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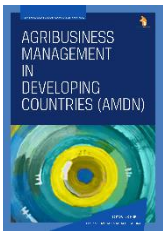

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REVIEW ARTICLE

EFFECTS OF DROUGHT STRESS ON GROWTH AND YIELD PARAMETERS OF *ZEA MAYS*- A COMPREHENSIVE REVIEW

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ABSTRACT

Maize serves as an important food source for human and livestock populations and its demand is heightening in response to the ever-increasing global population. Maize uses a total of 350-450 mm of water during its lifetime to complete its growth and development. However, as a result of global climate change and increased human activity, a significant portion of the Earth's land is suffering from drought, leading to frequent periods of dryness that hamper the production of maize. This review article recounts the consequences of imposing moisture stress on various developmental stages, phenology, morphology, harvest, and yield-attributing characteristics of the maize crop. To form this review article, research papers expatiating on the consequences faced by maize crops in response to moisture stress were retrieved to gain a thorough understanding of the subject. Drought stress affected both vegetative and reproductive growth stages of the maize plant with significant alterations in seed germination, biomass accumulation, days to anthesis and silking, pollen number, kernel number, kernel weight, grain yield, nutrient uptake, and soluble proteins. The result has shown a decline in the yield of maize by 70% in response to moisture stress imposed by drought conditions. The development of drought-resistant lines and irrigation facilities is thus expected to salvage crops and farmers from an impending crisis of drought spells brought about by climate change.

KEYWORDS

Abiotic stress, drought, corn, climate change, drought resilience

1. Introduction

Average global temperatures are anticipated to rise by 1.2-4.1 °C before the termination of this century, which is predicted to cause moisture stress in regions that were previously untouched and unanticipated. (Allen, 2001; IPCC, 2001). A considerable portion of the earth's land is plagued by drought as a consequence of global climate change and intensified human activity, and that is rising as one of the main variables compelling agricultural growth and yield (Osmolovskaya et al., 2018; Zhang et al., 2022). Due to the consequences of global climate change and the rise in temperatures thus accompanied, geographical variations in the rainfall patterns are expected to occur forecasting more frequent extreme weather events. Such modifications are probably going to influence the period and magnitude of drought stress faced by agricultural crops (Harrison et al., 2014). Abiotic stresses are known to pose restrictions on the yield of crops, and despite the prevalence of plenty of abiotic stresses, water scarcity is a recurrent phenomenon in the world's agriculture (Ali et al., 2016). Despite serving as an important food source for human and livestock populations and greater demand prevailing as a result of the burgeoning global population, environmental influences such as heat and drought are limiting Maize production levels today and in many places, it is expected that this will worsen with climate change (Liu et al., 2015).

C4 plants like maize hybrids need an adequate water supply for their entire growth cycle, but there are specific stages during which these plants are especially susceptible to soil moisture deficiency, and any form of aridity during these phases will result in considerable damage to yield (Mujtaba and Alam, 2002). According Maize required 368 kg of moisture to attain 1 kg of biomass accumulation to (Rana et al., 1999). Maize uses a total of 350-450 mm of water throughout its lifetime to sustain the life processes. Every mm of water accounts for the formation of 10-16 kg of kernels, and an established corn plant intakes 250 liters of water when fully mature (Du Plessis, 2003). By reducing stem height, stem diameter, leaf area, the number of kernels per ear, and thousand kernel weight, water stress reduced the yield of fodder and grains in Maize (Khan et al., 2001). A 40% decline in the kernels per ear was witnessed in maize varieties by (Kamara et al., 2003). This review article summarizes the impacts of imposing moisture stress on various crop growth stages, phenology, morphology, yield, and yield-attributing characteristics of the Maize crop.

2. Methodology

A Google Scholar and Research Gate-based literature review was done to gain a thorough understanding of the subject under review. Various research papers outlining the impacts of drought stress in maize were delved deeper to enhance comprehension of the subject. The reference section of individual research papers was also referred to for unlocking further details. A total of 27 research papers were studied to form this review article.

