Review Article

Agronomic interventions for alleviating water stress and optimizing productivity of field crops:A review

Abstract

Water scarcity is the most significant concern facing agriculture today. Agriculture currently utilizes more than 70% of the world's freshwater, with much of it lost through evaporation, leaching and runoff. Drought escape and drought tolerance are the two significant mechanisms for plant growth under water-stressed conditions. Drought, a primary abiotic factor, limits crop productivity. It is a climatic phenomenon characterized by a prolonged lack of rainfall, resulting in moisture loss from the soil and a lack of water potential in plant tissues. It prevents the crop from obtaining its potential yield and substantially reduces crop production.Field crop rely on rainfall and are vulnerable to unpredictable drought stress throughout their vegetative and reproductive growth cycle. Drought stress is typical during the flowering stage in mostly crops, resulting in lower yield when cultivated with scarce rainfall. It can be reduced through agronomic means, such as mulching, tillage, intercropping and nutrient management, as well as chemical measures, such as the use of soil additives herbal hydrogel (*Gond katira*), foliar spray of salicylic acid and potassium nitrate. Herbal hydrgel helps in reducing the effect of drought stress on plants while also promoting increased plant growth and opverall performance. Foliar application of salicylic acid boosted bioactive chemical synthesis in the presence of water deficiency. Potassium nitrate to enhance water uptake, promote longer pod length and improve drought tolerance in plants.

Key words: Field crops, drought stress, salicylic acid, herbal hydrogel (*Gond katira*), potassium-nitrate

Introduction

“Agriculture is a cause and a victim of water scarcity. The excessive use and degradation of water resources are creating threat to the sustainability of livelihoods dependent on water and agriculture” (Rasul, 2023). “There is a need for actions and strategies that holistically address the interlinkages among water scarcity, agricultural production, food security and climate change.Water stress is considered a worldwide problem and one of the most and major abiotic stresses. Over 25% of the world’s agricultural lands is now affected and suffering from water stress” (Abido and Zsombik, 2018). “Among all abiotic stresses, drought is considered the most damaging natural disaster due to its prolonged and extensive socioeconomic impacts” (Ahmadalipour*et al*., 2019). “About 330 million people in 2.5 lakh villages of 11 states in India were affected by drought in 2016 due to deficit rainfall during two consecutive years” (Jayan, 2019).“Drought stress causes a broad range of physiological changes and impairments of metabolic processes, which result in accumulation of reactive oxygen species” (Abid*et al*., 2018;Lawlor and Cornic, 2002,Qaseem*et al*., 2019).“The effect of water stressis more evident at vegetative stage than at reproductive stage”(Ratnasekera and Subhashi, 2015). “Water stress during vegetative phase limits root growth and reduces plant size,leaf area, accumulation of dry matter in pods, grain yieldand harvest index” (Rasul, 2023).

Stress mitigation strategies in field cropsAgronomic practices

“The moong bean varieties, *i.e*., Swarnaprabha and Kattamodan, with less leaf rolling,better drought recovery abilityand relative water content, increased membrane stability index, osmolyte accumulation and antioxidant enzyme activities pointed toward their degree of tolerance to drought stress” (Swapna and Shylaraj,2017). “Better performance due to higher water retention, photosynthetic performance and osmoregulation capacity was observed in legumes” (Zhang *et al*.,2019).

“Significant improvement in water-use efficiency was observed under conservation tillage over conventional tillage” (Busari*et al*., 2015;Johnson *et al*.,2018).“Tillage manages plant residue by incorporating into the soil or retaining on top layer to reduce erosion and to improve physical condition of the soil so that the soil can absorb the rainwater easily and soil erosion can be minimized to permit root elongation and proliferation due to low-density soil” (Lundy *et al*., 2015).“Conservation tillage is the method of soil tilling, in which, at least 30% of soil surface is covered with crop residues, which prevents from drought stress” (Ali *et al*., 2016).“Conservation tillage practices increased water use efficiency by 19.1-28.4 and 10.1-23.8% in wheat and maize,respectively” (Shao *et al*.,2016). “Similary, under zero tillage, the crops save 20-30% water”(Bhan and Behera,2014).

