24 Agronomic Interventions for Drought Management in Crops

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Abstract

Water stress is considered a worldwide problem and is one of the most and major disastrous abiotic stresses. India is the most vulnerable country for water stress because of population growth, changing demography, and land use change. Fast changing climate is further aggravating this problem by affecting rainfall and water-use pattern, groundwater availability, and runoff; thus, deficit in rainfall is the major cause of drought. Drought has its wider impact on all sectors, but agriculture is the most affected one because Indian agriculture still depends largely upon monsoon rainfall, and about 68% of cropped area in India is vulnerable to drought. Drought affects crop plants by hampering its growth and development. Drought stress reduces yield of crops by affecting germination, seedling growth, several physiological processes such as photosynthesis, respiration, assimilate transport, water relation, and nutrient uptake. To overcome the problem of drought, there is a need of interdisciplinary approach, i.e. agronomy, plant breeding, plant physiology, plant biotechnology, water engineering, and others, to develop new approaches in water use. Agronomic approaches such as mulching, conservation tillage, intercropping, early sowing, selection of crops and their varieties, and micro irrigation are technically feasible and economically viable options to overcome drought problem in crops.

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24.1 Introduction

World population is increasing at an alarming rate and is expected to reach seven billion by the end of 2050 (Ekebafe et al. 2011). Population growth and the resultant development of large high-density urban populations, together with parallel global industrialization, have placed major pressures on our environment, potentially threatening environmental sustainability and food security. This has resulted in global warming and the buildup of chemical and biological contaminants throughout the biosphere, but most notably in soils and sediments (Yazdani et al. 2007). During the twentieth century, the main emphasis of agricultural development all over the world was the increasing productivity per unit area of land used for crop production to feed the ever-increasing population. This was substantially accomplished through overexploitation of natural resources such as water and excessive use of fertilizers and pesticides (Bhat et al. 2009). Although this practice resulted in considerable increase in crop yields in the short term, it was not sustainable in the long run. The productive capacity of the arable land was impaired; the natural water resources were depleted and also polluted with hazardous pesticides and chemical fertilizers which threatened the survival and well-being of all life forms on earth. Therefore, the emphasis on agricultural development in the present century has shifted to the sustainable use of land, water, and plant resources in agriculture. The major goal of the present day agriculture is to maximize land and water productivity without threatening the environment and the natural resources.

Among all inputs for agriculture production, water is the most crucial. It enables a higher productive potential from the land and significant production response from associated use of high-yielding varieties, fertilizer, and others (Kukal et al. 2014). But water availability is continuously declining particularly in developing countries such as in India. By 2025, half of the world's population will be living in water-stressed areas (WHO 2018). 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).

Water is becoming a scarce commodity due to growing human population and severe neglect and overexploitation of this resource. Because of the growing population and indisciplined lifestyle, India is a more vulnerable country for water scarcity. So there is urgent need to make sustainable use of the available water resources.

According to an estimate, population in India is increasing day by day while average annual per capita availability of water is declining, and it is expected that per capita water availability could decline up to 1140 m^3 by 2050 (Table 24.1).

Table 24.1 Average annual per capita availability of water in India

Year	Population (million)	Per capita water availability (m^3/year)
2001	1029	1816
2011	1210	1545
2025	1394	1340
2050	1640	1140

Source: Agricultural Ministry of India, 2013

Table 24.2 Estimated water demand in India for different sectors

	Water demand (billion cubic meter)		
Sector	2010	2025	2050
Irrigation	688	910	1072
Industry	12	23	63
Energy	5	15	130
Drinking water	56	73	102
Others	52	72	80
Total	813	1093	1447

Source: Basin Planning Directorate, CWC, XI Plan Document. Report of the Standing Sub-Committee on "Assessment of Availability and requirement of Water for Diverse uses-2000"

