Occurrence of Salinity and Drought Stresses: Status, Impact, and Management

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The world's population is expected to reach nine billion by 2050 (FAO 2009), and the climate is also changing. Abiotic and biotic stresses are the major challenges in crop production worldwide, and climate change will likely lead to more severe abiotic and biotic stress conditions (Cobb et al. 2013). By the year 2050, 50% of all arable lands will be consequently threatened by global climate changes, low water availability, and salinization (Wang et al. 2003). Salinity and drought are the most severe abiotic stresses that threaten crop productivity worldwide (Guo et al. 2014). Drought is expected to increase in frequency and severity in the future due to climate change, mainly due to decreases in regional precipitation but also because of increasing evaporation driven by global warming (Lobell et al. 2008). Drought affects more than 10% of arable land, causing desertification, especially in arid and semiarid areas, while salinization is rapidly increasing on a global scale, declining average yields for most major crops (Bray et al. 2000). Soil salinization is one of the severe forms of soil degradation, which can arise from natural causes and human-mediated activity, such as irrigation in arid and semiarid regions (Rengasamy et al. 2010).

Water stress is found to be the most important limiting factor controlling primary production in terrestrial environments. Water stress is a limited water supply to plant roots, which reduces plants' transpiration rate. It is mainly caused by water deficit as a result of drought conditions or soil salinity. The effects of drought in agriculture are aggravated due to the depletion of water resources and the increased food demand

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from an alarming world population growth (O'Connell 2017). Drought is one of the most common environmental stresses affecting plant growth and development and is a challenge to agricultural researchers. Water comprises about 80–95% of the fresh biomass of the plant body and plays a vital role in various physiological processes, including many aspects of plant growth, development, and metabolism (Brodersen et al. 2019; Abbasi and Abbasi 2010). The drought's unpredictable nature depends upon various factors, such as uneven and erratic distribution of rainfall, high evapotranspiration demand, and low water-holding capacity around the rhizosphere (Passioura and Angus 2010; Devincentis 2020). Water stress numerously affects plants' growth and development. These changes depend on the severity, duration, and time course of water stress (Bradford and Hsiao 1982). Drought stress often induces stomatal closure that restricts the diffusion of CO_2 into the leaf or is due to non-stomatal limitations, which leads to a decrease of carbon assimilation and other processes of photosynthesis (Ashraf and Harris 2013; Guan et al. 2015; Paul et al. 2016).

More than 800 million ha of land worldwide are salt-affected, which has important consequences for the productivity of crops. Salinity is major stress limiting the increase in the demand for food crops. More than 20% of cultivated land worldwide (~about 45 ha) is affected by salt stress, and the amount is increasing day by day. Increased soil salt concentrations decrease the ability of plants to take up water leading to apparent water limitation or can lead to the accumulation of salt in the shoots, which negatively affects growth by impairing metabolic processes and decreasing photosynthetic efficiency, partly through stomatal closure (Flowers and Yeo 1995; Maser et al. 2002; Munns 2002; Roy et al. 2014). Salinity affects almost all aspects of plant development, including germination, vegetative growth and reproductive development, and decreasing water and nutrient uptake (Akbarimoghaddam et al. 2011; Singh and Chatrath 2001). Salinity can affect plant functions via two main mechanisms (Munns and James 2003; Munns and Tester 2008; Arzani and Ashraf 2016): (1) via inducing external osmotic pressure around the roots in the soil, which decreases the uptake of water leading to symptoms similar to those caused by drought, and (2) via toxic effect of salt ions, mostly Na^+ and Cl^-, which accumulate in the plant tissues, mostly in the leaves. Soil salinity is known to repress plant growth through osmotic stress, which is then followed by ion toxicity (James et al. 2011; Rahnama et al. 2010). During the initial phases of salinity stress, the water absorption capacity of root systems decreases, and water loss from leaves is accelerated due to the osmotic stress of high salt accumulation in soil and plants, and therefore salinity stress is also considered hyperosmotic stress.

Within an agricultural context, drought is a prolonged period of deficient precipitation that negatively impacts crop growth or yield. An increasingly warming climate is expected to intensify the frequency and severity of drought in the near future. As a consequence of the ongoing global climate changes, low water availability and salinization are expected to affect up to 50% of all arable lands by the year 2050 (Wang et al. 2003), which will hamper efforts to meet the dramatically increasing demand for food predicted by the same year (Cobb et al. 2013). Salinity affects almost all aspects of plant development, including germination, vegetative growth, and reproductive development. Soil salinity imposes ion toxicity, osmotic stress, nutrient (N, Ca, K, P, Fe, Zn) deficiency, and oxidative stress on plants, thus limiting water uptake from soil. The adverse effects of salinity on plant development are more profound during the reproductive phase. Therefore, it is necessary to improve management techniques to reduce the damage caused by drought and salinity. These management strategies are being useful for stress management in arid and semiarid climates.

1.1 Impact of Drought and Salinity

1.1.1 Drought

Drought, or lack of or insufficient rain for an extended period, causes a considerable hydrologic (water) imbalance and, consequently, water shortages, stream flow reduction, groundwater depletion, soil moisture, and crop damage. It occurs when evaporation and transpiration (water movement in the soil through plants into the air) exceed precipitation for a considerable period. Drought is the most severe physical hazard to agriculture in nearly every part of the world. Drought is expected to increase in frequency and severity in the future due to climate change, mainly due to decreases in regional precipitation but also because of increasing evaporation driven by global warming (Lobell et al. 2008). Several factors can cause plant water deficit, including inadequate precipitation, high evaporative demand, decreased groundwater level, and water retention by soil particles (Gimenez et al. 2005; Salehi-Lisar and Bakhshayeshan-Agdam 2016). Three main mechanisms that reduce crop yield by soil water deficit include (1) reduced canopy absorption of photosynthetically active radiation, (2) decrease in radiation use efficiency, and (3) reduced harvest index (Earl and Davis 2003).

