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23

Soil Salinity

Causes, Effects, and Management in Cucurbits

Akhilesh Sharma, Chanchal Rana, Saurabh Singh, and Viveka Katoch

CONTENTS

23.1 INTRODUCTION

23.1.1 What Is Soil Salinity?

Soil salinity is a major limiting factor that endangers the capacity of agricultural crops to sustain the growing human population. It is characterized by a high concentration of soluble salts that significantly reduces the yield of most crops. Soils with an electrical conductivity (EC) of the

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saturation soil extract of more than 4 dS m^{-1} at 25°C are called saline soils, which are equivalent to approximately 40 mM NaCl and generate an osmotic pressure of approximately 0.2 MPa. Salts generally found in saline soils include chloride and sulfates of Na, Ca, Mg, and K. Calcium and magnesium salts are at a high enough concentration to offset the negative soil effects of sodium salts. The pH of saline soils is generally below 8.5. The normal desired range is 6.0–7.0.

23.1.2 CHARACTERISTICS OF SALINE SOILS

1. The soluble salt concentration in the soil solution is very high, which also results in high osmotic pressure of the soil solution. Osmotic pressure is closely related to the rate of water uptake and growth of plants. This causes wilting of plants and nutrient deficiency. A salt content of more than 0.1% is injurious for plant growth (Table 23.1).
2. EC of the soil saturation extract is important as a measure for the assessment of saline soil for the plant growth and is expressed as dS m^{-1} (earlier mmhos cm^{-1}). Salinity effects are negligible below 2 dS m^{-1}. However, yields of very sensitive crops may be restricted between 2 and 4 dS m^{-1}, while yields of many crops may be restricted between 4 and 8 dS m^{-1}. On the other hand, only tolerant crops yield satisfactorily between 8 and 16 dS m^{-1}, whereas above 16 dS m^{-1}, only high-tolerant crops grow (Table 23.2).
3. Determination of water-soluble boron concentration is also an important parameter for characterization of saline soils. Boron concentration above 1.5 ppm is unsafe for plant growth.
4. Soil texture is also an important criterion to characterize saline soils. Sandy soils with 0.1% salt concentration cause injury to the growth of common crops, while the crops grow normally in clayey soils with the same salt content. Saturation percentage is considered as a characteristic property of every soil. For salinity appraisal, soil texture and EC of saturation extract are considered simultaneously.

TABLE 23.1
Characteristics of Salt-Affected Soils

Characteristics	Saline Soils	Sodic Soils
Content in soil	Excess of neutral salts	Excess of sodium salts
pH	<8.5	>8.5
EC (dS m^{-1})	>4	<4
Exchangeable sodium percentage (%)	<15	>15
Physical condition of soil	Flocculated	Deflocculated
Color	White	Black
Organic matter	Slightly less than normal soils	Low
SAR	<13	>13
Total soluble salt contents (%)	>0.1	<0.1

TABLE 23.2
Classification of Saline Soils

Salt Concentration of the Soil Water (Saturation Extract)		
(g/L)	(dS m^{-1})	Salinity
0–3	0–4.5	Nonsaline
3–6	4.5–9	Slightly saline
6–12	9–18	Moderately saline
>12	>18	Highly saline

23.1.3 Problems of Salt-Affected Soils

The various problems associated with saline soils that interfere with plant growth are as follows:

1. Soils are generally barren but potentially productive.
2. Saline soils have a high wilting point and low amount of available moisture.
3. Excessive salts in the soil solution increase the osmotic pressure of soil solution compared to cell sap, which makes it difficult for plant roots to extract moisture due to increased potential force that holds water. If salt concentration in the soil is greater than that of the plant, water moves from the plant into the soil, that is, plasmolysis, which leads to wilting/death of the plant.
4. High concentration of soluble salts cause toxicity to the plant, for example, root injury and inhibition of seed germination.

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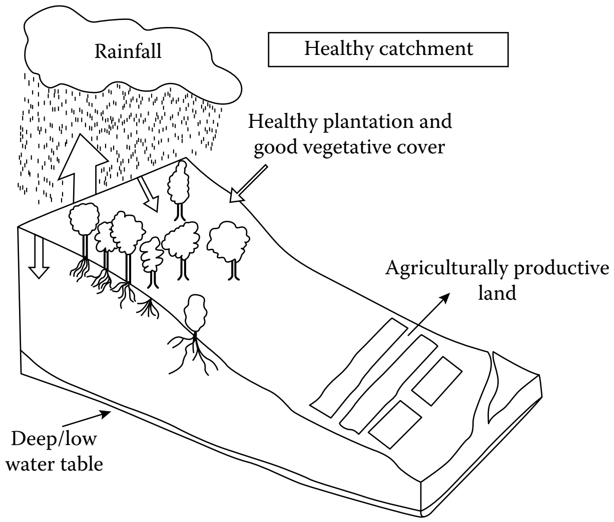
23.1.4 Present Status and Causes of Salinity

Salinization is a process that results in an increased concentration of salts in soil and water. Of these salts, sodium chloride is the most common. With an increase in concentration of soluble salts, it becomes more difficult for plants to extract water from the soil. Higher salt concentrations can be created by poor soil drainage, improper irrigation, irrigation water with high levels of salts, and excessive use of manure or compost as fertilizer. Salinization affects many irrigated areas mainly due to the use of brackish water. Salt-affected soils cover about 800 million ha of land, which accounts for more than 6% of the total land area in the world. There are two kinds of soil salinity, namely primary (natural) and secondary (due to human activity, i.e., dry land and irrigated land salinity). A majority of saline soils have emerged due to natural causes such as accumulation of salts over long periods of time in arid and semiarid zones (Munns and Tester 2008). This is because of the fact that the parent rock from which it formed contains salts, mainly chlorides of sodium, calcium, and magnesium, and to some extent, also contains sulfates and carbonates. Sea water is another source of salts in low-lying areas along the coast. Besides natural salinity, a significant proportion of cultivated land has become saline due to land clearing or irrigation.



