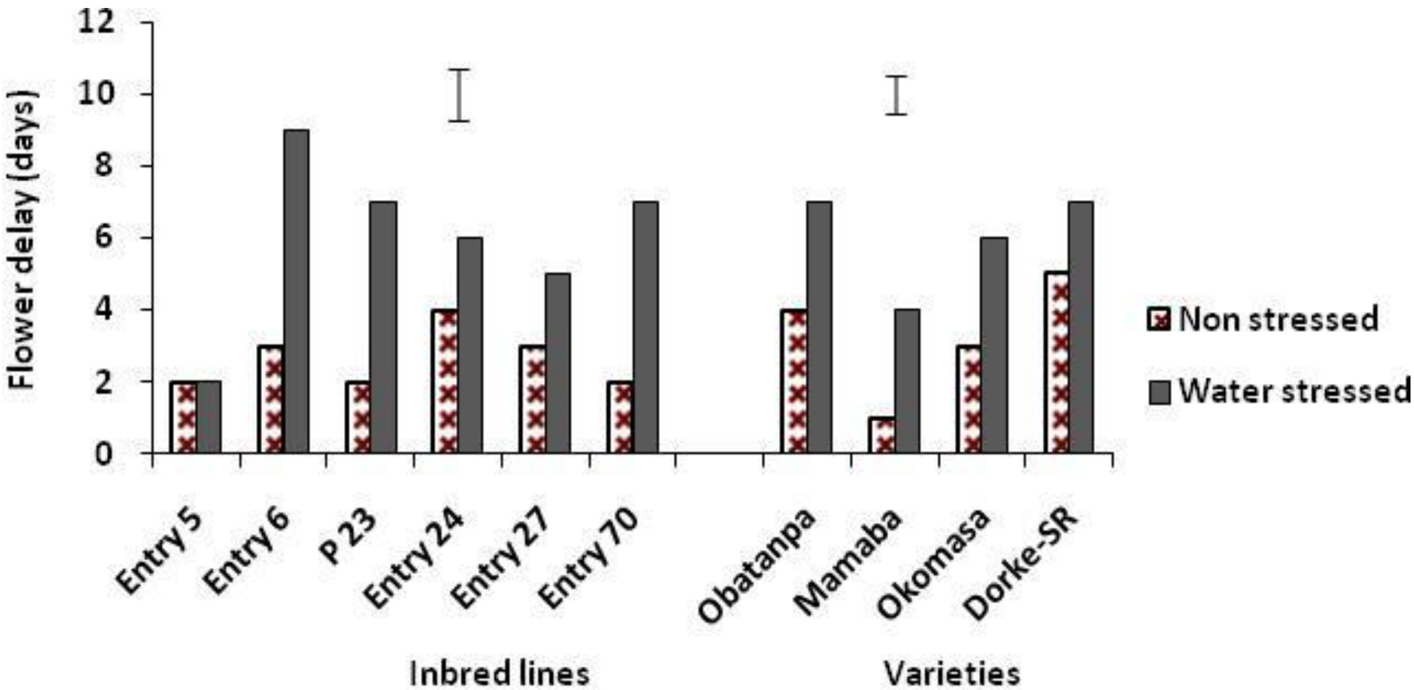

Figure 1. Anthesiis-silking intervals for the six inbred lines and the four varieties.

senescence which did not follow similar pattern as observed for leaf rolling. For the varieties, however, the trend followed similar pattern for both leaf rolling and leaf senescence. Entries 5 and 24 consequently appeared to have average leaf rolling scores less than 2 and Mamaba among the varieties obtained a rolling score of 1.88 (Table 2). Leaf senescence scores of 2.25, 2.12 and 2.88 (less than 30% dead leaf area) were recorded by Entry 5, Mamaba and Obatanpa, respectively.

Pairwise comparison of means for anthesis silking interval (ASI)

Highly significant ($p < 0.001$) differences were obtained for ASI (flower delay) in all the 10 genotypes excluding Entry 5 which showed no significant difference when the means of the water stressed plants were compared to the non stressed. Compared to the non stressed condition, increased flower delays of 2 to 6 days were observed in the water stressed inbred lines over the none stressed, except Entry 5 which maintained delay of 2 days for both conditions. Within the water stressed varieties, increased delays of three days were observed over the corresponding non stressed varieties and that was greater than the LSD (1.42) as shown in Figure 1. Strong negative correlations between ASI and grain yield were observed for both inbred lines and varieties with co-efficients of determination of 0.92 and 0.79 respectively (Figures 2 and 3).

