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Review Article

EFFECT OF DROUGHT ON FIELD PERFORMANCE OF MAIZE AND SORGHUM

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Abstract: Water scarcity is becoming an increasingly important issue in many parts of the world. Climate change predictions of increase in temperature and erratic rainfall mean that water will become even scarcer. Since agriculture is the major water user, efficient use of water in agriculture is needed for conservation of this limited resource. Increase in water use efficiency for enhanced drought tolerance can be achieved by different strategies such as change of crops capable of producing acceptable yields under deficit irrigation or rainfed situations. Scarcity of water is a severe environmental restriction to plant productivity.

Keywords: *Drought, growth, yield, maize, sorghum, Root traits*

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Introduction

Maize (*Zea mays* L.) is a miracle crop. Globally maize is the third most important cereal grain after wheat and rice. In Karnataka, it is the third largest cereal crop next to sorghum and paddy. Throughout the tropics, periodic drought caused sizeable reduction in maize yield. In India, majority of maize is grown under irrigated condition and most farmers in south India cultivate maize under rainfed condition. Maize often suffers from drought stress between flowering and grain filling (40-80% yield loss). So, drought is considered to be a major factor affecting plant growth and yield in rainfed areas.

In contrast, sorghum, which is a potential rainfed crop is widely grown in many arid and semi-arid areas of the world due to its ability to yield well under rainfed or water-limited conditions. Sorghum is reported to be more tolerant than maize to water deficit [1]. For this reason, sorghum appears to be a possible alternative to maize under water-limited conditions in the rainfed areas. Most of the published studies have been conducted in the semi-arid tropics, where both maize and sorghum are widely grown under rainfed conditions and farmers grow sorghum as an alternative crop in place of maize.

Effect of Drought on Field Performance of Maize

In the tropics, maize is subjected to extreme climatic conditions and biotic/abiotic pressures that limit crop growth and development, and eventually limit yield potential [2]. Among the abiotic stresses, drought is one of the most important constraints for maize production and productivity [3] and [4]; and large yield losses can occur when maize is exposed to drought conditions during critical stages of crop growth [5] and [6]. Drought occurrence during vegetative stage of crop severely affects the plant height. The reduction in plant height by 60 to 70 percent and 17 percent was observed due to water stress during knee height stage in Karnal (India) [7] and at vegetative stage in Thailand [8], respectively. In addition, maize plants exposed to water stress during the tasseling stage had the shortest final height of 152.1 cm in Turkey [9]. Similarly, the other growth parameters of maize such as roots and shoots were inhibited by about 50 percent at -0.8 and -0.6 MPa water deficit stress, respectively in India.

The root growth was relatively less affected due to stress than shoot growth [10]. A normal process in the life cycle of plants is senescence. In crops like maize, senescence starts before all leaf area is fully developed (i.e., previous to flowering) and progresses to an increased rate during the grain filling period [11] and [12]. Majority of the hybrids with score upto 2 were found tolerant with respect to this trait in the experiment conducted at Karnal, India. The reduction in grain yield due to water stress was more severe when it occurred during reproductive phase than during vegetative phase. When drought occurred during the vegetative period grain yield was numerically reduced by 6.6 and 11.1 percent in two years of field experimentation in African Sahel region on a clay loam soil. Similarly, when drought occurred during the early reproductive stage, significant yield reductions of 26.4 and 22.6 percent were observed for the respective seasons [13]. The greatest yield reduction was associated with stresses that were most intense during the 25 days period after flowering [14]. There was 30 to 40 percent reduction in grain yield (2.15 to 2.65 Mg ha^{-1}) of maize due to drought stress in Nigeria. Reduction in grain yield was greater in the low osmotic adjustment (LOA) crops with grain yield of the high osmotic adjustment (HOA) plants being between 38 percent and 58 percent (66.60 and 68 g $plant^{-1}$ in two field experimentation conducted at Argentina) higher than that of the LOA plants (48.3 and 43.0 g $plant^{-1}$, respectively). Drought significantly reduced the grain yield by 13 (6.15 Mg ha^{-1}), 21 (5.02 Mg ha^{-1}) and 32 percent (4.37 Mg ha^{-1}) during the three years of field experimentation in Thailand. Maize planted in Weslaco, Texas (2000) generated mean yields for 11 hybrids of 3 Mg ha^{-1} under water-deficit stress during flowering resulting in a yield loss of approximately 40 percent. In Chile (1999-2000) same 11 hybrids, resulted in a yield loss of 62 percent. However, the mean yield in Chile under water deficit stress was 7.48 Mg ha^{-1} [15]. The grain yield of CIMMYT and check hybrids was 3.01 and 2.53 Mg ha^{-1} under drought conditions, respectively [16]. It is well established that water deficit during anthesis can have disastrous effects on maize grain yield. During flowering stage, single day of drought can potentially decrease yield upto 8 percent [17]. Earlier flowering entries of maize generally performed better in water stressed environments and yields averaged less than 5 Mg ha-1 and yield gains were significant [18].