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 68% of cropped area in India is vulnerable to drought, out of which 33% receives less than 750 mm of mean annual rainfall and is classified as "chronically drought-prone" while 35% which receive mean annual rainfall of 750–1125 mm is classified as "drought-prone" (DAC and FW 2017). There were 10 drought years during 1950–1990. Since 2000, there have been six drought years: 2002, 2004, 2009, 2014, 2015, and 2016 (Kala 2017), and the frequency of drought is expected to be higher in the coming decades during 2020–2050 (Kulkarni et al. 2016). About 330 million people in 2.5 lakh villages of 11 states in India were affected by drought in the year 2016 due to deficit in rainfall during two consecutive years (Jayan 2019). About 163 million children face problem of malnutrition, dehydration due to shortage of drinking water, unhygienic conditions, and unavailability of other social well-beings due to this severe drought. Farmers suffered because of severe water shortage which resulted in their crop losses. There was also shortage of drinking water in some communities. The total water demand is projected to increase to 1093 BCM by 2025 and 1447 BCM by 2050 (Table 24.2). Domestic and industrial sectors will contribute more in additional water demand. Share of irrigation sector in total water demand is expected to decrease, but, in absolute terms, irrigation demand will increase.

The problem is further aggravated by the fast changing climate. Both demands and the ways in which water is used are affected by change in climate across regions. Both surface and groundwater availability will be affected due to changes in precipitation, increase in runoff, combined with changes in consumption and

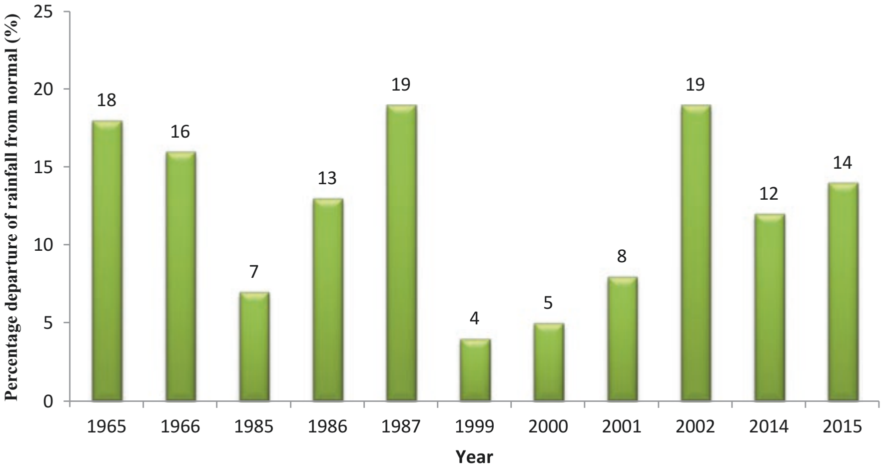

Fig. 24.1 Percentage departure of rainfall from normal for India as a whole (SW Monsoon) during successive drought years. (Source: Department of Agriculture, Cooperation and Farmer's Welfare (2016) Manual for drought management)

withdrawal. Deficit rainfall is the major cause of drought, and it is clear from the Fig. 24.1 that major drought years were the culmination of adverse rainfall event.

This problem is expected to be more severe in coming years which will increase the water shortages for many uses (NCA 2014). Due to global warming, atmospheric temperature is increasing and is expected to increase in coming years. Further, rate of evaporation will increases from both land and oceans due to increase in temperature of atmosphere. Atmosphere can hold 4% more water for every 1 °F increase (Triple Pundit 2017).

According to the prediction by IPCC, in India, temperature will increase up to 0.5–1.2 °C, 0.88–3.16 °C by 2020 and 2050, respectively. Already the temperature has increased by 0.60 °C in the last century, and by the end of this century, temperature particularly in the tropics and subtropics may exceed even the most extreme seasonal temperatures measured to date (Singh et al. 2014). It is a recognized fact that there is a steady decline of the water tables in key food-producing areas such as the Indo-Gangetic Plain. The combination of climate change, population growth, and the demographic change will intensify drought hazard, exposure, and vulnerability, respectively.

