Chapter

Salinity Stress in Arid and Semi-Arid Climates: Effects and Management in Field Crops

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Abstract

Salinity stress is one of the most vital abiotic stresses which results in significant damages of agricultural production, particularly in arid and semi-arid areas of the world. Salinity causes by high accumulation of soluble salt, especially NaCl in soil and water. Salinity hampers the growth and survival of many field crops such as rice, wheat, maize, cotton, sugarcane, and sorghum. It affects the plant growth by three ways such as osmotic stress linked with an increase of phytotoxic ions, ionic stress e in the cytosol, and oxidative stress facilitated by reactive oxygen species (ROS). These stresses caused by salinity hinder the water uptake, causes ion imbalance, ROS production, and hormonal imbalance, and results in the decline of photosynthesis activities reduce the plant growth and final yield. However, the sensitivity of field crops depends on the nature of cultivar and growth stages. There are many strategies to cope with salinity stress which are the development of salinity tolerant crop cultivators by using genetic and molecular techniques such as QTLs and CRISPR CAS9 technique, nutrients management strategies, use of hormones regulators (AVG, 1-MCP, D-31). This chapter will give a brief idea to the scientist to understand the effects of salinity on field crops and their management strategies.

Keywords: salinity, field crops, physiology, yield, sodium chloride,
reactive oxygen species

1. Introduction

The plant growth, development, and yield are negatively affecting by abiotic stresses such as drought, salinity, chilling, and high temperature. About 50% of plant productivity is under the influence of these abiotic stresses [1]. Among these abiotic stresses, salinity is considered as one of the most harmful agents for the plant life cycle. Salinity is an excess amount of salt in the soil, water, and plant. Salinity is frequently an underrated problem in the agriculture sector. It is estimated that salt affected area (sodic and saline) about 6% irrigated and 20% of world's total cultivable land is under the influence of salinity [2]. The irrigated areas of many countries are affected due to salinity in the world (**Table 1**) [3]. Salinity problem is caused by the natural and anthropogenic activities and increasing with time. It is also estimated that 50% of the cultivable land will effect due to salinity by 2050 [2]. On the contrary side, with the current speed of population increase in the world,

Country	Salt-affected area of irrigated in the world	
	Mha	**%**
China	6.7	15
India	7.0	17
Soviet Union	3.7	18
United States	4.2	23
Pakistan	4.2	26
Iran	1.7	30
Thailand	0.4	10
Egypt	0.9	33
Australia	0.2	9
Argentina	0.6	34
South Africa	0.1	9
Subtotal	29.6	20
World	45.4	20

where, mha = million hectare, % = percentage area. Source: Ghassemi et al. [3].

Table 1.
Global estimate of secondary salinity in irrigated lands of the world.

Soil types	ECe (dS/m)	ESP	SAR	pHs
Normal soil	<4	<15	<15	4.5–7.5
Saline soil	>4	<15	<15	<8.5
Sodic soil	<4	>15	>15	>8.5
Saline-sodic soil	>4	>15	>15	>8.5

Whereas, ECe = electrical conductivity, ESP = exchangeable sodium percentage, SAR = sodium adsorption ratio, and pHs = negative log of H^+ ion [12].

Table 2.
The USDA classification system of salt affected soils.

also need to produce more food up-to 70% till 2050 to feed the increasing mouths of the world [2].

Many major field crops such as wheat (*Triticum aestivum* L.), rice (*Oryza sative* L.), maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench), cotton (*Gossypium hirsutum*), and sugarcane (*Saccharum officinarum*), etc. show negative response towards salinity. However, plant performance and grain yield may not decrease until a 'threshold' salinity level is reached. Threshold levels of salinity are generally defined as the maximum amount of salt that a plant can tolerate in its root zone without impacting growth (**Table 2**). Plant physiology is very susceptible to high salinity in its rhizosphere and affects germination rate, growth stages, and ultimately plant yield [1]. Similarly, many other growth hampering effects on plants due salinity are low net CO_2 assimilation to plant tissues, leaf area, leaf cell enlargement, dry matter production, and relative growth, poor development of spikelets (rice and wheat), boll (cotton), etc. [4, 5]. There are many reasons for hampering of plant production under salinity. Generally, salinity affects plant growth in three ways, such as osmotic stress, ionic stress or ion imbalance, and oxidative stress [6]. Osmotic stress disturbs the salt water balance, which results in a high concentration of salts and loses of water in plant cell sap and tissues. This imbalance causes ion toxicity within plant tissues, and plant shows leaf burn or wilting symptoms due to Na^+ and Cl^- accumulation. Ionic stress also causes nutrients disequilibrium and results in reduce final germination percentage (FG %), decrease vegetative and reproductive growth, decline yield, and yield components of the plant under salinity. Similarly, ionic stress in the plant due to salinity causes reduction of photosynthesis activity, alteration of enzymatic activities, oxidative stress, disrupted the biochemical membrane structure and function, destroy the ultrastructural cellular components, and hormonal imbalance are the primary reason for the reduction of overall plant's growth and development [7, 8].

For better plant performance under salinity stress, natural adaptation responses at physiological, molecular, and cellular levels to tolerate salinity stress is of great concern. These adaptations are an osmotic adjustment, closure of stomata, Na^+ exclusion from older leaves, maintenance of K^+/N^+ equilibrium, and cytosolic K^+, transpiration efficiency, and increased antioxidant defense system are very important for ideal plant growth under salinity. Besides these, various other management strategies have been embraced on a scientific basis to improve plant growth efficiency under salinity. These strategies are genetic modification, identification, sequencing of gene, microarray analysis, and plant transformation, and agronomic strategies to reduce salinity stress by soils reclamation via water and nutrients management, seed priming, and usage of hormone regulator to create homeostasis in hormonal production under salinity. These management strategies are being useful for stress management, including salinity. In this book chapter, we will review the latest information about the 'Salinity Stress in Arid and Semi-Arid Climates: Effects and Management in Field Crops, which could be a good advantage to the scientific community and farmers for the understanding of salinity issue in the field crops and their solution.

2. Salinity stress and its causes

The ecological anxieties (biotic and abiotic stresses) have turned into essential threats to plant growth, development, and survival. Among these ecological anxieties, abiotic stresses, for example, drought, chilling or high temperature, and salinity inactively influencing the growth, biomass generation, and yield of many field crops. These threats are ending up more deteriorated by regular or human-made activities, which result in the excessive soluble salts accumulation in the underground water and soil. As concern salinity stress, about 20% of the world's land, and about 33% of the world's irrigated zone is under the impact of salinity [9]. Besides, salinity influenced areas are expanding at a rate of 10% yearly. The expanding of salinity issues are because of low precipitation, high surface evaporation, weathering of native rocks, irrigation with saline water, and poor agronomic practices. Salt influenced soils have various sorts that negative effect on agricultural production, for instance, irrigation-induced salinity and 'transient' dry-land salinity have been arranged in detail with different perspectives considered by [10], and illuminate that salinity in the soil is one of the vast abiotic stress that hamper the agricultural production in the world. The estimation has been done that >50% of the agricultural land would be affected by agricultural till 2050 [11].

