Effect of Salinity and Sodicity on Vegetable production and Remedial Measures: A Review

Abstract

Salinity is derived from the Latin word *salinium* which means "salt cellar" and it means "position or quality of being". Sodicity is indicative of the amount of interchangeable Na to Ca and Mg in soil. A high sodicity suppresses plant growth due to Na toxicity and nutrient imbalance in plants, as well as low availability of mineral nutrients in the soil. Salt stress is responsible for the decrease in plant growth and development and leads to changes in yield and quality in various plant species. Plants give a complex response to salinity and changes in morphology, physiology and metabolism of plants are observed. Effect of salinity on various vegetable crops *viz.* beetroot, cabbage, capsicum, kabuli chana, coriander, fenugreek, lettuce, onion, tomato, potato was reviewed. Salinity was adversely affected as a result of salinity: Seed germination, survival percentage, morphological characteristics, growth and yield, its components, dry and fresh weight were affected. Photosynthesis and respiratory rates of plants were reduced. Salinity reduced total carbohydrate, fatty acid, and protein content but notably increased amino acid levels. Asparagus and tomato growth were more suppressed in sodic soils than saline soils, indicating that asparagus and tomato are sensitive to sodicity. The bean also died in sodic soils, indicating that bean was very sensitive to sodicity. The adverse effects of alkaline water with the addition of gypsum and FYM showed a significant increase in crop growth and yield parameters.