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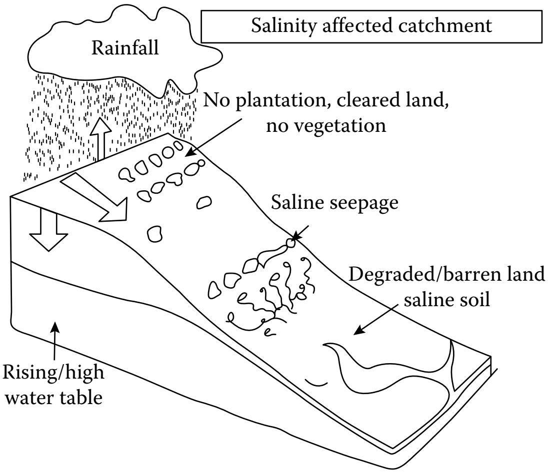

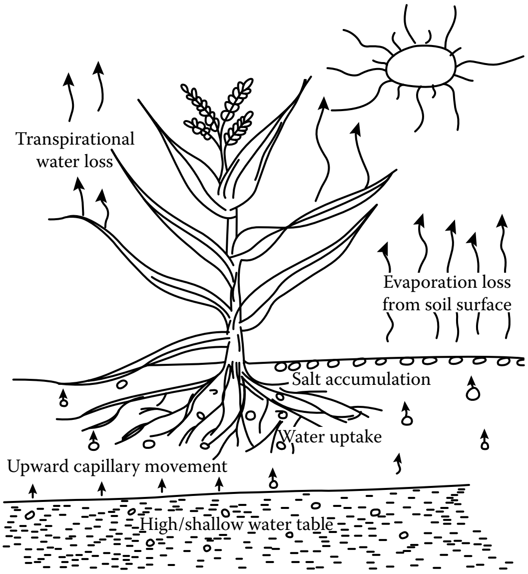

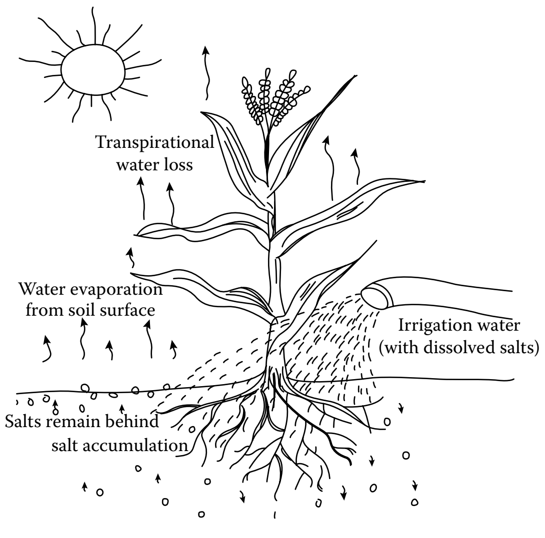

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These factors raise the water table and cause the accumulation of salts in the root zone. Presently, out of 230 million ha of irrigated land, around 45 million ha are salt-affected worldwide, which accounts for 20% of the irrigated area. About 1.5 million ha of land is taken out of production every year as a result of high salinity levels in the soil. The irrigation water contains calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^+). After irrigation, the water applied to the soil is used by the crop or evaporates directly from the moist soil. Ca^{2+} and Mg^{2+} often precipitate into carbonates, leaving Na^+ dominant in the soil (Serrano et al. 1999). The salt, however, is left behind in the soil. As a result, Na^+ concentrations often exceed those of most macronutrients by one or two orders of magnitude, and by even more in the case of micronutrients. High concentrations of Na^+ in the soil solution may depress nutrient-ion activities and produce extreme ratios of Na^+/Ca^{2+} or Na^+/K^+. The increase in cations and their salts, particularly NaCl, in the soil generates external osmotic potential, which can prevent or reduce the influx of water into the root. The resulting water deficit is similar to drought conditions and additionally compounded by the presence of Na^+ ions (Bohnert 2007). Highly saline soils are sometimes recognizable by a white layer of dry salt on the soil surface. Irrigated land though covers only 15% of the total cultivated land but has high productivity; as a result, they produce one-third of the world's total food.

23.1.5 SALINITY STRESS AND PLANT GROWTH

Plants are stressed in two ways in a high-salt environment. In addition to the water stress imposed by the increase in osmotic potential of the rooting medium as a result of high-solute content, there is the toxic effect of high concentration of ions. Few plant species have adapted to saline stress, but the majority of crop plants are susceptible (they may not survive or survive but with low yield). Soil salinity leads to reduction in biomass production by affecting important physiological and biochemical processes of the plant (Ahmad and John 2005; Ahmad 2010; Ahmad and Sharma 2010). At low salt concentrations, yields are either mildly affected or not affected at all (Maggio et al. 2001). With the increase in salt concentration, the yield reduction is drastic as most crop plants are not able to grow at high concentrations of salt. On the contrary, halophytes can survive salinity and have the capability to grow on saline soils of coastal and arid regions due to specific mechanisms of salt tolerance developed during their phylogenetic adaptation. High salinity affects plants in several ways like water stress, ion toxicity, nutritional disorders, oxidative stress, alteration of metabolic processes, membrane disorganization, reduction of cell division and expansion, and genotoxicity (Munns 2002b; Zhu 2007). These factors together hamper growth and development of the plant that may affect plant survival. During the onset and development of salt stress within a plant, all the major processes such as photosynthesis, protein synthesis, enzyme activity and energy, and lipid metabolism are affected (Parida and Das 2005). Therefore, as a result, premature senescence of older leaves and toxicity symptoms (chlorosis, necrosis) on mature leaves may occur (Hasegawa et al. 2000). In the initial stages, plants experience water stress that causes reduction of leaf expansion. The osmotic effects of salinity stress can be observed immediately after salt application and continue for the duration of salt exposure, which results in the inhibition of cell expansion and cell division along with stomatal closure (Flowers 2004). During long-term exposure to salinity, plants experience ionic stress, which can lead to premature senescence of adult leaves and thus a reduction in the photosynthetic area available to support further growth (Cramer and Nowak 1992). High salinity affects rhizosphere, which is bioenergetically taxing as microorganisms need to maintain an osmotic balance between their cytoplasm and the surrounding medium while excluding sodium ions from the cell interior, and as a result, sufficient energy is required for osmoadaptation (Oren 2002; Jiang et al. 2007).

Munns (2002a) described characteristic changes over different time scales in the plant's development, that is, from the imposition of salinity stress till maturity. Moments after salinization, cells dehydrate and shrink but regain their original volume hours later. Despite this recovery, cell elongation and, to a lesser extent, cell division are reduced, leading to lower rates of leaf and root growth.

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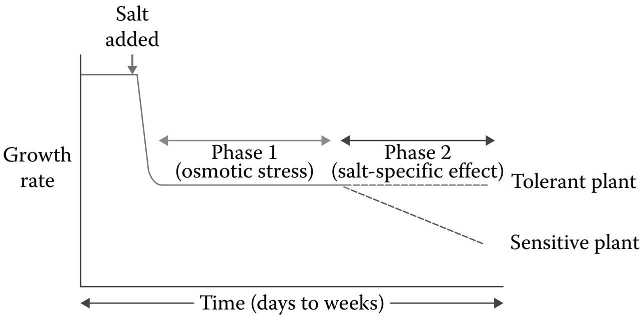

FIGURE 23.1 Two-phase growth response to salinity for genotypes differing in the rate of salt toxicity in leaves. (From Munns, R., *New Phytol.*, 167, 645, 2005.)