Salinity is the issue of almost all the continents and under a wide range of climates. However, the salinity issue is more in arid and semi-arid climate contrasted with the humid climate where yearly precipitation is not as much as evapotranspiration in the world. It is need of great importance to comprehend the mode and sources of salinity with classification, and its role in the plant life cycle. The characteristic critical source of salinity is the primary minerals in exposed layers of the earth crust by weathering process with the assistance of atmospheric

CO_2. The weathering of these primary mineral rocks in the earth crust is the primary source of all the dissolvable salts present in the soils and ocean. However, there are several other anthropogenic sources of salinity in the soil or water. Under arid to and semi-arid climates, the products from the weathering procedure of mineral and rocks accumulate in the soil and result in the advancement of salt-influenced soils (saline or sodic soil). Though, under a humid atmosphere, salt could not collect in-situ and filter down through the soil and transport to the close-by streams and waterways and caused the salinity in the water bodies [12]. The US Salinity Lab staffs (1954) group the salt-influenced soils (**Table 2**). These salt-affected soils types have unique nature of soluble salts. For instance, saline soil has $Cl^-$and SO_4^{2-} and CO_3^{2-} present and sodic or alkali soil has HCO_3^- of Na^+, and in exceptional cases with high CO_3^{2-} concentration with the capacity of alkaline hydrolysis. So also, saline sodic soil has predominant soluble salts of Na^+ with Cl^- and SO_4^{2-} with an average intensity of $NaHCO_3$ and Na_2CO_3 in a trace concentration. An ordinary soil has maximum nutrients for development and improvement of the plant. On the inverse, Salinity is one of the significant environmental element influencing plant growth and production. As indicated by FAO report, a saline soil is characterized as having a high concentration of soluble salts for the most of Sodium (Na^+), Calcium (Ca^{2+}), magnesium (Mg^{2+}) chloride (Cl^-) and sulfate (SO_4^{2-}). Magnesium sulphate ($MgSO_4$) and sodium chloride (NaCl, table salt), are among the most well-known soluble salts which are sufficiently high to influence plant growth and development.

2.1 Salinity effects on plant growth

Salinity influence crops in these ways: osmotic effect, specific ion effect, ion imbalance, and oxidative stress [6]. Salinity decline water uptake limit of plant, and causes a decrease in plant development. It might be explicit salt effects. If a high concentration of salt enters the plant, this high concentration of salt will increase at last ascent to a toxic level in older leaves causing early senescence and diminished the photosynthetic leaf area of a plant to a dimension that cannot support plant development [14]. Salinity seems to influence plant growth mechanism in two different ways, water relations, and ionic relations. Firstly, plants face water stress, which in cause decline leaf expansion. Secondly, long-term salt stress in soil and plant, plants involvement (Na^+ and Cl^-) ionic stress, which can prompt early senescence of older leaves [15] (**Figure 1**).

Plants experience the ill effects of the presentation of salinity until maturity [16]. Generally, the markers of salinity impacts in plants are impeded growth and small plants with fewer and smaller leaves. Munns [16] depicted salinity consequences for various plant development stages under a different period of the plant growth mechanism and development. After a couple of minute's introduction of salinity stress, dehydration and shrinkage of the cell begin, and following a couple of hours after the fact recovers their original volume. Regardless of this recovering of the original volume, cell elongation and cell division are diminished, prompting slower rates of root and leaf development. On the following days, a diminishing in cell division and lengthening change into slower leaf inception and size. Plants that are harshly salt influenced regularly build up obvious salt damage. As exposure of salinity extends to half a month, secondary shoot growth is influenced, and following a couple of months, clear changes observed in development and injury between salt-stressed plants and control. To comprehend these time-sensitive changes in light of salinity in plant development stages, the 'two-phase growth response to salinity idea created by [16]. The first phase of growth decline occurs within minutes after exposure to salinity. The decline of growth is because of the osmosis stress, osmotic changes