Pair-wise comparison analysis for ears per plant and grain yield (kg ha^{-1})

Highly significant variation was observed for ears per plant among the inbred lines and the varieties in both water regimes, except the non stressed varieties which failed to show any significant difference (Figure 5). Ears per plant ranged from 0.138 to 0.643 and from 0.395 to 0.758 in the water stressed and non stressed inbred lines, respectively. Entry 5 recorded the highest number of ears per plant in both conditions, and the non stressed plants had a 17.9% increase over that of the water stressed. With the exception of Entries 5, 24 and 27, differences among the inbred lines and varieties were significant ($p < 0.05$) when mean performances for ears per plant were compared under both water regimes.

Highly significant ($p<0.001$) variability existed for grain yield in both water stressed and non stressed conditions, apart from the non stressed varieties which showed significant difference at 0.05 probability level (Figure 4). Grain yields ranged from 272 kg ha^{-1} to 1023 kg ha^{-1} for the water stressed inbred lines and from 761 to 1508 kg ha^{-1} for the non stressed. Higher grain yield values were observed for Entry 5 and the lowest were recorded by Entry 6, when the mean performances of the inbred lines were compared under water stressed and non stressed conditions. P 23 had the highest grain yield of 1666 kg ha^{-1} which was 10.5% higher than Entry 5 in the non stressed condition, however, in the water stressed condition, P 23 had 98.6% lower yield than Entry 5.

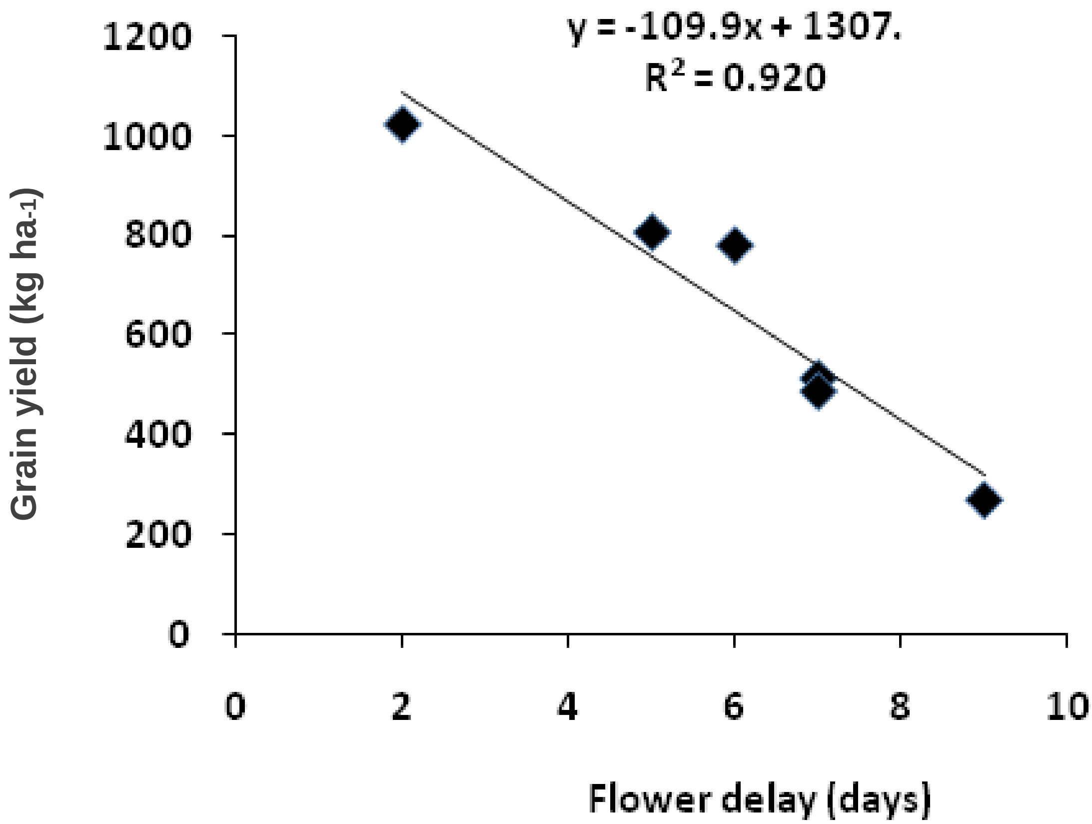

Figure 2. Relationship between grain yield and ASI for the inbred lines under water stress.