In addition, when drought occurred during tasseling or ear formation or during both stages, maize crop yielded only 9.99, 5.33 and 11.17; 9.70, 7.67 and 10.90; and 4.70, 6.68 and 9.58 Mg ha^{-1} during 1995, 1996 and 1997, respectively in Turkey. Grain yield decreased by 60 to 80 percent due to water stress at flowering stage in Thailand. Yield under stress at flowering shows a strong dependency on kernel number per plant ($r > 0.8$), barreness ($r > 0.7$) and Anthesis to Silking Interval (ASI) ($r > -0.4$ to -0.7) in tropical maize [19]. Under drought conditions, grain yield ranged from 1.20 to 2.65 Mg ha^{-1}; under drought 50 percent of the grain aborted during the 50 days following silking, with 75 percent of these losses occurred during the first 20 days [20].

Drought is known to significantly affect the stover yield of maize. Reduction in stover yield (3.68 to 3.78 Mg ha^{-1}) was to the extent of 9 to 22 percent in Nigeria. The total shoot dry matter of drought stressed maize was 8.1, 11 and 11.9 Mg ha^{-1} during the three years of field experimentation in Thailand.

The effect of drought on grain and stover yield generally leads to its significant effect on Harvest Index (HI). HI of drought stressed maize was 0.46, 0.52 and 0.54 during the three years of field experimentation in Thailand. The HI was highest (0.56) for drought stressed DK- 888 maize in 1995 experimental year. Water stress at tasselling and dough stages resulted in lowest HI [21]. Pre-anthesis drought can increase the HI of tropical lowland maize to 0.56.

Yield of any crop is determined by its yield components. Yield components of maize were significantly affected by drought occurrence at different crop growth stages [22]. Drought at knee height stage significantly reduced the number of cobs per plant in loamy soil. However, stress at knee-high or dough stage did not affect the number of grains per cob but there was significant reduction in 100-grain weight when drought occurred at grain filling stage [23]. Additionally, grain numbers and weight per grain were reduced by drought particularly in the LOA crops in Argentina. Drought significantly reduced the number of kernels per unit ground area and the average reductions was 26 (1630 kernels m-2), 9 (2120 kernels m^{-2}) and 18 percent (1950 kernels m-2) during the three years of experimentation. Similarly, kernel row number per ear, kernel number per ear and number of ears per plant in drought stressed maize were 12.6, 13.1 and 13.0; 21.9, 26.4 and 25.5; and 1.11, 1.16 and 1.12, respectively. Additionally, the average reduction of 1000-kernel weight due to drought was 9 (266 g), 3 (291 g) and 4 (257 g) percent, respectively. There was significant reduction in grain weight per ear due to drought in Turkey. Prolonged water stress throughout the growing season or before or after flowering stage reduced grain yield through lowering grain number per ear by 40 to 70 percent and /or 1000-grain weight. Ear weight per plant decreased by 60 to 80 percent due to water stress. In most studies, pre-anthesis drought stress affected both the kernel number and the 1000-kernel weight. Severe stress significantly reduced grain yield, above ground biomass, HI and kernel number per ear [24].

Effect of Drought on Field Performance of Sorghum

In contrast, Sorghum is said to be highly drought tolerant crop, but moisture stress at certain critical stages causes a reduction in growth and yield [25]. There was significant reduction in grain yield due to drought [26]. The yield reductions in sorghum was related to reduction in both grain number and grain size when water stress was imposed at anthesis and early grain filling stages [27]. There was significant reduction in grain yield and HI due to drought. However, stay green lines of sorghum have a higher yield of grain and biomass [28]. Under moisture stress condition, the dry weight of panicle, panicle length and 1000-grain weight exhibited maximum and significant positive correlation with grain yield [29].

Water stress during flowering stage reduces the number of grains panicle^{-1} that is partly compensated by an increase in grain weight and decrease in panicle weight. Grain yield under post-anthesis stress conditions was correlated with both grain number (r=0.723***) and grain size (r=0.339***) [30]. The weight of thousand grains was less sensitive to drought than weight of grains panicle^{-1} and number of grains panicle^{-1} and yielded 7.68 g panicle^{-1} and 350.6 grains panicle^{-1}, respectively in Spain. Higher grain number is most important for realizing the high yield potential. Several workers have reported positive relationship of grain number with grain yield in sorghum [31]. Thousand seed weight and grain number plant^{-1} had a significant positive correlation with grain and fodder yield [32] and; a positive association between plant height and grain yield of sorghum under drought condition has been reported [33]. Under moisture stress condition, higher HI values were found in non-glossy (dark green) than glossy genotypes (light green) and vice versa in grain yield [34]. There was significant reduction in biomass production (up to 30 %) under soil water stress in sorghum plant [35].