24.2 Effects of Drought on Plants

Drought is known to be the most harmful abiotic stress factor affecting growth and performance of different crops (Shah et al. 2017). Drought affects crop plants in following ways:

24.2.1 Germination and Plant Growth

Germination is the first stage where drought has its negative impact (Harris et al. 2002; Fahad et al. 2017). Seed germination is a complex process, and water absorption (imbibition) is the first step of germination (Molina et al. 2018). After imbibition of water, various metabolic processes such as synthesis of hydrolytic enzymes are active inside seed which hydrolyses the reserve food into simple available form for embryo uptake (Ali and Elozeiri 2017). Thus, drought stress reduces germination by limiting water imbibition (Farooq et al. 2009).

Drought stress reduces the plant growth by influencing various physiological as well as biochemical functions such as photosynthesis, chlorophyll synthesis, nutrient metabolism, ion uptake and translocation, respiration, and carbohydrates metabolism (Hussain et al. 2018). Plant growth is controlled by the rate of cell division, cell enlargement, and their differentiation. Cell growth is one of the most drought-sensitive processes due to the reduction in turgor pressure (Rezayian et al. 2018). During drought, plants have to act to maintain turgor, leading to a stop or slowing down of cell division and cell expansion, which reduces the average cell size (Weijde et al. 2017), reduced stomatal conductance, causing a decrease in C assimilation via photosynthesis (Christophe et al. 2011) resulted in poor growth of plant.

24.2.2 Water Relation

Water relations are influenced by certain factors including the leaf water potential, leaf and canopy temperature, transpiration rate, and stomatal conductance. Drought stress affects all these factors in plants; however, the most affected process is stomatal conductance. It has been reported that water stress frequently decreased leaf water status inducing low leaf water potential and relative water content (Trabelsi et al. 2019). Similarly, Sepehri and Golparvar (2011) recorded lower relative water content in leaves of canola in comparison to irrigated plots.

24.2.3 Photosynthesis

Photosynthesis is one of the key physiological phenomena which is most affected by the drought and heat stress (Fahad et al. 2017). Photosynthesis comprises various components, including the photosystems and photosynthetic pigments, the electron transport system, and CO_2 reduction pathways. A stress-induced negative effect on any component in these systems may lead to a reduction in the overall photosynthetic performance (Lamaoui et al. 2018). Such decrease in photosynthesis leads to plants absorbing more light energy than can be consumed by photosynthetic carbon fixation. The excess energy has the potential to trigger an increase in the production of reactive oxygen species (ROS) including O_2 and H_2O_2, which has been proven to hinder the synthesis of PSII core D_1 (Takahashi and Murata 2008). Water deficit induces degradation of photosynthetic pigments, reduces the amount of chlorophyll, and destroys photosynthetic system (Fathi and Tari 2016). To reduce transpiration rate, plants close its stomata earlier than normal condition. Due to early closure of stomata, plants cannot take sufficient amount of carbon which hampers photosynthetic rate. Shareef et al. (2018) also reported decline in photosynthesis in cotton due to stomatal closure, which negatively affects plant biomass partitioning, fruiting ability, and yield formation under drought condition.

24.2.4 Assimilate Partitioning

In general, the transport and partitioning of photoassimilate within the plant are strongly dependent on the assimilate production in the source, the rates of loading and unloading of the sieve-tube elements, the velocity of the phloem flow, and the sink incorporation rate (Bata et al. 2004). Limited photosynthesis due to water deficit stress disrupts carbohydrate metabolism and distribution in plant body, favoring the maximum proportion to leaves and roots for osmotic adjustment and the least toward fruiting fractions (Shareef et al. 2018). Drought stress decreases the photosynthetic rate and disrupts the carbohydrate metabolism and the level of sucrose in leaves that spill over to a decreased export rate (Gagne-Bourque et al. 2016). Limited photosynthesis and sucrose accumulation in the leaves may hamper the rate of sucrose export to the sink organs and ultimately affect the reproductive development (Farooq et al. 2009).

24.2.5 Nutrient Relation

Drought also has a strong impact on plant nutrient relations. Drought stress and associated reduction in soil moisture can reduce plant nutrient uptake by reducing nutrient supply through mineralization and also by reducing nutrient diffusion and mass flow in the soil. Most of the mineral nutrients are taken up by plant roots through mass flow and diffusion which requires moisture. Under water stress conditions, roots are unable to take up many nutrients from the soil due to a lack of root activity as well as slow ion diffusion and water movement rates (Silva et al. 2011). Drought could also decrease nutrient uptake by affecting the kinetics of nutrient uptake by roots (Christophe et al. 2011).