1.1.1.1 Plant Growth and Development

Drought stress is a limiting factor that alters plant growth and development aspects. The qualitative and quantitative attributes of plant growth result from interactive phenomena among genetic, physiological, ecological, and morphological characteristics under drought conditions (Wang et al. 2003; Farooq et al. 2009). Drought events limit plant performances in different developmental stages. Seed germination is the primary aspect of growth sensitive to drought stress. Germination is one of the most sensitive plant growth stages to water deficit (Farooq et al. 2009). Drought delays germination onset (El-Midaoui et al. 2001) with a substantial decrease in sunflower germination (Sajjan et al. 1999). Ample soil moisture is required to initiate the germination process. Imbibition by seeds is the first step, which depends on the water potential gradient between seed and soil. Any decrease in soil water potential causes a linear decline in seed germination (Wen 2015).

Water scarcity outbreaks are due to the occurrence of less or the absence of rainfall resulting in low soil moisture content and low water potential in aerial parts of the plant, such as leaves and stems (Ristvey et al. 2019). A decrease in growth rate under drought could be attributed to the inhibition of cell elongation because the water flow is interrupted from the xylem to the surrounding cells (Nonami 1998). Furthermore, shoot growth seemed to be more adversely affected than root growth (Bassiri et al. 1977). The soil moisture stress causes a decrease in seed germination, shoot length, fresh and dry weights of seedlings, shoot and root dry matter, and relative growth rate in safflower (Hojati et al. 2011). The roots strive to uptake more water through their expansion, which ultimately adapts plants to minimize stomatal water loss when there is a water deficit (Martínez-Vilalta and Garcia-Forner 2017). Typical drought stress symptoms in plants include leaf rolling, stunning plants, yellowing leaves, leaf scorching, and permanent wilting (Corso et al. 2020). Moreover, plant response to a given water deficit is strongly dependent on the previous occurrence and intensity of other drought stress events (Adnan et al. 2020; Battaglia et al. 2020; Hafez et al. 2015) and the presence of other stresses (Thomason and Battaglia 2020).

Water stress results in a decrease in the photosynthetic assimilation of carbon dioxide. This decrease is due to two reasons. First, the restricted diffusion of carbon dioxide in the leaf is due to the stomatal closure, and second, carbon dioxide metabolism is inhibited due to water stress. Experiments conducted on cowpea show that the decrease in carbon dioxide assimilation due to water stress is mainly due to stomatal closure, which reduces internal carbon dioxide and restricts water loss through transpiration (Souza et al. 2004). Drought stress after germination has systematic effect on growth with a reduction of water potential, relative water contents (Ünyayar et al. 2004), and turgor of plant cells (Benlloch-González et al. 2015), which elevates the concentration of solutes in the cytosol. These changes decrease cell elongation, thus leading to growth inhibition (Lisar et al. 2012). Growth inhibition is followed by less carbon assimilation, imbalanced mineral nutrition, and accumulation of abscisic acid (ABA), which causes wilting of plants (Farooq et al. 2012; Lisar et al. 2012). The adverse effects of drought stress on mineral nutrition and metabolism result in reduced leaf area and disruption of assimilate partitioning.

1.1.1.2 Plant Water Relations

Certain factors influence water relations, including the leaf water potential, leaf and canopy temperature, transpiration rate, and stomatal conductance. Exposure to drought stress disturbs all these factors in plants. However, stomatal conductance is most affected (Farooq et al. 2009). The increase in stomatal resistance reduces the rate of transpiration and, therefore, leads to an increase in leaf temperature because the process of transpiration is the crucial mechanism that controls leaf temperature (Arbona et al. 2013; Sapeta et al. 2013). Water potential is considered a reliable indicator of plants' response to water stress and decreases the water loss through stomata, which maintain the turgor pressure (Siddique et al. 2000; Terzi and Kadioglu 2006; Bayoumi et al. 2008). Plant water potential (PWP) and turgor are decreased under water-limited conditions; thus, plants cannot function correctly under these conditions (Zlatev and Lidon 2012; Osakabe et al. 2014; Zare et al.

2011). Drought stress decreases the water supply to the xylem, which reduces an adequate nutrient supply to the phloem, thus resulting in lower water potential. The relative water content (RWC) is decreased in the initial consequence of drought stress (Farooq et al. 2009). The lower RWC reflects substantial reductions of leaf water potential, which lead to the closing of stomata. A significant reduction in the leaf water potential and transpiration rate was observed under drought conditions, ultimately increasing the leaf and canopy temperature (Turner et al. 2001). The higher leaf temperature denatures various proteins and enzymes and reduces membrane permeability, and resultantly, multiple facets of plant metabolism are affected. These changes are the main reasons for the disturbance in photosynthesis, respiration, mineral nutrition, and synthesis of proteins and amino acids (Sapeta et al. 2013; Tiwari and Yadav 2020).

In summary, drought stress decreases the water supply to the xylem which decreases an adequate nutrient supply to the phloem, thus resulting in lower water potential. However, huge variability exists among different genotypes for maintaining water potential mainly due to the ability of water absorption and root system. A decrease in leaf water potential may provoke osmotic adjustment, which helps maintain leaf hydration at low leaf water potential. Leaf relative water content and leaf water potential in plants were affected by water deficit.

1.1.1.3 Mineral Uptake and Assimilation

Drought stress decreases transpiration rates and impairs active transport and membrane permeability, reducing crop plants' absorbing power (Kramer and Boyer 1995). Thus, the nutrient transport from root to shoot is restricted due to the weak absorbing power of the crop plants under drought stress. Drought stress also reduces the nutrient uptake by the roots and their translocation in the plant due to low transpiration rates, diminished active transport, and impaired membrane permeability (Hu and Schmidhalter 1998). Drought stresses significantly impacts the nutrient relations of plants. Many essential nutrients, including nitrogen, silicon, magnesium, and calcium, are uptaken by roots along with water; the drought conditions limit the movement of these nutrients via diffusion and mass, which leads to retarded plant growth (Barber 1995). Plants increase roots' length and surface area and change their architecture to capture less mobile nutrients (Lynch and Brown 2001). The soil moisture deficit at times reduces the growth of the roots and, hence, reduces the uptake of less mobile nutrients such as phosphorus (Garg 2003). Drought stress reduces soil N mineralization, which ultimately lowers N availability. A decreased transpiration due to drought stress is the other factor that lowers N transport from roots to the shoots (Tanguilig et al. 1987). The P uptake is hampered under moisture deficit conditions (Pinkerton and Simpson 1986). The primary reason for reduced P uptake is the restricted translocation of P to shoots, even under mild drought stress (Resnik 1970). The N and K utilization under drought stress at different growth stages is influenced by several factors, including physiochemical characteristics of the soil, duration, and intensity of drought relative to phenology, and the organism's evolutionary history (Killingbeck 2004; Silla and Escudero 2006).