“Rapid and healthy crop establishment leads to strong root development, which minimizes the effects of future drought stress” (Vance *et al*., 2014).“Under dry conditions, early seeding time is a key measure to match plant demand with water availability” (Bodner*et al*., 2015). “Higher grain yield was observed under early sowing in comparison of late sowing during *Kharif* season" (Shrestha *et al*., 2016;Prasad *et al*.,2017; Varma *et al*., 2014).

Mulching enhances water-use efficiency by enhancing infiltration rate (Ahmad *et al*., 2015), and reducing evaporation loss, runoff and temperature fluctuation increases drought tolerance (Ranjan *et al*., 2017). "Organic mulches act as a barrier to runoff and intercept raindrops, protecting the soil from splashing, particle detachment and clogging of surface soil pores, thereby contributing to the minimization of soil erosion" (Prosdocimi*et al*., 2016). "Crops give higher yield with mulching under drought stress" (Teame*et al*., 2017). "Mulching can improve water-use efficiency by 10-20%" (Kazemia and Safaria, 2018). "Mulches suppress the weeds growth mainly by restricting the light penetration into the soil and thus improve water availability to crop plants under drought conditions" (Tyagi*et al*.,2020).

"Intercropping in definite ratio may be followed in rain-fed areas to have minimum risk against total crop failure and also for better moisture utilization" (Gautam and Bana, 2014). "Intercropping is generally recommended for rain-fed crops to get stable yield" (Singh *et al*., 2014). Intercropping enhances soil water conservation and reduces runoff (Sharma *et al*., 2017), increaseswater use efficiency (Hu *et al*., 2017), and improves crop yield and the yield per unit of water supplied (Chen *et al*., 2018)."Both the wheat cultivars (Yecora E and Elissavet), the pea cultivar Olympos and their intercrops indicated high adaptation capacity to rainfed conditions, whereas, the pea cultivar Isard and its intercrop performed better under irrigation conditions, therefore, the intercropping of wheat with pea uses water resources of the environment more efficiently and couldbe used under dry land conditions for higher yield" (Pankou*et al*., 2021).

Application of nitrogen either through soil or through foliar spray is an important strategy to alleviate the adverse effect of drought (Ahmad *et al*., 2014).Higher yield of crop with foliar spray ofpotassium chloride 2% + sodium selenite 0.4% under drought conditions (Dewangan*et al*., 2017). Higher yield and profit with the application of potassium fertilizer were evident in many crops (Hussain *et al*., 2017). Potassium improves many physiological processes by the regulation of turgor pressure, photosynthesis, translocation of assimilates to various organs and enzymes activation and thus improves drought tolerance ability of plants (Raja *et al*., 2017).Maintenance of adequate potassium nutrition to plants has been found critical to mitigate drought stress (Khan *et al*., 2018).

Higher yield and water-use efficiency could be obtained with supplemental application of irrigation at critical stagesof crop growth (Abbas *et al*.,2014). Inkharif crops, life-saving irrigation wherever necessary can be supplied by ground water storage or by storing rain water during heavy rainfall (Yadav *et al*., 2014). Supplementary irrigation, especially during long dry spell after rainy months, could possibly alleviate moisture stress in growing crops (Praharaj *et al*., 2016).

Micro-irrigation techniques like sprinkler and drip should be promoted to reduce the risk of yield reduction (Ashoka *et al*., 2015). Drip irrigation can substantially improve water use efficiency by minimizing loss of water through runoff and evaporation (Jha *et al*., 2016). In drip irrigation system, water is slowly applied in the form of drop either on soil surface or directly into the root zone, through a network of valves, pipes, tubing and emitters (Kumar *et al*., 2016).A significant water saving was recorded in chickpea through drip irrigation on account of higher application efficiency and water supply to plant root zone with a discharge rate not more than infiltration rate of soil (Muniyappa *et al*.,2017). Around 50% saving of irrigation water along with higher productivity was observed under drip irrigation system (Mostafa *et al*.,2018).Sprinkler irrigation has resulted in 16.22% higher yield and 30.76% higher water productivity (Sharma *et al*.,2018).

