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

M Rajasekar, Syed Abul Hassan Hussainy and A Karthik

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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). 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). 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 CO₂ into the plant. Moreover, photosynthetic rate of the leaves decreases as the relative water content and leaf water potential decrease (Lawlor and Cornic, 2002) [40]. Ennahlil 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 CO₂ 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 Panntagar (Mishra et al., 2001) [51] and (480mm) New Delhi (Abdinpour 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 (Uwizeymana 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) [84] reported that IW/CPE ratio 0.6 recorded higher WUE in maize (6.94 kg ha⁻¹ mm⁻¹) compare to 0.8 and 1.0 (6.36 and 6.30 kg ha⁻¹ 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⁻¹mm⁻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) [46] 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, Maharashtra 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 (Bhat 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].

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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) [78, 58, 59, 42].

Plant fresh and dry biomass productions are adversely affected by water stress (Zhou et al., 2011) [83]. 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) [155]. 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) [81] 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) [138] 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) [77] 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) [144] 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, CO2 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 CO2 concentration at the site of carboxylation. Under severe water deficit both photosynthetic rate and concentration of CO2 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 osmo-lytes 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 Akhkhla 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) [23]. 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 CO2 (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 CO2 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 CO2 (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 CO2 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, 64]. 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. (Akhkhla 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) [3] showed that water deficit earlier in the growth of tomato caused a significant reduction in leaf chlorophyll content. Sandahya 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) [29]. 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 severely 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 as 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.