The stomatal closure is hampered by lower K supply because of loss of epidermal cell turgidity (Rahbarian et al. 2011) as stomatal closure needs back pressure exerted by fully turgid epidermal pavement cells, whereas the K accumulation is responsible for the required pressure (Roelfsema and Hedrich 2002; Habibi 2013). Root-microbe interactions also play an essential role in the nutrient relations of a plant. The impaired carbon and oxygen flux to the nodules and N accumulation under drought stress inhibited the N-fixing ability of certain legumes (Ladrera et al. 2007). The composition and activity of the soil microbial colonies are negatively affected by the soil water deficit, which eventually disturbs the plant nutrient relations (Schimel et al. 2007). In conclusion, drought significantly reduces mineral uptake and disturbs nutrient balances (Gunes et al. 2008). Nutrient imbalances ultimately seriously affect various growth and developmental processes. However, plant species and genotypes within species vary in their response to water deficit stress in this regard (Garg 2003).

1.1.2 Salinity

Salinity is the primary environmental stress source that restricts agricultural productivity and sustainability in arid and semiarid regions by reducing the germination rate and delaying germination and subsequent seedling establishment. Salt negatively affects crop production worldwide. Crops exhibit a spectrum of responses under salt stress. Salinity not only decreases the agricultural production of most crops but also affects soil physicochemical properties and the ecological balance of the area. The saline condition causes many adverse effects on plant growth due to the low osmotic potential of the soil solution (osmotic stress), specific ion effects (salt stress), nutritional imbalances, or a combination of these factors (Ashraf 2004). All these factors cause adverse effects on plant growth and development. Salinity affects almost all aspects of plant development, including germination, vegetative growth, and reproductive development. Soil salinity imposes ion toxicity, osmotic stress, nutrient (N, Ca, K, P, Fe, Zn) deficiency, and oxidative stress on plants, thus limiting water uptake from the soil. This number could be increased in the future due to increased land salinization due to contaminated artificial irrigation, climate change, and unsuitable land management. Salinity is a significant stress responsible for the inhibition of seed germination or reduction in germination percentage and a delay in crop germination time.

1.1.2.1 Plant Growth and Development

Salinity is the most important abiotic stress that inhibits growth and productivity of crops, and it is one of the world's primitive and most widely distributed environmental challenges. Salinity is defined as the presence of an excessive concentration of soluble salts in the soil which suppresses plant growth (Zaki 2011). The drastic effect of salt stress can be seen in terms of yield loss. The primary effects related to crop yield can be germination, which either decreases or sometimes ceases under extreme saline conditions. Soil salinity has an overall detrimental impact on plants' health. High levels of soil salinity can significantly inhibit seed germination and seedling growth, due to high osmotic potential outside the seed inhibiting the absorption of water or the toxic effect of Na^+ and Cl^- (Khajeh-Hosseini et al. 2003). Salt stress had adverse effects on the functioning and metabolism of plants considerably hindering the productivity (Khan and Srivastava 1998). Salinity has diverse outcome on plants; for example, salt in the soil solution diminishes the accessibility of water to the roots, and the salt reserved in the plant will rise to toxic effect in several tissues of plants (Munns et al. 1995). Plant growth depends on photosynthesis; therefore, environmental stresses affecting growth also affect photosynthesis (Taiz and Zeiger 1998). Iyengar and Reddy (1996) attributed decreases in photosynthetic rate as a result of salinity to a number of factors: dehydration of cell membranes which reduces their permeability to CO_2. High salt concentration in soil and water creates high osmotic potential which reduces the availability of water to plants. A decrease in water potential causes osmotic stress, which reversibly inactivates photosynthetic electron transport via the shrinkage of intercellular space. Salt toxicity is caused particularly by Na^+ and Cl^-. According to Banuls et al. (1990), Cl inhibits photosynthetic rate through its inhibition of NO_3-N uptake by the roots. Stomata closing reduces the CO_2 supply. The reduction in stomatal conductance results in restricted availability of CO_2 for carboxylation reactions (Brugnoli and Bjorkman 1992). Iyengar and Reddy (1996) reported that stomatal closure minimizes loss of water by transpiration, and this affects chloroplast light harvesting and energy conversion systems, thus leading to alteration in chloroplast activity.

1.1.2.2 Effects on Plant Water Uptake

Salinity is an important environmental factor that can severely inhibit plant growth and agricultural productivity. In addition to the toxic effects of the sodium and chloride ions, salinity disturbs the plant's water relations due to decreased availability of water from soil solution due to lowered osmotic potential (Munns 2005). Root is the primary site for plants to uptake water. Root hydraulic conductance represents water uptake capacity and mainly depends on the driving force, root anatomy, and root water permeability (Steudle 2000; Sutka et al. 2011). Osmotic stress is the first stress experienced when a plant is exposed to saline soil; it immediately influences plant growth (Horie et al. 2011). One of the primary responses of plants to osmotic stress is a decrease in root hydraulic conductance (Lp) (Boursiac et al. 2005). High concentrations of salt in solution result in increased osmotic stress, which limits water absorption by the plant and in turn affects leaf water content, stomatal conductance (gs), leaf growth, and photosynthesis (Boursiac et al. 2005; Munns and Tester 2008). High concentrations of salts outside the roots result in increased osmotic stress, which induces root water uptake difficulties, causing leaf water imbalance and ultimately reducing plant growth (Boursiac et al. 2005; Munns and Tester 2008).