Over the next days, reduction in cell division and elongation translates into slower leaf appearance and size. Plants that are severely salt-stressed often develop visual injury due to excessive salt uptake. After a few weeks, lateral shoot development is affected, and after some months, clear differences in overall growth and injury are observed between salt-stressed plants and their nonstressed controls. Based on these sequential differences in response to salinity, a two-phase model describing the osmotic and ionic effects of salt stress (Figure 23.1) was proposed by Munns (2002a, 2005). Identification of plant genotypes capable of increased tolerance to salt and incorporation of these desirable traits into economically useful crop plants may reduce the effect of salinity on productivity. Plants sensitive or tolerant to salinity differ in the rate at which the salt reaches toxic levels in leaves. Timescale is days or weeks or months, depending on the species and the salinity level. During phase 1, growth of both types of plants is reduced because of the osmotic effect of the saline solution outside the roots. During phase 2, old leaves in the sensitive plant die and reduce the photosynthetic capacity of the plant. This exerts an additional effect on growth. However, the physiological, biochemical, and molecular mechanisms of salt tolerance in plants are not yet sufficiently understood, and hence progress in developing salt-tolerant crops has been slow (Lauchli and Grattan 2007).

23.2 STATUS OF CUCURBITS IN RELATION TO SALINITY

The Cucurbitaceae family ranks among the highest of plant families for number and percentage of species used as human food. It consists of 98 proposed genera with 975 species mainly in tropical and subtropical regions, the most important of which are *Cucumis* (cucumber, musk melon), *Cucurbita* (squash, pumpkin, zucchini, some gourds), *Lagenaria* (bottle gourd), *Citrullus* (watermelon), and many others. Cucurbits are grown around the tropics and in temperate areas and are sensitive to frost. Cucurbit crops are, in general, similar in their appearance and requirements for growth. A majority of them are annual bearing vines with trailing growth habit, grown during summer season. They require congenial environmental conditions for better growth to harness maximum productivity per unit area.

Cucurbits differ considerably in their ability to tolerate salinity stress. A majority of the cucurbits are moderately sensitive to salt stress. Cucumber (*Cucumis sativus* L.) and musk melon (*Cucumis melo* L.) are moderately sensitive to salinity. Salinity improves the musk melon fruit quality by increasing the dry matter, total sugars, total soluble solids, and pulp firmness. Squash (*Cucurbita pepo*) is moderately salt tolerant. Villora et al. (1999) reported that salinity improves zucchini fruit quality through enhancement of physical (fruit firmness) and chemical properties (total soluble solids). Similarly, bitter gourd or balsam pear (*Momordica charantia* L.), widely recognized for its hypoglycemic properties, is one of the extensively grown cucurbitaceous vegetables reported to have salinity tolerance. Trajkova et al. (2006) reported that cucumber is more susceptible to NaCI than $CaCI_2$, which points to Na-specific salinity effects. This may be attributed to inefficient compartmentation of Na within the cell, which forces the plant to exclude Na from the leaf. To exclude Na, the plant must expend energy for osmotic adjustment. When Na exclusion breaks down, the plant suffers directly from Na toxicity at a biochemical level.

However, research on crop improvement under a stress situation on cucurbits is very meager. Watermelon (*Citrullus lunatus* L.) is moderately sensitive to salinity, and the reduction in yield due to salinity ranged from 0% at 2.5 mmhos cm^{-1} to 10% at 3.3 mmhos cm^{-1}, 25% at 4.4 mmhos cm^{-1}, 50% at 6.3 mmhos cm^{-1}, and 100% at 10 mmhos cm^{-1} (Yetisir and Uygur 2010). Dhillon et al. (2012) reported that Indian germplasm of cucurbits exhibit few salt-tolerant lines and also, it has been mentioned that bottle gourd withstands salt stress better than watermelon and winter squash.

Salinity Reaction		
Low Tolerant/Sensitive	**Medium-Tolerant/Sensitive**	**Highly Tolerant/Sensitive**
Nil	Cucumber (*C. sativus* L.), musk melon (*C. melo* L.), squash (*C. pepo* L.), pumpkin (*Cucurbita maxima* Duch.), bottle gourd (*Lagenaria siceraria* Standl.), watermelon (*C. lunatus* Thunb.), winter squash (*Cucurbita moschata* Duch.)	Ash gourd (*Benincasa hispida* Thunb.), bitter gourd (*M. charantia* L.)

23.3 STRATEGIES TO COMBAT SOIL SALINITY IN DIFFERENT CUCURBITS

Plant growth under salt stress conditions is a complex mechanism, and the way it is affected by the stress is not fully understood because the response of plants to excessive salinity is multifaceted and involves changes in plant morphology, physiology, and metabolism (Ali et al. 2012). Identification of plant genotypes capable of increased tolerance to salt and incorporation of these desirable traits into economically useful crop plants may reduce the effect of salinity on productivity. The improvement of salinity tolerance in the crops through conventional breeding has very limited success due to genetic and physiological complexity of this trait (Flowers 2004). In addition, tolerance to saline condition is a developmentally regulated and stage-specific phenomenon, that is, tolerance at one stage of plant development does not always correlate with tolerance at other stages (Foolad 2004). Breeding for salt tolerance requires effective screening methods, existence of genetic variability, and ability to transfer the genes to the species of interest. In addition to tolerant cultivars, several cultural practices needs to be applied with an aim that each contribute to a certain extent to allow plants to better withstand the deleterious effects of salt. Some of the proposed practices, like the application of chemical fertilizers at levels somewhat above the optimum in freshwater irrigation and the application of chemical amendments or leaching salts to deeper soil layers, are hardly compatible with the urgent need to preserve the environment (Cuartero et al. 2006).