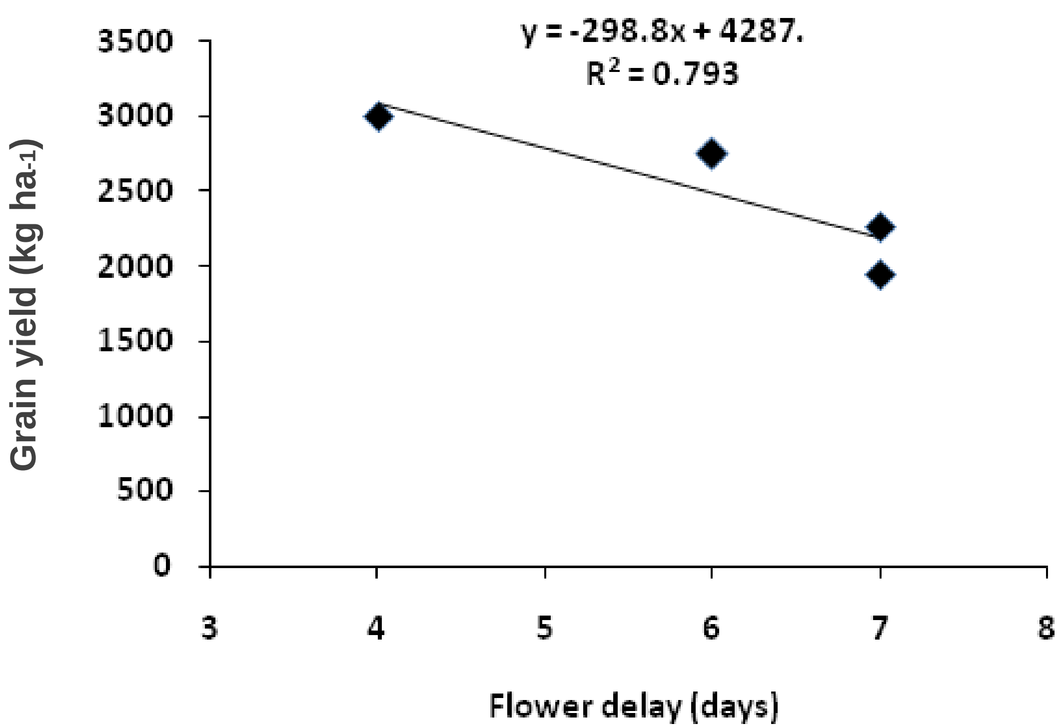

Figure 3. Relationship between grain yield and ASI for the varieties evaluated under water stressed condition.