Chemical measures

Hydrogel application results in enhancement of soil physical, chemical and biological properties with positive effects on plant growth and development (Abobatta, 2018).Plants can survive and sustain their life cycle through hydrogel conditioning in areas, where the shortage of water is a serious issue (Tu *et al*., 2018). Hydrogel (super absorbent) is one of the most popular and commercially available soil additivesused to reduce water runoff, infiltration rate in field and irrigation requirement of several crops by improving water holding capacity (Laxmi S., 2019). It is also known to increase plant survival time under drought conditions (Jerszurki*et al*., 2017;Ayangbenro and Babalola, 2020). Water loss through evaporation in hydrogel amended soil is lower than the soil with no hydrogel amendment (Saha, 2020).

Under water stress conditions, there was an increase in root development with the rise in K content in mung bean (Nisha *et al.*, 2014).Potassium indirectly promotes the transfer of photosynthates gradually towards the roots for nodule utilization, increasing root nodules under water stress conditions (Suryapani and associates, 2014).The effect of potassium application is evident in enhancing the tolerance of plants under water stress conditions (Zain and Ismail, 2016).The key functions of salycilic acid in drought stress alleviation include promoting seedling growth, enhancing plant antioxidant capacity, regulating plant water balance, promoting the expression of stress-related genes in plants and regulating plant physiological metabolism (Aiman *et al*., 2018). As a crucial chemical, salycylic acid has been found to alleviate drought stress in plants to some extent (Munsif *et al*., 2022). Salycilic acid can enhance plant drought tolerance by regulating root growth, improving leaf water use efficiency, stabilizing cell membranes and modulating the antioxidative enzyme system. Meanwhile, relevant studies also indicated that the biosynthesis of salycilic acid also exerted certain regulatory effects on normal plant growth and development, which is beneficial to the enhancement of plant tolerance to various kinds of stress (Rekhter*et al*., 2019; Lefevere *et al*., 2020; Peng *et al*., 2021; Ullah *et al*., 2023).In addition, other relevant studies have also demonstrated the important regulatory role of salycilic acid in plant drought tolerance (Alam *et al*., 2022; Das *et al*., 2023; Duvnjak *et al*., 2023; Guo *et al*., 2023; Moustakas *et al*.,2023; Tanveer *et al*., 2023).

Impact of stress mitigation strategies on plant growth and yield parameters

Salicylic acid controls a variety of physiological functions in plants, including photosynthesis, nitrogen metabolism, glycine betaine synthesis and antioxidant synthesis, which ensures plant resilience to abiotic stress management (Khan *et al*., 2014; Miura and Tada, 2014). Fertilizer containing potassium higher soluble sugar concentration may act as a solute for osmotic regulation and/or a substrate for root-based synthesis of proteins and polysaccharides, which in turn promote the development of entire plants under water stress (Semida*et al*., 2014). Plants that receive adequate potassium are more resistant to drought stress, water shortage conditions and water use efficiency, all of which encourage crop development and yield (Hassan *et al*., 2017). Under water deficit, foliar application of salicylic acid improved the leaf relative water content and photosynthetic pigments in crops (Razmi *et al*., 2017). Salycilic acid preserves water in plant cells, which stimulates enzyme activity under stressful conditions, improving metabolism and yield. This could be the reason why salycilic acid boosts yield in stressed plants (Ezzo *et al.*, 2018). Application of recommded dose of fertilizer + potassium @ 30 kg ha^{-1} + two foliar spray of KNO_3 @ 1% at flowering and pod formation stage showed synergistic effects on nutrients (N, P and K) uptake. It was also discovered that providing potassium to cultivars under water stress boosted soil fertility (Bhadane*et al.*, 2019).The application of salycilic acid increased the activity of antioxidant enzymes, such as ascorbate peroxidase and chloramphenicol acetyltransferase, which might have helped in alleviating the negative effect of water stress on plants (Shemi*et al.*, 2021; Sultana *et al.*, 2024). Foliar application of salycilic acid could be a promising strategy to mitigate water stress inplants (Sultana *et al.*, 2024) since it can manage metabolic pathways and enhance the plants' defense against water deficits (Ghahremani *et al.*, 2023).

Salycilic acid made the plant more resistant to drought, and it might be utilized to boost and stabilize crop output under stressful conditions(Sharma *et al.*,2017). Under salt and drought stress, the exogenous application of salycilic acid promoted both root and stem growth (Movahhedi-Dehnavi*et al.*, 2019).Plant development is influenced bysalycilic acid in a number of ways, including seed germination,induction of flowering, root growthand ion uptake under water stress conditions(Bagautdinova*et al.*, 2022; Liu *et al.*, 2022).