23.3.1 SOURCES OF TOLERANCE AND DEVELOPMENT OF GENOTYPES TOLERANT TO SALINITY

23.3.1.1 Conventional Breeding Approaches

To ensure sustainable productivity of agricultural crops in the future, there is a need to select and characterize salt-tolerant plants. In order to improve salt tolerance through breeding, genetic variability for the trait is required. The genetic pool of cucurbits possess only partial degree of tolerance to salinity along with their nonstable nature toward salt tolerance (Hasegawa et al. 1980), which makes it even more difficult to cope with. The results of most studies have shown that the resistance to salt stress is usually correlated with a more efficient antioxidant system. The quantitative nature of salt tolerance has its roots in the physiological processes that involve multiple genes, each with a small and unknown effect (Quesada et al. 2000). Major efforts are being directed toward the genetic transformation of plants in order to raise their tolerance (Borsani et al. 2003), and in spite

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of the complexity of the trait, the transfer of a single gene or a few genes has led to improvement in salt tolerance. Evaluation of salt-tolerant lines through screening and then hybridizing them with high-yielding lines to incorporate salt-tolerant genes by backcrossing has been suggested by many researchers (Munns et al. 2006). Salt-tolerant lines are not as such available in abundance, and their identification is very cumbersome. It is complicated to improve salinity tolerance of cucurbits through simple selection procedures or pedigree breeding due to the presence of dominance gene action (Kere et al. 2013). Yeo et al. (1988) and Cuartero and Fernandez-Munoz (1999) suggested pyramiding of desired genes in a single genotype.

Cucumber is one of the most important cucurbits grown throughout the world and is sensitive to salinity (Dorota 1997), though certain reports categorized it as moderately sensitive to salt stress (Maas 1993), indicating genotypic variation for salt tolerance. Salt stress in cucumber involves both osmotic stress, by limiting absorption of water from soil, and ionic stress, resulting from high concentrations of potentially toxic salt ions within plant cells (Savvas et al. 2005). Therefore, cucumber production in saline soils requires salt-tolerant varieties. Tiwari et al. (2011) were of the opinion that the most feasible alternative to grow crops under salinity prone environments is through genetic improvement. For breeding salt-tolerant cucumber, an understanding of the mechanism of inheritance pattern involved in salinity tolerance is required. Being native to India and despite its wide genetic variability, no information is available for salinity tolerance in cucumber (Malik et al. 2010). Cucumber lines 'CRC 8', 'CHC 2', 'G 338', 'CH 20', and '11411Sare' are known to be tolerant to soil salinity (Kere et al. 2013). The musk melon line Calif-525 is salt tolerant (Shannon et al. 1984; Whitaker 1979).

Of late, Munns et al. (2012) developed tolerant wheat through conventional breeding. This provides hope for genetic improvement of salt-tolerant cucumber if accurate selection and screening methods are identified. However, the genetics of salt tolerance in cucumber is poorly understood (Tiwari et al. 2011) due to the complexity of salt tolerance (Munns and Tester 2008). Therefore, it is necessary to investigate viable selection traits that can predict salinity tolerance of cucumber at the seedling stage. The potential for genetic improvement of salt tolerance in cucumber is feasible if the gene action of superior parents is fully understood and a suitable breeding program is employed (Dashti et al. 2012). Munns et al. (2006) suggested that exploitation of naturally occurring inter and intra-specific genetic variability by hybridization of selected salt-tolerant genotypes with high-yielding genotypes adapted to a specific environment is a descent approach to develop salt-tolerant varieties.

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23.3.1.2 Screening Techniques Against Salt Stress

To identify salt-tolerant plants, they have to be screened in saline medium/conditions. Plants do not develop salt tolerance unless they are grown in saline conditions, which means that they must be hardened to salt stress (Levitt 1980). Various methods are used for screening segregating material for salt resistance. The commonly used methods are lysimeter microplots, sand culture, and solution culture tanks. Replicated experiments are conducted over seasons to get more reliable results. Genotypes that survive under salinity conditions are considered as tolerant and screened further. In cucumber, cultivars 'Keyan' and 'Danito' were identified as salinity-tolerant cultivars (Baghbani et al. 2013). Na^+ exclusion is widely accepted as an efficient salt selection criterion for cereals (Munns and Tester 2008; Munns et al. 2012).

Malik et al. (2010) have partly explained the mechanism by identifying the parameters as an index for *in vitro* screening of salt tolerance in cucumber genotypes and found that the salt-tolerant genotype (Hazerd) successfully tolerated highest salinity level (120 mM) by accumulating significantly higher levels of free proline and exhibited higher antioxidant enzyme (superoxide dismutase [SOD] and peroxidase [POD]) activities besides showing low lipid peroxidation and electrolyte leakage with slight reduction in photosynthetic pigment. Furthermore, higher salinity tolerance was also correlated to limited translocation of Na^+ ions to leaves, resulting in the maintenance of high K^+/Na^+ ratio.

23.3.1.3 Nonconventional Breeding Methods for Salinity Stress Resistance

In watermelon, transgenic plants have been produced expressing the *HAL1* gene under the control of 35S promoter with a double enhancer sequence from the cauliflower mosaic virus and RNA4 leader sequence of alfalfa mosaic virus (Ellul et al. 2003). The constitutive expression of HAL1 gene showed a beneficial effect on rooting of plants grown under *in vitro* saline conditions.

Since salt concentration in soil is highly variable, it is necessary to frequently test genotypes/plants tolerance to salinity in several salt concentrations applied to root system. Genotype × salt treatment interaction has been found in several occasions and species (Lee et al. 2004). When appropriate segregant populations (RIL or DH) are grown in at least two salinity conditions (control and saline), more quantitative trait loci (QTL) have been identified in saline than in control conditions, and significant QTL × E interaction has been found in all the experiments designed to detect the interaction. It is necessary to assess that QTL detected under saline conditions are expressed in different salt concentrations, otherwise QTL should be found for each specific salt concentration on which tolerant genotypes are to be grown.

Furthermore, in salt-tolerant lines, identifying molecular markers tightly linked to the gene of interest can give us a lead to reduce the otherwise significant influence of environmental factors as suggested by Ashraf et al. (2008). The halo-tolerance due to HAL1 gene of *Saccharomyces cerevisiae* has been identified and confirmed as a molecular tool for genetic engineering for salt-stress protection in watermelon and other crop species (Ellul et al. 2003). In another study by Kere et al. (2013), a strong, positive correlation was opined between the RLN14 (relative leaf number) and TOL (tolerance), whereas VL (vine length) and TOL indicated a weak negative correlation but notably RLN14 and VL showed a strong negative correlation.