References
1. Abedinpour M, Sarangi A, Rajput TBS, Man Singh, Pathak H, Ahmad T. Performance evaluation of AquaCrop model for maize crop in a semi-arid environment. Agricultural water management. 2012; 110:55-66.
2. Adamu, Chigign. Response of Maize (Zea mays L.) Hybrids to Irrigation Scheduling During Rabi Season in Malaprabha Command Area. UAS, Dharwad, 2011.
3. Ahmad, Ishfaq, Syed Aftab Wajid, Ashfaq Ahmad, Muhammad Jehanzeb Masud Cheema, Jasmeet Judge. Optimizing irrigation and nitrogen requirements for maize through empirical modeling in semi-arid environment. Environmental Science and Pollution Research. 2019; 26(2):1227-1237.
4. Akkhia, Abbeldar, Tahar Boutraa, Ali Alhejely. The rates of photosynthesis, chlorophyll content, dark respiration, proline and abscisic acid (ABA) in wheat (Triticum durum) under water deficit conditions. International Journal of Agriculture and Biology. 2011; 13(2).
5. Alex, Lennox, Yu-Min Wang, Ching-Hsiang Hsieh, Tsou I. Using deficit irrigation approach for evaluating the effects of water restriction on field grown tomato (Lycopersicon esculentum). African Journal of Agricultural Research. 2012; 7(14):2083-2095.
6. Almeselmani, Moaed, Abd Al-rzak Saud, Kamal Al-zubi, Fouad Hareri, Mahran Al-nassan et al. Physiological attributes associated to water deficit tolerance of Syrian durum wheat varieties. Experimental Agriculture and Horticulture. 2012; 8:21-41.
7. Anjum SA, Farooq M, Wang LC, Xue LL, Wang SG, Wang L et al. Gas exchange and chlorophyll synthesis of maize cultivars are enhanced by exogenously-applied glycinebetaine under drought conditions. Plant, Soil and Environment. 2011; 57(7):326-331.
8. Asewar BV, Raja V, Sudhakar C, Baby Akula, Baig IMB. Growth and Yield of Maize-Rajmash Cropping Sequence Affected by Different Agronomic Practices, 2018.
9. Ashraf M, Arfan M, Shahbaz M, Ashfaq Ahmad, Jamil A. Gas exchange characteristics and water relations in some elite okra cultivars under water deficit. Photosynthetica. 2002; 40(4):615-620.
10. Atkin, Owen K, David Macherel. The crucial role of plant mitochondria in orchestrating drought tolerance. Annals of botany. 2008; 103(4):581-597.
11. Bhagat AP, Bhole VM, Saogi BV, Kubde KJ, Kharche VK, Kadu PR et al. Reciprocating preliminary effect on fodder maize as influenced by irrigation regimes and fertilizer levels grown in summer season, 2019.
12. Bibe, Sandip Manoharrao. Studies on irrigation and fertigation management in post Kharif maize. Vasantrao Naik Marathwada Krishi Vidyyapeeth, Parbhani, 2016.
13. Bunnag, Sumontip, Prapaporn Pongthai. Selection of rice (Oryza sativa L.) cultivars tolerant to drought stress at the vegetative stage under field conditions. American Journal of Plant Sciences. 2013; 4(09):1701.
14. Chaves MM, Oliveira MM. Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture. Journal of Experimental Botany. 2004; 55(407):2363-2384.
15. Cincera, Irene, Tommaso Frioni, Virginia Ughini, Stefano Poni, Daniela Farinelli et al. Intra-specific variability of stomatal sensitivity to vapour pressure deficit in Corlylus avellana L. A candidate factor influencing different adaptability to different climates? Journal of plant physiology. 2019; 232:241-247.
16. Dalvi US, Chavan UD, Kachare DP, Naik RM. Proline metabolism in sorghum and chickpea cultivars during water stress. Indian Journal of Plant Physiology. 2007; 12(3):287-289.
17. Denmead OT, Robert H Shaw. The Effects of Soil Moisture Stress at Different Stages of Growth on the Development and Yield of Com 1. Agronomy Journal. 1960; 52(5):272-274.
18. Dhandha SS, Sethi GS. Tolerance to drought stress among selected Indian wheat cultivars. The journal of agricultural science. 2002; 139(3):319-326.
19. DMR. Annual Report, Directorate of Maize Research, Indian Council of Agricultural Research, New Delhi, 2012.
20. Durand, Jean-Louis, Kenel Delusca, Ken Boote, Jon Lizzio, Remy Manderscheid et al. How accurately do maize crop models simulate the interactions of atmospheric CO2 concentration levels with limited water supply on water use and yield? European journal of agronomy. 2018; 100:67-75.
21. Dwivedi SK, Sahana Basu, Santosh Kumar, Gautam Kumar, Ved Prakash, Sanjeev Kumar et al. Heat stress induced impairment of starch mobilisation regulates pollen viability and grain yield in wheat: Study in Eastern Indo-Gangetic Plains. Field Crops Research. 2017; 206:106-114.
22. Eissa, Mamdouh A, Nadia MK Roshdy. Effect of nitrogen rates on drip irrigated maize grown under deficit irrigation. Journal of Plant Nutrition. 2019; 42(2):127-136.
23. Ennahli Said, Hugh J Earl. Physiological limitations to photosynthetic carbon assimilation in cotton under water stress. Crop Science. 2005; 45(6):2374-2382.
24. Fahramand Mohammad, Malike Mahmood, Alireza Keykha, Mohsen Noori, Khashayar Rigi. Influence of abiotic stress on proline, photosynthetic enzymes and growth. Int Res J Appl Basic Sci. 2014; 8(3):257-265.
25. Fanish S, Anitta, Muthukrishnan P, Santhi P. Effect of drip fertigation on field crops-a review. Agricultural Reviews. 2011; 32(1).
26. Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA. Plant drought stress: effects, mechanisms and management. In Sustainable agriculture, Springer.
27. Flexas, Jaume, Josefinna Bota, Josep Cifre, José Mariano Escalona, Jeroni Galmés et al. Understanding down-regulation of photosynthesis under water stress: future prospects and searching for physiological tools for irrigation management. Annals of applied Biology. 2004; 144(3):273-283.
28. Galmés J, Ribas-Carbó M, Medrano H, Flexas J. Response of leaf respiration to water stress in...
Mediterranean species with different growth forms. Journal of Arid Environments. 2007; 68(2):206-222.

29. Galmes Jeroni, Miquel Angel Conesa, Joan Manuel Ochogavia, Juan Alejandro Perdomo, David M Francis, Miquel Ribas-Carbó et al. Physiological and morphological adaptations in relation to water use efficiency in Mediterranean accessions of Solanum lycopersicum. Plant, Cell & Environment. 2011; 34(2):245-260.

30. Garg Balvinder K, Uday Burman, Shyam Kathju. The influence of phosphorus nutrition on the physiological response of moth bean genotypes to drought. Journal of Plant Nutrition and Soil Science. 2004; 167(4):503-508.

