Challenges and Strategies to Improve Drought Tolerance in Plants Through Agronomic Managements

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Abstract

Agriculture production and productivity are prone to abiotic and biotic stresses. Biotic stresses comprise insect–pest incidences, while abiotic stresses come from environmental factors that include drought, floods (both due to irregular pattern of rainfall), temperature extremes (heat, cold chilling/frost), chemical stress (excess of soluble salts, low pH/acid), nutritional deficiencies and imbalances, physical factors (susceptibility to erosion, steep slopes, surface crusting and sealing, low water-holding capacity, impeded drainage, low structural stability, root-restricting layer, high swell/shrink potential) (Minhas et al. 2017 Abiotic stress management for resilient agriculture. Springer, Berlin). These factors coupled with inherent productivity potential of cultivated/selected varieties define the crop productivity in an ecosystem. The intensity and impact of any stress amplify under limited natural resources availability. Indian agriculture being rainfed is subjected to extremities of rainfall pattern. Drought is the recurring phenomenon in rainfed areas although from past few years' floods have also become more frequent owing to changing climatic conditions. The impact of drought is not just confined to agriculture production, as it severely affects livestock also and brings in misery in the affected areas with people struggling to survive and threatening national food and nutritional security. To mitigate drought stress, initiatives have to be taken at microlevel and management includes agronomic (in situ water conservation, integrated farming system, crop diversification, contingency plan, watershed management, mulching, etc.), engineering (grading, bunding, terracing, land capability classification, runoff management, etc.), and physiological interventions (role of plant growth regulators, enzymatic activities, use of

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reflectants/protectants, developing drought tolerance, and mitigating mechanisms in plants, etc.).

Keywords

Stress · Drought · Tolerance

24.1 Introduction

World's population is increasing at a faster pace, while the land under cultivation is shrinking due to demand from other sectors. This is posing a major threat to environmental sustainability and food security (Yazdani et al. 2007). Shrinking resources creates additional pressure on the limited available resources and leads to overexploitation of natural resources especially water along with excessive use of fertilizers and pesticides which has deteriorated the soil quality further (Bhat et al. 2009). Abido and Zsombik (2018) had observed that 25% of the world's agricultural lands are now affected by water stress and by 2025, half of the world's population will be living in water-stressed areas (WHO report).

Agriculture is an input driven enterprise and water is the most critical input for successful crop production. Any deviation from normal can offset the expected output. Owing to the burgeoning population and scarcity of natural resources, the stress on already limited water resources in India is increasing every year (Table 24.1). Per capita availability of water in India has reduced from 1816 m^3 to 1140 m^3 with simultaneous population rise from 1029 to 1640 million in 50 years (pib.gov.in).

Along with it, water demand for different sectors has increased from 813 to 1447 billion cubic meters in 40 years (Basin Planning Directorate, CWC 2019) (Table 24.2). It is inferred from the data discussed that water demand exceeds water availability and gap is increasing with each year. To minimize the gap, sector-wise water distribution and consumption have to be regulated and critical measures are needed to be taken. Agriculture sector has the major share in water demand and consumption among all sectors, so agronomic interventions involving less water for irrigation with high productivity have to be promoted at large scale.

Crop productivity is determined by the crops genetic potential and its interaction with the environment which can be modified with best agronomic practices. In a meeting at Stanford University, a group of experts—including crop scientists from

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: pib.gov.in (2015)

Table 24.2 Estimated water demand in India for different sectors

Sector	Water demand (billion cubic meters)		
	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 (2019)

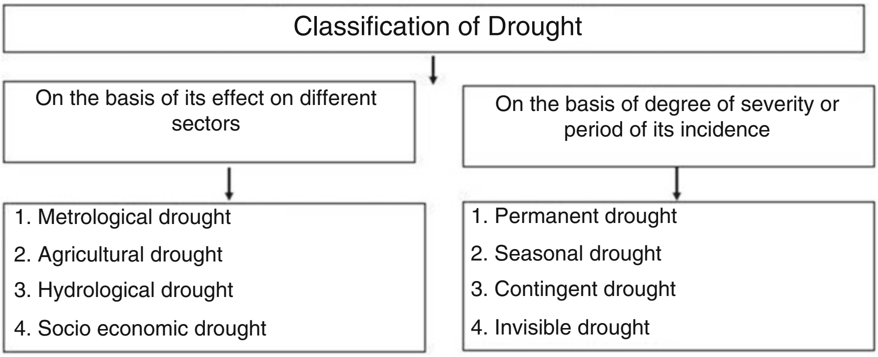
seed companies—concluded as part of their recommendations that "particularly for managing moisture stress in rainfed systems, agronomy may well offer even greater potential benefits than improved crop varieties" (Lobell 2009). Different crops/varieties have different genetic potential depending upon their adaption abilities. Stresses in plants lead to crop failures and crops adapt different defense mechanisms to cope up with the stress imposed on it. Biotic stresses like insect-pest attack can be managed through integrated approach and timely intervention can help in reducing yield loss to a great extent. Abiotic stresses like low or high water stress, temperature stress, salt stress, etc. are difficult to predict and manage as these are generally weather driven with limited scope of modification, thus leading to major yield losses. Although plants have their own adaptive mechanism against any adverse environment condition the degree of tolerance and adaptability to abiotic stresses varies among different crops and within crop, different varieties. Crop physiology undergoes significant changes throughout its life cycle as plants grow from seed to its vegetative phase and ultimately culminating into reproductive phase to complete its life cycle. But under stress, the physiological changes within the plants vary depending upon the degree of stress imposed on plants and plant's ability to withstand that stress. Water and temperature stress are the two major abiotic constraints that occur frequently and in tandem with each other in Indian conditions. The response time to deal with these stresses is very limited and chances of crop failure become high. It requires mid-season corrections through agronomic management but the abrupt physiological changes within plants lead to losses and damage to plant growth. Low water stress or drought inhibits crop growth and restricts its life cycle.