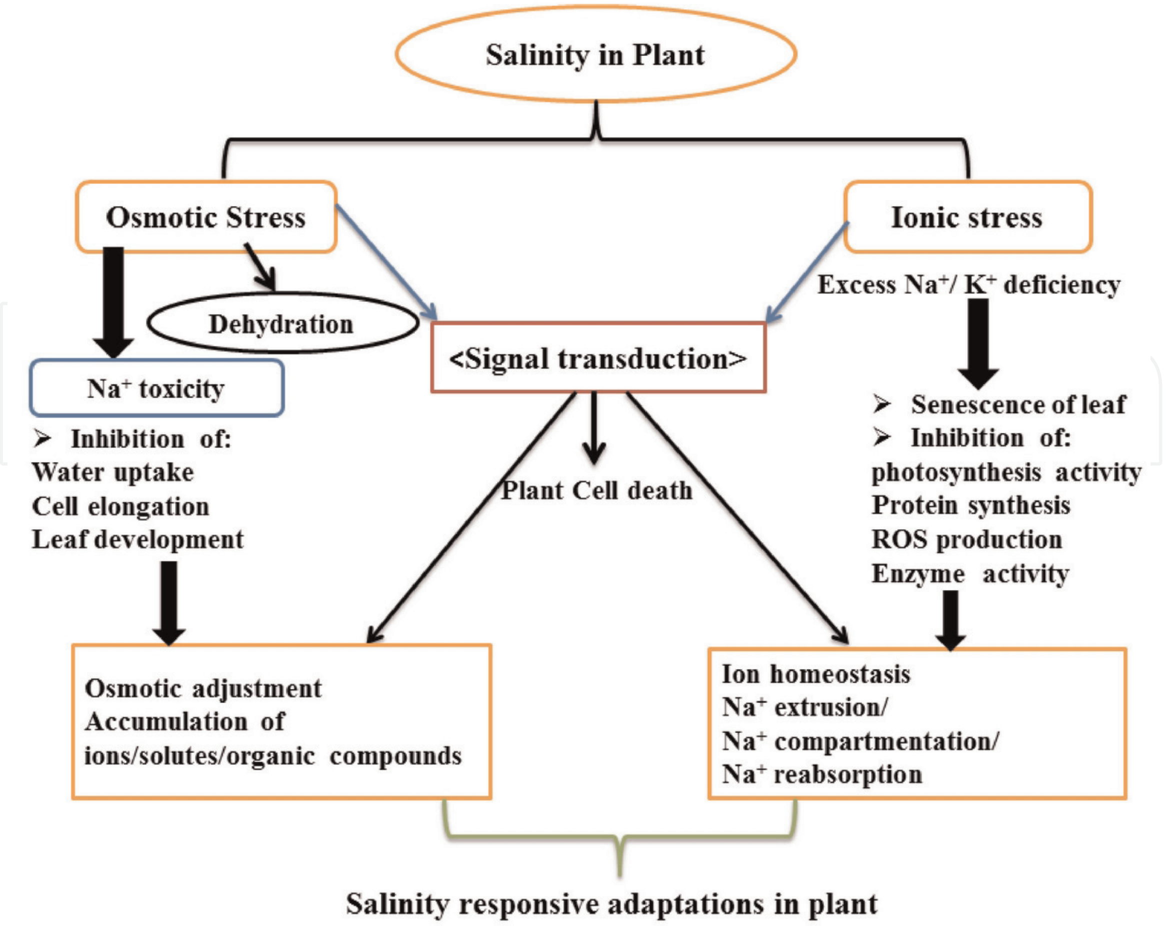

Figure 1.
Salinity response adaptations in plant. Extracted from Kumar et al. [17] and Hussain et al. [18].

outside the root surface, causing changes in osmotic impacts. In the wake of taking some days, weeks or even months the other slower impact (explicit salt impact), bringing about the aggregation of salt in leaves, basically in older leaves and salt toxicity in the plant. This salt toxicity in the plant can cause the death of leaves and decrease the total photosynthetic leaf area. Thus, there is a decrease in the availability of photosynthate to the plant and influence the overall carbon (CO_2) balance essential for sustainable plant growth and development [16] (**Figure 1**).

2.1.1 Salinity and ion toxicity in plant

The important harmful effect of salinity is the sodium and chloride ions accumulation in plant tissues and soil [19]. The higher concentration of soluble salts in the soil profile may cause physiological drought to plant, that is, reduction in uptake of water due to salt accumulation in the root zone [20]. The entrance of sodium and chloride ions into the plant cell from soil causes ion imbalance in plant and soil and excessive uptake of these ions by plant causing many problems related to the physiology of plant's tissues such as root, leaf, grain, fruit, or fiber [21]. Similarly, the reduction of plant osmotic potential, excessive uptake of Na^+ and Cl^- in the cell, and disruption of cell metabolic functions is due to ion toxicity [21]. Excessive sodium ion in plant tissues harms the cell membrane and plant organelles, and as a result, cell death of plant [22]. These physiological changes in the plant include the membranes disruption, reactive oxygen species (ROS) production, reduction of photosynthesis rate (Pn), and scavenging of antioxidants [21]. Consequently, the accumulation of soluble salts in the rhizosphere is one of the main reasons for low crop productivity.

2.1.2 Salinity and nutrient imbalance in plant

Salinity has direct effects on nutrients imbalance between soil and plant. The most important harmful effect of salinity is the sodium and chloride ions accumulation in plant tissues and soil [19]. High sodium ion (Na^+) concentration has an antagonistic effect on potassium (K^+) ions [23]. Moreover, N uptake reduction by the plant has also been observed under high salt conditions [24]. 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 [23, 25].

2.1.3 Salinity and oxidative stress in plant

The production of reactive oxygen species (ROS), like oxygen radical (O^{2-}), superoxide (OH^-), and H_2O_2 under salinity is high [30]. These oxidative species can interrupt the routine functions of various cellular plant modules. For example, DNA, proteins, and lipids, are interfering metabolism of the plant [26].

2.1.4 Salinity and hormonal response in the plant

The phytohormones are naturally produced in a chemical form called plant growth regulators. The phytohormones are active signal compounds which show response against salinity stress and reduce the plant growth [27]. Under salinity stress, the ethylene, cytokinin, and gibberellic acid concentration decreased, and abscisic acid contents increased. This alteration of hormones effects plant growth, such as germination, tiller formation, and reproductive growth. For example, poor development of rice and wheat spikelets, boll of cotton, etc.

3. Effects of salinity on field crops

Fulfill the food demand and livelihood of the increasing population by 2050, a remarkable increase about 50% more yield in the form of grain, fiber, sugar, etc. is required from major field crops such as wheat, rice, and maize sorghum, cotton, and sugarcane [28]. However, the purpose of competing for the demands of human beings on the globe while combating abiotic stresses, including salinity. The different crop has different responses against abiotic stresses such as salinity. Salinity suppresses the crop plants growth, development, and productivity. The sensitivity of the crops varies from low to high concentration of soluble salts or EC (**Table 3**). At low salt concentrations, yields are slightly affected or not affected at all in some crops [29]. Whereas the most plants, glycophytes, including the most crop plants, decrease yield towards zero or even plant death as soluble salt concentrations increase by 100–200 mM NaCl due to low resistance and tolerance capacity of plants [30] (**Table 3**).

3.1 Salinity and rice (*Oryza sativa* L.)

Rice is monocot and belongs to a C3 plant with salinity responsive behavior as compared to other field crops [37]. Rice is vital to the lives of billions of people around the globe. Rice is grown in many parts of the world, especially in Asia, Latin America, and Africa, and taken as a chief food item for more than 50% population of the world [38]. Rice is among the first five major carbohydrate crops for the population of the world, particularly for Asian countries. Only Asia contributes 90% of total rice cultivation in the world. From this 90%, China contributes 30%, India

Crop type	Tolerance based on	Threshold EC levels (dS m^{-1})	25% yield loss (dS m^{-1})	50% yield loss (dS m^{-1})	Zero yield (dS m^{-1})	Ranking	References
Wheat	Grain yield	6–8	6.3	10	16–24	MT	[31]
Rice	Grain yield	3	3.2	3.5–4	8–16	S	[32]
Maize	Ear FW	1.8	2.5–6.8	8.6	15.3	MS	[33]
Sorghum	Grain yield	6.8	7	10	30	MT	[34]
Cotton	Seed cotton	7.7	8.3 7	17.0	16–24	T	[35]
Sugarcane	Shoot DW	1.7	3.9	13.3	16–24	MS	[36]

Where EC = electrical conductivity, FW = fresh weight, DW = dry weight, S = sensitive, MS = moderately sensitive, MT = moderately tolerant, and T = tolerant.

Table 3.
Salt tolerance classification of major field crop.

(21%), and Pakistan (18%) respectively, while remaining 30% is contribution belongs to Japan, Thailand, Indonesia, and Burma [39]. Rice is a high yielding crop. However, the current average yield is 8–10 t/ha for *indica* rice, 10–15% yield is lower than its potential [40]. This rice production gap is due to many reasons, such as environmental stresses (biotic or abiotic), management strategies, and nutrients deficiencies.