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23.3.2 GRAFTING AS A TOOL TO MANAGE SALINITY STRESS

Salt tolerance is a complex characteristic both genetically and physiologically (Flowers 2004), which ultimately provides limited success through conventional breeding methods. Therefore, grafting can represent an interesting alternative to avoid or reduce yield losses caused by salinity stress in high-yielding genotypes belonging to Cucurbitaceae family. Grafting as a tool for enhancing the plant characteristics is well known, and investigations have indicated that grafting may limit nutrient and heavy metal toxicity (Edelstein et al. 2005; Arao et al. 2008; Rouphael et al. 2008a; Savvas et al. 2009). Grafting is an integrative reciprocal process and, therefore, both scion and rootstock can influence salt tolerance of the grafted plants. Biochemical mechanisms of uptake in the roots are governed by the demand in the sink, that is, shoot (Marschner 1995). However, the uptake efficiency depends upon the rootstock. So, grafting can serve as an important tool to prevent salt stress by inhibiting Na and Cl uptake. Grafted plants grown under saline conditions often exhibited better growth and yield, higher photosynthesis and leaf water content, greater root-to-shoot ratio, higher accumulation of compatible osmolytes, abscisic acid and polyamines in leaves, greater antioxidant capacity in leaves, and lower accumulation of Na^+ and/or Cl^- in shoots than ungrafted or self-grafted plants.

Grafting of bottle gourd rootstock affects nitrogen metabolism in NaCl-*stressed* watermelon leaves and enhances short-term *salt* tolerance. The plant growth, nitrogen absorption, and assimilation in watermelon were investigated in self-grafted and grafted seedlings using the salt-tolerant bottle gourd rootstock 'Chaofeng Kangshengwang' exposed to 100 mM NaCl for 3 days. Biomass and NO^{3-} uptake rate were significantly increased by rootstock, while these values were remarkably decreased by salt stress. However, compared with self-grafted plants, rootstock-grafted plants showed higher salt tolerance with higher biomass and NO^{3-} uptake rate under salt stress. These results indicated that the salt tolerance of rootstock-grafted seedlings might be enhanced owing to the higher nitrogen absorption and the higher activities of enzymes for nitrogen assimilation induced by the rootstock (Yang et al. 2013). As reported by Goreta et al. (2008), when watermelon

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(‘Fantasy’) was grafted onto ‘Strongtosa’ rootstock (*C. maxima* Duch. × *C. moschata* Duch.), the reductions in shoot weight and leaf area due to exposure to salinity were lower in ungrafted plants. Similarly, Yetisir and Uygur (2010) demonstrated that grafted ‘Crimson Tide’ watermelon onto rootstocks of *C. maxima* and *L. siceraria* resulted in higher growth than ungrafted plants under saline conditions (8.0 dS m^{-1}).

Romero et al. (1997) compared the effect of salinity (4.6 dS m^{-1}) on two varieties of melon (*C. melo* L.) grafted onto three hybrids of squash (*C. maxima* Duch. × *C. moschata* Duch.) with its effects on ungrafted melons and found that grafted melons were more tolerant to salinity and gave higher yields than ungrafted ones. Huang et al. (2009b) determined the fruit yield response of cucumber variety, ‘Jinchun No. 2’ either self-grafted or grafted onto the commercial salt-tolerant rootstock ‘Black Seeded’ fig leaf gourd (*Cucurbita ficifolia* Bouche) and Chaofeng Kangshengwang (*L. siceraria* Standl.) and studied the response under different saline conditions (0, 30, or 60 mM NaCl). Plants grafted onto ‘Figleaf Gourd’ and ‘Chaofeng Kangshengwang’ had higher fruit number and marketable fruit yield compared to self-grafted plants at all salt levels. The total fruit yield of plants grafted onto ‘Figleaf Gourd’ increased by 15%, 28%, and 73% under 0, 30, and 60 mM NaCl stress, respectively, whereas the respective values were 14%, 33%, and 83% in the plants grafted onto ‘Chaofeng Kangshengwang’ over self-grafted plants. They concluded that grafting cucumber onto ‘Black Seeded’ figleaf gourd increased plant tolerance to salinity induced by major nutrients.

Rouphael et al. (2008b) attributed the improved crop performance of grafted cucumber plants on pumpkin rootstock to the ability of the pumpkin rootstock to check the accumulation of Cu. Pumpkin plants have a deep and sturdy root system, which gives them an advantage to adapt to saline conditions. Melon plants grafted onto the commercial rootstock ‘TZ-148’ (*C. maxima* Duchesne × *C. moschata* Duchesne) prevented boron toxicity (Edelstein et al. 2005, 2007). Rouphael et al. (2012) suggested that the use of salt-tolerant *Cucurbita* hybrid rootstocks (*C. maxima* Duch. × *C. moschata* Duch.) ‘P360’ and ‘PS1313’, respectively, can improve melon and cucumber photosynthetic capacity under salt stress and consequently crop performance.

El-Shraiy et al. (2011) highlighted the significance of grafting cucumber on salt tolerance rootstock (Shintosa Supreme pumpkin), which increased fruit yield, fruit number, fruit weight, fresh and dry weight, plant height, leaf area, and leaf and relative water content (LRWC) compared to ungrafted plants under saline conditions. These positive effects of grafting cucumber significantly increased chlorophyll, carotenoid, proline, and total soluble protein concentrations although there was a reduction in titratable acidity, total soluble solids, and EC in fruit juice compared to ungrafted plants.

The use of rootstocks to combat salinity has also resulted in improved plant vigor through efficient use of nutrients and water, disease tolerance, cold tolerance, heat tolerance, and tolerance to wet soil conditions (Lee et al. 2010). Colla et al. (2005) ascribed that different rootstocks show variable results. The rootstocks of *Cucurbita* spp. and *Lagenaria* spp. serve as the best as they have the potential of improving the salt tolerance of scion by reducing the Na uptake better than *Citrullus* spp. and *Cucurbita* spp. In contrast, Taffouo et al. (2008) concluded that *Lagenaria* spp. is best suited to tolerate saline conditions. However, in an argument report stating similar sensitivity for grafted and nongrafted watermelon plants, the increased yield was due to grafting per se (Colla et al. 2006). Many reports suggest grafting to be an efficient way out for saline soils (Lauchli and Epstein 1970; Xiang et al. 2009; Lee et al. 2010). Different research reports revealed that the losses due to salinity in cucurbitaceae family can be avoided or negated by grafting cucurbits onto rootstocks capable of ameliorating salt-induced damage to the shoot (Estan et al. 2005; Wei et al. 2007; Zhu et al. 2008a,b; He et al. 2009; Huang et al. 2010; Yetisir and Uygur 2010; Zhen et al. 2010). Thus, the identification of compatible rootstocks with tolerance to other types of salinity is a basic requirement for the continued success of grafting (Colla et al. 2010) (Table 23.3).