Drought Irrigation or water is an important critical input in agricultural production. Any deviation from normal can offset the expected output. Drought in acute terms can be explained as shortage of available water to crops during major portion of cropping season which may be due to substantial deviation of rainfall from normal or uneven and untimely temporal/spatial distribution pattern leading to severely impaired crop production (DA&FW 2016). It can be further classified into meteorological, agricultural, hydrological, and socioeconomic drought depending upon the impact on ground and surface water resources, cropping pattern and choices adopted, agro-climatic features, socioeconomic vulnerability of local population. It is considered as the major factor which can limit the agricultural production to a large extent and the major drought years have also coincided with substantial production decline and increased commodity prices. Drought can manifest itself into three major impacts on agriculture:

1. Impact on farm production and farmer: Drought induced stress are directly related with reduced farm production and increased farmer distress. However in low production years, higher commodity prices can slightly offset this impact.
2. Market level impact: Agricultural output is known to drive market prices. Any reduction is going to increase the retail prices of agricultural commodities. This impacts the sectors which depend upon agriculture inputs the most. For example, reduced maize production can spiral upwards the price of feed used in poultry which can further eat away the buying power of purchasers.
3. Ecological impact: Reduced production during drought years put extra burden on environment through disturbed food chain and other cascading effects like soil erosion, dust bowls, reduced acreage, and reduced biodiversity.

24.2 Concept of Drought

In arid regions, drought is a common phenomenon and the terms, arid and drought, are sometimes used interchangeably. Arid climate is a permanent feature in an area, while drought is a temporary event. Drought is related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to crop growth stages) and the effectiveness (i.e., rainfall intensity, number of rainfall events) of the rains. It should not be viewed as a physical or natural event only as its impact is multifaceted. It can bring economic, social, and environmental hardship, which increases vulnerability of societies limiting their capacity to overcome its stress and impacts cultural, health, and welfare of the affected area. So in order to plan strategies for drought management it is better to understand its concept and its manifestation. In conceptual terms, drought can be simplified as a period of deficient precipitation, resulting in extensive damage to crop growth and development leading to loss of crop yield. In operational definition, drought can be categorized on the basis of its effect on different sectors or its relevance to users and on the basis of the degree of severity or period of its incidence:



Classification of drought on the basis of its effect on different sectors or its relevance to users:

1. *Meteorological drought*: Meteorological drought is commonly based on precipitation amount and time. Its significant departure from normal average over a certain period of time leads to meteorological drought and is region-specific.
2. *Agricultural drought*: Agricultural drought is more concerned with the impact of drought on crop production. It is said to occur when there is not enough soil moisture to meet a crop water requirement at a particular time. This leads to significant physiological changes and negatively impacts crop productivity of that area. Impact of agricultural drought can be modified to some extent through agronomic management options.
3. *Hydrological drought*: Hydrological drought refers to deficiencies in surface and subsurface water supplies. This drought can directly be measured as stream/river flow and as lake, reservoir, and groundwater levels. Because there is a time lag between the time of rain falling and its appearance in streams, rivers, lakes, and reservoirs, hydrological measurements are not the earliest indicators of drought. Engineering measures are more suited to modify hydrological drought.
4. *Socioeconomic drought*: Socioeconomic drought occurs when physical water shortage starts to affect people, individually and collectively. Most socioeconomic definitions of drought associate it with the supply and demand. Socioeconomic drought occurs when the demand exceeds the supply as a result of a weather-related shortfall in water supply.

Classification of drought on the basis of the degree of severity or period of its incidence and its impact on agriculture:

1. *Permanent drought*: It refers to recurrent and continuous phenomenon of limited water availability or drought conditions owing to arid agroecological conditions. These areas are categorized as deserts which have sparse vegetation cover but its vegetation is well adapted to limited moisture conditions. Agriculture

opportunities are limited under these situations and need major land configuration modification to increase area under cultivation.