31. Goyal Vinod, Sudha Jain, Binothi NR, Renu Munjal. Leaf water relations, diffusive resistance and proline accumulation in hybrid pearl millet under depleting soil moisture content. Indian Journal of Plant Physiology. 2001; 6(1):41-45.

32. Hashemi, Abolhassan M, Stephen J Herbert, Daniel H Putnam. Yield response of corn to crowding stress. Agronomy Journal. 2005; 97(3):839-846.

33. Hnilickova H, Duffek J. The effect of water deficit and subsequent regeneration on selected physiological characteristics in tomatoes (Lycopersicon esculentum). Scientia Agriculturae Bohemica (Czech Republic). 2004.

34. Hussaini MA, Ogunlela VB, Ramalan AA, Falaki AM. Mineral composition of dry season maize (Zea mays L.) in response to varying levels of nitrogen, phosphorus and irrigation at Kadawa, Nigeria. World Journal of Agricultural Sciences. 2008; 4(6):775-780.

35. Jain Meeta, Sunita Kataria, Mamta Hirve, Rajkumar Prajapati. Water Deficit Stress Effects and Responses in Maize. In Plant Abiotic Stress Tolerance, Springer, 2019, 129-151.

36. Johari Pireivatilou M. Effect of soil water stress on yield and proline content of four wheat lines. African Journal of Biotechnology. 2010; 9(1).

37. Jones Hamlyn G, Rachid Serraj, Brian R Loveys, Lzhong Xiong, Ashley Wheaton, Adam H Price. Thermal infrared imaging of crop canopies for the remote diagnosis and quantification of plant responses to water stress in the field. Functional Plant Biology. 2009; 36(11):978-989.

38. Kamara AY, Menkiv A, Badu-Apaku B, Ibikunle O. The influence of drought stress on growth, yield and yield components of selected maize genotypes. The journal of agricultural science. 2003; 141(1):43-50.

39. Kammur Mouneshwari R, Arjun Sulagitti, Mahesh Kadagi, Biradar AP. An experience of hydroponics fodder production by farmers of Bagalkot district. Journal of Pharmacognosy and Phytochemistry. 2019; 8(1):1033-1035.

40. Kar Gouranga, Harsh Nath Verma. Phenology based irrigation scheduling and determination of crop coefficient of winter maize in rice fallow of eastern India. Agricultural water management. 2005; 75(3):169-183.

41. Khan Muhammad Bismillah, Nazim Hussain, Muhammad Iqbal. Effect of water stress on growth and yield components of maize variety YHS 202. Journal of Research Science. 2001; 12(1):15-18.

42. Kipkorir EC, Dirk Raes, Massawe B. Seasonal water production functions and yield response factors for maize and onion in Perkerra, Kenya. Agricultural water management. 2002; 56(3):229-240.

43. Kudoyarova Guzel R, Lidia B Vysotskaya, Alla Cherkozyanova, Ian C Dodd. Effect of partial rootzone drying on the concentration of zeatin-type cytokinins in tomato (Solanum lycopersicum L.) xylem sap and leaves. Journal of Experimental Botany. 2006; 58(2):161-168.

44. Kumar Ravi Ranjan, Krishna Karajol, Naik GR. Effect of polyethylene glycol induced water stress on physiological and biochemical responses in pigeonpea (Cajanus cajan L. Milsp.). Recent Research in Science and Technology, 2011; 3(1).

45. Kumari Meena, Sain Dass, Vimala Y, Pawan Arora. Physiological parameters governing drought tolerance in maize. Indian Journal of Plant Physiology. 2004; 9:203-207.

46. Lawlor D Wit, Cornic G. Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. Plant, Cell & Environment. 2002; 25(2):275-294.

47. Maiti Arpan Kumar, Nima Chandra Saha, Goutam Paul. Effect of lead on oxidative stress, Na+ K+ ATPase activity and mitochondrial electron transport chain activity of the brain of Clarias batrachus L. Bulletin of environmental contamination and toxicology. 2010; 84(6):672-676.

48. Majumder, Debiyoti, Kingra PK, Kulal SS. Water productivity of spring maize under modified soil microenvironment. Journal of Agrometeorology. 2016; 18(1):134.

49. Manivannan P, Abdul Jaleel C, Kishorekumar A, Sankar B, Somasundaram R, Sridharan R et al. Changes in antioxidant metabolism of Vigna unguiculata (L.) Walp. by propiconazole under water deficit stress. Colloids and Surfaces B: Biointerfaces. 2007; 57(1):69-74.