TABLE 23.3
Exclusion and/or Inclusion of Na^+ and Cl^- in Grafted Vegetables under Saline Conditions

Scion Species	Rootstock Species	Ion Exclusion and/or Inclusion in the Scion	Ion Exclusion and/or Inclusion in the Rootstock	References
Cucumis sativus L.	*Cucurbita moschata*	Na^+ exclusion		Chen and Wang (2008)
Cucumis sativus L.	*Cucurbita ficifolia*	Na^+ exclusion		Chen and Wang (2008)
Cucumis sativus L.	*Cucurbita moschata*	Na^+ exclusion and Cl^- inclusion	Na^+ and Cl^- inclusion	Zhu et al. (2008a)
Cucumis sativus L.	*Lagenaria siceraria*	Na^+ and Cl^- exclusion	Similar Na^+ and Cl^-	Huang et al. (2009a,c)
Citrullus lanatus	*Lagenaria siceraria*	Na^+ exclusion	Na^+ inclusion	Zhu and Guo (2009)
Citrullus lanatus	*Cucurbita maxima* × *C. moschata*	Na^+ exclusion and Cl^- inclusion		Colla et al. (2006)
Cucumis melo L.	*Cucurbita maxima* × *C. moschata*	Na^+ and Cl^- exclusion		Romero et al. (1997)

Source: Colla, G. et al., *Sci. Hortic.*, 127, 147, 2010.

23.3.3 CHEMICAL AMENDMENTS TO AMELIORATE SOIL SALINITY STRESS

Soil amendments are the materials applied to the soil with an objective to make the soil suitable for plant growth and development. Salinity is considered as an undesirable chemical property of the soil, which causes poor and scattered seed germination besides difficulty in seedling establishment and burning of plant tissues. This reduces crop yield due to poor plant growth and in extreme cases, may lead to death of plants. The most effective way to handle this problem is to change the old soil by replacing it with soil containing desirable characteristics. This is practically not feasible. However, the chemical properties of saline soils can be improved with desirable characteristics to some extent by the addition of organic matter and different chemical amendments. In addition, leaching or removal of soluble salts can also reduce salinity in soils. Some of the proposed practices, viz., application of chemical amendments or leaching salts to deeper soil layers, seed priming, etc., have been advocated. All chemical amendments are not suitable for all soil conditions, for example, gypsum is suitable in saline soil having a pH range up to 9, while limestone is suitable in saline soil with a pH less than 8.

Saline soils can be ameliorated by replacing excess sodium (Na^+) from the cation exchange sites, by providing calcium (Ca^{2+}) as a source. However, worldwide, the cost of chemical amendments has, in general, increased because of the reduction in subsidies for their purchase. The reclamation of saline soils can be done by using different methods such as physical amelioration (deep ploughing, subsoiling, sanding, profile inversion), chemical amelioration (use of gypsum, calcium chloride, limestone, sulfur, and iron sulfate), and electroreclamation through treatment with electric current (Mahdy 2011). The most effective methods are based on the removal of soluble sodium and changing the ionic composition of soils through applied chemicals and simultaneous leaching of sodium salts from the soil profile (Chhabra 1994). The use of organic matter improves the soil structure and permeability. This enhances leaching of salt, reduces surface evaporation, and inhibits salt accumulation in the surface layers. In addition, it also increases water infiltration, water-holding capacity, and aggregate stability and reduces EC (Qadir et al. 2001). The organic matter of high cation exchange capacity (CEC) can adsorb some soluble salts, decrease pH, and promote aggregation. The decrease in pH below 8 can lead to charging of clay minerals and electrostatic adsorption of the organic compounds.

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23.3.3.1 Calcium

Application of Ca^{2+} has been shown to ameliorate the adverse effects of salinity in a variety of plant species (Caines and Shannon 1999; Shabala et al. 2003; Arshi et al. 2005; Renault 2005). Calcium (Ca) plays an essential role in processes that preserve the structural and functional integrity of plant membranes, stabilize cell wall structure, regulate ion transport and selectivity, and control ion-exchange behavior as well as enzyme activities (Esringu et al. 2011). It has been hypothesized that a high concentration of Ca can protect the cell membrane from the adverse effects of salinity (Kaya et al. 2002). Maintaining an adequate supply of calcium in saline soil solutions is an important factor in controlling the severity of specific ion toxicities, particularly in crops that are susceptible to sodium and chloride injury (Grattan and Grieve 1999).

Cerda and Martinez (1988) reported calcium deficiency in addition to sodium toxicity under saline conditions in cucumber. Application of Ca ameliorates the adverse effect of salinity in plants by facilitating greater potassium (K) in Na selectivity (Hasegawa et al. 2000). Dabuxilatu and Ikeda (2005) reported that an increase in Ca concentration had an ameliorative effect on cucumber plants where the growth was inhibited due to salinity. The cation imbalance due to increased Na^+ concentration and decreased K^+ and Mg^{2+} concentrations might be responsible for growth inhibition in cucumber plants. They were of the view that the beneficial effect of a high Ca concentration in a saline environment would be due to the maintenance of K/Na selectivity and adequate Ca status in roots.

Lei et al. (2014) found that supplementary $Ca(NO_3)_2$ at 10 mM ameliorated the negative effects of NaCl on plant dry mass, relative growth rate, as well as Ca^{2+}, K^+, and Na^+ content, especially for pumpkin rootstock-grafted cucumber plants. The addition of Ca^{2+} in combination with pumpkin rootstock grafting is a powerful way to increase cucumber salt tolerance as supplementary $Ca(NO_3)_2$ distinctly stimulated the plasma membrane H^+-ATPase gene (PMA) expression as well as higher plasma membrane Na^+/H^+ antiporter encoding gene (SOS_1) expressions than the self-grafted plants under NaCl + Ca treatment. Ca and N supplemented into the soil in the form of $Ca(NO_3)_2$ can significantly improve plant growth, fruit yield, and membrane permeability affected by high salinity along with correcting both Ca and N deficiencies. Calcium nitrate applied at 1 g/kg to the soil offers an economical and simple solution to crop production problems caused by high salinity in the soils of arid and semiarid regions of the world (Kaya and Higgs 2002).

23.3.3.2 Silica

Silica (Si) is beneficial for the growth of many plants under various abiotic (e.g., salt, drought, and so on.) and biotic (diseases and insect-pests) stresses (Ali et al. 2012). There are different mechanisms by which Si mediates salinity tolerance in plants (Liang et al. 2005) including increased plant water status (Chinnusamy et al. 2005), salt stress due to ion toxicity (Romero-Aranda et al. 2006), enhanced photosynthetic activity and maintenance of ultra structure of leaf organelles (Shu and Liu 2001), stimulation of scavenging system of reactive oxygen species (Zhu et al. 2004), immobilization of toxic Na ion (Liang et al. 2003), reduced Na uptake in plants and enhanced K uptake (Liang et al. 2005), and higher K:Na selectivity (Hasegawa et al. 2000). Its application helps to improve the defensive system of the plants by producing antioxidants, which in turn detoxify reactive oxygen species. Morphological and physiological improvement in plants was observed due to Si deposition within the plant body under salt stress conditions. Silicon improves growth and dry matter production under salt stress conditions. Silicate has increased resistance against salinity in cucumber (Amirossadat et al. 2012). Si may be involved in the metabolic or physiological changes in plants, and its addition may protect the plant tissues from membrane oxidative damage under salt stress, thus mitigating salt toxicity and improving the growth of cucumber plants (Zhu et al. 2004). It is, therefore, suggested that supplemental application of Si must be included in salt stress alleviation management techniques.