2. *Seasonal drought*: The areas where precipitation offers some scope for crop cultivation and where annual rainfall is defined and period of dryness is already known. Mono cropping can be adopted in these areas. Moisture conservation through agronomic modification like planting date, choice of crop and variety offers major scope to cope with drought stress and in achieving better germination and good crop stand.
3. *Contingent drought*: Sudden and unexpected deviation in precipitation amount and time leads to contingent drought where normally intensive agriculture is practiced. Sub-humid to humid climate comes under this category with ample rainfall to support at least two crops in an year. Measures like residue retention or mulching, removal of older leaves, use of nanoparticles, soil absorbents, antitranspirants offer opportunities for reduced evaporative and transpiration losses leading to better adaptation during contingent drought.
4. *Invisible drought*: Drought which occurs in humid climate is known as invisible drought. It occurs when evapotranspiration losses are higher than soil moisture supplying capacity even though there is ample rainfall in that area. Higher temperature, salt content in soil may the reason for invisible drought. This leads to changes in crop physiology and decline in crop yields.

24.3 Effect of Drought on Plants

1. *Impact on plant germination and growth*: Drought brings in abrupt changes in physiology and bio-chemical behavior of the plants like photosynthesis, nutrient metabolism, translocation, and absorption (Hussain et al. 2018). Under water stress conditions, water required for seed imbibition is limited (Molina et al. 2018) which affects several metabolic processes (Farooq et al. 2009; Fahad et al. 2017) like synthesis of hydrolytic enzymes. These enzymes are important for hydrolysis of reserve food into simple available form for embryo uptake (Ali and Elozeiri 2017) and hence germination. Therefore drought during initial growth stages is known to drastically impact germination of crops. For plant growth and development, cell expands in size due to turgor pressure which is generated by water absorption, but under limited moisture availability, plants tend to maintain its turgidity by reducing cell size (Weijde et al. 2017) which leads to poor growth, reduced photosynthesis, and crop yield (Christophe et al. 2011).
2. *Effect on photosynthesis and water absorption*: Plant physiology is determined by enzymatic activities being influenced by abiotic factors especially temperature and water stress (Fahad et al. 2017). Plant-water relation is affected by temperature, water availability that directly influences leaf water potential, canopy temperature, and transpiration and respiration activities. Trabelsi et al. (2019) reported decreased leaf water potential and relative water content under water stress conditions which reduces the activities of photosynthetic pigments (Fathi and Tari 2016). Due to high temperature or reduced availability of moisture,

plants tend to close their stomata to minimize transpiration losses. But this abnormal closure of stomata hampers photosynthesis (Shareef et al. 2018) which affects biomass partitioning and yield under drought conditions.

3. *Impact on nutrient uptake and yield*: Plants absorb nutrients through transpirational pull and drought stress in plants reduces plant nutrient uptake by reducing nutrient diffusion and mass flow in the soil (Silva et al. 2011). Under water deficit, root activity gets reduced and it slows down ion diffusion and finally nutrient uptake by the plants through roots (Christophe et al. 2011). Yield of a crop is the assimilate of its partitioning into reproductive form in cereals (Pandey et al. 2017). Mid-season moisture stress brings abrupt physiological changes in the plants by accelerating its phenology (Marjani et al. 2016). High temperature at grain ripening phase hastens leaf senescence, reduces grain filling duration, and increases grain filling rate (Bali and Pannu 2017). The yield obtained under such conditions has shrinked grains with less individual grain weight and size. So, drought brings a drastic change in phenology and physiology of the crops.

Drought Management Strategies Drought poses a significant threat to our social and economic life by reducing crop productivity. Its impact spans over many sectors of the economy as water is integral part for our survival and it is an important component to produce goods and provide services. So, drought management strategies are to be formulated with a contingency plan for real-time implementation and important interventions in this regard are:

- Tolerant or adaptive varieties
- Short-duration crops
- Land preparation and tillage
- Irrigation management
- ET loss management through different methods
- Rainwater management

The process of formulating the implementation strategies in drought management involves preparedness and real-time contingency measures in the fields. Preparedness involves anticipation of timing of drought occurrence which can be gauged from observing past events/meteorological data or from utilizing the local indigenous knowledge. In areas with limited access to early weather warning system and lack of formal education, indigenous knowledge comes in handy in preparing to cope better with abiotic stresses. In a study conducted by Muyambo et al. (2017), several early signs of imminent drought have been documented which help farmers in coping better to drought related stress by adopting suitable agronomic management practices. Along with it land and soil management options like broad bed furrows, compartmental bunding, slope within the fields, trenches etc. also offer advantages in drought years (Table 24.3).

Table 24.3 Indigenous knowledge to mitigate drought risk

Species	Behavior	Description in relation to drought or rain
Snakes	Movement of snakes in one direction	Drought expected
Bees	When bees fly in a certain direction	Drought expected
Frogs	Noise by frogs in afternoon	Drought expected
Horse	Horse jumping playfully	Precipitation expected
Butterflies	Butterflies flying together	Drought with a good farming season

Source: Muyambo et al. (2017)

Table24.4 Recommended cropping pattern depending upon precipitation availability

Annual rainfall (mm)	Cropping pattern to be adopted
350–625	Single crop in kharif
650–750	Intercropping
780–900	Sequential cropping
900 and above	Sequential cropping

Real-time contingency measures include mulching, water conservation techniques, antitranspirants' spray, etc. to avoid ET losses and to conserve moisture for critical stage in crops (Srinivasarao et al. 2013).