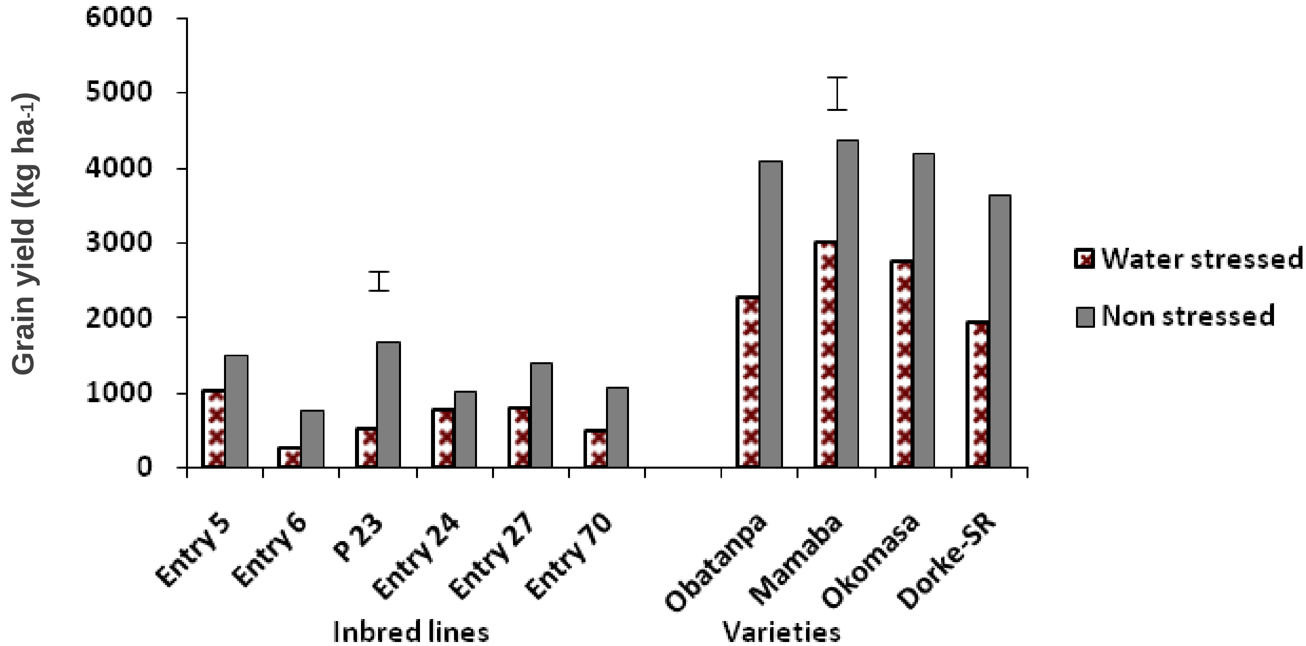

Figure 4. Grain yield of the six inbred lines and the four varieties in the water stressed and non stressed sites.