24.2.6 Yield

Yield is a function of yield attributing traits, primarily productive tillers, numbers of grains per spike, thousand grain weight, etc. (Pandey et al. 2017). Water shortage at different stages of plant negatively affect crop yield. Marjani et al. (2016) reported that mid-season drought stress causes early maturing in chickpea due to acceleration of phonological process which resulted low yield. The severity and duration of drought stress determine the extent of the yield loss (Zhang et al. 2018). Drought during grain filling, especially if accompanied by high temperatures as is common, hastens leaf senescence, reduces the duration of grain filling, and reduces the weight of the grains (Giunta et al. 1993), and thus reduces yield. Carrijo et al. (2017) reported 22.6% yield loss in rice attributed to the reduction in photosynthetic activity and lower supply of assimilates that support reproductive development and seed growth under drought. The drought induced at the preanthesis stage shortened the time to anthesis while after anthesis reduced the period of grain filling in cereals (Fahad et al. 2017). A significant reduction in the grain yield of barley (*Hordeum vulgare* L.) was observed under drought conditions mainly because of less number of fertile tillers and grains along with reduced test weight (Samarah 2005). Drought-induced reduction in the yield might be due to various factors such as decrease rate of photosynthesis, poor assimilate partitioning, poor flag leaf development, and/or shrinkage of grains.

24.3 Agronomic Practices for Drought Management

24.3.1 Mulching

Evapotranspiration process is the primary pathway of water loss in croplands (Morison et al. 2008). Around 30–60% of total applied water which is not directly utilized by crops is considered as unproductive water loss (i.e., evaporation). Therefore, reduction of unproductive soil evaporation in croplands is a promising way to improve water-use efficiency. Bare soil exposed to heat and wind loses more water through evaporation. Mulching can improve water-use efficiency by 10–20% (Ossom et al. 2001; Ramakrishna et al. 2006; Kazemia and Safaria 2018; Waraich et al. 2011). Mulching enhances water-use efficiency by enhancing infiltration rate (Ahmad et al. 2015) and reducing evaporation loss (Kar and Singh 2004; Ramakrishna et al. 2006), runoff (Ahmad et al. 2015), and temperature fluctuation (Ranjan et al. 2017). Ahmad et al. (2015) recorded higher water-use efficiency, relative water content of leaves, and less weed population under mulch treatment compared to without mulch under water stress condition. Teame et al. (2017) recorded higher yield of sesame with mulching. Weeds compete with crop plants for water and other growth factors and remove considerable amount of water from crop land. To produce a unit of dry matter, weeds require more water than most of our crop plants (Abouziena et al. 2014–2015), resulting in higher yield loss (Verma et al. 2015). Mulches suppress the weeds growth mainly by restricting the light penetration into the soil and thus improve water availability to crop plants under drought situation. Thus, mulching is cheap and the best option under drought condition to save crops from total failure.

24.3.2 Tillage

Evaporation from soil surface is the major part of water loss from field, and evaporation mostly occurs when the soil surface is open. Conservation tillage is the method of soil tilling in which at least 30% of soil surface is covered by residue

(Ali et al. 2016). Crop residue on the soil surface reduces evaporation. Residue insulates the soil from solar energy and reduces evaporation. Less soil disturbance in conservation tillage limits moisture loss from the soil profile, as less soil surface is exposed to drying. Conservation tillage reduces soil compaction and crusting and adds considerable amount of organic matter in soil which increases infiltration rate and water-holding capacity of soil (Wallander et al. 2013). Shao et al. (2016) found that conservation tillage approaches increased WUE by 19.1–28.4% and 10.1–23.8% in wheat and maize, respectively. Similarly, Bhan and Behera (2014) observed 20–30% saving of water under zero tillage. Sisti et al. (2004) reported that conservation tillage enhances soil structure, mitigates high temperatures and drought stresses, and decreases water losses and consequently increases WUE. Su et al. (2007), Busari et al. (2015), and Johnson et al. (2018) also recorded significant improvement in water-use efficiency under conservation tillage over conventional.