Among the abiotic stresses, especially salinity is among the essential causes of this low yield. The morphological characteristics of rice are severely affected by salinity [41]. Rice plant responds differently against salinity compared to other field crops. The intent of salinity in rice plant life cycle varies from growth stages, and cultivar to cultivar, that is, the early seedling growth stage is more sensitive than the tillering stage in rice plant [14]. The threshold level of salt stress for rice is 3 dS m^{-1} [42]. However, a significant reduction in seedling growth and fresh weight were observed with increased salt stress from 1.9 to 6.1 dSm^{-1} and 5 to 7.5 dSm^{-1}, respectively [43]. Many studies also exposed that salinity stress decrease rice stand density and production of seedling biomass, which shows the high sensitivity against salinity [4, 44].

The first organ of the rice plant that keeps in contact with soluble salt is a root [45]. The root is responsible for the entrance of hydrogen peroxide (H_2O_2) and solutes by through different pathways such as symplastic, apoplastic, and transcellular, respectively. So, transport of water and solutes through the apoplastic pathway is vital in rice [46]. Mostly Na$^+$ transport in rice shoots via the apoplastic passage where Na$^+$ transports by apoplast through Casparian tubes [47]. As a result of this Na$^+$ accumulation, a significant reduction in numbers of root per plant, root length, and shoot length occurred under increased salinity [48]. Based on these proofs, the reduced root and shoot lengths are considered two indicators of rice plant response to salinity.

Moreover, cell division and cell elongation in rice plant are severely affected by salinity, which results in a reduction of the root, leaf growth, and yield [16]. Rice plant shows response very soon after the exposure of salinity stress and affects plant growth. For example, rice leaf mortality boosted with increased salinity in almost all rice cultivars at early seedling stage [14]. Some rice cultivars showed leaf mortality up to 0–300% after 1 week of salinity exposure [16]. Salinity effect cause panicle sterility and poor development of inferior and superior spikelets, which result in the reduction of rice grain yield [4]. Many rice cultivars showed panicle sterility at pollination and fertilization stages due to some genetic mechanisms and nutrient deficiencies resulting from salinity stress [49], which leads to a decrease in grain setting rate, pollen viability, and decline of the stigmatic surface.

3.1.1 Salinity and rice physiology

Plant physiological traits are susceptible to the high soluble salts in its rhizosphere. Salinity has bunch of adverse effects on physiology of rice plants, such as hinder the net photosynthesis (Pn), stomatal conductance (Gs), transpiration rate (Tr), photosynthetically active radiation (PAR), degradation of pigment and relative water content (RWC) as well as affect the water use efficiency (WUE) [50]. As far as photosynthesis activity is a concern, rice plants under salinity have decreased photosynthetic efficiency through the complex of photosystem II (PSII). Furthermore, chlorophyll contents in rice leave tissues are damaged by the excessive accumulation of Na^+ and Cl^-, which hamper the primary electron transport in PSII [51]. The chlorophyll contents (chl a, b, and carotenoids) in rice leaves were significantly declined under salinity [52]. High salinity also reduces the quantum yield of the complex PSII, and to decrease K^+/Na^+ ratio. All these factors cause adverse pleiotropic effects on rice physiology and development at the molecular and biochemical levels [53], and cause abnormal rice growth, development, and ultimately plant death [19].

3.1.2 Salinity and ion imbalance in rice plant

Ion imbalance is the ultimate effect of salinity. Under salinity, the severe competition of Na^+ and Cl^- with K^+, Ca^{2+}, and NO_3^- occurs. Generally, high NaCl concentration in the soil and plant decrease the reduce N, P, K, Ca, Mg, and Mn in rice root and shoot, and increases Na^+ and Cl^-, and increases Na^+/K^+ and Na^+/Ca^{2+}, Ca^{2+}/Mg^{2+}, and Cl^-/NO_3^- ratio leads to specific ion (Na^+ and Cl^-) toxicity in plant's organelles [54, 55]. Similarly, boron (B), silicon (Si), and zinc (Zn) availability decreased to the rice plant, and increased cadmium (Cd) toxicity subjected to salinity [56, 57].

3.2 Salinity and wheat (*Triticum aestivum* L.)

Wheat is a worldwide staple food belongs to the *Poaceae* family. Wheat ranks as the first position in grain production globally. About 36% population of the world consume Wheat as a staple food and provides carbohydrates (55%) and 20% of the food calories (20%), and protein contents (13%), which is higher than other cereals crops worldwide [58]. However, wheat production is severely affected by salinity. Wheat is susceptibility to salinity starts at 6 dS m^{-1}. Under salinity, water potential in soil lower down and Na^+ concentration within plant tissues increases, and as a result wheat plant faces osmotic and ionic stresses. Salinity stress having passive impacts on agronomic, physiology, and chemical characteristics of the wheat plant. As salinity level crosses the threshold level (6 dS m^{-1}) of the wheat plant, germination rate, net photosynthesis rate, transpiration rate decrease, and yield, and increases the Na^+ and Cl^- in the wheat plant which disturbs the normal metabolism of the plant [58]. Similarly, water use efficiency (WUE), production of reactive oxygen species (ROS) and scavenging of antioxidants are attributes of the wheat plant affected by salinity.

3.2.1 Salinity and agronomic attributes of wheat

Salinity stress hinders the germination rate (GR) and speed of germination, which is the vital process of the plant cycle, and an important indicator of growth and yield components of the plant, but depend on nature of cultivar. For example, at 125–200 mM NaCl and 12.5–16 dS m^{-1} salinity levels, germination time increased and decreased the GR and germination index [59–61]. During the germination process under salinity, seed faces the osmotic stress, which imbalance the enzymatic activities necessary for nucleic acid and protein metabolism, hormonal imbalance, and ultimate the disturb the seed reserves [62]. Along with these germination characteristics, salinity also affects the other agronomic parameters such as root length, shoot length, root and shoot dry weight, plant height, leaf area, tillering dynamics, and spikes numbers per plant at the early seedling stage. At the early growth stage of the wheat plant, plant shows high sensitivity at 120, 125, 150 mM NaCl, and 16 dS m^{-1}, even seedlings death occurs [11, 63]. Furthermore, wheat seedlings also reduce its growth; even exposure to salinity stress is for a few days (7–10 days) at 100 mM NaCl salt level. Similarly, yield components such as the number of spikes per plant, spikes length, and the number of spikelets per spike, above ground biomass, 1000-grain yield, harvest index, and grain yield per plant decreased with increased salinity stress [64]. However, when the wheat plant cross the threshold level of salinity (6 dS m^{-1}), wheat grain yield reduces at the rate of 7.1% with increasing salinity of per dS m^{-1} and significant yield reduction occurs at 15 dS m^{-1} [65].