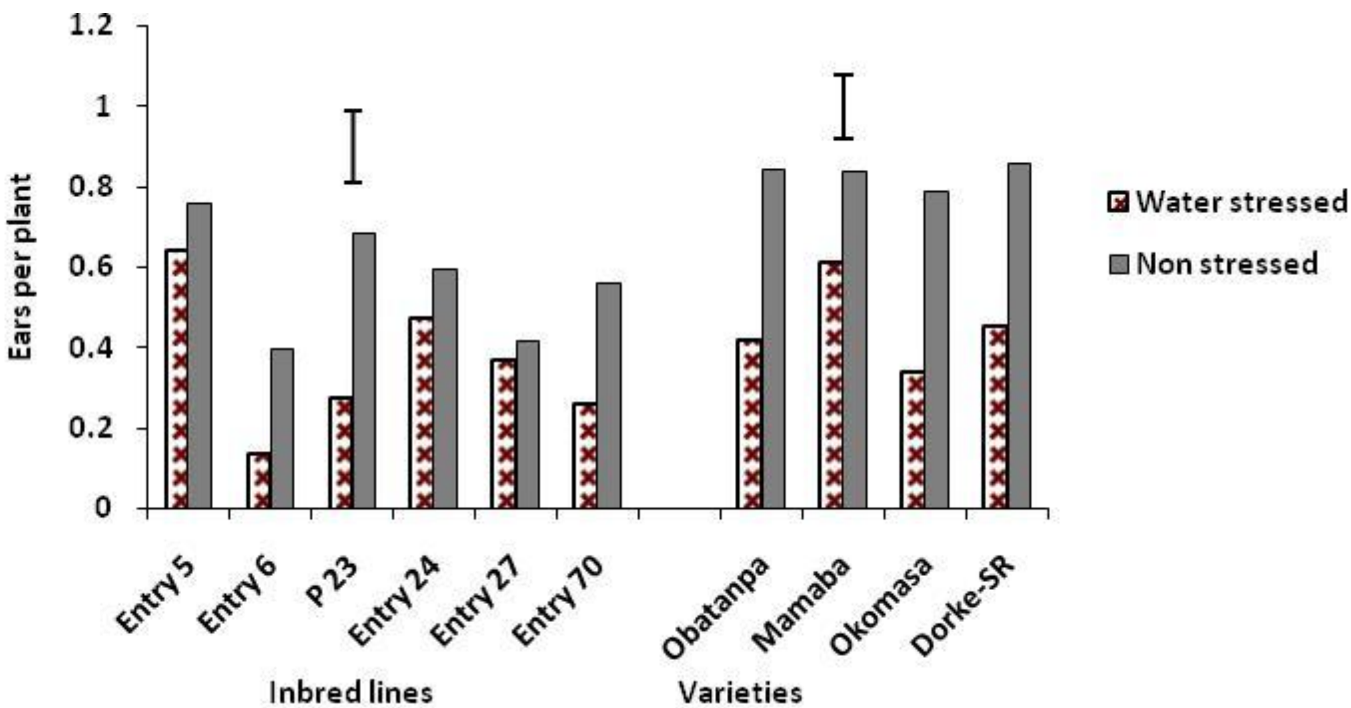

Figure 5. Ears per plant for the water stressed and the non stressed genotypes.

Within the varieties, Mamaba had the highest grain yield of 3006 and 4379 kg ha^{-1} for the water stressed and non stressed conditions, respectively. The greatest yield reductions of 1950 and 3640 kg ha^{-1} among the varieties were observed for Dorke-SR under the two water regimes, respectively. Although Entry 24 recorded

Table 3. Drought intensities based on grain yield and number of ears per plant in water stressed and non stressed conditions for the six inbred lines and the four varieties evaluated on the field.

Index	**Drought intensity**	
Trait	Inbred lines	Variety
Grain yield	0.48	0.39
Ears per plant	0.39	0.45

Table 4. Drought indices based on grain yield and number of ears per plant in water stressed and non stressed conditions for the six inbred lines and the four varieties evaluated on the field.

Inbred lines	**Drought index**
Entry 5	0.67
Entry 6	1.33
P 23	1.44
Entry 24	0.48
Entry 27	0.90
Entry 70	1.13
Variety	
Obatanpa	1.13
Mamaba	0.79
Okomasa	0.87
Dorke-SR	1.21

relatively low yields in both water stressed and non stressed conditions, it was the only genotype that showed no significant difference ($p< 0.001$) between the two water regimes.

Drought intensity and index

The drought intensities calculated for grain yield and number of ears per plant was 0.48 and 0.39 for the six inbred lines respectively, whilst the four varieties also recorded values of 0.39 and 0.45, respectively (Table 3). The drought intensities for grain yield were subsequently used for the calculation of drought index for the ten genotypes evaluated.

A drought index based on grain yield aided the selection and ranking of the genotypes with respect to drought. Drought index based on grain yield ranged from 0.48 to 1.44 for the inbred lines and from 0.79 to 1.21 for the varieties (Table 4).

Identification of drought tolerant genotypes was finally based on a correlation between relative grain yield under water stressed condition and the respective drought indices obtained as shown in Figures 6 and 7. The relative grain yield of the inbred lines under water stressed condition negatively correlated with the drought indices developed. A similar trend was also observed for the varieties.

DISCUSSION

Genotypes with leaf rolling indices greater than 2 might be susceptible to drought because at that stage the leaf rim actually begins to roll as reported by Bänziger et al. (2000). Any genotype that shows this rolling index might not exhibit full photosynthetic capacity and might further have impaired dry matter production. Eventually, partitioning of assimilates from the leaves (source) to the grain (sink) might be considerably reduced as reported by Bänziger et al. (2000). Among the varieties, Mamaba appeared tolerant by obtaining a leaf rolling score of 1.88 under field conditions. The drought tolerance identified in these genotypes in terms of leaf rolling implies wider leaf surface area exposed for adequate solar radiation interception and hence relatively good photosynthetic capacity. This agrees with a report by Prabhu and Shivaji (2000) that the main effect of drought in the vegetative period is to reduce leaf growth and induce leaf rolling, so the crop intercepts less sunlight.

Less than 30% dead leaf area was observed for Entry 5, Mamaba and Obatanpa and this implied their ability to maintain over 70% stay green in their leaves even towards the end of grain-filling. The ability of these genotypes to delay senescence indicates their efficiency in maintaining relatively high plant water status despite the low moisture level within the plant environment as reported by Fischer and Sanchez (1979) and Otoole and Chang (1979), that in spite of low moisture condition in a plant's entire environment, a drought tolerant plant will be able to maintain a relatively high plant water status.

