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Effect of moisture deficit conditions on the performance of maize (*Zea mays*): A review

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Abstract
Maize (*Zea mays* L.) a high yielding C4 plant is susceptible to thrive under moisture stress conditions. This review article deals on the affect of moisture stress on the morphology and physiology of maize plant and the irrigation management practices that have shown substantial advancements. Several studies revealed negative effects of moisture stress on maize crop wherein severe impact on the cell ultrastructure with reduced relative water content have been noted. As a significance, stomatal conductance is reduced as a result of increased stomatal resistance, followed by proline accumulation with reduced transpiration and respiration thereby disrupting the source to sink relationship which adversely reduce the yield attributes and yield of maize. Maize responds well to irrigation, but, irrigation with increased water use efficiency needs to be quantified to combat the increasing water crisis. Irrigation based on climatological scheduling which takes into consideration the factors like season, climate, soil conditions and growth stages of plants shown to perform wonders in improving the productivity and profitability of cultivation.

Keywords: Maize, moisture stress, morphological parameters, physiological parameters

Introduction

Maize (*Zea mays* L.) is the third most important cereal crop in India after rice and wheat which is also known as “Queen of Cereals” and plays pivotal role in agricultural economy as food for larger section of population, raw materials for industries and feed for animals. It is one of the leading crops grown in the world with an area of 197 million hectare with a production of 1134 million tonnes and productivity of 5.7 tonnes of grain per hectare. In India, maize is grown in an area of 9.2 million hectare, with a production of 28.7 million tonnes and the average productivity is 3.0 tonnes per hectare (FAOSTAT, 2017). In Tamil Nadu, maize is cultivated in an area of 0.31 million hectare with a production of 0.95 million tonnes and productivity of 3.0 tonnes per hectare (India STAT, 2017).

Maize is grown all over the world under a wide range of climates. The current crisis in agricultural production revolves around many issues and ineffective water management is one among them. Irrigation water is becoming a critical scarce resource and expensive due to higher demand by industry and urban consumption and on another side ground water is depleting at an alarming rate (GOR, 2007) and therefore farming strategies to reduce irrigation water losses and enhance crop water productivity (WP) need special attention. Approximately, one third of the cultivated area of the world suffers from chronically inadequate supplies of water (Massacci *et al*., 2008) [50]. Water deficit is the major abiotic factor limiting plant growth and crop productivity around the world (Kramer, 1983) which is responsible for severe yield reduction in maize by 40% on a global scale (Daryanto *et al*., 2015). Deficit irrigation (DI) is an option where water availability limits conventional irrigation and reduces the risk of yield reduction due to terminal dry spell (Singh *et al*., 2010). Earlier, the farmers used their own experience by way of observing about the soil and plant conditions to decide the time of irrigation. Subsequently, with the knowledge gained through research on the soil-plant-water-climate interaction, scientific methods of irrigation scheduling have become possible.

The climatological approach is based on the knowledge that water use by crops is primarily governed by the evaporative demand of the climate. Climatological approach aims at irrigating the crops based on IW/CPE ratio (Prihar, 1974) [67]. Drought stress is considered to be a moderate loss of water, which leads to stomatal closure and limitation of gas exchange.

Stomatal closure decreases water loss, and the movement of CO_2 into the plant. Moreover, photosynthetic rate of the leaves decreases as the relative water content and leaf water potential decrease (Lawlor and Cornic, 2002) [46]. Ennahli and Earl (2005) [23] reported that, under moderate stress, the photosynthetic rate remained unaffected with significant decrease in the carboxylation while, under severe water deficit both photosynthetic rate and concentration of CO_2 at the site of carboxylation decreased. Photosynthesis plays a major role in determining crop productivity in all species and is directly affected by water stress.