3.2.2 Salinity and wheat physiological traits

Photosynthesis activities such as net photosynthesis rate (Pn), stomatal conductance (Gs), transpiration rate (Tr), intercellular CO_2 concentration, and water use efficiency (WUE) affected by salinity. The Pn badly influenced by the high accumulation of Na^+ and Cl^- in the chloroplast tissues [66]. These parameters (Pn, Tr, Gs, intercellular CO_2 concentration) are reduced under 150 mM NaCl salinity level. Similarly, a decrease in photosynthesis pigments was observed at 320 mM NaCl concertation, and after 10 days exposure of NaCl, the chlorophyll contents (chl a, b, and carotenoids) decreased [67]. WUE and RWC also affect by osmotic stress caused by salinity. Water potential lower down with increased salinity levels and as a result relative RWC in the wheat plant decreased by 3.5% in the salt tolerant cultivar and 6.7% in salt-sensitive cultivar after 6 days exposure of NaCl (100 mM NaCl) [68]. Along with this leaf water potential and WUE also decrease in 150 mM NaCl and 16 dS m^{-1} salinity levels. For example, water content percentage in root reduced and increased in shoots and spike of wheat cultivar Banysoif 1. Similarly, at 320 mM NaCl, the RWChas decreased in leaves of wheat cultivar *T. monococcum* seedlings [69].

3.2.3 Reactive oxygen species production and scavenging of antioxidants

Reactive oxygen species (ROS) increase under salinity in the plant. However, when plant faces high salinity, the production of ROS reduces the scavenging system and stops the oxidative stress. This change occurs in plants due to the reduction of CO_2 availability in leaves and inhibits fixation of carbon, and excitation energy enhance which expose the chloroplast, all these happened due to stomatal closure. ROS such as H_2O_2, superoxide ($O2^{\bullet -}$), hydroxyl radical ($OH^{\bullet}$), and singlet oxygen ($^1O_2$) are produced under increasing salinity stress in the plant [62, 65]. Osmotic stress caused by salinity is the leading cause of ROS production and results in the cellular damage by oxidation of lipids, proteins, and nucleic acid. The oxidative stress is caused by an imbalance in ROS production and scavenging of antioxidants in plant tissue. As a result of ROS production, phytotoxic reactions in plants occur such as lipid peroxidation, protein degradation, as well as DNA mutation [70]. For example, exposure of salinity levels 5.4 and 10.6 dS m^{-1} for about 2 months caused a significant increase in lipid peroxidation and hydrogen peroxide (H_2O_2) in seedlings of the wheat-sensitive cultivar [71]. Similarly, H_2O_2 (60%) and MDA (73%) increased at 300 mM NaCl salinity level, and decreased ascorbic acid (AsA) content (52%) in wheat seedlings [67]. For a short period salinity exposure such as after 5 days, MDA contents increased by 35%, and after 10 days, MDA contents increased by 68% at 100 mM NaCl salinity level in wheat leaves. Along with these, the concentration of salt levels in term of EC levels such as 2, 4, 8, and 16 dS m^{-1} EC effects the lipid peroxidation, MDA increased significantly and varied from cultivar to cultivar.

Plants also have an anti-oxidative system to compete against adverse salinity conditions. Therefore, under unfavorable conditions (salinity) plant produce antioxidant enzymes in an excessive amount such as superoxide dismutase (SOD), POD, CAT, GR, and APX, etc. which reduce the damage caused by salinity. A study showed that, under increased salinity stress, the SOD, CAT, POD, GR, ascorbic acid (AsA) and APX activities increased irrespective to the nature of wheat cultivar [68]. After 10 days of salinity stress at 100 mM of NaCl showed significant higher POD and SOD contents and non-significant increase in the CAT and APX contents with a decrease in GR and DHAR contents in wheat seedlings [67].

3.2.4 Ion imbalance in wheat

Salinity stress also causes an imbalance in ion uptake and ion toxicity in the plant. Na^+ absorption varies from nature of wheat cultivars against salinity stress [68]. Salinity increase the intake of Na^+ and Cl^- and reduced the K^+ and Ca^{2+} uptake along with the lower accumulation of NO_3^- and PO_4^{3-} in wheat seedlings under 125 mM of NaCl level for one-week exposure, and decreased the K^+/Na^+ ratio in wheat shoots at 120 mM of NaCl [11, 65, 66]. Similarly at high EC 15–16 dS m^{-1}, K^+ accumulation significantly decreased, and under medium salinity stress, Na^+ and Cl^- accumulation increase and decreased the uptake of K^+, Ca^{2+}, and Zn^{2+} [64, 65, 72].

3.3 Salinity and maize (*Zea mays* L.)

Maize is an important cereal crop which is being cultivated over a large area under a wide spectrum of edaphic and climatic conditions. It is categorized as a C4 plant of the *Poaceae* family and is moderately sensitive to salinity [73]; nevertheless, a considerable intraspecific genetic potential against salinity also exists in the maize. The threshold level of salinity for maize is 0.25 mM NaCl or 1.8 dS m^{-1}, and a further increase in salinity may stunt growth and cause severe damages [74].

3.3.1 Salinity and maize growth

Salinity significantly induces the detrimental changes in growth and development of maize, but the response of maize varies with the crop growth stage and degree of stress. The short term exposure to salinity may influence the growth of maize plants duet to osmotic stress without causing the ionic toxicity. The germination and early seedling stages of maize are more sensitive to salinity than later developmental stages. Generally, salinity during germination period delays the initiation, reduces the rate, and increases the dispersion of germination phases [75]. Salinity induces the detrimental impact on seed germination; (a) by sufficiently reducing the osmotic potential of the soil, leading to retard the water absorption by seed, and (b) by inducing Na^+ or Cl^- or both ions toxicity to the seed embryo. Therefore, hyper-osmotic effects and toxic stress of Na^+ and Cl^- ions on germinating seeds under saline conditions may delay or reduce germination [75]. Maize as a salt-sensitive crop, the shoot growth in maize is sharply reduced during the osmotic stress phase [76]. However, Schubert et al. [77] proved that it was cell wall extensibility, which limited the cell extension growth during osmotic stress phase than turgor in the cells. In crux, salinity-induced growth reduction in maize is primarily due to the suppressed leaf initiation and expansion, as well as internode growth and also by increased leaf abscission. Additionally, Salinity reduced the grain number and weight, leading to low grain yield of maize. This reduction was due to the limitation of the sink and reduced activity of acid inverses in developing maize grains lead to poor kernel setting as well as reduced grain numbers.