Flower delay beyond five days might cause reduced photosynthesis and pollination per plant which may result in significant yield reductions as confirmed by Grant et al. (1989). Ne-Smith and Ritchie (1992), and also Bolanos and Edmeades (1996) stated in their report that when photosynthesis and pollination per plant at flowering is reduced by drought and several other abiotic stresses, silk growth is delayed leading to an easily measured increase in ASI and kernel abortion. Entry 5 solely proved outstanding compared to all the genotypes when ASI was used as an indicator and this explains why Entry 5 within the inbred lines recorded the highest grain yields at the water stressed site. Also, the strong negative correlation between ASI and grain yield for both inbred lines and varieties indicated that a shorter ASI is required for complete pollination and fertilization and ultimately high grain yield.

The trend of ears per plant was not different from that of grain yield for both inbred lines and varieties under the two water regimes. This finding explains why Bänziger et al. (2000) placed ears per plant second to grain yield when ranking six secondary traits recommended for

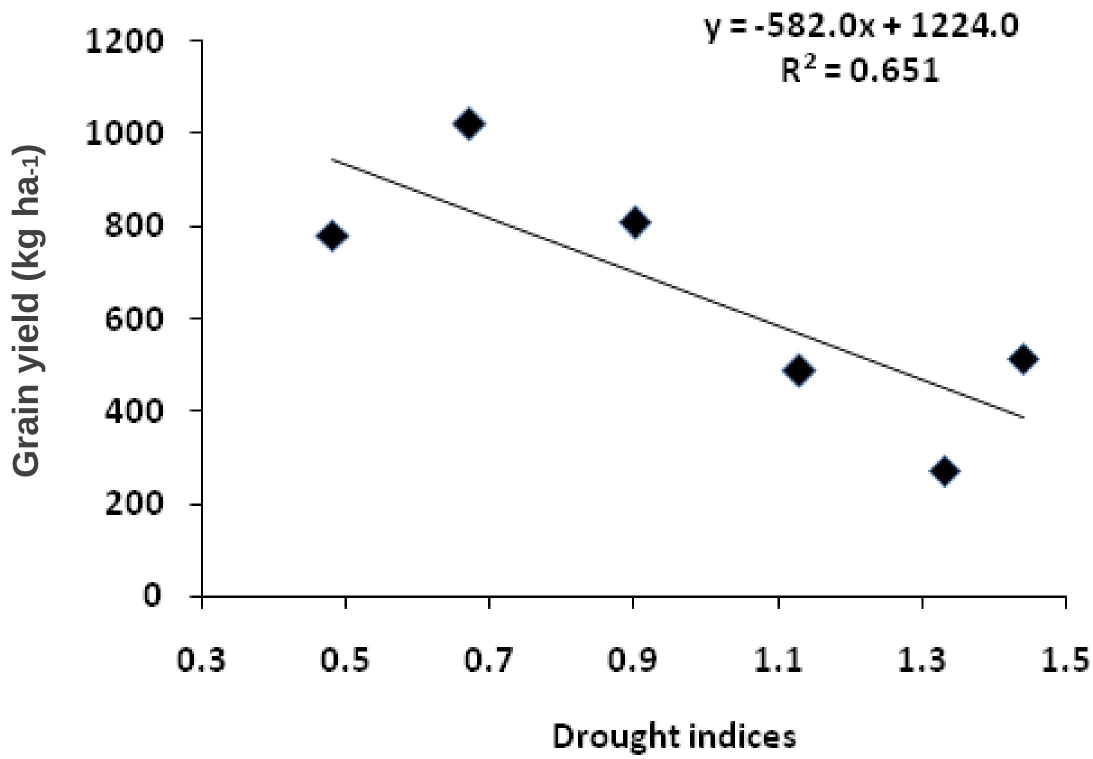

Figure 6. Relationship between grain yield of inbred lines under water stressed condition and drought indices based on grain yield.