Irrigation management for maize

1. Water requirement

The water requirement for optimum yield in maize has been estimated very widely depending upon location, climate (season), soil, variety and irrigation methods. Water requirement for maize under drip irrigation was around 300 mm (Viswanatha *et al*., 2002) [83] in sandy soil of Tamil Nadu and 400 mm at coastal regions of Karnataka (Kammar *et al*., 2019) [39]. In India the net water use was highest (470 mm) at Pantnagar (Mishra *et al*., 2001) [51] and (480mm) New Delhi (Abedinpour *et al*., 2012). Furrow irrigated corn in Central Asian Uzbekistan water use ranged from 547 to 629 mm (Fanish *et al*., 2011) [25]. Optimum irrigation was 520 mm at semi-arid regions with sandy loam soils of Faisalabad, Pakistan (Ahmad *et al*., 2019) [3]. At Rwanda, South Africa the maize water requirement was 330 mm (Uwizeyimana *et al*., 2019) [82]. In egypt, water requirement of maize under rainfed condition was around 630 mm (Eissa and Roshdy, 2019) [22]. In northern China, summer irrigate maize water use was 250 mm (Wu *et al*., 2019) [85] and 540 mm in northwest china (Zhang *et al*., 2019) [87]

2. Frequency of irrigation

Norwood (2000) [59] found that, single irrigation given at tassel initiation stage alone increased maize yield by 29% when comparing to no irrigation in addition to that irrigation during the vegetative stage and grain-filling stage increased yield of 11 and 13%, respectively. In irrigated maize, maximization of yield through optimization of irrigation has been under investigation for many years. The optimum number of irrigations was three to four as observed by Kar and Verma (2005) [40] and reported that higher yield was recorded in four irrigations while WUE was found higher in three irrigations. It may be due to increase in crop water use without a corresponding increase of yield. Generally, six irrigations are required for maize grown in rabi season with 20 to 25 days interval in such a way that one irrigation has to be given at the time of flowering then two irrigations at silking stage and one irrigation at kernel stage. Suppose only five irrigations are going to be given skip the irrigation at vegetative stage. While four irrigations only possible means irrigation at vegetative stage and soft dough stage can be avoided. (DMR, 2012) [19].

3. Scheduling of irrigation

In light textured soils, scheduling the irrigation at 30% depletion of available soil moisture is best suited for crop growth and development while, in heavy soils, irrigation at 70% DASM at vegetative stage and 30% DASM during reproductive stage is more desirable for obtaining good production (MOA, 2015) [54]. Earlier, the farmers used their own experience by way of observing about the soil and plant conditions to decide the time of irrigation. Subsequently, with the knowledge gained through research on the soil-plant-water-climate interaction, scientific methods of irrigation scheduling have become possible.

a) Climatological approach

The climatological approach, which is of the recent origin, is based on the knowledge that water use by crops is primarily governed by the evaporative demand of the climate, provided, there is adequate moisture supply, ground is fully covered and the crop in actively growing stage. Climatological approach aims at irrigating the crops based on IW/CPE ratio (Prihar, 1974) [67].

Tyagi *et al*. (2003) [80] conducted a study on sandy loam soil of Hissar and revealed that in spring maize, irrigation scheduling at IW/CPE 0.6 produced higher number of cob per plant (1.53), cob length (18.1 cm), number of kernels per cob (393.3), test weight (188.3 g) grain yield (5.1 t ha^{-1}) and stover yield (13.9 t ha^{-1}) than IW/CPE ratio of 0.2 and 0.4. Mugalkhod (2005) [55] conducted a study on clay soil at Kolhapur during rabi season and found that scheduling of irrigation at IW/CPE 0.8 and 1.0 produced significantly higher DMP (775.1 and 791.0 q ha^{-1}, respectively) compare to IW/CPE 0.4 and 0.6 ratio owing to increase in plant height, number of leaves and dry matter accumulation in maize.