3.4 Salinity and cotton (*Gossypium hirsutum*)

Cotton is grown as the most important fiber oilseed crop, providing 35% of the total fiber used globally [78]. About 29.5 million hectares of cotton were grown during 2016–2017 with a total production reaching to 106.49 million bales during 2017 [79] worldwide. *Gossypium hirsutum* is giving over 90% of the world cotton crop annually, after spreading from its origin in Mesoamerica to more than 50 countries in Northern and Southern hemispheres.

3.4.1 Effects of salinity on cotton plant

Cotton is mostly grown in arid and semi-arid regions of the world, where water shortage is a dominant factor [80]. In general, salinity severely hinders cotton growth and development, including the reduced plant height, fresh and dry weights of shoot and roots, leaf area index, node number, canopy development, photosynthesis, transpiration rate, stomatal conductance, yield, fiber quality, and root development [81]. However, cotton is considered a moderately salt tolerant crop which can withstand EC up to 7.7 dS m^{-1} [34]. Generally, salinity effects on cotton at all ontogenetical levels, from molecular to organismal, which lead towards the reduced plant growth, economic yield, and fiber quality. But these effects depend on the timing and intensity of salt stress, the plant growth stage, and the species. Therefore, seed germination and early seedling stage of cotton are considered as the most sensitive stages to salinity [1]. It has been advocated that plants having a higher tolerance to salinity generally maintain lower Na^+/K^+ ratio in their tissues [82]. Furthermore, Wang et al. [83] found that soil ECe and sodium absorption ratio (SAR) values of root zone were significantly and linearly correlated with the final germination percentage of the cotton. The FG% was adversely affected by increasing EC and SAR. These results also show that the vulnerability of cotton plants towards salinity increases with increase in plant age. Therefore, cotton plant is more sensitive to the salinity during peak flowing period, leading to less number of bolls, boll weight, and lint yield [84]. Many studies [34, 85] also reported up to 50% yield reduction when the salinity level was increased from 7.7 to 17.0 dS m^{-1}. Soil salinity also induces a wide range of morpho-physiological and biochemical changes that adversely affect the cotton growth and productivity. Additionally, plant biomass accumulation and the final output are pre-determined by the rate of photosynthesis, salinity induced a direct impact on both stomatal and mesophyll conductance [86].

3.4.2 Salinity and fiber quality

The production of higher fiber quality is a key objective of cotton breeding and genetics programs globally [87]. However, salinity induced lower lint percentage and fiber quality parameters, including fiber length, strength, and micronaire [84].

However, salinity during the flowering season imposed no detrimental impacts on fiber quality, but salinity after flowering resulted in reduced fiber quality.

3.5 Effects of salinity on sorghum [(*Sorghum bicolor* L.) Moench]

Sorghum is monocot species, and C4 plant with high photosynthetic capability and productivity has a spot with *Poaceae* family. The most of the sorghum species found in Australia and the rest of the world (Asia, Africa, Mesoamerica, India, and Pacific Oceans). Sorghum is the extremely beneficial yield, which can be used for essentialness source, human sustenance (grain), domesticated animals feed (grain and biomass), and mechanical reason (fiber or paper and treatment of natural side-effect). The sorghum biomass is used as fuel (ethanol generation) and sugar substrate through aging (methane creation) [88].

3.5.1 Effects of salinity on sorghum

The sorghum plant has an extraordinary adjustment potential to abiotic stresses, particularly high salinity, which is significant for genotypes developing in an extreme environment [89, 90]. By and large, sorghum is considered as a respectable salinity tolerant species with genotypic varies from cultivar to cultivar. The threshold level of salinity for grain sorghum is (6.8 dS m^{-1}), and the reduction reaches 25% and 50% at 7 and 10 dSm^{-1} respectively [34]. Salinity also influences the sorghum plant's physiological procedures, for example, seed germination rate, K^+ take-up, net photosynthesis rate (Pn), biomass amassing, and biochemical qualities (chlorophyll substance or electrolyte leakage). In sorghum plants, a notable salinity induced phenotype of plant growth was observed after 4 days of exposure of 200 mM NaCl salinity stress [91]. Similarly, in sweet sorghum, salinity increase the duration of germination and reduced germination percentage [92].

3.5.2 Effects of salinity on ROS production in sorghum

Under salinity stress, the production of reactive oxygen species (ROS) and an increase in the antioxidant enzymatic activity is a vital component of salt tolerance capacity of the plant. Salinity stress is linked with associated with enhanced antioxidant activity. Salinity decreased superoxide dismutase (SOD), ascorbate peroxidase (APX), catalase (CAT), peroxidase (POX), and glutathione reductase (GR), and total antioxidant and phenol contents of tissues in sorghum cultivars [93]. The stem yield and soluble carbohydrate contents decreased as salinity level increased in sweet sorghums cultivars such as Keller and Sofra, and in one-grain sorghum cultivar Kimia, whereas it is also reported that at the higher salinity stress the sorghum cultivar 'Keller' showed high sucrose contents and stem yield [90].

3.5.3 Salinity and ion toxicity in sorghum

The large aggregation of toxic ions such as Na^+ and Cl^- causes unsettling influence in ion uptake and K^+ status of plant tissues. In this manner, it is the high K^+/Na^+ perception and the conservation of low Na^+/K^+ ratio in plant tissues, which describe as salt-tolerant genotypes [94]. The Na^+ content in sorghum plant's tissue enhanced with excessive Na^+ contents, and as a result of significant contrasts in Na^+ contents of root and shoot among genotypes. Lesser accumulation of Na^+ in the shoot might be due to lower Na^+ uptake by the root or from the variation in the Na^+ transfer rate to the shoot. For example, salt-tolerant sorghum variety (Jambo) amassed less Na^+ concentration in the root and shoot tissues than the salt-sensitive genotypes and kept up lower Na^+/K^+ ratios both in the root and shoot [95]. Particular testimony of Na^+ ions in the shoot depends on leaf base [96], and enhancing levels of Ca^{2+} in the control condition increased plant growth and brought down Na^+ take-up of sorghum plants [97]. The high Ca^{2+} accumulation in leaf and root tissues were observed in the salt-tolerant genotype Jambo than the salt sensitive varieties, Payam and Kimia [98].

3.6 Effects of salinity on sugarcane (*Saccharum* sp.)

Sugarcane is a key commercial and irrigated crop of the tropical and subtropical areas of the world [99]. Sugarcane is propagated further by setts from the stem cuttings of mature plants (one-year-old crop). Sugarcane is an important source of sugar in Asia and Europe. It also supplied the basic raw material for the production of jaggery (Gur), white sugar, and khandsari. Further, sugarcane juice is widely being used for drinking and beverage purposes.