24.4 Various Agronomic Interventions for Managing Drought Stress/Risk for Sustainable Production Are

1. *Selection of appropriate cropping system, drought resistant crops and cultivars*: In arid climates, drought preparedness is the only way to survive and sustain. Selection of drought tolerant crops and varieties are important pre-requisites for sustainable crop production in drought-prone areas (Singh et al. 2014). Short duration and less water requiring crops are to be encouraged. Moreover, crops with waxy leaves, awns, narrow leaf structures, etc. should be preferred as they tend to save moisture loss from the plants. Selection of crops like pearl millet, gram, mustard, cotton, sunflower etc. should be encouraged in drought-prone areas to achieve good crop production. Depending upon the amount of rainfall in area, cropping pattern and varieties are to be selected (Tables 24.4, 24.5, and 24.6).

2. *Tillage modification to manage drought stress*: Tillage is mechanical manipulation of soil to prepare land for cultivation of crops. Number of tillage operation, timing, and depth plays an important role from the viewpoint of water conservation. Conventional tillage which is also known as intensive tillage includes multiple tillage operations to incorporate residue into the soil and preparing fine seed bed for fast and better seed establishment, fertilizer incorporation, and per emergence herbicide application. Conversely, conservation tillage or minimum

Table 24.5 Efficient crops in drought-prone areas

Location	Traditional crop	Yield (kg ha^{-1})	Efficient crops	Yield (kg ha^{-1})
Bellary	Cotton	200	Sorghum	2670
Varanasi	Wheat	860	Chickpea	2850
Ranchi	Upland rice	2880	Corn	3360
Indore	Green gram, wheat	1180, 1120	Soybean, safflower	3330, 2420
Agra	Wheat	1030	Rapeseed-mustard	2040
Hissar	Wheat	320	Sativa	1610
Udaipur	Corn	1800	Sorghum	2900
Rewa	Soybean	400	Soybean	1200

Adapted from DA&FW (2016)

Table 24.6 Drought tolerant cultivars released in India

Crop	Drought tolerant cultivars
Rice	Anjali, Vandana, Sahabhagi Dhan, DRR Dhan 42 (IR64 Drt 1), Satyabhama, Birsa Vikas Dhan 203, DRR Dhan 43, Rajendra Bhagwati, Birsa Vikas Dhan 111, JaldiDhan 6
Maize	HM 4, Pusa Hybrid Makka 1, DHM 121, Pusa Hybrid Makka 5, Buland
Wheat	HI 1531, PBW 527, HI 8627, NIAW 1415, K 8962, HD 2888, PBW 644, HD 2987, WH 1080, HD 3043, PBW 396, K 9465, MP 3288, HPW 349, HD 4672
Pearl millet	HHB-226, HHB 67 improved, Dhanshakti, GHB 757, GHB 719, Pusa Composite 443, HHB 234, Mandor Bajra Composite 2, RHB-177
Sorghum	CSH 19 R, CSV 18, CSH 15R
Chickpea	Vijay, RSG 14, Vikas, ICCV 10, RSG 888, Pusa 362, Vijay
Barley	RD 2660, K603
Groundnut	TAG-24, Ajaya, ICGV 91114, Girnar 1, Kadiri 6
Sugarcane	Co 86032, Co 98014 (Karan-1), Co 0238, Co 0403, Co 0239, Co 0118, Co 06927
Soybean	JS 95-60, NRC 7
Cotton	Veena, Raj DH 7, HD 324, CICR-1,Surabhi, Pratap Kapi, Suraj, AK 235

Source: PIB (2015)

tillage involves minimum disturbance to soil and retention of residues on the soil surface. The selection of tillage operation and residue management option has profound effect on movement of water (runoff/infiltration/retention/evaporation). In drought stress management, water conservation is the key; therefore, selection of appropriate tillage operation is very crucial to mitigate drought damage. Retention of crop residues on the topsoil surface can improve water infiltration rate due to surface roughness which further decreases the surface runoff and erosion chances (Moore 2015). It has been observed that zero tillage combined with residue retention has potential to trap 70% more water as compared to conventional tillage, which is very crucial in water limited conditions observed during drought (Al-Kaisi 2020). This observation is also reflected in adoption of no till by farmers during drought years where extreme dry conditions favor increased adoption rate of no tillage by farmers whereas wet conditions (floods) do not reflect change in tillage adoption pattern (Ding

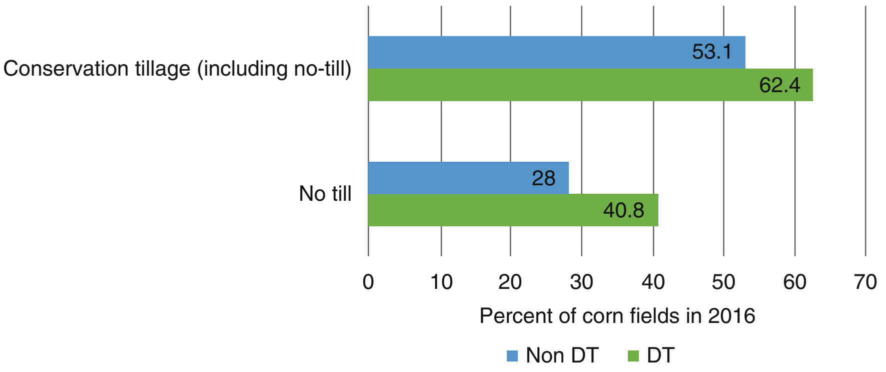


Fig. 24.1 Share of US drought tolerant (DT) and non-DT fields that used conservation tillage and no-tillage in 2016. Source: USDA (2016)

et al. 2009). No till or conservation tillage also compliment where other drought management options are adopted, for example, farmers in USA who planted drought tolerant (DT) maize mostly adopted conservation tillage or no tillage at their farms (Fig. 24.1). Reduced evaporation losses coupled with better water retention may be the reasons for adoption of conservation tillage which improves the chances of survival and better productivity of drought tolerant maize.