Salinity has a dual effect on plant growth via an osmotic effect on plant water uptake and specific ion toxicities. Osmotic stress and ionic toxicity both affect all major plant processes (Yadav et al. 2011). Plants are able to take up water and essential minerals because they have a higher water pressure than the soil under normal conditions. When salt stress occurs, the osmotic pressure of the soil solution is greater than that in plant cells. Thus, the plant cannot get enough water (Kader and Lindberg 2010). By decreasing the osmotic potential of the soil solution, plant access to soil water is decreased, because of the decrease in total soil water potential. As the soil dries, the concentration of salt in the soil solution increases, further decreasing the osmotic potential. In order to maintain water uptake from a saline soil, plants must osmotically adjust. When plants are exposed to osmotic stress, their immediate response is to close the stomata to decrease the transpiration rate and thereby to reduce water loss (Cornic 2000). The closure of the stomata also reduces CO_2 fixation and decreases the photosynthetic rate. In order for plant growth to continue, however, the plant must maintain an optimal stomata aperture. Due to salt stress, cells will have decreased turgor and its stomata will close to conserve water. Stomatal closing can lead to less carbon fixation and the production of reactive oxygen species (ROS) such as superoxide and singlet oxygen. Reactive Oxygen Species disrupt cell processes through damage to lipids, proteins, and nucleic acids (Parida and Das 2005).

The osmotic and ionic stress induced by salinity can halt plant growth as the plant focuses its energy on conserving water and improving ionic balance. With the reduction in water potential gradient between soil and plant under soil moisture deficit conditions, the uptake capacity of roots becomes limiting. Root hydraulic conductivity decreases under drought, limiting roots' water uptake capacity from the soil (Zhu et al. 2021). Aquaporin controls the root hydraulic conductivity, and generally under moisture deficit condition, the expression of genes coding for aquaporin is downregulated, which ultimately lowers down the root water uptake capacity (Mukarram et al. 2021). Under stress, due to continuous transpiration loss and lower soil moisture, the xylem cavitation gradually increases which ultimately reduces the hydraulic conductance in plants and blocks the water movements in the plant (Mukarram et al. 2021).

1.1.2.3 Effect on Mineral Uptake, Nutrient Imbalance, and Specific Ion Toxicity

Plants absorb nutrients from the soil through water, which provides a medium for nutrients to move within the soil matrix and from soil to plants. Soil moisture deficit condition decreases the nutrient uptake from soil. The reduction in nutrient uptake may attribute to a decrease in the nutrient supply through mineralization, reduction in diffusion, and mass flow of nutrients in the soils (Bista et al. 2018). The kinetics of nutrient uptake by the roots also reduced the rate of nutrient uptake under drought stress (Luo et al. 2018). The reduced translocation of nutrients from root to shoot also contributes to a reduction in the nutrient status of different plant parts (Luo et al. 2018). The microbial growth in the rhizosphere is also affected under deficit soil moisture, which ultimately affects the nutrient uptake by roots (Karlowsky et al. 2018).

Salt accumulation in the root zone causes the development of osmotic stress and disrupts cell ion homeostasis by inducing both the inhibition in uptake of essential elements such as K^+, Ca^{2+}, and NO_3^- and the accumulation of Na^+ and Cl^-.

Accumulation of injurious ions may inhibit photosynthesis and protein synthesis, inactivate enzymes, and damage chloroplasts and other organelles (Paranychianakis and Chartzoulakis 2005). These effects are more critical in older leaves, as they have been transpiring the longest so they accumulate more ions (Munns et al. 2002). Plant deficiencies of several nutrients and nutritional imbalances may be caused by the higher concentration of Na^+ and Cl^- in the soil solution derived from ion competition (i.e., Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+}, and Cl^-/NO_3^- in plant tissues) (Grattan and Grieve 1992). Ca deficiency symptoms are common when the Na^+/Ca^{2+} ratio is high in soil water. Soil salinity significantly reduces plant phosphorus (P) uptake because phosphate ions precipitate with Ca ions (Bano and Fatima 2009). Some elements, such as sodium, chlorine, and boron, have specific toxic effects on plants. Excessive sodium accumulation in cell walls can rapidly lead to osmotic stress and cell death (Munns 2002). Plants sensitive to these elements may be affected at relatively low salt concentrations if the soil contains enough of the toxic element. Because many salts are also plant nutrients, high salt levels in the soil can upset the nutrient balance in the plant or interfere with the uptake of some nutrients (Blaylock 1994).

Salinity has direct effects on the nutrient imbalance between soil and plant. The most important harmful effect of salinity is the sodium and chloride ion accumulation in plant tissues and soil (Nishimura et al. 2011). High sodium ion (Na^+) concentration has an antagonistic effect on potassium (K^+) ions (Jung et al. 2009). Moreover, N uptake reduction by the plant has also been observed under high salt conditions (Abdelgadir et al. 2005). Similarly, salinity has an antagonistic effect on P, K^+, Zn, Fe, Ca^{2+}, and Mn, while it has a synergistic effect on N and Mg in field crops such as rice (Jung et al. 2009; Garcia et al. 2010). The entrance of sodium and chloride ions into the plant cell from the soil causes ion imbalance in plant and soil, and excessive uptake of these ions by plants causes many problems related to the physiology of plant tissues such as root, leaf, grain, fruit, or fiber (James et al. 2011). Similarly, the reduction of plant osmotic potential, excessive uptake of Na^+ and Cl^- in the cell, and disruption of cell metabolic functions are due to ion toxicity (James et al. 2011). Excessive sodium ion in plant tissues harms the cell membrane and plant organelles, resulting in cell death of plant (Siringam et al. 2011).

Ionic toxicity occurs when concentrations of salts are imbalanced inside cells and inhibit cellular metabolism and processes. Sodium ions at the root surface disrupt plant nutrition of the similar cation potassium by inhibiting both potassium uptake and enzymatic activities within the cell. Ion toxicity is the result of replacement of K^+ by Na^+ in biochemical reactions, and Na^+ and Cl^- induced conformational changes in proteins. For several enzymes, K^+ acts as a cofactor and cannot be substituted by Na^+. High K^+ concentration is also required for binding tRNA to ribosomes and thus protein synthesis (Zhu 2002). Ion toxicity and osmotic stress cause metabolic imbalance, which in turn leads to oxidative stress (Chinnusamy et al. 2006). Specific ion toxicity, which results from the excessive uptake of certain ions, is the primary cause of growth reduction under salt stress (Chinnusamy et al. 2005). Toxic ions in salt-affected soils are usually sodium, chloride, and sulfate (Ghassemi et al. 1995; Munns and Tester 2008). Excessive sodium ion (Na^+)

accumulation causes ion toxicity and interferes with plant metabolism, while accumulation of potassium ion (K^+) can alleviate Na^+ toxicity by adjusting osmotic potential through ion balance. Many physiological studies have demonstrated that Na^+ toxicity is not only due to toxic effects of Na^+ in the cytosol but also because K^+ homeostasis is disrupted possibly due to the ability of Na^+ to compete for K^+ binding sites. Similarly, the reduction of plant osmotic potential, excessive uptake of Na^+ and Cl^- in the cell, and disruption of cell metabolic functions are due to ion toxicity (James et al. 2011). Excessive sodium ion in plant tissues harms the cell membrane and plant organelles, resulting in cell death of plant (Siringam et al. 2011).