3.6.1 Salinity and sugarcane production

The salinity is a major environmental concern, responsible for a significant decline in sugarcane yield [100]. The sugarcane production is low under less fertile soil caused by salinity stress. This plant is categorized as a moderately salt sensitive species which can withstand the ECe up to 1.7 dS m^{-1}. But, a further increase in EC could induce the adverse effects on its production. The detrimental impacts of salinity at germination or bud emergence stage mainly varied across the different species. Akhta et al. [101] reported a significant reduction in sprout emergence at different days after sowing under moderate and severe salinity stress depends on the nature of cultivars.

Under severe salinity stress conditions, growth could be significantly influenced by the accumulation of active oxygen species [102]. Vasantha et al. [103] observed the reduced leaf area index (LAI) of sugarcane by 36% during Formative Growth

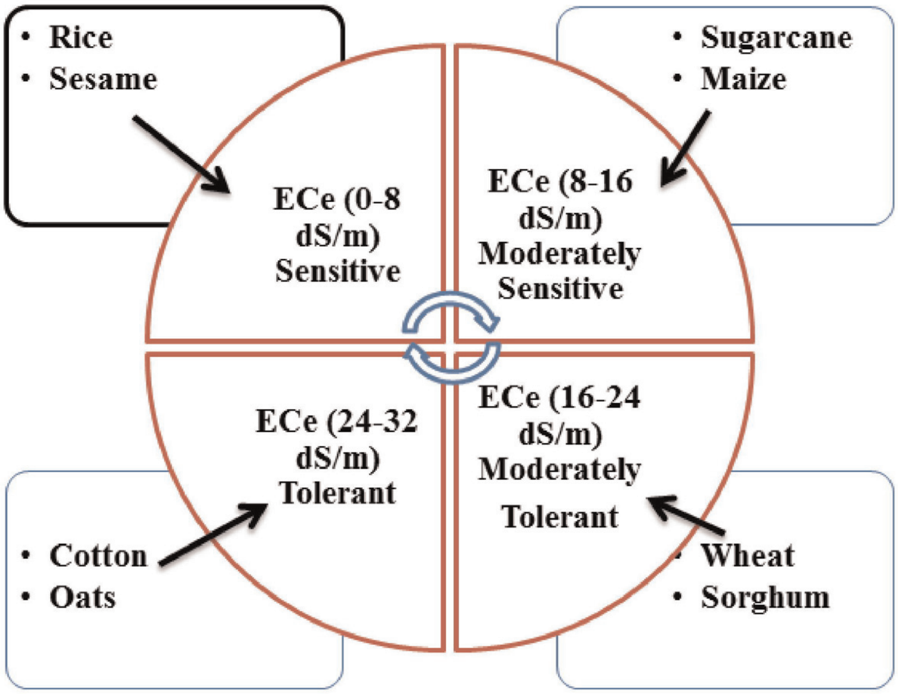

Figure 2.
Classification of field crops subjected to salinity stress. Extracted from Maas and Grattan [105].

Phase (FGP) and by 21% during Grand Growth Period (GGP). Additionally, they observed it decreased in biomass accumulation by 44% during FGP and 32% during GGP. The significant reduction in shoot and root biomass accumulation in sugarcane sprouts with increasing salinity level from normal to 120 mM NaCl [101]. Similarly, the increasing NaCl level resulted in a reduction of the shoot, root length, root volume, and leaf area of sugarcane seedlings by 36–41, 29–42, and 52–66%, and chlorophyll contents by 20.0–45.0% respectively [104]. The other factors which directly reflect the depletion of growth of sugarcane are linked with alterations in gas exchange parameters, and reduced transpiration and photosynthetic rates due to stomatal closure. As concern sugarcane yield and related traits, the sucrose juice (6%) of sugarcane was significantly reduced induced during Grand Growth Period (GGP) and so also the brix [103]. Similar to the millable canes (MC) and cane yield were reduced drastically under salinity. The MC decreased by 8.0–100% by exposing under salinity. Additionally, salinity caused negative impacts on cane yield, cane length, and single cane weight. Hence, the different field crops showed a different level of response to salinity stress depends on their genetic nature and as EC increased from 32 dS m^{-1}, the yield is unacceptable from the most of the field crops (**Figure 2**) [105].

4. Management strategies

There are two groups of management strategies against salinity, first one natural adaptation responses towards salinity, and second are human-made management strategies to handle the salinity stress in field crops or plants. Tolerance or resistance of rice plant to salt stress involves many adaptive responses at molecular, cellular, and physiological levels. Among the natural management strategies by the plants to salinity stress based on three strategies: (i) exclusion of Na^+ from the cytoplasm due to low uptake, or pumping out of the ion from the cell by active mechanisms, (ii) requisitioning of Na^+ into the vacuole and (iii) preferential accumulation in the leaf tissues. However, the genotypes with high leaf Na contents proved to be generally salt sensitive, and only those can tolerate high tissue concentrations, which can sequester Na^+ into the vacuoles of leaf cells. The essential processes leading to plant adaptation to high salinity include ionic, metabolic, and osmotic adjustments. The salt-resistant genotypes can successfully cope with osmotic and ionic stresses caused by the excess of NaCl; they can effectively reduce the oxidative damage and can detoxify the harmful metabolites [106].

4.1 Natural adaptation responses towards salinity by plant

4.1.1 Osmotic adjustment

Osmotic adjustment is the best and favorable plant physiological strategy to endure concentration of toxic ion (Na^+ and Cl^-) in cytoplasm and compartmentalization in vacuoles, and define the salinity tolerance limits for plant [107]. Under osmotic stress, accumulation of free sugar, glycine betaine, organic solutes, and the proline in the plant's cytoplasm is also an important strategy to cope with the salinity stress [108]. This phenomenon is important to handle the antagonistic abiotic stresses, including salinity and maintain the homeostasis in osmotic or ionic signaling [17]. Similarly, leaf area or leaf architecture is also an important trait of the plant, which can reduce the excessive amount of Na^+ in leaves through dilution effects and the transpiration force [109].

4.1.2 Closure of stomata

The ultimate response of plant subjected to salt stress is the closure of stomata [110]. The carbon dioxide assimilation decrease, as EC level increase (0–20 dS m^{-1}) which results in plant growth reduction as well as the closure of stomata. This closure of stomata decreased the intracellular (Ci) CO_2 partial pressure leading to hampering the Pn [5]. High salinity stress in rhizosphere decrease the transpiration rate (Tr), reduce the root water potential. Salinity stress enhances the biosynthesis of abscisic acid (ABA) and closes the stomata after reaching the guard cells. ABA passage from root to shoot causes closure of stomata and save the leave tissue from dehydration [54, 111]. Mostly, salinity hinders Pn in various crop plants. However, the sound reasons for lower Pn are stomatal closure, lower sink activity, reduced efficiency of rubisco, dislocation of vital cations from the membrane structure of leaf which lead to changes in permeability, and swelling and inefficiency of the grana [112], or might be due to the direct effects of salinity on conductance of stomata through a decrease in guard cell turgidity and CO_2 partial pressure within plant cell [113]. Closure of stomata plays a vital role to survive with salinity stress. Chen and Gallie [114] studied that the ascorbate or ascorbic acid (AsA) redox state controls the transpiration rate and conductance of stomata. Stomatal guard cells control through Na^+ which control transpiration rate according to the concentration of salt presented in soil environment [115].