Foliar application of salicylic acid is an efficient technique that can decrease the detrimental effects of drought stress and boost crop output (Kazemi, 2014).Salycilic acid helps in synthesis of osmotic substances, preserving intracellular oxidative equilibrium and enhancing the control of mineral nutrient intake and helps the plants to develop resistance against abiotic stressors (Khan *et al.*, 2015).

Under drought conditions, seed priming by potassium nitrate increased the leaf nitrate reductase activity of the seedlings (Kumar *et al.*,2014).The application of 2% KNO_3 in fodder legume crop resulted in 26.7 and 27.5% higher pod and grain yield, respectively than the control(Kumar *et al.*,2014).A foliar spray of KNO_3 at 150 ppm 25 DAS increased total chlorophyll content by 26.5 and 3.3% at 40 and 50 DAS, respectively in legume cropsunder drought conditions (Mubeen *et al.*, 2014).Greater plant biomass (1239 kg ha^{-1}) and height (48.1 cm) was recorded with foliar application ofsalycilic acid as compared tocontrol (Farjam *et al.*,2015). Seed coating with herbal hydrogel (Gond-Katira) resulted in increased plant height and tillers m^{-2}(Lather *et al*.,2015). Foliar application of salicylic acid and potassium for reducing drought stress in legumes (Majeed *et al*., 2016).Foliar spray of potassium nitrate 1% in legumes under water deficiency conditions significantly increased the plant height, leaf area, shoot dry weight and relative leaf water contentas compared to control (Rao *et al*.,2016).Foliar treatment of salicylic acid 75 ppm + 2% urea during flower initiation considerably improved the plant height, number of branches, dry matter accumulation and chlorophyll content under water stressconditions (Sarita *et al*., 2020).The application of Pusa and herbal hydrogel increased the grain, straw and biological yield by 6.65-13.69, 6.90-14.41 and 6.79-14.09%, respectivelyas compared to control (Kumar *et al*.,2019;Kumar *et al*.,2020). Foliar spraying of potassium nitrate 0.5% resulted in increased seed output (865 kg ha^{-1}) in legume crops ascompared to water spray (Kumar *et al*.,2020a).The application of hydrogel 3 kg ha^{-1} resulted in a greater percentage of Sennoside A (1.78%) and Sennoside B (1.69%) in pods as compared to other treatments under drought conditions (Jnanesha*et al*.,2021).

“Salicylicacid treatment significantly increased growth, photosynthesis, yield and the activity of andoxidative enzymes,*viz*. catalase, peroxidase and superoxide dismutase in chickpea plants exposed to 0, 25, or 50 mg Cd per kg of sod, however, the treatment did not prove to be fruitful in alleviating completely the stress generated by 100 mg Cd per kg of soil”(Alyemeni*et al*.,2014). “The maximum response was generated in plantssprayedwith10^{-5}molL^{-1}ofsalycilic acid,showingastatisticallysignificantincrease innet photosynthesis (46.92%)over that of the control under drought stress conditions” (Hayat *et al*., 2014).“Combinedsprayof2%ureaand0.25%multiplex increased plant height, number of branches and dry matter per plant under water stress conditions” (Ganga *et al*., 2014). “Foliar application of potassium nitrate @ 2% + boric acid 50 ppm + zinc sulphate 1% at 30 and 60 DAS was found to be superior in increasing seed yield under water stress conditions (GowthamiandRao, 2014). Hydrogel had a positive effect on photosynthesis by gradually pumping water into the plant” (Tango *et al*., 2014).“The treated plants with salycilic acid survive more, exhibit higher relative growth rate and more leaf area and dry mass production under water stress conditions” (Boukraâ*et al*., 2015). “Sprays of KNO$_3$ 1.0% twice at 45 and 60 DAS improved all the growth parameters, *viz*. plant height (cm), number of branches plant^{-}