50. Massacci A, Nabiev SM, Pietrosanti L, Nematov SK, Chernikova TN, Thor K et al. Response of the photosynthetic apparatus of cotton (Gossypium hirsutum) to the onset of drought stress under field conditions studied by gas-exchange analysis and chlorophyll fluorescence imaging. Plant Physiology and Biochemistry. 2008; 46(2):189-195.

51. Mingchi Liu, Liu Xiangli, Hao Jing, Gao LiHong. Effect of simulated drought stress on plant growth, yield and fruit properties of tomato. Acta horticulturae. 2010; (856):193.

52. Mishra BK, Chaturvedi GS. Flowering stage drought stress resistance in upland rice in relation to physiological, biochemical traits and yield. Int. J. Curr. Microbiol. App. Sci. 2018; 7(2):71-82.

53. Mishra H, Rathore T, Savita U. Water-use efficiency of irrigated winter maize under cool weather conditions of India. Irrigation Science. 2001; 21(1):27-33.

54. MOA. Ministry of Agriculture. British, Columbia, 2015.

55. Mugalkhod, Anil Kumar S. Response of baby corn to planting methods and irrigations schedules under drip. UAS, Darwad, 2005.

56. Mustek JT, Dusek DA. Irrigated corn yield response to water. Transactions of the ASAE. 1980; 23(1):92-0098.

57. Nayyar Harsh, Deepit Gupta. Differential sensitivity of C3 and C4 plants to water deficit stress: association with oxidative stress and antioxidants. Environmental and Experimental Botany. 2006; 58(1-3):106-113.

58. Norwood Charles A, Randall S Currie. Tillage, planting date, and plant population effects on dryland corn. Journal of production agriculture. 1996; 9(1):119-122.

59. Norwood Charles A. Water Use and Yield of Limited-Irrigated and Dryland Corn. 1 Mention of a trade name does not imply endorsement by Kansas State University over comparable products. Kansas Agric. Exp. Stn.
Contribution no. 99-345-J. Research supported in part by a grant from the Kansas Corn Commission." Soil Science Society of America Journal. 2000; 64(1):365-370. doi: 10.2136/sssaj2000.641365x.

60. Ohashi Y, Nakayama N, Saneoka H, Fujita K. Effects of drought stress on photosynthetic gas exchange, chlorophyll fluorescence and stem diameter of soybean plants. Biologia plantarum. 2006; 50(1):138-141.

61. Pandey Veena, Alok Shukla. Acclimation and tolerance strategies of rice under drought stress. Rice Science. 2015; 22(4):147-161.

62. Parida Asish Kumar, Vipin S Dagaonkar, Manoj S Phalak, Laxman P Aurangabadkar. Differential responses of the enzymes involved in proline biosynthesis and degradation in drought tolerant and sensitive cotton genotypes during drought stress and recovery. Acta Physiologiae Plantarum. 2008; 30(5):619-627.

63. Parthasarathi T, Vanitha K, Velu G. Impact of irrigation water stress and plant population on water productivity and maize yield. Madras Agricultural Journal. 2013; 100(1-3):95-97.

64. Parvathi MS, Karaba Nataraja N, Yashoda BK, Ramegowda HV, Mamrutha HM, Rama N. Expression analysis of stress responsive pathway genes linked to drought hardiness in an adapted crop, finger millet (Eleusine coracana). Journal of plant biochemistry and biotechnology. 2013; 22(2):193-201.

65. Patel, Pradeep Kumar, Hemantaranjan A, Sarma BK. Effect of salicylic acid on growth and metabolism of chickpea (Cicer Arietinum L.) under drought stress. Indian J. Plant Physiol. 2012; 17(2):151-157.

66. Pettigrew WT. Physiological consequences of moisture deficit stress in cotton. Crop Science. 2004; 44(4):1265-1272.

67. Prihar SS. Scheduling irrigations to wheat, using pan evaporation. Indian Journal of Agricultural Science. 1974; 44:567-571.

68. Ramachandiran K, Pazhanivelan S. Abiotic factors (nitrogen and water) in maize: A review. Agricultural Reviews. 2016; 37(4).