Adamu (2011) [2] observed that LAI and dry matter production at harvest stage were higher in irrigation scheduled at 75% CPE (3.2 and 143 g $plant^{-1}$, respectively) than 50 and 100% CPE in sandy loam soil of Punjab. Bibe (2016) [12] conducted a study on sandy loam soil at Hissar in maize during summer and found that the plant height and growth attributes like number of leaves, leaf area and leaf area index were significantly higher in IW/CPE ratio of 0.75 than 0.5.

Hussaini *et al*. (2008) [34] reported that IW/CPE ratio 0.6 recorded higher WUE in maize (6.94 kg ha mm^{-1}) compare to 0.8 and 1.0 (6.36 and 6.30 kg ha mm^{-1}, respectively) in sandy soil during rabi season at Samaru, Nigeria. In Coimbatore scheduling irrigation at IW/CPE 0.8 produced higher grain and stover yield in maize (5960, 11428 kg ha^{-1}) compare to IW/CPE 0.6 and 0.4 (Parthasarathi *et al*., 2013) [63]. Ramachandiran and Pazhanivelan (2016) [68] observed that, irrigation scheduling at IW/CPE ratio of 0.5 recorded maximum water use efficiency in maize during summer and kharif (20.6 and 17.3 kg $ha^{-1}mm^{-1}$) than 0.75 and 1.0 ratio (summer 18.7, 14.4 and kharif 11.7 and 11.1 kg ha^{-1} mm^{-1}, respectively) in sandy clay loam soil of Tamil Nadu. Majumder *et al*. (2016) [48] found IW/CPE 1.0 produced higher maize grain yield than IW.CPE 1.2 and 0.75. In maize – kidney beans cropping system, irrigation scheduling at IW/CPE ratio of 1.0 recorded increased crop productivity (Asewar *et al*., 2018) [8].

Scheduling of irrigation at 70 percent of crop coefficient is more suitable for producing better nutrient uptake and maize grain yield (Eissa and Roshdy, 2019) [22]. Irrigating maize once in 12 days under surface irrigated condition and once in 6 days in drip irrigated condition is more reliable for obtaining better water use and yield as reported by Zhang *et al*. (2019) [87]. In Akola, Maharastra scheduling irrigation based on IW/CPE 1.2 recorded higher growth parameters and was on par with IW/CPE 1.0 however higher water use efficiency was recorded in IW/CPE 0.6 (Bhagat *et al*.) in maize.

Water deficit on plant growth and development

The maize crop exhibits reduction in yield with response to soil water deficit at any stage of the crop growth (Mustek and Dusek, 1980; Rhodes *et al*., 1995; Saneoka *et al*., 1995) [56, 70, 72] revealed that stress during vegetative stage was harmful to the crop while at tasseling and silking, still more harmful in terms of crop performance. Many researches show that maize grain yield was very sensitive to soil moisture stress during tasseling to grain filling stage (Smith and Riley, 1992; Norwood and Currie, 1996; Norwood, 2000; Kipkorir *et al*., 2002) [76, 58, 59, 42].

Plant fresh and dry biomass productions are adversely affected by water stress (Zhou *et al*., 2011) [88]. It affects leaf size, stems extension, and root proliferation, troubles plant water relations, and decreases water use efficiency. It disrupts photosynthetic pigments and reduces the gas exchange and the production of active oxygen species leading to decrease in plant growth and yield (Jain *et al*., 2019) [35]. Water deficit affects the leaf area index by reducing leaf number per plant, individual leaf size and leaf longevity which was directly proportional to the soil water potential. Expansion in leaf area depends on leaf turgor, temperature, and photo-assimilation supply, drought-induce reduction in leaf turgor and photoassimilation with increased surface temperature of the leaf leads to suppression of leaf area expansion (Zarrouk *et al*., 2019) [86]

1. **Effect of water deficit on plant morphological characteristics**

Khan *et al.* (2001) [41] conducted a study on different irrigation levels in maize and concluded that water stress and plant growth parameters like, height, stem diameter and leaf area are indirectly proportional. Kamara *et al.* (2003) [38] imposed water deficit on different growth stages of maize and revealed that water deficit had major impact at silking stage. The total biomass accumulation was reduced by 37% at silking stage whereas it was 34% at grain filling stage and 21% at maturity. During water stress the plant height and leaf area index reduction was mainly due to the decline in cell division and early leaf senescence (Manivannan *et al*., 2007) [49].