1.2 Management Strategies

1.2.1 Drought

In the theory of evolution by Darwin, he describes "survival of the fittest" which means that a fit individual survives and others diminish. Only those crops which are successful under a harsh environment can withstand stress. It is crucial for crop scientists to develop strategies to make the crop plants fit for harsh environmental conditions under climate change. Various management strategies have been opted by different scientists in different agroclimatic regions to improve crop performance under drought stress. These strategies are discussed critically in the following section. These approaches have significant potential to overcome the drastic effects of drought, but their application is mostly limited to lab conditions.

1.2.1.1 Use of Mineral Nutrients and Organic Manures

Water stress induces a reduction in plant tissue water levels and subsequently affects leaf water potential, leaf elongation, leaf photosynthesis, protein synthesis, N metabolism, and cell membrane properties which leads to a reduction in plant productivity (Shangguan et al. 2000). Mineral nutrients are usually taken from soils as inorganic ions required for plant growth and development. Under drought conditions, nutrient uptake is impaired due to reduced soil moisture, leading to the slow diffusion of mineral nutrients from the soil to the root surface. Hence, the translocation speed to the leaves is also reduced. Drought induces early closure of stomata, thus reducing the transpiration rate, and also limits the transport of nutrients from the root to the shoot. Thus, drought stress reduces the availability and transport of nutrients in the soil matrix and plant tissues (Silva et al. 2011). However, adequate nutrition of plants under water deficit may improve the performance of crops. N and K are primary macronutrients required by plants in large amounts and govern several developmental processes such as photosynthesis, translocation of photosynthates from roots to shoots, protein synthesis, stomatal closure, water use efficiency, and regulation of enzymes (Salami and Saadat 2013). The application of nitrogen significantly improved crop performance under drought stress. N also plays a significant role in preventing plasma membrane damage and osmotic adjustment. N application under drought stress increases N, K, Ca, and glycine betaine concentrations in leaf tissues. Drought stress enhances malondialdehyde (MDA) concentration in leaves, while nitrogen supplementation reduces MDA in both control and water-stressed plants (Saneoka et al. 2004). Under drought stress, nitrogen supply improves photosynthetic pigment contents and photosynthetic capacity by increasing leaf area (LA), enhancing photosynthetic efficiency, and alleviating photo-damage under water stress (Wu et al. 2008). Crops significantly enhance their water usage ability and help in drought resistance with phosphorus application (Hansel et al. 2017). Under drought stress P nutrition increases the root growth (Singh and Sale 1998), increases stomatal conductance and faster the nitrate reductase activity (Oliveira et al. 2014), leaf area and photosynthesis (Singh et al. 2006), higher cell-membrane stability and water relations (Kang et al. 2014). Potassium is well-known for its osmoregulatory functions in crops. It regulates stomatal conductance and water uptake; the optimum K application increases WUE (Jatav et al. 2014). Potassium fertilization facilitates plant tolerance via different mechanisms such as osmotic adjustment, maintaining the activity of aquaporins and hence water uptake, cell elongation, promotion of root growth and cell membrane stability, stomatal regulation, as well as detoxification of reactive oxygen species resulting in improved drought stress tolerance (Wang et al. 2013). These nutrients enhance the tolerance against drought stress by improving protein synthesis, stomatal regulation, homeostasis, and osmoregulation through quenching the ROS (Cakmak 2005). Organic manures are another viable option that improves drought tolerance when applied alone or in combination with synthetic fertilizers (Esmaeilian et al. 2012). These manures are a beneficial source of significant nutrients and affect the temporal dynamics of nutrient availability through improving soil physicochemical properties (Paul and Beauchamp 1993). Vermicomposts have consistently improved seed germination, growth, and development more than converting mineral nutrients into more plant-available forms. Taleshi et al. (2012) detected that seed yield and yield components increased with the application of vermicomposts under water stress.

1.2.1.2 Seed Priming

Drought stress exposure adversely affects plant growth and productivity via non-normal physiological processes. Various seed priming techniques have been experimented to mitigate the adverse effect of drought stress on plant performance. Priming is an alternative technique to overcome these limitations and serves as a means to boost the stress tolerance potential of plants (Sen and Puthur 2020a; Thomas and Puthur 2020). Seed priming is a pre-sowing seed treatment that allows the controlled hydration of seeds to imbibe water and go through the first stage of germination but does not allow radical protrusion through the seed coat (McDonald 2000). Pre-sowing seed priming consists of priming the seeds in water with or without organic and inorganic salts in a controlled environment, followed by shade drying before sowing. The hydration process is performed using different techniques, e.g., immersion of seeds in water (hydropriming), osmotic solution (osmotic priming), chemicals (chemical priming), or hormones (hormonal priming) (Nawaz et al. 2013).

Priming can improve germination by enhancing the physiological metabolism like the activity of alfa amylase and increase in soluble and proline contents during germination without involving any lag phase or activation period, which increases seedling vigor in normal and stress conditions (Singhal and Bose 2020). Seed priming helps to ameliorate drought stress by adopting several strategies such as early mobilization of seed food reserves, elongation of embryo cells, endosperm weakening, etc., which enhances the pre-germination metabolic activities resulting in uniform and high germination percentages (Chen and Arora 2013). Priming has a critical function in improving germination and growth in a variety of crops under various abiotic stressors (Paparella et al. 2015; Zheng et al. 2016; Hussain et al. 2017). It activates numerous stress-responsive genes, enabling earlier germination and greater abiotic stress tolerance (Manonmani et al. 2014; Paparella et al. 2015; Wojtyla et al. 2016). Seed priming induces mild plant stress and activates stress-responsive genes and proteins, like late embryogenesis abundant (LEAs), that potentially cause drought stress tolerance (Chen and Arora 2013; Sen and Puthur 2020b; Thomas and Puthur 2020). Seed treatments prior to germination induce a particular physiological state called primed state, which augments several cellular responses (Wojtyla et al. 2016). As a result, plants are equipped to respond quickly to further stress exposure (Farooq et al. 2020). The seedlings emerging from primed seeds are characterized by early and uniform germination, and an overall enhancement in various growth features can be noted in its life span (Jisha et al. 2013; Huang et al. 2020; Khalaki et al. 2021).