3. *Improved irrigation efficiency to manage drought*: India is a dynamic country with many agroecological zones falling into its geography. The increasing population depending on limited natural resources put great pressure on its ecology. Rainfall plays a critical role in Indian agriculture. It is a gamble of monsoon and a good amount of rainfall which ensures high groundwater recharge with proper management. Both surface water and groundwater are used for irrigating the fields. In rainfed areas, it is very important to utilize the water very efficiently. In drought-prone areas, irrigation with utmost precision and high efficiency system is the priority. The efficiency of canal system is less than 40%, while groundwater irrigation efficiency is approximately 50%. Still there is huge water loss that needs to be tapped in drought-prone areas. Hence, high water efficiency systems are to be understood and implemented. Strategies should be made to bring every single drop of water to the plants directly without getting wasted midway. Micro-irrigations systems have very high potential in improving the water efficiency to more than 90% and can provide the critical irrigation to crop in drought scenario. Micro-irrigation system has immense scope for water conservation and attaining higher crop productivity. Crop water requirement can be fulfilled by just providing adequate moisture to the roots. Conversely, excess water applied to the soil works as an early shock to the crop plants due to anoxia and subsequently, when water subsides, then roots are able to absorb the

moisture through capillaries and provide it to whole plant. Through micro-irrigation system, that initial shock to the plants can be avoided and rather drop wise irrigation ensures direct absorption by crop roots. This helps in improving water use efficiency and thus helps in attaining optimum crop productivity (Ashoka et al. 2015) in water limited environments. Extreme climate events like drought, floods, cyclones, heat waves, frost, etc. have a direct impact on agriculture followed by adverse impact on human and animal lives. Loss in crop productivity hampers our food security which has larger impact on the society and economy. With extremities in temperature and rainfall pattern in India, it is very important to implement strategies with extensive planning which give a wider scope of adaption to the farmers.

4. *Increase in soil organic matter*: A large amount of scientific evidence shows that organic matter is the most important trait in making soils more resistant to drought and able to cope better with less and more erratic rainfall (Bot and Benites 2005; Lal 2008; Pan et al. 2009; Riley et al. 2008). To minimize the impact of drought, soil needs to capture the rainwater that falls on it, store as much of that water as possible for future plant use, and allow for plant roots to penetrate and proliferate. Problems with or constraints on one or several of these conditions cause soil moisture to be one of the main limiting factors for crop growth. The capacity of soil to retain and release water depends on a broad range of factors such as soil texture, soil depth, soil architecture (physical structure including pores), organic matter content, and biological activity. However, appropriate soil management can improve this capacity. Practices that increase soil moisture content can be categorized into three groups: (1) those that increase water infiltration; (2) those that manage soil evaporation; and (3) those that increase soil moisture storage capacities. All three are related to soil organic matter. And this organic matter can be efficiently increased through crop residue mulching. Let us look how crop residue mulching can perform all these three practices. The crop residue amount increasing on the soil surface reduces the evaporation rate (Gill and Jalota 1996; Prihar et al. 1996). Consequently, the application of crop residue is the best practice to add organic amendment in soil and cover it surface. For obtaining sustainable development, crop residue properly manages to simultaneously increase soil organic carbon, soil nutrients, water availability and productivity requirement as well as livestock fodder. The availability of plant water content was significantly lower in conventional tillage as compared to zero tillage under rice wheat cropping system as reported by Bhattacharyya et al. (2006, 2008). Increased levels of organic matter and associated soil fauna lead to greater pore space with the immediate result that water infiltrates more readily and can be held in the soil (Roth 1985). The improved pore space is a consequence of the bioturbating activities of earthworms and other macro-organisms and channels left in the soil by decayed plant roots. Organic matter contributes to the stability of soil aggregates and pores through the bonding or adhesion properties of organic materials, such as bacterial waste products, organic gels, fungal hyphae, and worm secretions and casts. Moreover, organic matter intimately mixed with mineral soil materials has

a considerable influence in increasing moisture holding capacity. Especially in the topsoil, where the organic matter content is greater, more water can be stored. Hudson (1994) showed that for each 1-percent increase in soil organic matter, the available water-holding capacity in the soil increased by 3.7%. Soil water is held by adhesive and cohesive forces within the soil and an increase in pore space will lead to an increase in water-holding capacity of the soil. As a consequence, less irrigation water is needed to irrigate the same crop. In general, a 1% increase in SOM content increased AWHC, on average, up to 1.5% times its weight, depending on soil texture and clay mineralogy. These values were consistent with the theoretical calculations that showed that the potential AWHC increase (on a volumetric basis) from a unit increase in SOM (% weight) is about 1.5–1.7% for the 0–8% SOM range. This equates to 10,800 L of water for each additional 1% increase in SOM (up to 8% SOM) for a layer thickness of 15 cm covering 0.4 ha area (an acre furrow slice).