Suralta and Yamauchi (2008) [79] reported that the reduced nodal root production in drought condition influenced the formation of root biomass in rice. Drought led to substantial impairment in maize growth by reduction in plant height, leaf number, LAI, cob length and dry matter production. According to Farooq *et al.* (2009) [26], the changes in leaf size and stomatal opening as potential adaptive mechanisms which helped the plant avoid drought, by reducing the rate of transpiration. Water deficit in the early stages of tomato showed a greater effect on reduction in plant height (Alex *et al*., 2012) [5]. Almeselmani *et al*. (2012) [6] stated that more number of tillers m-2 were recorded in tolerant and moderately tolerant wheat varieties compared to drought susceptible varieties. Drought stress suppressed leaf expansion, tillering and midday photosynthesis (Bunnag and Pongthai, 2013) [13] that led to lower production of biomass in rice.

Dwivedi *et al.* (2017) [21] found that heat and drought stress at reproductive stage caused reduction in plant height (8.87%), number of tillers (12) and leaf area by (34.87%) in rice compared to the control plot. Durand *et al*. (2018) [20] found that under drought conditions, early senescence resulted in the reduction in leaf area, dry matter production in maize.

2. **Effect of water deficit on physiological characteristics**

a) **Relative water content**

Relative water content (RWC) was a measure of plant water status, which reflected the metabolic activity in tissues and was used as an index for dehydration tolerance.

Goyal *et al.* (2001) [31] reported that a significant reduction in RWC was observed during stress condition in pearl millet. RWC had decreased significantly in water stressed plants at both vegetative and flowering stages of moth bean. Under drought stress conditions, RWC was also proposed as an important indicator of water status than other water potential parameters (Dhanda and Sethi, 2002) [18]. In general, early flowering genotypes maintained higher RWC than late flowering genotypes of bean under water stress condition (Garg *et al*., 2004) [30]. Nayyar and Gupta (2006) [57] reported that when leaves were subjected to drought, they exhibit large reductions in RWC and water potential.

Water stress treatments led to gradual decline in leaf RWC in french bean cultivars. The stressed plants of tolerant cultivar maintained relatively balanced RWC. As the stress duration increased, there was decline in RWC (Upreti and Murti, 2005) [81]. Galmes *et al*. (2011) [29] reported that the leaf RWC significantly decreased in all accessions of tomato under water stress conditions. Kumar *et al*. (2011) [44] also noticed a significant reduction in RWC under water stress condition in pigeon pea.

b) **Effect of water deficit on stomatal factors and non-stomatal factors**

Closure of stomata is considered to be a plant tolerance mechanism to avoid the water loss but it leads to limit the gas exchange process. Negative correlation between leaf water content and stomatal conductance has been observed by Socias *et al.* (1997) [77].

Pettigrew (2004) [66] speculated that rehydrated plants has higher chlorophyll content, net photosynthetic rate and increased PSII quantum efficiency compared to normally irrigated plants. Similarly, Massacci *et al*. (2008) [50] observed that, higher efficiency of photosynthesis in PSII reaction center with enhanced electron transport under moisture deficit condition and also observed increased photo respiration during water deficit initiation to inhibit the reactive oxygen production which will cause damage in the photosynthetic apparatus.