24.3.3 Intercropping

Intercropping systems are generally recommended for rain-fed crops to get stable yields (Singh et al. 2014). Intercropping in definite ratios 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 enhances soil water conservation and reduces runoff (Sharma et al. 2017), increases the WUE (Hu et al. 2017), and improves crop yield and the yield per unit of water supplied (Chen et al. 2018). Intercropping reduces the inter-row evaporation, controls excessive transpiration, increases water storage in root zone, and creates a favorable microclimate which is advantageous to the plant growth and development (Zhang et al. 2012). Bharti et al. (2007) in maize + potato, Caihong et al. (2015) in wheat + faba bean, Roy et al. (2015) in maize + mungbean, and Sun et al. (2018) in maize + alfalfa recorded higher water-use efficiency under intercropping as compared to sole cropping.

24.3.4 Selection of Crop and Varieties

Selection of those crops and their varieties which are adapted to the available water is very important under drought condition (Singh et al. 2014). Crops and varieties that need shorter duration to mature and require less water need to be encouraged in the drought-prone areas. Crops such as pear millet, sorghum, gram, barley, mustard, cotton, sunflower, and castor are more drought tolerant. Thus, diversification of high water-demanding crops with low water-demanding crops can enhance profit and WUE in drought prone areas (Bobojonov et al. 2013).

Among the 42 rice varieties, Swapna and Shylaraj (2017) identified two rice varieties, i.e., Swarnaprabha and Kattamodan, with less leaf rolling, better drought recovery ability, as well as relative water content, increased membrane stability index, osmolyte accumulation, and antioxidant enzyme activities pointed toward their degree of tolerance to drought stress. Similarly, Zhang et al. (2019a, b) reported better performance of Longzhong alfalfa variety due to higher water retention, photosynthetic performance, and osmoregulation capacity, lowest lipid peroxidation, and the higher antioxidant enzyme activities. Thus, crops and their varieties should be chosen according to availability of water.

24.3.5 Nutrient Management

Application of different nutrients also reduces the damaging effects of drought stress and improves the growth and physiological performance of plants. Rational nutrient input enhances crop intake of total water, especially from deep layer, increases WUE, brings full utilization of soil water, and thereby decreases the possibility of crops suffering from drought during dry spell (Li et al. 2009). Maintenance of adequate potassium nutrition to plants has been found critical to mitigate drought stress (Khan et al. 2018). 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). Hussain et al. (2017) recorded higher yield and profit when maize crop was sprayed with potassium fertilizer. Similarly, Dewangan et al. (2017) recorded higher yield of pear millet with the foliar spray of 2% KCl + 0.4% sodium selenite under drought condition. Adequate K further lowers the ROS production by reducing the activity of NAD(P)H oxidases and maintaining photosynthetic electron transport (Cakmak 2005). Potassium play important role in stomatal regulation, osmoregulation, energy status, charge balance, protein synthesis, homeostasis, maintenance of turgor pressure, and reduction in transpiration which lead to saving of water under water stress condition (Waraich et al. 2011).

Nitrogen also has positive impact on drought resistance by promoting root growth (Zhang et al. 2007; Saud et al. 2017). Nitrogen application either through soil or through foliar feeding is an important strategy to alleviate the adverse effect of drought (Ahmad et al. 2014). Krobel et al. (2011) recorded higher water-use efficiency with the application of nitrogen + phosphorus under water stress condition.

24.3.6 Early Sowing

Among the many mitigation measures that may be taken, shifting sowing dates is one of the easiest and the most effective ways to match the crop with seasonal patterns of rainfall and temperature (Zhang et al. 2019a, b). Under dry conditions, optimization of seeding time is a key measure to match plant demand with water availability (Bodner et al. 2015). Sowing/planting should be done at those times which will avoid probable stress periods during critical stages of the crop or by manipulating the ratio of early to late season water use. Rapid and healthy crop establishment leads to strong root development, which minimizes the effects of future drought stress (Vance et al. 2014). Early seeding shifts sensitive stages such as flowering and grain filling to periods of better water availability (Bodner et al. 2015). Samarah and Al-Issa (2006) recorded higher seed germination, yield attributing characters, and yield of barley under early sowing as compared to late sown condition under semi-arid condition. Similarly, Varma et al. (2014), Khan et al. (2002), Shrestha et al. (2016), and Prasad et al. (2017) recorded higher grain yield of maize under early sowing in comparison to late sown during kharif season.