3. Discussion

3.1 Effect on The Vegetative Stage

Prolonged drought during the growth stages of maize had a substantial impact on various aspects of maize development, leading to a pronounced reduction in leaf area, stem diameter, plant height, and the accumulation

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of biomass. The severity of drought impact on crop vegetative attributes varied prominently depending on the developmental stage coupled with the intensity and period of drought stress (Ge Sui, et al., 2012). This implies the significance of applying irrigation during critical crop growth stages, because certain phases of crop growth are more susceptible to the effects of drought stress than others, and imposing drought stress on those critical stages poses a detrimental reduction in the growth of the plant and the final yield.

3.1.1 Seed Germination and Biomass Accumulation

The larger impact of moisture stress on the initial sprouting of seeds can be attributed to the fact that water scarcity posed more influence on germination potential rather than germination rate (Liu et al., 2015). Drought stress diminishes the germination potential of seeds by lowering their viability. Inadequate germination of maize seeds is directly linked to subpar performance after sprouting (Radić et al., 2007). In the early stages of growth, water stress adversely affects several aspects of maize seed quality, including seed vigor, water absorption, germination capacity, germination speed, the development of plumule and radicle, and the growth of roots and shoots (Aslam et al., 2015).

Deficiency of soil moisture reduced biomass plus its components, also decreased the percentage of shoots but raised the percentage of below-ground biomass, due to the evacuation of moisture in deeper soil horizons when cropland is inflicted by drought stress (Ge, Sui, et al., 2012; Soler et al., 2007). Thus, greater root length can be attributed to drought stress leading to increased underground biomass. The ability of the leaves to emerge, extend, and increase in numbers was also hampered under drought stress. Growth of the leaves is inhibited relatively more pronouncedly than that of the roots under such scenarios. Drought stress led to decreases in both the fresh plant weight and the weight of plant matter after drying (Efeoğlu et al., 2009), which might raise questions in the prevalent school of thought that instigates the understanding of increased underground biomass during drought conditions, but the increment in the underground biomass alone cannot ensure the increment in the overall plant biomass under drought conditions.

Also, cell division and enlargement of the plant are negatively impacted by water-scarce situations and water would be transferred from older leaves to newer ones, inducing premature aging of the leaves (Ge, Sui, et al., 2012). The senescence thus progresses from the older leaves to the younger leaves in such scenarios. Treatments subjected to severe drought stress exhibited obvious indications of visible wilting during the middle of the day and the aging of lower leaves. The expansion of maize leaf was severely hindered at – 4 bars, while the expansion was nil when water potential in the leaves was close to -8 bars (Herrero and Johnson, 1981). This implies that the mobility of water is hindered under drought conditions that accelerate the drought effects.

Water stress during the rapid vegetative and stem elongation phase shortens internodes, lowering the plant's height. Maize grown under off-season rainfed conditions, that face frequent spells of drought are subjected to exhibit a lower LAI (because of a decrease in leaf size), crop height, and eventually, decreased biomass accumulation, in comparison to the well-watered environments (Çakir, 2004; Soler et al., 2007). Drought stress also led to the accumulation of Abscisic Acid (ABA) in crops thus accounting for the closing of the stomata, which reduced Relative Water Content (RWC), water potential as well as the photosynthetic activity producing plants with lower biomass and slower growth rate (Efeoğlu et al., 2009; Goodarzian Ghahfarokhi et al., 2015). Thus, the lower biomass of crops under moisture stress conditions is validated by several explanations. But, since the dehydration induced by drought is often reversible, RWC was found to significantly increase during recovery, when the drought-subjected plants were restored with irrigation (Efeoğlu et al., 2009). Closing of the stomata is one of many primary reactions to the stress caused by reduced moisture levels shown by the crop plants. A reduction in the reaction center content is brought about by the strong decline in the uptake of CO_2, thus reducing the need for the phytochemistry products: ATP and NADPH. Leaf rolling: another vegetative retaliation of the plants against drought stress has limited light absorption, but has also been the plant's defense mechanism to combat water loss through transpiration by reduction in the surface area (Efeoğlu et al., 2009). Thus, the mechanism of leaf rolling implies protection against transpiration loss, but it cannot be understated that the protection thus offered is at the cost of the photosynthates accumulation.