Physiological Parameters

Relative Water Content (RWC)

Role of water in various growth and metabolic activities of plants needs no elaboration [36]. The RWC in the leaves of maize plants at low water potential (-1.4 MPa) decreased significantly compared to control. The RWC in droughted maize was 71.39 to 75.34 percent which was significantly lower than control (99.02 to 99.56%) [37]. RWC, leaf water potential and crop water stress index were less sensitive to water deficit during flowering phase than during vegetative phase of maize [38].

Water deficit at anthesis and grain filling stage decreased RWC. However, significantly higher RWC was recorded in M-35-1 (81.2%) followed by CSV-14R and RSLG-383 at 50 percent flowering [39]. Significantly positive correlation of RWC with grain yield was noticed in grain sorghum [40]. The RWC value was about 96.6 percent in droughted sorghum in Germany [41]. The RWC in apical leaves of stay-green lines of sorghum was about 81 percent which was much higher than non-stay green lines (38 %) [42]. The RWC values for different genotypes recorded were 70.9 to 77.9 percent under drought stress situation.

Anthesis to silking interval (ASI)

Short anthesis to silking interval proved to be a good indicator of drought tolerance in maize. Genotypes with short ASI of less than 2 days were found tolerant for drought and showed comparatively lesser reduction in yield while those with longer interval (6.9 days) under stress and severe stress were found more susceptible and maximum yield reduction was noticed in Karnal (India). When drought stress occurred just before flowering of maize, silk emergence was delayed by 6-9 days. The asynchrony between male and female flowering dates was found strongly associated with variation in grain yield. Under stress condition ASI was 6 days or even more in Spain [43].

Water deficit delayed flowering by 90 DAS and maturity by 148 DAS in maize [44]. There was a significant reduction in days to 50 percent silking (-2 to -3 %) and days to 50 percent tasselling (-1 to -3 %) of maize due to drought stress across various genotypes. In Nigeria genotypes took 55.38 to 58.13 days to 50 percent silking and 53.00 to 55.44 days to 50 percent tasselling under drought condition; hence there was 16 percent increase in ASI due to drought stress and 25 percent yield reduction. Similarly, days to 50 percent silking increased in drought stressed maize and were 65.6 to 69.8 days. ASI increased from about 3 to 7 days under severe stress. Water deficit increased the average ASI of maize to 4.5 days from an average of 1 day under normal conditions [45].

Root traits

Root systems obviously play an important role in water acquisition for plants and are a significant component of tolerance to water stress [46]. Root to shoot ratio of maize was found to be 0.011 and 0.069 under low water stress at 52 and 73 days after planting(DAP). Whereas it was 0.47 under higher water stress at 73DAP [47].

Leaf chlorophyll concentration estimates (SPAD values)

An alternative to tissue test is a chlorophyll test, using a chlorophyll meter to estimate N in the plant. All the maize genotypes showed increasing meter reading values as plants aged until silking. But the correlation coefficients between SPAD readings and grain yields were generally lower. Total chlorophyll per leaf area (mg/cm^2) had a near-linear relationship (R^2=0.91) with the SPAD. In the USA under severe post-flowering drought conditions, the staygreen lines such as B35 had SPAD values above 40 and an average total chlorophyll concentration of 0.085mg/cm^2 in their top leaves. The extremely susceptible lines, such as Tx7000, had SPAD value of about 14 and essentially had no chlorophyll in leaves [48].

Conclusion

Drought is a serious causal factor of reduced crop yields than any other abiotic stresses. As one of the most widely distributed crops, maize plants frequently suffer from drought stress, which causes great losses in the final kernel yield. Hence, sorghum is found to be alternate crop to maize in the areas which are suffering from frequent drought.

Application of Review: Now a days most of the maize growing area is suffering from frequent drought. Drought imposes serious hampering effects on growth and development of crop plants. Survival of the fittest enabled the superiorly evolving plants to prevail in the environment. In this situation the farming community can opt for sorghum as an alternate crop against maize.

Review Category: Agronomy

Abbreviations: MPa: Mega Pascal, Mg: Mega gram, ha^{-1}: per hectare, $Plant^{-1}$: per plant, CIMMYT: International Maize and Wheat Improvement Center, DAS: Days After Sowing, SPAD: Soil Plant Analysis Development

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