24.3.7 Life-Saving or Supplemental Irrigation

Application of water at critical growth stages of crop during prolong dry spell to save crops from total failure is known as life-saving irrigation or supplemental irrigation. Every crop is more sensitive at specific growth stages for drought, and lack of moisture at these stages may cause total crop failure; these stages are called critical crop growth stages. Under drought situation, crops can be profitably raised with one or two need-based life-saving irrigations applied according to crop need during its specific critical growth stages for realizing the best achievable yield in a given set of conditions (Oweis and Hachum 2006; Praharaj et al. 2017). Supplementary irrigation especially during long dry spell after rainy months could possibly alleviate moisture stress in growing crops (Praharaj et al. 2016). It is better to apply limited amount of water during critical growth stages through drip or sprinkler irrigation. Thorve et al. (2009) recorded 88 and 65% more grain and fodder yields of rabi sorghum with two life-saving irrigations, one at earhead initiation and the second at flowering stage as compared to no irrigation. Abbas et al. (2014) recorded the highest yield and water-use efficiency in wheat with supplemental irrigation at critical growth stages. Similarly, Raja et al. (2012) also reported significant effect of supplemental irrigation on yield in maize, greengram, sesame, okra, and chili crops. It is better to apply life-saving irrigation for kharif crops by ground water storage wherever necessary and by storing rain water when heavy rainfall occurs (Yadav et al. 2014).

24.3.8 Micro Irrigation

In areas where water is scarce, micro irrigation techniques like sprinkler and drip should be promoted to reduce the risk of yield reduction (Ramamurthy et al. 2009; Ashoka et al. 2015). In drip irrigation system, water is slowly applied in the form of drop either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters (Kumar et al. 2016). Drip irrigation can substantially improve WUE by minimizing evaporative and runoff loss of water (Jha et al. 2016) because water is applied at the rate which is less than the rate of infiltration. Ramamurthy et al. (2009) with drip irrigation recorded 28–58% higher water-use efficiency than broad bed furrow and 45–68% higher than the flood method of irrigation in cotton. Muniyappa et al. (2017) recorded significant water saving in chickpea with drip irrigation due to higher application efficiency and supplied water to root zone with a lower discharge rate not more than infiltration rate of soil. Mostafa et al. (2018) also noticed around 50% saving of irrigation water under drip irrigation system.

Sprinkler irrigation is also advantageous compared to the surface methods as water can be delivered at a desired and controlled rate, thereby ensuring a uniform distribution of water and hence high WUE (Yadvinder-Singh et al. 2014). In sprinkler method, water is applied to the crops like natural rainfall through the network of pipes and sprinklers. In this method, water-use efficiency is enhanced due to reduced runoff loss. Sharma et al. (2018) recorded 16.22% higher yield and 30.76% higher water productivity under sprinkler irrigation than the border irrigated wheat. Similarly, Jha et al. (2019) and Home et al. (2002) recorded substantially higher water-use efficiency in wheat and okra under sprinkler irrigation system compared to basin irrigation.

24.4 Conclusion

Drought is affecting over 25% of the world's agricultural land. It is a major impediment in achieving sustainable agriculture for future where we will have to face problems including food insecurity and less-fertile soils. Feeding the future population is one of the major challenges for agriculturists. Our agriculture is dependent on water availability, but our water resources are declining day by day because of overexploitation and misuse. Global warming further increases the problem of water scarcity by affecting rainfall. It is expected that this problem will be more devastating in coming years. Therefore, there is a need to adopt various management techniques in order to combat the problem of drought. There are several agronomic approaches such as tillage, mulching, intercropping, nutrient management, less water demanding crops, and their varieties; by adopting these practices, we can take profitable crop production in drought areas.

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