Seed priming is an easy and non-monitoring technique that shows noticeable results in improving plant establishment and growth development, particularly under abiotic stress conditions. Therefore, seed priming can be used to ameliorate the negative effects of drought stress on germination, growth, and yield of crops to a significant extent.

1.2.1.3 Application of Plant Antitranspirants

Water deficit is one of the main abiotic stresses, restricting the growth and productivity of plants and causing alternations in plant physiology and biochemistry (Bakry et al. 2016). Nearly 95–98% of the water absorbed by the plant is lost in transpiration (Prakash and Ramachandran 2000; Gaballah et al. 2014). Antitranspirants are chemical compounds that favor reduced transpiration rates from plant leaves by reducing the size and number of stomata and gradually hardening them to stress (Ahmed and Ahmed 2014; El-Khawaga 2013). Applying plant antitranspirants is one of the main tools to balance leaf transpiration and water loss prevention (Goreta et al. 2007). It is a substance involved in increasing drought stress resistance. Foliar sprays markedly increase all growth parameters and relative water content and may reduce transpiration. Based on the mode of action, antitranspirants are classified into three types. The metabolic or stomata closing type such as exogenous abscisic acid (ABA) reduces transpiration by physiologically inducing stomatal closure (AbdAllah et al. 2018). The reflective class (e.g., kaolin) enhances leaf surfaces' light reflectance properties to minimize leaf temperature and consequently the transpiration rate (Glenn 2012). The third group, called the film-forming antitranspirants (e.g. di-1-*p*-menthene), as used here, reduce transpiration by physically blocking stomatal pores when a spray application has dried on the leaf surface (Palliotti et al. 2010). Kaolin spray was found to decrease leaf temperature by increasing leaf reflectance and to reduce transpiration rate more than photosynthesis in many plant species grown at high solar radiation levels (Nakano and Uehara 1996). Film-forming and reflecting antitranspirant were found to be nontoxic and have a longer period of effectiveness than metabolic types. Kaolin spray reduces leaf temperature through rising leaf reflectance which decreases the transpiration rate more than the photosynthesis of plants grown at high solar radiation levels (Nakano and Uehara 1996). Studies by Cantore et al. (2009) reported that on tomato and potato, the foliar application of kaolin suspension reduces plant stress which is essential for the best plant growth, yield, and quality. Water stress substantially impacts yield. Hence, the application of antitranspirant immediately prior to this stage may conserve water and improve grain set which could outweigh the photosynthetic limitations (Kettlewell et al. 2010).

1.2.1.4 Planting Density and Planting Date

Beyond the use of water deficit, another option to increase yield is the planting density technique. Optimization of plant density is the main strategy for increasing yield. The increase in planting density should be carefully chosen so that intraspecific competition does not happen and it results in the best use of available resources for grain growth and yield. Higher planting densities have enabled earlier canopy closure, which increases the season total light interception per ground area (Thornley 1983) and also reduces soil evaporation (Richards 1991) which otherwise helps limit water available for transpiration that supports photosynthesis. Nielsen et al. (2002) and Parker et al. (2016) pointed out that too early maize planting was associated with potentially under-optimal soil and weather planting conditions, while too late planting exposes plants to a reduced growing season length, low temperatures, and low-income solar radiation. Crop dry biomass and kernel weight decrease with delayed planting date due to low and decreasing temperature and radiation during the grain filling stage (Andrade et al. 1993).

1.2.2 Salinity

Soil salinization is a serious land degradation problem in most coastal regions worldwide due to the use of saline water for irrigation (Chi et al. 2021; Huang et al. 2022; Sun et al. 2020). Appropriate land management is an important prerequisite for improving the soil quality and productivity of saline soil (Basak et al. 2022). There are two groups of management strategies against salinity: first one is natural adaptation responses toward salinity, and second are human-made management strategies to handle the salinity stress in field crops or plants. Salinity occurs because of excessive accumulation of soluble salts via soil chemical properties and irrigated water. As a result of salinity stress and ion (Na^+ and Cl) toxicity, the disturbance of ion imbalance occurs. The natural management strategies by the plants to salinity stress are based on three strategies: (1) exclusion of Na^+ from the cytoplasm due to low uptake or pumping out of the ion from the cell by active mechanisms, (2) requisitioning of Na^+ into the vacuole, and (3) preferential accumulation in the leaf tissues. Among the human-made management strategies, the salinity problems can manage plant growth by adopting agronomic strategies such as water and nutrient management to improve soil health, plant growth, and input use efficiency (IUE) under salinity (USSLS 1954).

1.2.2.1 Physical Management of Saline Soil

1. Scraping: When soluble salt accumulates on the soil surface, scraping helps to remove salts. The salts accumulated on the surface can be removed by mechanical means. This is the simplest and most economical way to reclaim saline soils if the area is very small, e.g., small garden lawn or a patch in a field. This improves plant growth only temporarily as the salts accumulate again and again.
2. Subsoiling: Soil in deep layers has less salt content compared to above layers. Subsoiling breaks the top custard soil and makes more permeable. Subsoiling is "deep ripping" to improve soil properties at deeper layers where a dense soil layer (or hard pan) exists, thereby limiting the penetration of roots and water infiltration.
3. Deep plowing: Chisel plow is needed for deep plowing in order to increase the permeability for better leaching.
4. Leveling: Surface leveling is to get uniform leaching entire land should be levelled avoiding unnecessary wastage of water.