5. *Residue retension/mulching*: Evapotranspiration losses are major water losses from crop lands (Morison et al. 2008). So, under drought, it becomes very important to minimize the losses so that all the water should be diverted to crop plants. Land without plantation is exposed to high radiation and thus evaporation losses are high in such areas while if temperature is high and relative humidity is low then transpiration losses from the plants will be high. To avoid evaporation losses, mulching is very important mitigation strategy. It improves water regulation in the plant system, reduces runoff, reduces weed infestation, and regulates the soil temperature (Waraich et al. 2011; Kazemia and Safaria 2018). Soil cover protects the soil against the impact of raindrops, prevents the loss of water from the soil through evaporation, and also protects the soil from the heating effect of the sun. Soil temperature influences the absorption of water and nutrients by plants, seed germination and root development, as well as soil microbial activity and crusting and hardening of the soil. Mulching with crop residues or cover crops regulates soil temperature. The soil cover reflects a large part of solar energy back into the atmosphere and thus reduces the temperature of the soil surface. This results in a lower maximum soil temperature in mulched compared with unmulched soil.
6. *Biodiversity*: Under present and future scenarios of a changing climate, farmers' reliance on crop diversity is particularly important in drought-prone areas where irrigation is not available. Diversity allows the agroecosystem to remain productive over a wider range of conditions, conferring potential resistance to drought (Naeem et al. 1994). In the dry-hot habitats of the Middle East, some wild wheat cultivars have an extraordinary capacity to survive drought and make highly efficient use of water, performing especially well under fluctuating climates (Peleg et al. 2009). Researching the diversity and drought coping traits of wild cultivars provides scientists with new tools to breed crops better adapted to less rainfall. In Italy, a high level of genetic diversity within wheat fields on nonirrigated farms reduces the risk of crop failure during dry conditions. In a modeling scenario, where rainfall declines by 20%, the wheat yield would fall sharply, but when diversity is increased by 2% not only is this decline reversed,

above average yields can also be achieved (Di Falco and Chavas 2006, 2008). In semi-arid Ethiopia, growing a mix of maize cultivars in the same field acts like an insurance against dry years. Fields with mixed maize cultivars yielded about 30% more than pure stands under normal rainfall years but outperformed with 60% more yield than monocultures in dry years (Tilahun 1995). Crop genetic diversity is the richness of different genes within a crop species. This term includes diversity that can be found among the different varieties of the same crop plant (such as the thousands of traditional rice varieties in India), as well as the genetic variation found within a single crop field (potentially very high within a traditional variety, very low in a genetically engineered or hybrid rice field). Cropping diversity at the farm level is the equivalent to the natural species richness within a prairie, for example. Richness arises from planting different crops at the same time (intercropping a legume with maize, for example), or from having trees and hedges on the farm (agroforestry). Farm-level cropping diversity can also include diversity created over time, such as with the use of crop rotations that ensure the same crop is not grown constantly in the same field. Farm diversity at the regional level is the richness at landscape level, arising from diversified farms within a region. It is high when farmers in a region grow different crops in small farms as opposed to large farms growing the same cash crop (for example, large soya monocultures in Argentina).

7. *On-farm rainwater harvesting (RWH) pond*: There are numerous research works which show that drought/water scarcity is very harmful for crop production. But nowadays climate change has worsen the situation even in the areas where water scarcity was not so much. Climate change has significantly affected the livelihood and income of farmers across the globe (IPCC 2014). Rainwater harvesting (RWH) in ponds can be a promising way to include resilience in the system against water scarcity and climate change. RWH in this context can be described as a method of inducing, collecting, storing, and conserving local surface runoff for agriculture production (Ibraimo 2007). This harvested water can be easily used without significant treatment (Nolan and Lartigue 2017). Farm pond technology has the potential to increase availability of water for supplemental irrigation, increase in cropped area and productivity leading to increase in net returns from crops (Rao et al. 2017). Nearly 25–30% of crop productivity may enhance through farm pond intervention as harvested rainwater available for providing one or two protective irrigations to crops at critical growth stages during dry spells and droughts (Dupdal et al. 2020). Rainwater buffer tank significantly reduces the runoff peak flow hence had the capacity to protect against the adverse effects of flood such as damage to properties and loss of life (Qin et al. 2019).