Relation with water use efficiency: Documentation of low water use efficiency was done for plants subjected to water stress, due to the prevalence of lower area of leaves permitting a pronounced loss of applied irrigation water in the form of evaporation, rather than its possible application in the transpiration (Ge, Sui, et al., 2012; Soler et al., 2007). The applied water for irrigation, instead of being utilized for plant metabolism via transpiration, is lost to the atmosphere as evaporation, prominently reducing the Water Use Efficiency. On the farmer's level, practices such as mulching thus ensure protection against evaporative loss and sustain the availability of scarce water to be utilized by drought-affected plants for the functioning of their metabolic activities.

3.2 Effect on reproductive stage

Restriction of water during the reproductive stage can seriously reduce corn cultivar growth and yield components: such as NKRPE, NKPR, 100 seed weight, seed yield, and biological yield (Sellamuthu et al., 2022).

Effect on Tasseling, Silking, and ASI: Tasseling and ear formation stages are the two most sensitive stages to drought stress conditions, that can result in severe yield reduction. Plants show relative tolerance to water stress in the vegetative and milking stages than that in the tasseling and grain formation stages. Moisture stress lasting for two and seven days in the tasseling stage incurs yield reductions of as much as 22 and 50% respectively (Çakir, 2004). This infers the deduction that, under the availability of limited water resources, critical stages such as tasseling and grain formation stage must be prioritized for irrigation, as compared to the vegetative and milking stages.

Drought stress before tasseling has reduced the number of pollens produced per plant, but no effect was seen on pollen number in imposing stress at the later developmental stages. The Anthesis silking Interval (ASI) increased in reaction to moisture stress before silking. Imposing moisture stress resulted in a delay in silk emergence in Maize plants by an average of 3-4 days than the well-watered plants, thus increasing the interval between tassel emergence and silking, and also the ASI (Hall et al., 1982; Herrero and Johnson, 1981) . Pollen viability was unaffected by drought stress in the ontogenic stages. (Hall et al., 1982). The application of irrigation right at the inception of tasseling pronouncedly fostered the growth of the crop plant (Çakir, 2004). Likewise, both tasseling and silking were delayed by 4-5 days in drought-imposed plants of 35% Field Capacity (FC), compared to well-irrigated plants of 75% FC (Ge, Sui, et al., 2012).

Higher ASI under moisture stress conditions can be explained by findings such as silk emergence being slower in plants subjected to low moisture levels than the irrigated ones. The expansion of the ear silks seized at an ear leaf water potential approximately to -9 bars. Much of the silk not being able to elongate, remained inside the sheath of the ear leaf, thus constraining the possibility of pollination (Herrero and Johnson, 1981). This might infer the detrimental possibility that under drought stress, silk might not emerge at all, thus validating the essence of irrigating during the critical stage of silking when the water resource is scarce and irrigation numbers are limited.

Effect on Pollen grains: On the contrary, not much effect was seen on the pollen viability under drought conditions because of pollen harboring small vacuole. For pollen development, higher temperature is much more detrimental than drought stress as the plants cultivated in natural field settings experience nighttime recovery. Because of the availability of dew throughout the night, plants and pollen regain turgidity, and because pollens are shed in the early morning, germination of pollen in silk is not hampered even during drought conditions (Herrero & Johnson, 1981).

Effect on Grain filling and yield: Water shortages following anthesis reduce the volume of the embryo and delay the time of grain filling by producing premature endosperm desiccation. Additionally, drought stress shortens the effective grain-filling period, which lowers grain yield (Ge, Sui, et al., 2012). Corn yield response to moisture stress does not alter depending on the source, be it salinity or drought, as both of these sources influence the plants on a similar basis (Katerji, 2003). Yield reduction in maize due to drought can be as much as 70% (Kamara et al., 2003).