Upon relief from the water stress, CO_2 concentrations returned to control levels, photosynthetic rates remained low indicating metabolic and non-stomatal inhibition (Pettigrew, 2004) [66]. Ennahli and Earl (2005) [23] reported that under moderate stress, the photosynthetic rate remained unaffected with significant decrease in the velocity of carboxylation of Rubisco without affecting the CO_2 concentration at the site of carboxylation. Under severe water deficit both photosynthetic rate and concentration of CO_2 at the site of carboxylation decreased. In water stress there will be a progressive increase in water potential leading to complete closer of the stomata (Cincera *et al*., 2019) [15].

c) **Proline content**

Proline an amino acid, acts as osmo-protectant under different abiotic stresses like, drought, salinity and extremes of temperature. As an osmolyte, it serves as an indicator of abiotic stress responses. Proline concentration was used with other physiological parameters to understand the physiological responses of plants to drought (Parvathi *et al*., 2013) [64]. Dalvi *et al*. (2007) [16] stated that the differences recorded in free proline content of drought tolerant and susceptible genotypes of both sorghum and chickpea were significant. Parida *et al*. (2008) [62] suggested that the levels of both osmolytes namely; proline and glycine betaine increased simultaneously under water stress condition and could be used to select the drought tolerant segregating population involving breeding of cotton for drought tolerance.

Johari Pireivatlou (2010) [36] reported an increased proline content was observed in tolerant wheat cultivar by water stress at 30 per cent field capacity than control. Similarly, increase in free proline content due to water deficit was reported by Akhkha *et al*. (2011) [4] in wheat. Patel *et al*. (2012) [65] showed that the proline content was increased significantly by drought stress in chickpea. Under water stress, proline content increased more than other amino acids (Fahramand *et al*., 2014) [24]. Thus, proline content could be used as criterion for screening drought tolerant rice varieties. Similarly, various studies confirmed the accumulation of proline in rice genotypes exposed to drought stress (Pandey and Shukla, 2015) [61]. Proline accumulation promoted plant damage repairability by increasing the antioxidant activity during drought stress (Mishra and Chaturvedi, 2018) [52].

3. Gas exchange parameters

a) Transpiration rate

Transpiration is the process of water loss in the form of water vapour from leaves and other aerial parts of plant. Under water stress, transpiration decreased as a reflex to drought stimuli (Souza *et al*., 2004) [78]. Under severe stressed condition, there was a significant reduction in transpiration rate in maize lines (Kumari *et al*., 2004) [45]. According to Kudoyarova *et al*. (2006) [43], partial drying of root zone decreased the whole plant transpiration rate by 22 per cent in tomato plants. Similar results were reported in rice by (Jones *et al*., 2009) [37].

In tomato, Mingchi *et al*. (2010) [51] found that the stomatal conductance was affected under simulated drought stress. Reduction in stomatal conductance decreased transpiration and limited the photosynthesis rate in rice (Sikuku *et al*., 2010) [74]. Anjum *et al*. (2011) [7] indicated that drought stress in maize led to considerable decline in transpiration rate (37.84%), water use efficiency (50.87%), intrinsic water use efficiency (11.58%) and intercellular CO_2 (5.86%) as compared to well water control.

b) Stomatal conductance

Ashraf *et al*. (2002) [9] observed that in grafted and 100% stressed bhendi plants, stomatal conductance varied from 0.09 to 0.12 mol m-2 s^{-1}, while in non-grafted it was 0.4 to 0.12 mol m^{-2} s^{-1} at the same level of water stress. Reduced stomatal conductance and photosynthetic rate were observed under 50 per cent and 100 per cent water stress than control in bhendi.

Water stress in different cultivars of tomato reduced the rate of photosynthesis, transpiration, leaf temperature and increased the stomatal resistance (Hnilickova and Duffek, 2004) [33]. Besides the above, subtle change in the intercellular CO_2 concentration was observed in soybean by (Ohashi *et al*., 2006) [60].