Keyword: Saltnity, Sodicity, Vegetable crops, Salinity and sodicity management

1. Introduction

Salinity is the dissolved salt content of a body of water. It can also refer to the salt content of the soil. Saline soil is defined as a high concentration of soluble salts, sufficient to affect plant growth. Salinity occurs through natural or human-induced processes that result in the accumulation of dissolved salts in soil water to an extent that inhibits plant growth. Sodicity is a secondary consequence of salinity in clay soils, where leaching through natural or human-induced processes washes soluble salts into sub-soil, and binds sodium to the negative charges of the soil. The salinity in a given land area depends on various factors such as the amount of evaporation that increases the salt concentration and the amount of precipitation that decreases the salt. Irregular irrigation, inadequate drainage, incorrect fertilizer application can result in salinity and it is especially high in protected farming. The problem of salinity arises due to the accumulation of soluble salts in the root zone. These excess salts reduce plant growth and vigour by altering water uptake and causing ion-specific toxicity or imbalances. Installing good drainage is usually the cure for these problems, but salinity problems are often more complex. To increase the productivity of salt affected soils, proper management practices along with periodic soil testing are required. Salinity is derived from the Latin word *salinium* which means "salt cellar" and it means "position or quality of being". Saltiness alludes to the presence of solvent salts in soil or water. The plant's salt tolerance or resistance is usually the inherent capacity of the plant, to counteract the effects of high salts in the root zone or on the leaves of the plant without a significant adverse effect (West, 1978). Soil salinization is a large factor contributing to the defeat of productivity of cultivated soils. Although difficult to estimate accurately, the area of salinized soils is increasing and this phenomenon is particularly acute in irrigated soils. It was estimated 20% (45 million ha) of irrigated land, producing one-third of the world's food, is salt-affected (Shrivastava and Kumar, 2015). This rate is accelerated by climate change, excessive use of ground water, increasing use of low-quality water in irrigation and large-scale introduction of irrigation associated with intensive farming and poor drainage. On the other hand, the tendency to increase the efficiency of irrigation water use, as verified in many areas due to water scarcity and the use of low-quality water can lead to the accumulation of salts in the soil, as the leaching fraction is reduced and the salts contained in the irrigation water are not sufficiently leached. It is estimated that by 2050, 50% of the world's arable land will be affected by salinity (Bartels and Sunkar, 2005). Amassing of overabundance salt in the root zone brings about the incomplete/complete loss of soil profitability around the world. The problem of soil salinity is most widespread in arid and semi-arid regions, but salt-affected soils also occur extensively in sub-humid and humid climates, especially in coastal areas through estuaries and rivers and sea water enters through groundwater, causing massive salinization. Soil salinity is also a serious problem in areas where high salt content groundwater is used for irrigation. This is a major challenge for crop plants which limits agriculture worldwide, especially on irrigated fields (Rausch *et al*., 1996). Exorbitant soil saltiness diminishes the profitability of numerous horticultural harvests, including vegetables which are especially delicate to the ontogeny of the plant. Plant sensitivity to salt stress is reflected in loss of turgor, growth reduction, wilting, leaf curling and epinasty, leaf abscission, decreased photosynthesis, respiratory changes, loss of cellular integrity, tissue necrosis, and potentially death of the plant (Jones, 1986; Cheesemann, 1988). Saline soil is usually defined as one in which the electrical conductivity (EC) of the extract saturation (ECE) in the root zone exceeds 4 dS m^{-}1 (about 40 mM NaCl) at 25 dC and contains 15% interchangeable sodium. In this ECE, the yield of most crop plants is reduced, although many crops show a decrease in yield at low ECs (Munns, 2005; Jamil *et al*., 2011). Soil salinization causes soil erosion on a global scale and reduces crop productivity (Acosta *et al.*,2011). Salt stress is one of the most cruel environmental factors limiting the productivity of vegetable crops because most vegetable crops are glycophytes in nature. Tolerance of salt in vegetables is important due to their cash value. One-third of the land irrigated worldwide is affected by salinity (Allen *et al*., 1994). Various environmental stresses *viz*. high winds, extreme temperatures, soil salinity, drought and flood have affected the production and cultivation of agricultural crops, this soil salinity is one of the most devastating environmental stresses large in cultivable land area, crop productivity and quality causes deficiency (Yamaguchi and Blumwald, 2005; Shahbaz and Ashraf, 2013). The urgency of feeding the world's growing population while combating soil pollution, salinization, and desertification has given significant importance to plant and soil productivity research. In such circumstances, it not only requires appropriate biotechnological tools to improve crop productivity, but also to improve soil health through the mutual relationship of plant roots and soil microorganisms (Lugtenberg *et al*., 2002). Microorganisms can play an important role in this regard if we use their unique properties such as tolerance to saline conditions, genetic diversity, synthesis of compatible solutes, growth of plant promoting hormones, bio-control ability and their interactions with crop plants. Ensuring adequate food production is a major issue in the context of a growing human population. To reduce the area of irrigation land, salinity often has the greatest effect due to inappropriate techniques of irrigation. To expand the food supply, there is a need to create salt -tolerant crops, which can develop effectively on salt-influenced lands. Among crops, vegetables hold a central place in the human diet because their nutritional values provide vitamins, mineral, dietary fibre anti- oxidants etc. Saltiness influences each part of vegetable harvest advancement, including their morphology, physiological capacity and yield. The development of salt-tolerant farming usually requires the transfer of multiple genes due to the multi-faceted character of plant resistance or tolerance to this abiotic stress (Bohnert and Jensen, 1996). Generally, vegetables have higher economic value per unit applied crops and field crops. This can be of great benefit to small farmers, as vegetables can be grown in small areas, under intensive processes. Vegetable crops usually require more water and more frequent irrigation than other agricultural crops. Creation of vegetable harvests in parched and semi-dry areas with low precipitation and high temperatures requires a huge contribution of composts and water system. However, the increase in soil and water salinity is closely related to irrigation and fertilization practices (West, 1978). Salt focused on soils are known to smother the development of plants (Paul, 2012). Plants in their natural environment are colonized by endocellular and intracellular microorganisms (Gray and Smith, 2005). Rhizosphere microorganisms, particularly beneficial bacteria and fungi can improve plant performance under stress environments and, as a result, directly and indirectly increase yield (Dimkpa *et al*. 2009). Rhizobacteria (PGPR) that promote the growth of some plants can provide plants with a direct stimulus on growth and development, providing plants with fixed nitrogen, phyto-hormones, iron that are sequestered by the bacteria siderophores, and soluble phosphates went (Hayat *et al.,* 2010). Others protect the plant indirectly from soil-borne diseases, most of which are caused by pathogenic fungi (Lutgtenberg and Kamilova, 2009). Salt is naturally present in soil, surface water and ground water systems. The most common salt that produces salinity is sodium chloride, but it may contain other salts such as magnesium, calcium, or potassium. Soluble salts have less sodic clay but are relatively high in interchangeable sodium. Sodic soil is unsuitable for many plants due to high sodium concentrations, which can cause plant roots to deteriorate, and due to their high pH, which typically range from 8.5 to 12.0. These high sodium levels disrupt the soil's chemical and physical composition. As a result, the soil surface has low permeability to air, rain and irrigation water.. The soil is sticky when wet, but hard flakes and crusts are formed upon drying. This phenomenon cannot occur in sandy soils because they lack soil content (Devi and Arumugam, 2019). Abiotic stress means any stress for plants that suppresses their ability to grow and develop. Abiotic stress reduces crop yield by about 69%. The major abiotic stress factors are drought, extreme temperatures and high salinity of the soil (Alkahtani, 2018). Due to natural and anthropogenic reasons, about 950 million hectares of land is affected in arid and semi-arid areas (Aronson,1985). According to adaptive development, plants can be divided into two types: first, halophytes *i.e.* plants that can survive under salt stress and second, are glycophytes *i.e*. those who cannot survive under salt stress (Gupta and Huang, 2014). Halophytes respond to salinity at the cellular, tissue, and whole plant levels (Aslam *et al.*, 2011). Halophytes have the best germplasm to survive saline conditions and can thrive in conditions of extreme salt stress (Mishra and Tanna, 2017). Many regions in the world have soil that is too salty for economic crops that affect plant growth through oxidative stress and osmotic effects (Joseph *et al*, 2011). The most important problem for agricultural crops is the high salinity conditions in productive agricultural land. It is roughly calculated that about 10% of the land surface and 50% of the irrigated land are affected by saline soil. Plants give a complex response to salinity and changes in morphology, physiology and metabolism of plants are observed. Salinity causes cellular water loss, ion toxicity, nutrient deficiency and oxidative stress in plants which leads to various problems such as growth, molecular damage and plant death. There is a global annual loss in agricultural production of about $ 10 billion due to salt affected land (Xu and Mou, 2016).