Effect on kernel number: Kernel number significantly purloined with increasing duration of medium water stress conditions (Ge, Sui, et al., 2012). Barren or poorly filled ears have resulted because silking was delayed to such an extent that all or much of the pollens were shed (Herrero & Johnson, 1981). A lower kernel number per cob for maize plants grown in water-stress conditions was found, as compared to those grown in water-sufficient conditions. Drought stress when grains are filling in the cob doesn't affect the number of grains unless severe drought is imposed at the onset of the grain filling (Soler et al., 2007). On subjecting the tasseling stage to drought stress, the number of grains decreased by 20%. If both the tasseling and ear formation stages were subjected to drought stress, 32-50% reductions in the kernel number were obtained (Çakir, 2004). Kernel number witnessed a significant reduction in reaction to drought stress (Hall et al., 1982). Discarding irrigation during tasseling and ear formation stage results in lower success in kernel set because of the abortion of the young embryos at low water potential brought about by drought stress at 5 days around pollination (Çakir, 2004). Due to water stress, the intermediates required for the formation of starch get finished and the starch present in the ovary is drained, leading to abortion (Ge, Sui, et al., 2012).

Effect on kernel weight: Water stress significantly reduced grain growth and ear development resulting in significant reductions in kernel weight (Ge, Sun, et al., 2012; Kamara et al., 2003). A decline in the yield of the water-stressed plants is attributed to the underdeveloped kernels, resulting in a potential reduction in the average kernel weight (Soler et al., 2007). Irrigation during the milking stage has a positive impact on the kernel weight. If irrigation is applied during the Vegetative and milking stage and discarded during Tasseling and Ear formation stage, the extent of the kernel set is low, however, the thousand-grain weight of such set grains will be higher because of the prevalence of decreased grains per cob giving rise to the less rivalry for water and nutrients while the grains are filling. (Çakir, 2004). Over 75% of the differences in grain yields during drought can be attributed to variations in the number of ears and kernels per plant. Ear number and kernel number per plant were more significant factors in determining grain yield than kernel weight. The weight of individual kernels appeared to have a more significant influence on grain yield, only in adequately watered conditions (Bolaños and Edmeades, 1996).

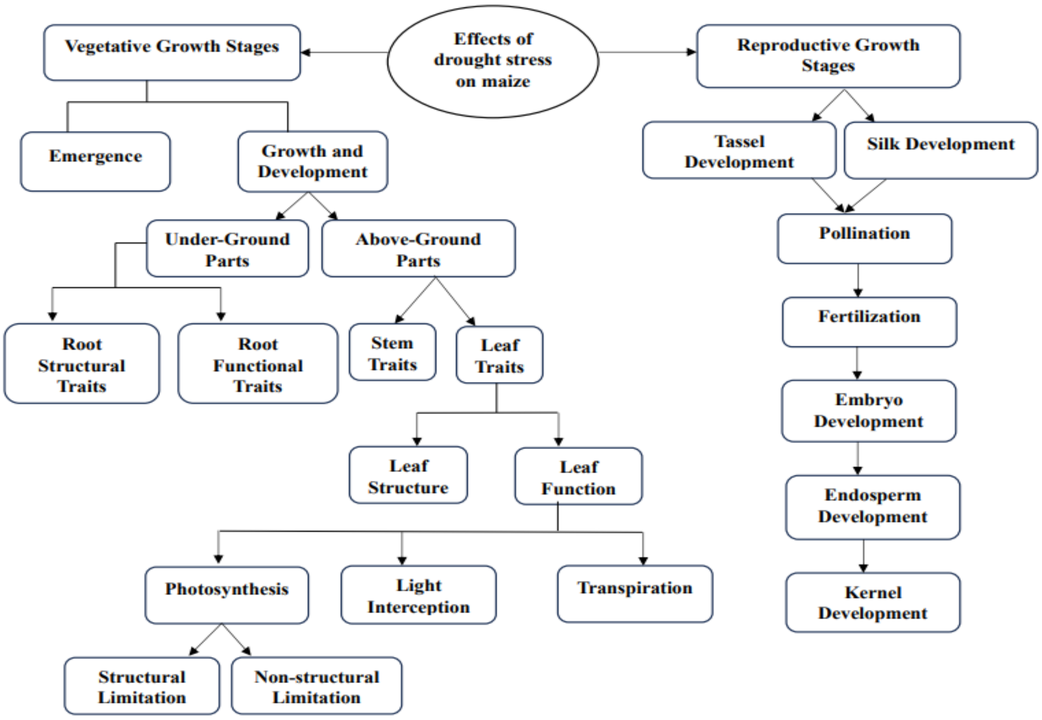

Figure: The impact of drought stress on the vegetative and reproductive phases of maize growth (Aslam et al., 2015)