   Flushing: Washing of surface salts by flushing water. This is especially practicable for soils having a crust and low permeability. However, this is not a sound method of practice.
5. Sand mixing: Permeability was very low in heavy clay soil. Applying and mixing sand in soil with 30–40% clay content increases the permeability and gets higher leaching efficiency.
6. Leaching: When soil elements, after dissolving with water, go down from the upper parts to the lower level, it is called leaching. Dissolve and translocate the soluble salts downward below 45–60 cm. This water, along with the water supply to crops, takes away salts after dissolving them. That is why more water is required in this method. This process is mostly adopted in the dry season. The fields are divided into small fragments through bunding on the boundary so that water is conserved there, reducing the effect of salts. This salt accumulation can be controlled by applying water in addition to the ET water requirement of the crop. This extra water will usually push the salts below the root zone. The amounts of water required for leaching (leaching requirement—LR) can be calculated by standard procedures (Ayers and Westcot 1985).

   Leaching requirement: The amount of water needed to remove the excess soluble salts from the saline soils is called the leaching requirement or the fraction of the irrigation water that must be leached through the root zone or soil profile to control soil salinity at any specific level (salt balance):

$$\text{Leaching Requirement (LR)} = \frac{\text{EC}_{\text{iw}}}{\text{EC}_{\text{dw}}} = \frac{D_{\text{dw}}}{D_{\text{iw}}}$$

where
EC = electrical conductivity in dS m^{-1}
iw = EC of irrigation water in dS m^{-1}
dw = EC of drainage water in dS m^{-1}
D_{dw} = depth of drainage water in in.
D_{iw} = depth of irrigation water in in.

7. Drainage: An effective and good drainage system is required to flush excess salts from the root zone. It requires lowering the groundwater table and effectively leaching salts from the root zone. "Biodrainage" is also practiced as it involves growing certain trees along the canal or field boundaries, of which water demand is very high. It controls salinity and rising water tables.
8. Subsurface drainage: It is used to remove excess water present in the root zone. It brings down the water table and provides air circulation in the root zone. Tiles improve subsurface drainage. Besides this, tube wells are also installed in the area of the shallow water table to improve vertical drainage which helps in lowering water table.

1.2.2.2 Chemical Method

Gypsum Application

Sodium content and presence of carbonate and bicarbonate of the soil increased ESP more than 15 or pH more than 8 (saline-sodic soil) for replacing the Na^+ by Ca^{2+} and subsequent leaching of Na^+. Gypsum is primarily used on Na-affected soils as a source of Ca^{2+} ions to displace Na^+ ions, which tend to disperse soil particles and restrict water infiltration. The resulting displaced Na^+ ions are leached readily from the soil profile. Gypsum is a neutral salt that does not directly reduce pH. However, it can indirectly lower the pH of sodic soils by reducing the hydrolysis reactions associated with Na^+ ions on the exchange complex.

Nutrient Addition

Salt-affected soils suffer from many troubles around the world, such as limited crop production due to their abiotic stresses, particularly in arid and semiarid regions (Nan et al. 2016; Zhang et al. 2017). Proper plant nutrition is one of the most important strategies to alleviate this salt stress in crop production. In general, plants uptake their nutrients from the soil solution and/or by foliar application for plant growth, development, and other processes. The bioavailability of these soil nutrients is totally controlled by many factors, including soil characterization (e.g., soil pH, salinity, nutrient biogeochemical cycles, and physicochemical processes) and environmental and climatic changes. Concerning the effects of soil salinity on the nutrition of plants, nutrient plant disturbances reduce plant growth by affecting the transport and partitioning of different nutrients. Soil salinity also may cause deficiencies or imbalances in plant nutrients, due to the competition of Na^+ and

Cl^- with many plant nutrients such as Ca^{2+}, K^+, and NO_3^--N. Plant nutrients give the plants full power during their entire life and help plants ameliorate different stresses including abiotic and biotic. The use of fertilizers in somewhat greater quantities than normal in saline soils is beneficial. Application of nutrients like NPK and magnesium reduces the toxicity effects of saline soil and raise optimum crop growth and yield. Nitrate reduces chloride uptake, while potassium reduces Na uptake (Martinez and Cerda 1989). K^+ foliar and soil application significantly reduces the toxic effect of saline soil by maintaining the water balance and ion ratio (Golezani and Abriz 2018). Normally, deficit of zinc, iron, manganese, and nitrogen elements is found in saline soils. Hence, productivity can be increased by the use of these elements. Foliar selenium and silicon in combination or alone improved transpiration rate, water relations, photosynthetic attributes, chlorophyll contents, and the growth of wheat seedlings under stressed conditions. This increase is due to the accumulation of osmoprotectants (e.g., proline, soluble protein, and soluble sugar) and the increase in antioxidant enzyme activity (Sattar et al. 2017).

1.2.2.3 Organic Manure

Soil salinization is a serious land degradation problem in most coastal regions worldwide due to the use of saline water for irrigation (Chi et al. 2021; Huang et al. 2022; Sun et al. 2020). Appropriate soil management is an essential prerequisite for improving the soil quality and productivity of saline soil. Soil management practices include tillage, mulching, and crop residue management. In general, a large amount of organic residue and waste are produced in the world every year; more importantly, the improper disposal of these organic residues has led to severe environmental pollution and nutrient losses (Bai et al. 2016; Hazrati et al. 2020; Jia et al. 2018). Recycling these organic residues to farmland is a common agricultural practice for increasing soil fertility and agricultural productivity during decades (Meena et al. 2016; Sun et al. 2020; Wu et al. 2021). Organic amendments, such as livestock manure, plant residue and waste, and bioorganic fertilizer, are better practices to reclaim saline soil by alleviating soil salinity, improving soil fertility, and promoting crop growth (Chen et al. 2021; Cui et al. 2021; Huang et al. 2019; Leogrande and Vitti 2018; Wu et al. 2019). Straw mulching is very promising option for farmers to control soil salinity as it reduces soil water evaporation and regulates soil water and soil movement. Straw mulching seems to decrease the salt content on the surface of the soil by regulating the salt vertical distribution, which could reduce the salt damage to the crops, enhance their yields, and reduce the risk of soil salinization and erosion. Mulching with crop residues or live crops reduces the evaporation of moisture from the soil surface compared to barren soil. It reduces salts' upward pull from groundwater table (Siyal et al. 2001). Organic manure has a high water-holding capacity. When a sufficient amount of organic manure is added, the water holding capacity of soil increases. As a result, the conductivity of the soil solution decreases.