References

Abido WAE, Zsombik L (2018) Effect of water stress on germination of some Hungarian wheat landraces varieties. Acta Ecol Sin 38:422–428

Ali A, Elozeiri AA (2017) Metabolic processes during seed germination. Intech Open, London, p 141

Al-Kaisi M (2020) Residue management consideration for this fall [WWW Document]. Iowa State Univ. Ext. Outreach. https://crops.extension.iastate.edu/blog/mahdi-al-kaisi/residue-management-consideration-fall

Ashoka P, Kadasiddappa MM, Sanjey MT (2015) Enhancing water productivity through microirrigation technologies in Indian agriculture. Ann Plant Soil Res 17:601–605

Bali A, Pannu RK (2017) Quality parameters and yield of wheat as influenced bysowing dates and irrigation levels under semi-arid conditions of Hisar. Ann Agric Res 39(1):20–25

Basin Planning Directorate, CWC (2019) XI Plan Document. Report of the standing sub-committee on "Assessment of availability and requirement of water for diverse uses-2000". Accessed 23 Mar 2019

Bhat NR, Suleiman MK, Abdal M (2009) Selection of crops for sustainable utilization of land and water resources in Kuwait. World J Agric Sci 5:201–206

Bhattacharyya R, Singh RD, Chandra S, Kundu S, Gupta HS (2006) Effect of tillage and irrigation on yield and soil properties under rice (Oryza sativa)-wheat (Triticum aestivum) system on a sandy clay loam soil of Uttaranchal. Indian J Agric Sci 76(7):405–409

Bhattacharyya R, Kundu S, Pandey SC, Singh KP, Gupta HS (2008) Tillage and irrigation effects on crop yields and soil properties under the rice–wheat system in the Indian Himalayas. Agric Water Manag 95(9):993–1002

Bot A, Benites J (2005) Drought-resistant soils. Optimization of soil moisture for sustainable plant production. Food and Agriculture Organization of the United Nations. Land and Water Development Division

Christophe S, Jean-Christophe A, Annabelle L, Alain O, Marion P, Anne-Sophie V (2011) Plant N fluxes and modulation by nitrogen, heat and water stresses: a review based on comparison of legumes and non-legume plants. In: Shanker A, Venkateswarlu B (eds) Abiotic stress in plants-mechanisms and adaptations. IntechOpen, Rijeka, pp 79–118

DA&FW (2016) Manual for drought management by Department of Agriculture & Farmer Welfare

Di Falco S, Chavas J-P (2006) Crop genetic diversity, farm productivity and the management of environmental risk in rainfed agriculture. Eur Rev Agric Econ 33:289–314

Di Falco S, Chavas J-P (2008) Rainfall shocks, resilience, and the effects of crop biodiversity on agroecosystem productivity. Land Econ 84:83–96

Ding Y, Schoengold K, Tadesse T (2009) The impact of weather extremes on agricultural production methods: does drought increase adoption of conservation tillage practices? J Agric Resour Econ 34:395–411

Dupdal R, Patil SL, Naik BS, Ramesha MN (2020) Role of farm pond in improving productivity and farm income in dryland area. Life Sci Leaflets 128(2020):09–14

Fahad S, Bajwa AA, Nazir U, Anjum SA, Farooq A, Zohaib A, Sadia S, Nasim W, Adkins S, Saud S, Muhammad Ihsan Z, Alharby H, Wu C, Wang D, Huang J (2017) Crop production underdrought and heat stress: plant responses and management options. Front Plant Sci 8(1147): 1–16

Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA (2009) Plant drought stress: effects, mechanisms and management. Agron Sustain Dev 29:185–212

Fathi A, Tari DB (2016) Effect of drought stress and its mechanism in plants. Int J Life Sci 10(1): 1–6

Gill BS, Jalota SK (1996) Evaporation from soil in relation to residue rate, mixing depth, soil texture and evaporativity. Soil Technol 8(4):293–301

Hudson BD (1994) Soil organic matter and available water capacity. J Soil Water Conserv 49(2): 189–194

Hussain HA, Hussain S, Khaliq A, Ashraf U, Anjum SA, Men S, Wang L (2018) Chilling and drought stresses in crop plants: implications, cross talk, and potential management opportunities. Front Plant Sci 9(393):1–21

Ibraimo NM (2007) Rainwater harvesting technologies for small scale rainfed agriculture in arid and semi-arid areas. Int J Educ Res 1(6):1–3

IPCC (2014) Climate change impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp 688. Sweetbriar Brook, Ampthill, Storbritannien, p 66

Kazemia F, Safaria N (2018) Effect of mulches on some characteristics of a drought tolerant flowering plant for urban landscapes. Desert 23(1):75–84

Lal R (2008) Managing soil water to improve rainfed agriculture in India. J Sustain Agric 32:51–75

Lobell DB (2009) Climate extremes and crop adaptation. Summary statement from a meeting at the program on Food Security and Environment, Stanford, CA, held on June 16-18, 2009

Marjani A, Farsi M, Rahimizadeh M (2016) Response of chickpea (Cicer arietinum L.) genotypes to drought stress at different growth stages. Int J Agric Biosyst Eng 10(9):1–5

Minhas PS et al (2017) Abiotic stress management for resilient agriculture. Springer, Berlin. https://doi.org/10.1007/978-981-10-5744-1_1

Molina R, Lopez-Santos C, Gomez-Ramirez A, Vilchez A, Espinos JP, Gonzalez-Elipe AR (2018) Influence of irrigation conditions in the germination of plasma treated nasturtium seeds. Sci Rep 8:16442

Moore LE (2015) Tillage, residue management and their effect on soil moisture. Drought Manage Factsheet 2