^{1}, nodules plant^{-1}and total dry matter plant^{-1} in crop under water stress” (Hiwale, 2015).“Application of salycilic acid has a positive effect in ameliorating the oxidative damages in plant and increases the yield” (Hossain *et al*., 2015).“Foliar application of KNO_3 2% four times improved all the growth parameters as compared to control” (Kumar and Srivastava, 2015).“Salicylic acid can reduce the sensitivity of plants to environmental stresses through the regulation of antioxidant defence system, transpiration rate, stomatal movement and photosynthetic rate” (Nazar*et al*., 2015). “Application of exogenous salycilic acidcouldhelp in reducing the adverse effects of drought stress and might have a key rolein providing tolerance to stress by promoting growth and accumulation ofproline, soluble sugars and photosynthetic pigments in plant leaves” (Vaisnad*et al*.,2015).“The increase in number of seeds per pod under increasing levels of salicylic acid might be due to increased mobilization of metabolites to the reproductive sinks” (Khatun*et al*., 2016).“Application of salycilic acid resulted in a positive effect by protecting plants against oxidative damage caused by drought stress” (Najafabadi and Ehsanzadeh, 2017; Wang*et al*., 2019;Sankari *et al*., 2019).“Hydrogel retains its structural integrity and absorbs water from the environment, helping under drought conditions” (Montesano *et al*., 2015; Domalik-Pyzik*et al*., 2019; Qu and Luo, 2020).“Hydrogel also increased the plants’ life span by approximately 9-14 days” (Song *et al*., 2020; Shankarappa*et al*., 2020).“Hydrogel applicationprovided22-45% moreplant growth under water stress conditions” (Nassaj-Bokharaei*et al*., 2021).“Addition of hydrogel to soil (in different types of soil and with different hydrogel amounts) increases the water holding capacity of the soil by 56 to 81% under water stress” (Saha*et al*., 2021).“Hydrogel application under water stress conditions increased plant height, stem diameter, leaf length and vegetative period along with overall growth of plant” (Albalasmeh*et al*., 2022; Radian *et al*., 2022; Prisa and Guerrini, 2022;Watcharamul*et al*., 2022). “Hydrogel increased the yield of some crops as compared to the control”(Rajanna*et al*.,2022).The leafarea and calyx yield of *Hibiscus sabdariffa* L. (Besharati*et al*., 2022) and vegetative growth of plants (Alshallash*et al*., 2022) increased even under water stress conditions due to hydrogel applications, which increased leaf area, as well as yield of the crops by 35 to 60% under water stress and encouraged the development of *Brassica rapa*ssp. *chinensis* var. parachinensis (Zhu *et al*., 2022a,b).

"Salycilic acid is of great potential to improve photosynthesis and chlorophyll content in wheat"(Khalvandi*et al*., 2021)."In *Camellia oleifera*, salycilic acid level declines during drought stress, exhibits stronger antioxidant capacity, water regulation ability and drought stress protection"(Guo*et al*., 2023). "Substantial reduction of drought influence and enhancement of grain yield and water use efficiency by co-application of K+ and salycilic acidand regulation of stress response in wheat" (Munsif*et al*., 2022;Duvnjak *et al*., 2023)."Salycilic acid mitigates the oxidative damage and alleviates water deficiency stress in potato (Acevedo *et al*., 2023).Salicylic acid helps in regulation of stomatal aperture and adaptation to soil salinity and drought stress in rice" (Xu *et al*., 2023).

Conclusion

The reviewed studies collectively emphasize the crucial role of potassium nitrate, salicylic acid and other nutrients in enhancing crop productivity and quality under drought stress. Potassium nitrate application leads to improved nutrient content in crops and soil fertility,mitigates deficiencies and boosts seed yield and quality. Salicylic acid treatment counteractes drought stressand promotes growth and yield. Additionally, foliar application of various compounds, such as urea and KNO_3, showcased significant effects on growth parameters and yield. These findings underscore the importance of targeted nutrient applications for optimal crop performance, demonstrating the potential for advanced agricultural practices to enhance agricultural productivity sustainably.In conclusion, stress management practices in agriculture are pivotal for enhancing crop productivity and quality. The utilization of herbal hydrogel gond-katira (*Tragacanthkatira*) has shown promise in mitigating various stressors. Additionally, incorporating foliar nutrition, such as urea and salicylic acid, as demonstrated by several researchers, can enhance plant resilience to stressors like heat or nutrient deficiencies. The use of innovative technologies like herbal hydrogel systems, offers a sustainable approach to address crop stress under moisture-limited conditions.

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