1.2.2.4 Seed Priming

Salt stress substantially reduces and delays germination in crops due to salinity-induced osmotic stress and toxic effects of Na^{+} and Cl^{-} ions on germinating seeds. Different strategies are used to improve the salinity tolerance of other cultivated crops; one of the best approaches is seed priming, which has been evaluated as an active method to alleviate salinity stress (Munns and Gilliham 2015; Banerjee and Roychoudhury 2018; Farooq et al. 2019). Seed priming is a short-term and pragmatic approach to coping with salt stress. In seed priming, seeds can imbibe in low water potential, permitting partial imbibition without radicle protrusion. Seed priming enables faster and better germination in plants under stressful conditions. Primed seeds can activate the signal pathways during the early growth stage and trigger a faster stress response. This condition stimulates many of the metabolic processes involved with the early phases of germination, and it has been noted that seedlings from primed seeds emerge faster, grow more vigorously, and perform better in adverse conditions (Cramer 2002).

1.2.2.5 Selection of Crops and Crop Rotations

Using salt-tolerant crops is one of the most important strategies to solve the problem of salinity. Salt-tolerant agricultural crops are recommended to grow in salt-affected soils to reduce crop yield losses under saline conditions. Salt-tolerant varieties have been developed which grow very well in these soils. Salt-tolerant crops and cultivars capable of increasing in unreclaimed or partially reclaimed soils represent such a strategy. Salt-tolerant cultivars give stable yields and significantly reduce the need to apply amendments to enhance soil productivity (ICAR–CSSRI 2015).

On the basis of crop tolerance to the quality of irrigation water or soil salinity, the crops can be classified in four groups.

1	Highly tolerant crops	Barley, sugar beet, date palm, cotton
2	Tolerant	Wheat, rice, sorghum, maize, tapioca, mustard, coconut, spinach, *Amaranthus*, pomegranate, guava, ber
3	Semi-tolerant	Ash gourd, bitter gourd, brinjal, cabbage, cluster bean, pea, lady's finger, muskmelon, onion, potato, dolichos, sweet potato, tomato, turnip, water melon
4	Sensitive	Radish, carrot, tomato, potato, onion, coriander, cumin, mint, grape, sweet orange

S. No.	Crops	Varieties
1	Rice	CSR10, CSR13, CSR23, CSR27, Basmati CSR30, CSR36, CSR43, CSR46, CSR49, CSR52, CSR56, CSR60, and CSR76
2	Wheat	KRL283, KRL213, KRL210, KRL19, KRL 1-4
3	Mustard	CS 60, CS 58, CS 56, CS 54, CS 52
4	Chickpea	Karnal Chana-1
5	Lentil	PDL-1, PSL-9

(continued)

S. No.	Crops	Varieties
6	Dhaincha	CSD 137, CSD 123

These soils should not be kept fallow, but cultivation should be continuously done according to crop rotation. Crops should be sown which can bear salts, mainly beet, potato, barley, wheat, cotton, etc.

1.2.2.6 Irrigation Practices (Method of Water Application and Frequency of Irrigation)

Water management is very crucial to manage salt-affected soils. Efficient irrigation through modification in irrigation scheduling and decreasing water consumption may reduce salinization process. The irrigation method and volume of water applied have a pronounced influence on salt accumulation and distribution. Flood irrigation and an appropriate leaching fraction generally move salts below the root zone. Different irrigation methods like drip irrigation, sprinkler irrigation, and furrow-irrigated plot are helpful in reducing the saline condition. Drip irrigation is considered the most efficient because it applies water precisely at the root zone. The water application is more or less uniform and can be operated frequently. It maintains high soil matric potential (SMP) in the root zone and thus compensates for the decreased osmotic potential caused by irrigation with saline water (Goldberg et al. 1976). Drip irrigation has the potential of increased yield under saline soil conditions. In drip-irrigated plots, water moves away from the emitter and salts concentrate where the water evaporates. Unlike flood irrigation, drip irrigation might increase the risk of salinization of upper soil horizons but prevents salt from leaching to groundwater (Marchand and Abd El Hadi 2002). Similar results can be obtained with a properly managed sprinkler irrigation system. In furrow-irrigated plots, water moves from the furrow into the bed via capillary flow. When adjacent furrows are irrigated, salts concentrate in the center of the intervening bed. Manipulating bed shape and planting arrangement are often used to avoid salt damage in furrow-irrigated row crops.

When adopted, an irrigation system should permit frequent, uniform, and efficient water application with as minimum percolation loss as possible, but without curtailing essential leaching requirements. In addition, a good irrigation system should also avoid using saline water at the seed germination stage (a very sensitive stage). Where appropriate and good quality water is also available, farmers should practice using recycled water for irrigation. Salinity affects the sprouting of seeds. Hence, during the first irrigation, more quantity of water should be supplied to neutralize the effect of salts. Thereafter, even during subsequent irrigation, along with reducing the quantity of water, even the duration between two irrigations should be reduced so that soil does not get dry and the dissolution of salts continues in the soil. Deficit irrigation involves the application of water below full crop water requirements, so that a mild crop water stress is allowed with bearable effects on yield. Deficit irrigation strategies save water but also have the potential to improve the management of soil salinity by better control of rising water tables and by reducing the ingress of salts by irrigation water.

1.3 Conclusions

Salinity and drought are two of the most serious abiotic stresses that threaten crop productivity worldwide. Drought affects more than 10% of arable land, causing desertification, especially in arid and semiarid areas, while salinization is rapidly increasing on a global scale, declining average yields for most major crops. Drought is the most severe hazard to agriculture in nearly every part of the world. Drought stress is well recognized as a limiting factor that alters multiple aspects of plant growth and development. Salinity not only decreases the agricultural production of most crops but also affects soil physicochemical properties and ecological balance of the area. Therefore, it is necessary to improve management techniques to reduce the damage caused by drought and salinity. Therefore, a holistic approach considering the different management options to deal with drought and salinity stress may be a win-win approach in the future. Therefore use of mineral nutrients and organic manures, seed priming, application of plant antitranspirants, planting density, planting date, selection of tolerant crops, varieties, crop rotation, method of water application, and frequency of irrigation play critical roles in plant adaptation to salinity and drought stress. These management strategies are useful for stress management in arid and semiarid climates.

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