Anjum *et al*. (2011) [7] indicated that drought stress in maize led to considerable decline in stomatal conductance (25.5%) and intercellular CO_2 (5.8%) as compared to well irrigated control. The response pattern of crop yield and gas exchange parameters to heat and drought stress in rice imposed at different growth stages might provide basis for selecting the most tolerant variety to combined stresses in order to stabilize yield and solve food crisis (Sikuku *et al*., 2012) [72].

c) Effect of water deficit on photosynthesis

In general plant productivity was determined by the photosynthesis of the plant in all the species and it is directly affected by water stress as the result of reduction in relative water content and leaf water potential (Lawlor and Cornic, 2002) [46]. Closer of stomata directly affects the CO_2 diffusion from outside to the site of carboxylation takes place. The reduction in carbon dioxide diffusion is mainly due to reduced conductance of mesophyll (Chaves and Oliveira, 2004; Flexas *et al*., 2004; Warren *et al*., 2004) [14, 27, 84]. Maiti *et al*. (2010) [47] confirmed that the decrease in ATP content due to water deficit in cotton at reproductive stage and increase in nicotinamide adenine dinucleotide phosphate (NADP) was observed while the 3-phosphoglyceric acid (3-PGA) and pyruvate content remain unaffected by the water stress.

Sikuku *et al*. (2010) [74] indicated that the inhibition of chlorophyll synthesis and inability of sensitive wheat to withstand water deficit. (Akhkha *et al*., 2011) [4] confirmed that the highest reduction in the photosynthetic rate was observed in susceptible wheat cultivar to water stress (30% FC). Alex *et al*. (2012) [5] showed that water deficit earlier in the growth of tomato caused a significant reduction in leaf chlorophyll content. Sanadhya *et al*. (2012) [71] opined that the water stress reduced the photosynthetic rate with increased levels of stress in mungbean.

d) Effect of water deficit on respiration

Plants energy was obtained from respiration by producing water, carbon dioxide and adenosine 5-triphosphate (ATP) during this process oxygen was used to react with sugars (Glucose). The respiration rate was varying in day and night time during day time the respiration rate was 25% while in night it was nearly 100% (Galmés *et al*., 2007) [28]. According to Atkin and Macherel (2008) [10], respiration rate during day time was increased by 12% in response to moisture deficit and it varies with plant, genotype, growth stage of the plant and also severity of stress. During the drought period ATP demand for photosynthetic activity gets reduced. Jain *et al*. (2019) [35] reported that water deficit stress increased the maize plant respiration by 34%.

4. Effect of water deficit on yield

Plant dry matter production and yield depends on leaf area, leaf development which was primarily affected by water stress hence, the light interception tend to decline and severally affects the dry matter production and yield of the crop (Sinclair and Muchow, 2001) [75]. Adamu (2011) [2] found that, under limited irrigated condition water use efficiency was higher than that of full irrigation but in terms of profitability full irrigation was more desirable.

In well irrigated condition higher maize grain yield was recorded 11.8 t ha^{-1} in limited irrigated condition the yield was 10.1 t ha^{-1} while, under rainfed condition yield was 5.6 t ha^{-1} (Hashemi *et al*., 2005) [32]. When maize plants were exposed to drought stress at tasseling stage, it led to substantial reduction in yield and yield components such a seed rows cob^{-1}, number of seeds row^{-1}, 100 seed weight, number of seeds cob^{-1}, grain yield $plant^{-1}$, total drymatter production $plant^{-1}$ and harvest index (Anjum *et al*., 2011) [7]. Reddy *et al*. (2012) [69] observed that in maize irrigation scheduled at IW/CPE ratio of 0.6 was recorded 31 per cent and 16 per cent lower yield than irrigation scheduled at 1.0 and 0.8 respectively.

Conclusion

From the present review it is well known that, maize is very sensitive crop to moisture deficit and its growth and development is significantly affected by water stress, with primary impact on plant morphology, cell ultrastructure and physiological process. Improper water availability has shown to adversely affect the crop with reduced relative water content, reduced stomatal conductance, increased proline content, along with reduced transpiration and respiration rates which ultimately affect the yield potential of the crop. Maize has shown positive response to irrigation but, in order to improve water use efficiency optimum irrigation based on climatological scheduling is to be quantified for different season, crop growth stages as well as soil conditions.

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