Salinity is becoming a major problem day by day due to improper management of natural resources. Salinity produces water and ionic imbalances in plants due to the existence of toxic ions. The plant affected by salt stress show growth and the colour of the leaf becomes darker (Rani *et al*., 2019). Plants respond to salt stress in two distinct phases, one is an osmotic phase that impedes the growth of young leaves and the other is an ionic phase which speeds up the senescence of mature leaves (Munns *et al*., 2008). In general, it also reduces the photosynthetic and respiratory rate of plants. Salinity also affects total carbohydrate, protein content, and fatty acids but it helps to increase amino acid levels, especially helping to increase timeline levels. It has been commonly observed that plants grown under salt stress have some higher secondary plant products than crops grown under natural conditions. The interaction between salinity and the other environment determines the salinity tolerance of plants. Salinity affects plant production, especially in arid and semi-arid regions. The harmful effects of salt stress can be classified into three groups: (1) the first group where it produces water stress in plants by reducing the osmolarity of the soil solution, (2) the second group where soil aeration and permeability of water is forbidden by the degradation of the physical structure of the soil, and (3) the third group where the concentration of certain ions is increased which inhibits plant metabolism and mineral nutrient imbalance (Said-Al Ahl *et al*., 2011). High concentrations of sulphates, carbonates and bicarbonates also affect saline soils. Poor soil structure and poor aeration are also the reasons (Waisel, 2012). Salinity reduces the germination rate at low concentrations and the germination percentage at high concentrations. This effect may be due to anaerobic conditions that lead to failure of active transport and exclusion processes in the root membrane. Single salt solutions have differential effects on germination, but mixed salts respond more uniformly and are mainly related to osmotic potential. Salinity often affects development time. Flowering in onions occurs earlier under salt stress, but salinity delays flowering of tomatoes. The yield component and growth parameters also show differential responses to the salinity stress. In low salinity, root growth is often less affected, or sometimes stimulated by saline growth, as compared to shoot growth. Underground growth of turnip (Francois, 1984) and carrot (Bernstein and Ayers, 1953) was more sensitive to salinity than root growth. Asparagus spear yield was less affected by salinity than fern production (Francois, 1987) and salinity inhibited artichoke bud growth more than shoot growth (Francois, 1995). The general effect of salinity is to reduce the growth rate as a result of smaller leaves, shorter stature and sometimes fewer leaves. The initial and primary effect of salinity, especially low to moderate concentrations, is due to its osmotic effects (Jacoby, 1994). Not all salinity effects can be negative, salinity may have some favourable effects of yield, quality, and disease resistance. In spinach, for example, yields may initially increase from low to moderate saltiness (Osawa, 1963). Sugar content increase in carrot and starch content decreases in potatoes as salinity increases (Bernstein, 1959), cabbage heads are more solid at low salinity levels, but less compact when salinity increases (Osawa, 1961). Celery has been reported to be more resistant and more susceptible to blackheart (Aloni and Pressman, 1987). As the soil becomes more saline, the plants are not able to draw as much water from the soil. This is because the roots of the plant have varying concentrations of ions (salts) that create a natural flow of water from the soil to the roots of the plant. As the salinity level in the soil is near the roots, the water decreases and the probability of entering the root decreases. In fact, when the salinity level of the soil is high enough, the water in the roots is drawn back into the soil. Plants become unable to take enough water to grow. Each plant species naturally differs in levels of root salts. This is why some plants may continue to thrive when they have died. If the concentration of salts in the soil is high enough, the plant will wilt and die, regardless of the amount of water (Devi and Arumugam, 2019). The majority of vegetable crops present low tolerance to continuously planted saltwater. The classes of salt tolerance are sensitive, moderately sensitive, moderately tolerant, tolerant and unsuitable for crops. Most vegetable crops are sensitive or moderately sensitive (Maas, 1990; Hanson *et. al*, 2006). Asparagus has been considered the most salt tolerant vegetable crop**.**