Morison JIL, Baker NR, Mullineaux PM, Davies WJ (2008) Improving water use in crop production. Philos Trans R Soc B 363:639–658

Muyambo F, Bahta YT, Jordaan AJ (2017) The role of indigenous knowledge in drought risk reduction: a case of communal farmers in South Africa. Jamba 9:420. https://doi.org/10.4102/jamba.v9i1.420

Naeem S, Thompson LJ, Lawler SP, Lawton JH, Woodfin RM (1994) Declining biodiversity can alter the performance of ecosystems. Nature 368:734–737

Nolan, Lartigue (2017) Evaluation of the performance of rainwater harvesting systems for domestic use in Tlalpan, Mexico City. Civil Eng J. https://doi.org/10.28991/cej-2017-00000080

Pan G, Smith P, Pan W (2009) The role of soil organic matter in maintaining the productivity and yield stability of cereals in China. Agric Ecosyst Environ 129:344–348

Pandey G, Yadav L, Tiwari A, Khatri HB, Basnet S, Bhattarai K, Gyawali B, Rawal N, Khatri N (2017) Analysis of yield attributing characters of different genotypes of wheat in Rupandehi, Nepal. Int J Environ Agric Biotechnol 2(5):2374–2379

Peleg Z, Fahima T, Krugman T, Abbo S, Yakir D, Korol AB, Saranga Y (2009) Genomic dissection of drought resistance in durum wheat x wild emmer wheat recombinant inbreed line population. Plant Cell Environ 32:758–779

PIB (2015) Press information bureau [WWW Document]. Press release by PIB, Gov. India, Minist. Agric. Farmers Welf. https://pib.gov.in/newsite/PrintRelease.aspx?relid=123999. Accessed 11 August 2022

Prihar SS, Jalota SK, Teiner. (1996) Residue management for reducing evaporation in relation to soil type and evaporativity. Soil Use Manag 12:150–157

Qin Y, Huang Z, Yu Z, Liu Z, Wang L (2019) A novel buffer tank to attenuate the peak flow of runoff. Civil Eng J 5(12):2525–2532

Rao S, Rejani R, Rama Rao CA, Rao KV, Osman M, Srinivasa Reddy K, Kumar M, Kumar P (2017) Farm ponds for climate-resilient rainfed agriculture. Curr Sci 112(3):471–477

Riley H, Pommeresche R, Eltun R, Hansen S, Korsaeth A (2008) Soil structure, organic matter and earthworm activity in a comparison of cropping systems with contrasting tillage, rotations, fertilizer levels and manure use. Agric Ecosyst Environ 124:275

Roth CH (1985) Infiltrabilität von Latosolo-Roxo-Böden in Nordparaná, Brasilien, in Feldversuchen zur Erosionskontrolle mit verschiedenen Bodenbearbeitungs-systemen und Rotationen. Gött. Bod. Ber. 83:1–104

Shareef M, Gui D, Zeng F, Ahmed Z, Waqas M, Zhang B, Iqbal H, Fiaz M (2018) Impact of drought on assimilates partitioning associated fruiting physiognomies and yield quality attributes of desert grown cotton. Acta Physiol Plant 40:71

Silva EC, Nogueira RJMC, Silva MAM, Albuquerque B (2011) Drought stress and plant nutrition. Plant Stress 5(1):32–41

Singh L, Beg MKA, Akhter S, Qayoom S, Lone BA, Singh P, Singh P (2014) Efficient techniques to increase water use efficiency under rainfed eco-systems. J Agric Search 1(4):193–200

Srinivasarao C, Chary R, Mishra G, Nagarjuna PK, Maruthi S, Venkateswarlu B, Sikka AK (2013) Real time contingency planning: initial experiences from AICRPDA. All India CRIDA, ICAR, Hyderabad

Tilahun A (1995) Yield gain and risk minimization in maize (Zea mays) through cultivar mixtures in semi-arid zones of the Rift Valley in Ethiopia. Exp Agric 31:161–168

Trabelsi L, Gargouria K, Hassena AB, Mbadra C, Ghrab M, Ncube B, Staden JV, Gargour R (2019) Impact of drought and salinity on olive water status and physiological performance in an arid climate. Agric Water Manag 213:749–759

USDA (2016). No-till and conservation tillage practices are more common on fields planted with drought-tolerant corn [WWW Document]. USDA Natl. Stat. Serv. https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=93264. Accessed 11 November 2022

Waraich EA, Ahmad R, Ashraf MY, Saifullah AM (2011) Improving agricultural wateruse efficiency by nutrient management in crop plants. Acta Agric Scand B Soil Plant Sci 61(4): 291–304

Weijde TVD, Huxley LM, Hawkins S, Sembiring EH, Farrar K, Dolstra O, Visser RGF, Trindade LM (2017) Impact of drought stress on growth and quality of miscanthus for biofuel production. Glob Change Biol Bioenergy 9:770–782

Yazdani F, Allahdadi I, Abas AG (2007) Impact of superabsorbent polymer on yield and growth analysis of soybean (Glycine max L.) under drought stress condition. Pak J Biol Sci 10:4190–4196