69. Reddy, Malla M, Madnaja B, Vishnu Vardhan Reddy D. Response of maize (Zea mays) To irrigation scheduling and nitrogen doses under no till condition in rice fallsows. The Global users can now retrieve the articles from Journal on the repository of Commonwealth Agricultural Bureaux International (CABI) on, 2012, 6.

70. Rhodes, Carol A, Kathleen A Marrs, Lynn E Murry. Transformation of maize by electroporation of embryos". In Plant Cell Electroporation and Electrofusion Protocols, Springer, 1995, 121-131.

71. Sanadhya, Dheera, Ekta Kathuria, Kakralya BL, Malik CP. Influence of plant growth regulators on photosynthesis in mung bean subjected to water stress." Indian J. Plant Physiol. 2012; 17(3-4):241-245.

72. Saneoka, Hirofumi, Chie Nagasaka, Daniel T Hahn, Wen-Ju Yang, Gnanasiri S Premachandra et al. Salt tolerance of glycinebetaine-deficient and-containing maize lines. Plant Physiology. 1995; 107(2):631-638.

73. Sikuku PA, Netondo GW, Onyango JC. Physiological and biochemical responses of five nerica rice varieties (Oryza sativa L.) to water deficit at vegetative and reproductive stage, 2012.

74. Sikuku PA, Netondo GW, Onyango JC, Musyimi DM. Effects of water deficit on morphology and physiology of three varieties of NERICA rainfed rice (Oryza sativa L.), 2010.

75. Sinclair, Thomas R, Russell C Muchow. System analysis of plant traits to increase grain yield on limited water supplies. Agronomy Journal. 2001; 93(2):263-270.

76. Smith MS, Riley TJ. Direct and interactive effects of planting date, irrigation, and corn earworm (Lepidoptera: Noctuidae) damage on aflatoxin production in preharvest field corn." Journal of economic entomology. 1992; 85(3):998-1006.

77. Socias X, Correia MJ, Chaves M, Medrano H. The role of abscisic acid and water relations in drought responses of subterranean clover. Journal of Experimental Botany. 1997; 48(6):1281-1288.

78. Souza RP, Machado EC, Silva JAB, Lagôa AMMA, Silveira JAG. Photosynthetic gas exchange, chlorophyll fluorescence and some associated metabolic changes in cowpea (Vigna unguiculata) during water stress and recovery. Environmental and Experimental Botany. 2004; 51(1):45-56.

79. Suralta Roel R, Akira Yamauchi. Root growth, aerenchyma development, and oxygen transport in rice genotypes subjected to drought and waterlogging. Environmental and Experimental Botany. 2008; 64(1):75-82.

80. Tyagi Narendra K, Dinesh K Sharma, Surendra K Luthra. Determination of evapotranspiration for maize and berseem clover. Irrigation Science. 2003; 21(4):173-181.

81. Upeti KK, Murti GSR. Water stress induced changes in common polyamines and abscisic acid in French bean.” Indian Journal of Plant Physiology. 2005; 10(2):145.

82. Uwizeyimana, Dieudonne, Stephen M Mureithi, Sithon M Mvuyekure, George Karuko, Geoffrey Kironchi. Modelling surface runoff using the soil conservation service-curve number method in a drought prone agro-ecological zone in Rwanda. International Soil and Water Conservation Research. 2019; 7(1):9-17.

83. Viswanatha GB, Ramachandrappa BK, Nanjappa HV. Soil–plant water status and yield of sweet corn (Zea mays L. cv. Saccharata) as influenced by drip irrigation and planting methods. Agricultural water management. 2002; 55(2):85-91.

84. Warren Ch R, Livingston NJ, Turpin DH. Water stress decreases the transfer conductance of Douglas-fir (Pseudotsuga menziesii) seedlings. Tree Physiology. 2004; 24(9):971-979.

85. Wu, Dong, Shibo Fang, Xuan Li, Di He, Yongchao Zhu, Zaiqiang Yang. Using irrigation intervals to optimize water-use efficiency and maize yield in Xinjiang, northwest China. The Crop Journal, 2019.

86. Zhou, Jian-bin, Chun-yan Wang, Hong Zhang, Fang Dong, Xian-feng Zheng, William Gale et al. Effect of water saving management practices and nitrogen fertilizer rate on crop yield and water use efficiency in a winter wheat–summer maize cropping system. Field Crops Research. 2011; 122(2):157-163.

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