23.3.3.3 Other Nutrients

Salt stress also has significant effects on nitrogen (N) nutrition in plants. Salinity reduces the uptake of NO_3 in many plant species, mostly due to the high Cl content of saline soil (Esringu et al. 2011). The effectiveness of N application under salinity stress conditions has been observed in cucumber (Cerda and Martinez 1988) and melon (Feigin et al. 1987). The form in which N is supplied to salt-stressed plants can influence salinity-N relations as well as affect the relation of salinity with other nutrients (Martinez and Cerda 1989). Melon plants supplemented with ammonia were more sensitive to salinity than nitrate-fed plants when grown in solution cultures (Feigin 1990). In addition, Martinez and Cerda (1989) found that Cl^- uptake was reduced in cucumber when only nitrate was added to the solution but when half the nitrate in the solution was replaced by ammonia, Cl accumulation was enhanced. They further observed that accumulation of K in the plant increased with nitrate as the only N-source, whereas there was reduction in K when both nitrate and ammonia were used. Similar effects were found in salt-stressed melon (Feigin 1990; Adler and Wilcox 1995). The relationship between salinity and N is complex. The majority of studies indicate reduction of N accumulation in the shoot. In contrast, increased accumulation or no effect of N has also been reported. There is no supporting evidence in favor of reports stating growth limiting effects of reduced N accumulation under saline conditions (Grattan and Grieve 1999).

The effects of phosphorus (P) have been found to be very complex and are known to vary with growing conditions of the plant, plant type, and even cultivar (Grattan and Grieve 1994). Salinity decreases the concentration of P in the plant tissue (Sharpley et al. 1992), but differences among studies may be ascribed to variation in P concentration in different experiments and also due to the occurrence of interactions among other nutrients simultaneously. The reduction in availability of phosphate in saline soils may be attributed to ionic strength effects decreasing phosphate activity and sorption processes controlling phosphate concentrations in soil solution and due to low-solubility of Ca–P minerals. Therefore, phosphate concentrations decreased with increase in salinity ($NaCl + CaCl_2$).

Potassium (K) is also a major plant macronutrient that plays an important role in stomatal behavior, osmoregulation, enzyme activity, cell expansion, neutralization of nondiffusible negatively charged ions, and membrane polarization (Elamalai et al. 2002). Metabolic toxicity of Na is largely due to its ability to compete with K for binding sites essential for cellular function (Bhandal and Malik 1988). High NaCl has shown to induce K deficiency in melon. The supplementation with KNO_3 and proline significantly ameliorated the adverse effects of salinity on plant growth, fruit yield, and other physiological parameters by maintaining membrane permeability and increasing concentrations of Ca^{2+}, N, and K^+ in the leaves of plants subjected to salt stress (Kaya et al. 2007). Foliar application of KNO_3 at 250 ppm induced increased fruit formation and fruit weight in bottle gourd grown under saline conditions (Ahmad and Jabeen 2005). Similarly, Al-Hamzawi (2010) observed the efficacy of foliar application of KNO_3 at 15 mM in enhancing total yield along with different growth and yield parameters and simultaneous increase in storage life.

Similarly, magnesium (Mg) is an important component of chlorophyll and plays a vital role in photosynthesis; in addition, it assists in phosphate metabolism, plant respiration, protein synthesis, and activation of several enzyme systems in the plant (Marschner 1995). Ibekwe et al. (2010) reported that the effects of salinity, boron, and pH were more severe on the rhizosphere bacterial population during the first week of growing cucumber and further salinity impact decreases with plant growth. Thus, early detection of stress may provide some remedial action to improve soil quality and crop performance.

23.3.3.4 Proline in Alleviating Salt Stress

Salinity stress decreases amino acids in plants, viz., cysteine, arginine, and methionine, whereas proline concentration rises in response to salinity stress. Proline accumulation is a well-known measure adopted for the alleviation of salinity stress. Intracellular proline, which is accumulated

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during salinity stress, not only provides tolerance toward stress but also serves as an organic nitrogen reserve during stress recovery. Huang et al. (2009a) reported that foliar application of proline on the salt-sensitive cucumber cultivar 'Jinchun No. 2' significantly alleviated the growth inhibition of plants induced by NaCl, which could be partially attributed to higher leaf relative water content and POD activity, higher proline and Cl^- contents, and lower malondialdehyde content. Similar effects of proline on alleviation of salinity-induced damage were reported by Yan et al. (2012) in melon cultivars, namely 'Yuhuang' and 'Xuemei'.

23.3.4 SEED PRIMING

Priming is one of the physiological methods that improves seed performance and provides faster and synchronized germination (Sivritepe et al. 2003). Salinity has an adverse effect on seed germination of several vegetable crops by creating an osmotic potential outside the seed inhibiting the absorption of water or by the toxic effect of Na^+ and Cl^- (Khajeh-Hosseini et al. 2003). Osmotic and saline stresses are responsible for the inhibition and delay of germination and plant growth (Almansouri et al. 2001). Water uptake during the imbibition phase decreases and salinity induces an excessive absorption of toxic ions in the seed (Murillo-Amador et al. 2002). Priming of seeds with water (Casenave and Toseli 2007), inorganic salts (Patade et al. 2009), osmolytes, and hormones (Iqbal and Asraf 2007) has been demonstrated as a successful cost-effective strategy for improving seed vigor and seedling growth under saline conditions (Foti et al. 2008). Priming improves germination, emergence, and establishment of several seed species (Singh 1995; Basra et al. 2005). NaCl priming could be used as an adaptation method to improve salt tolerance of seeds. Higher salt tolerance of plants from primed seeds seems to be the result of a higher capacity for osmotic adjustments since plants from primed seeds have more Na and Cl in roots and more sugar and organic acids in leaves in comparison to nonprimed seeds (Cayuela et al. 1996). Passam and Kakourioitis (1994) found that seed priming enhances germination, emergence, and growth under saline conditions in the cucumber, but benefits of NaCl priming did not persist beyond the seedling stage. On the other hand, Franco et al. (1993) observed that melon is salt tolerant between the fruit development and harvest stage, but it is sensitive during germination and seedling growth stage. Priming of melon seeds with NaCl resulted in increased salt tolerance in seedlings of melon cultivars 'Kirkagac' and 'Hasanbey' (Sivritepe et al. 1999). In other studies, priming with NaCl increased salt tolerance of seedlings by promoting K and Ca accumulation besides inducing osmoregulation by the accumulation of organic solutes, enhancing yields and quality of melon seeds (Sivritepe et al. 2003) and cucumber (Esmaielpour et al. 2006). Joshi et al. (2013) reported the beneficial effects of presoaking (priming) treatment with 2 mM $CaCl_2$ solution for 24 h under saline conditions on germination and seedling growth of cucumber, which could be ascribed to its role in activation of antioxidant system and accumulation of proline. Balouchi (2014) observed that osmopriming by PEG (−5 bar) and hydropriming on *C. pepo* was good for germination and seedling growth under saline conditions. Primed seeds should be sown immediately after priming since they lose their storage life instantly (Basra et al. 2003).