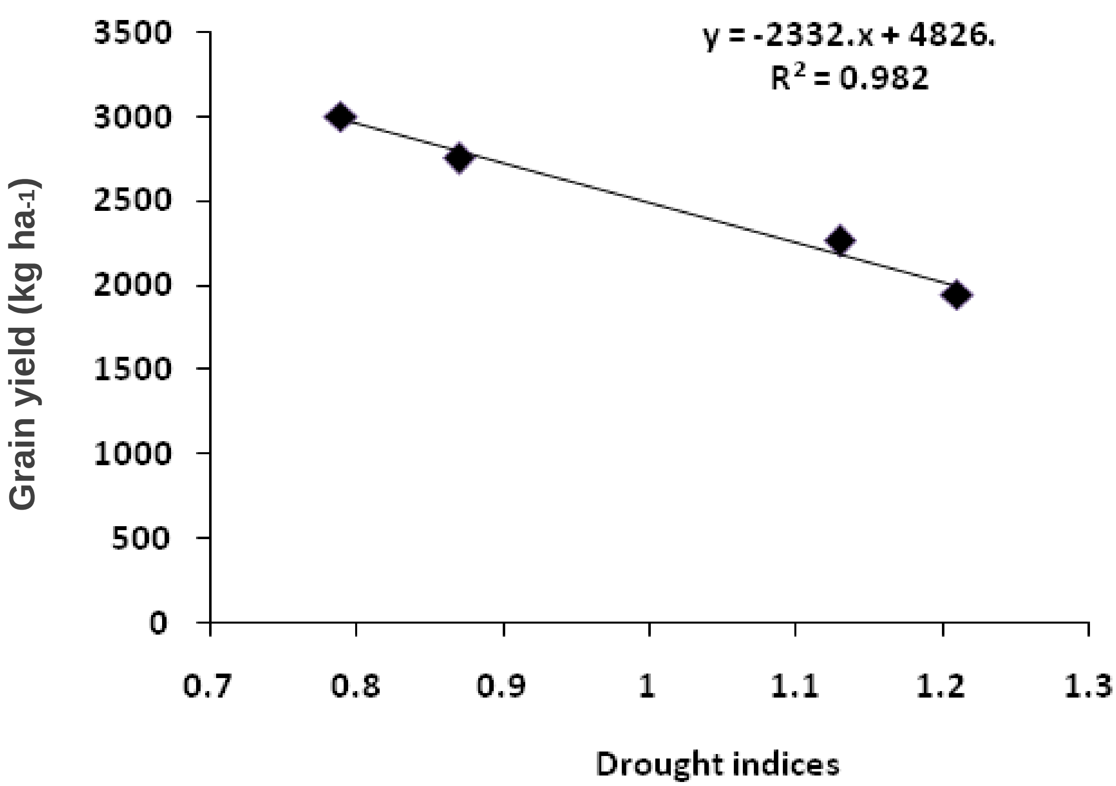

Figure 7. Relationship between grain yield of varieties under water stressed condition and drought indices based on grain yield.

identifying drought tolerant maize genotypes in decreasing order of importance. With respect to grain yield, Entries 24 and 5 were able to maintain high levels of tolerance. The implication is that although Entry 27 had relatively higher number of ears per plant, reductions in actual kernel formation occurred and hence could not translate relatively higher number of ears per plant into relatively higher grain yield. Indeed, this finding confirms an observation by Bänziger et al. (2000) who stated that because of the considerable variation in shelling percentage under drought, grain mass but not ear mass should be used for calculating grain yield. Also the observation found in Entry 27 agrees with a report 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.

The negative correlation observed between grain yield and the drought indices developed for both inbred lines and varieties indicated that grain yield increased with decreased drought index and vice-versa. However, the relationship was very strong among the varieties than the inbred lines since the varieties had a stronger negative correlation co-efficient than the inbred lines. Therefore, genotypes with low drought indices have higher potentials of obtaining high grain yields, especially under drought conditions.

Conclusions

Entries 5 and 24 are recommended for use in developing drought tolerance in maize breeding programmes. Mamaba among the varieties is recommended for maize growers in potentially drought prone areas specifically, in the Guinea savanna, Sudan savanna and forest-savanna transition zones of Ghana.

The secondary traits chosen for the ranking procedure including grain yield proved to be effective indicators for the identification and selection of drought tolerant maize genotypes with the aid of drought intensity and index.

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