3.3 Effect on Nutrient Uptake

The capacity of roots to uptake nutrients from soil, which are the plant's principal source of nutrients, and the stem's ability to transfer those nutrients were negatively impacted by soil drought. The nutrient decline is associated with decreased absorption of nutrients (especially of Phosphorus and Potassium) due to a reduction in the transpiration process during moisture deficiency conditions (Sun, Ge et al., 2012). Nitrogen Uptake was also found to be affected by the soil moisture status, suggesting that Nitrogen uptake in maize in both aerial and root biomass was substantially higher in irrigated plants. The increase in Nitrogen uptake under N fertilized and irrigated conditions is reckoned to be due to the enhanced plant biomass under such conditions, thus influencing more uptake of nutrients. Irrespective of the fertilizer treatment, Greater nitrogen absorption occurred in the plants not affected by moisture deficiency. Deficiency of plant available moisture thus diminished the plants' nitrogen recovery, resulting in a simultaneous rise in leftover nitrate levels in the soil (Rimski-Korsakov et al., 2009). In the pragmatic realm, the reduced N recovery by plants under drought stress suggests the need to deliberately apply Nitrogen fertilizers in lower amounts, as doing so lessens the wastage of applied fertilizers and also reduces the residual Nitrogen in the soil.

3.4 Effect on Soluble Proteins

The overall amount of soluble protein found in the roots and leaves of maize fluctuated initially in increasing and then decreasing direction due to stress imposed by moisture deficiency. The severity and length of the moisture deficiency had an impact on the quantity of reduction. Final soluble proteins initially increased under moisture deficiency conditions because of the appearance of new stress-related proteins; however, total soluble proteins decreased as a result of a severe reduction in photosynthesis. Protein synthesis was drastically decreased or possibly stopped since the necessary ingredients weren't available due to a decline in photosynthesis. Dehydrin-like proteins were expressed in response to the increased moisture deficiency and declining water potential. Dehydration and dehydrin accumulation are well associated, as the dehydrin proteins were collected in the roots and leaves of maize plants with declining water potentials accompanied by drought. Some proteins increased while others decreased in response to the drought stress, where, the proteins triggered by drought stress are involved in the plant's reaction to the stress. Dehydrin proteins thus accumulated could defend the cells against additional drying under moisture deficiency (Mohammadkhani and Heidari, 2008). An interpretation that soluble proteins are significant in plants' defense mechanism against drought stress can be drawn from the aforementioned debate.

3.5 Effect on Pigments

The chlorophyll content is greater in irrigated plants than in those under moisture deficiency stress (Majid Khayatnezhad, 2012). Under water stress, chlorophyll contents (a, b, a+b) were found to decline pronouncedly, but under recovery, these values reached normal levels. Drought stress gives rise to an undeniable depletion of photosynthetic reaction centers (PS I and PS II), as is indicated by the reduction in the chl-a concentration imposed by drought. Anthocyanin and proline content of the plants were also found to proliferate under drought stress. Proline, being an osmolyte, is commonly used by plants to enhance membrane stability and also to maintain the protein configuration at reduced water potential. Reduction in the carotene levels under drought stress can be validated by the pigment's association with the photosynthetic reaction centers, which as well, is reduced under a drought environment (Efeoğlu et al., 2009).

4. Conclusion

Drought stress is thus found to pose detrimental impacts on various growth stages, nutrient uptake, and soluble protein constitution in maize. As the global concerns regarding climate change and its implications in agriculture and food production are increasingly becoming a priority, it is indispensable to develop drought-resistant lines based on the knowledge of drought-responsive traits and adaptive mechanisms from a wide genetic pool of landraces, wild and modern cultivars to address the public concerns regarding an impending crisis of climate change surrounding the people, their farms and the farming that they do with their crops. In addition to that, the government must invest its resources to develop the irrigation sector so as to avail enough water for agricultural crops despite the persistence of unreliable and erratic rainfall patterns.

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