23.3.5 ADDITIONAL PRACTICES FOR AMELIORATION OF SALINE SOILS

It is essential to consider the following points before reclamation of saline soils:

1. Good quality irrigation water with low salt content. It is important to determine total soluble salt, sodium adsorption ratio (SAR), and sometimes boron also.
2. Degree of salinity.
3. Nature and distribution of salts in the root zone.
4. Level of subsoil water (water table).

As mentioned earlier, a majority of crop plants are susceptible to salt injury during germination or in the early seedling stages. Any management practice that helps in reducing salt concentration during these stages would benefit the crop by promoting plant growth and development. Salts in the root zone are dynamic and often vary with climate. In case of well-drained soils, rains tend to push salts below the root zone, while dry periods bring salts near the soil surface. In contrast, the water table rises close to the surface during the rainy period in poorly drained soils and as a result salts move upward with the water, causing high salinity than during the dry period. Hence, the selection of crops for planting according to their salt tolerance can be done according to climate cycles and soil drainage classification. This indicates that planning for cultivation of annual crops like a majority of cucurbits is easier than for perennials. The following technical requirements are necessary for the reclamation of saline soils.

23.3.5.1 Adequate Drainage

Salt problems often occur in soils with poor internal drainage. Low-permeability soil layers may restrict the flow of water from deeper layers much slower than evapotranspiration (ET) from the soil surface. In such situations, select those crops like bitter gourd and ash gourd that can tolerate salinity without much reduction in yield. Artificial drains can also be provided to allow the removal of leaching water and salts from soils.

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23.3.5.2 Quality of Water and Irrigation Frequency

Irrigation management can be used to decrease the level of salts in the root zone of the crop. The management of saline soil becomes difficult if the irrigation water contains high salt concentration and the situation becomes worse if the seasonal rainfall is less. Permeability of the subsurface soils is important for salt management. Leaching of sufficient salts down (beyond the root zone) has an indirect correlation with evapotranspiration (bringing water and salts back toward the surface). So, it is essential to apply quality irrigation water; free/low in salt contents (1500–2000 ppm total salts), particularly sodium, by leaching of salts below the root zone to ensure optimal soil conditions for better plant growth. Leaching works well on saline soils that have good structure and internal drainage. Frequent irrigations leach salts more efficiently from the soil profile by diluting salt accumulation in the root zone and thereby reducing salinity to a certain extent. The salts cannot be dissolved and leached out of the soil if water infiltration does not take place in the soil.

Preplant irrigation helps in flushing out/leaching the salts concentrated on the surface of saline soils. Cucurbits are more susceptible to salt injury during germination or in the early seedling stages. An early-season application of good quality water at frequent intervals may provide good conditions for the crop to grow through its most injury-prone stages.

23.3.5.3 Appropriate Planting Method

The salinity impact may be reduced if the planting of seeds/seedlings is done at appropriate positions on the ridges. Depending upon the irrigation system, the furrows, ridges, and planting of seed/seedlings can be planned. In general, planting should be done on the shoulder of the ridge rather than on the top or center, while irrigation is applied through furrows on both sides of the ridge because evaporation will cause accumulation of more salts at the ridge top or center. On the other hand, if irrigation is applied in alternate furrows, then plant only on one shoulder of the ridge, closer to the irrigated furrow.

23.3.5.4 Mulching

Mulching with crop residues helps in reducing evaporation from the soil surface. This, in turn, reduces the upward movement of salts and lessens the accumulation of salts. Inorganic mulches integrated with the drip irrigation system effectively reduce salt concentration. Subsurface drip irrigation pushes salts to the edge of the soil wetting front, reducing harmful effects on seedlings and plant roots.

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23.3.5.5 Deep Tillage

In saline soils, accumulation of salts is close to the surface. Deep tillage would mix the salts present in the surface zone and would reduce the concentration of the salts near the surface. In the impervious hard pan soils, salt leaching process does not occur. Chiseling would be effective to improve water infiltration and downward movement of salts.

23.3.5.6 Bioamelioration of Saline Soils

The beneficial effects of arbuscular mycorrhizal fungi (AMF) to promote plant growth and salinity tolerance have been reported by many research workers. They promote salinity tolerance by employing various mechanisms by enhancing and improving nutrient acquisition (Al-Karaki and Al-Raddad 1997), plant growth hormones, rhizospheric and soil conditions (Lindermann 1994), physiological and biochemical properties of the host (Smith and Read 1997), and defending roots against soil-borne pathogens (Dehne 1982). In addition, AMF can improve water absorption capacity of plants by increasing root hydraulic conductivity and favorably adjusting the osmotic balance and composition of carbohydrates, which may lead to an increase in plant growth and subsequent dilution of toxic ion effect (Evelin et al. 2009). These benefits of AMF may provide an opportunity for bioamelioration of saline soils. In addition, potential salt-tolerant bacteria isolated from the soil or plant tissues help to alleviate salt stress by promoting seedling growth and increase biomass of crop plants grown under salinity stress (Chakraborty et al. 2011).

23.4 CONCLUSIONS

Salinity would be a major threat to the agriculture sector in the near future. A lot of research work has been done on cucurbits with respect to salinity management. There is a need to concentrate more on the development of salinity-resistant/salinity-tolerant cultivars for sustainable production. In addition to tolerant cultivars, several economic, cultural practices need to be standardized with the aim that each contributes to a certain extent to allow plants to better withstand the deleterious effects of salt. The most practical approach would be to integrate traditional breeding approaches with genetic manipulation and soil amelioration practices to cope with the increasing soil salinity constraints.

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