4.2 Agronomic practices to cope salinity

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. By adopting some measures, these problems can manage plant growth by adopting some agronomic strategies such as water and nutrient management to improve soil health, plant growth, and input use efficiency (IUE) under salinity [116].

4.2.1 Water and nutrient management strategies

Irrigation water with high electrical conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), and pH value also causes of salinity stress and plant growth reduction [117]. For the better survival of plant against salinity stress, a wise water management strategy is indispensable. Availability of good quality irrigated water is very vital for the survival of crop plant and yield [118]. The usage of good quality water is a good option to drain or leeched down the soluble salts from the root zone for better soil management and plant growth [118]. The canal water is a good replacement of brackish underground water for irrigation of field crops. If canal water is unavailable, the use of gypsum with brackish underground water is the best option, and it increased 25–294% rice yield and 182% wheat production under salinity [119]. Similarly application of canal water with 100% gypsum help to lower the ECe, pH value, and SAR of soil at 0–30 cm depths than saline water with 100% gypsum in field crops [120]. In case of less availability of good quality water, then the 25% gypsum amendment with unfit irrigating water is the best option. The wise use of less good quality is than never mix up with the unfit underground water or tub well water, and follows the irrigation scheduling [119].

The management of salinity stress by nutrient management is the wise use of calcium (Ca^{2+}) source in the form of gypsum ($CaSO_4{\cdot}2H_2O$) and to improve soil water infiltration and better plant growth. Application of gypsum (100%), a combination of gypsum + farmyard manure (FYM) + H_2SO_4, $CaSO_4{\cdot}2H_2O$ + FYM + chiseling, pyrite, and humic acid (HA), in rice, wheat, sorghum crop improved soil properties, plant biomass, and yield [118, 121]. Application of N, P, K, S, Zn, B, and Mn separately or with different combination increased rice total above ground biomass and grain production under salt-affected soils [122, 123]. Humic acid improves nutrients availability by chelating with unavailable nutrients (P, K, Ca, Fe, Zn, and Cu) and buffered pH value, and enhanced soil microbial, enzymatic and physiological activities, and plant growth under salinity [121, 124]. The combined effect of humic acid (HA) with gypsum (24 and 48 kg/ha) in rice was higher than the alone effect of HA on ECe and SAR due to its chelating effect with other nutrients subjected to salinity [125]. The use by-product of sugarcane (press-mud), green manure, poultry manure, and Sesbania as a cover crop for amendment of soil to reduce the effect of salinity which is a source of macro and micronutrients especially Zn and S in crops are also good options [126]. There are some other useful agronomic practices to reduce the effect of salt stress on the plant are periodic use of fresh water, subsoiling, deep tillage, sanding, and application of organic and inorganic fertilizers, and adopting crop rotation [118].

4.2.2 Application of hormones regulators

The hormonal imbalance is one of the salinity effects on plants. There are many plant growth regulators being used as hormones regulator or plant growth regulators such as aminoethoxyvinylglycine (AVG), ethephon, and 1-methylcyclopropene (1-MCP) for ethylene inhibitor under salt stress and enhance the boles and spikelets development in rice and cotton respectively [4]. Similarly, exogenous applications of abscisic acid (ABA), brassinosteroids (BRs) or their analogs (D-31, D-100, etc.) are good option to improve plant performance under salinity [127, 128].

4.2.3 Traditional breeding for salt tolerance

To meet the demand for food and livelihood of the increasing population on the globe, the increase in the agriculture production is indispensable. Therefore, many efforts have been made to improve salinity tolerance capacity of the crops through conventional plant breeding and biotechnology [129]. Salinity tolerance is a complex trait both at the genetic and physiological level and controlled by polygenes. It has been speculated that salinity tolerance seems to be regulated by independent genes at different growth stages [130]. Traditional breeding has been considered as a more promising and efficient approach to improve the salt tolerance. Conventional breeding involves identification of QTLs using closely linked markers along with their phenotypic evaluation. One of the best-studied QTL for salt tolerance; saltol was identified by the conventional breeding approach in rice [131]. This QTL was found to control shoot Na^+/K^+ ratio at the seedling stage. So, the identification of new QTLs and later pyramiding of these QTLs would lead to the development of the more promising salt tolerant line. Marker-assisted backcrossing (MAB), which is one of the best traditional breeding approaches that involve the transfer of the specific allele at target locus from donor to recipient parent, can be used for this purpose. Traditional breeding mainly relied on the use of diverse germplasm resources to identify the landraces showing salt tolerance and then map the locus responsible for salt tolerance. This can be seen as an advantage as well as a disadvantage. Salt tolerance is an outcome of involvement of diverse cellular processes like ion transport and homeostasis, osmoregulation, and oxidative stress protection. Identification and characterization of key genes for salt tolerance would need the collective application of advanced molecular mapping, genomics, transcriptomics, and proteomics approaches.

4.2.4 Molecular breeding to improve salt tolerance

Many salt tolerance genes have been discovered by using traditional breeding techniques, such as subtractive hybridization, differential hybridization, and through genetic information from the model organism. Furthermore, protein crystallography, a proteomic study has enabled researchers to the exploration of the protein's structure and function for salt tolerant genes. After salt tolerance gene identification, many latest techniques for foreign gene transformation to the desired plant can help to improve field crop production. Such as CRISPR CAS9, PEG-mediated gene transfer, electroporation, partial or the micro projectile bombardment, microinjection, and Agrobacterium-mediated gene transfer. These techniques are available for many crops.

5. Conclusions and future perspectives

Salinity stress is the one of the key growth hampering agents for field crops. Salinity not only effects the plant growth but also affect yield by creating osmotic, ionic, and oxidative stresses. From this chapter, it is concluded that, the rice (sensitive), sugarcane and maize (moderately sensitive, wheat and sorghum (moderately tolerant), and cotton (tolerant) subjected to salinity. There are many management strategies, including traditional soil, water, and nutrient management strategies as well as genetic modification and by using molecular breeding, tools are suitable for producing salt tolerance cultivars. The bunch of information in this chapter wills able the scientific community to understand the role of salinity stress in field crops and their management options [115].

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