Soil salinity problem

Soil salinity is a huge problem for agriculture under irrigation. Soils with low agricultural potential in hot and dry regions of the world are often saline. Most of the crops in these areas are grown under irrigation, and to exacerbate the problem, inadequate irrigation management leads to secondary salinization that affects 20% of irrigated land worldwide (Glick et al., 2007). Irrigated agriculture is a major human activity, often leading to secondary salinization of land and water resources in arid and semi-arid conditions. The salts in soil are in the form of ions (electrically charged forms of atoms or compounds). Ions are released from weathering minerals in the soil. They can also be applied through irrigation water or as fertilizers, or sometimes migrate upstream from shallow groundwater into the soil. When rainfall is insufficient to leach ions from the soil profile, soil salts accumulate resulting in soil salinity (Blaylock et al., 1994). All soils contain some water-soluble salts. Plants absorb essential nutrients in the form of soluble salts, but excessive accumulation suppresses plant growth. During the past century, physical, chemical, and/or biological land degradation processes have resulted in serious consequences for global natural resources (such as compaction, inorganic/organic contamination, and low microbial activity/diversity). The area of affected soil continues to increase every year due to the introduction of irrigation in new areas (Patel et al., 2011). Salinization is recognized as one of the main threats to environmental resources and human health in many countries, affecting approximately 1 billion hectares worldwide/globally, about 7% of the Earth's continental range, approximately 10 times the size of a country like Venezuela or 20 times the size of France (Metternicht and Zinck, 2003; Yensen, 2008). It is estimated that about 7 million hectares of land in India is covered by saline soil (Patel et al., 2011). Most of which occurs in the Indogenetic Plain covering the arid regions of Gujarat and Rajasthan and the semi-arid regions of Gujarat, Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh are also largely affected by saline land.

2. Causes to Salinity

2.1 Primary cause

Saline soils that contain igneous rocks, volcanic rocks, sandstones, alluvial and lagoonal deposits are formed by natural geological, hydrological, and pedoliprocesses. Evapo-transpiration plays a major role in dry and semi-arid regions in the process of saline soil formation. The major causes of salinity are in coastal areas, uneven water invasions and rivers.

Table 1: Vegetable crops classified based on tolerance to soil salinity

Less tolerant	Moderately tolerant	Highly tolerant
➢ Pea ➢ Radish ➢ Snake gourd ➢ Beans ➢ Brinjal ➢ Sweet Pepper ➢ Potato ➢ Sweet Potato	➢ Tomato ➢ Chilli ➢ Watermelon ➢ Cucumber ➢ Summer squash ➢ Bottle gourd ➢ Cabbage ➢ Cauliflower ➢ Broccoli ➢ Muskmelon ➢ Onion	➢ Asparagus ➢ Beet ➢ Kale ➢ Turnip ➢ Bitter gourd ➢ Ash gourd ➢ Palak ➢ Lettuce

(Devi and Arumugam, 2019)

Table 2: Salt-Affected Soils

Type	**EC(Ds/m)**	**pH**	**SAR**	**ESP**
Saline	>4	<8.5	<13	<15
Sodic	<4	>8.5	>13	>15
Saline-Sodic	>4	<8.5	>13	>15

(Sharma, 2016)

2.2 Secondary Cause

This includes soils that have been affected by humans. Humans refers to improper method of irrigation or water quality used to irrigate crops, it is poor, leading to soil salinity. Water logging due to improper irrigation leads to anthropogenic in arid and semi-arid areas. Second reason improper irrigation that causes salinitation of the soil include:

(1) The main cause of salinity and alkalinity is deforestation which results in the salt resettling in upper and lower levels.

(2) Industrially dispersed and wastewater of air-borne and water-borne salts respectively.

(3) Chemical contamination also leads to salinization which is much more seen in modern agricultural systems mainly in intensive farming systems and greenhouses.

(4) Another reason is overgrazing which is generally seen in arid and semi arid regions.

(Said-Al Ahl *et al*., 2011).

Salt Stress Tolerance of Plants

According to the United Nations Environment Program, approximately 20% agricultural land and about 50% crop land the world is facing the problem of salinity. Calories and nutrients the possibilities of agricultural production are limited by salt the stress condition of the land. These restrictions are most commonly seen areas that have problems due to inadequate distribution of food basic Infrastructure. The genetic determinants of salt tolerance and yield stability are a fundamental resource of biotechnology. Substantial researches efforts have to be focused identify salt tolerance and the effects of components which regulates commands during stress episodes. Additional resource information which shows perception of how plants become aware about the salt stress, how they defend the stress, and acquires the steady growth in the saline land. Hyperosmotic stress and ion imbalance cause high salinity which shows secondary effect. Basically, plant tolerate or stay away from salt stress which means they are in during salt stress or the resting phase of the cells will be adjust to saline conditions. Tolerance are classified into those that are used to reduce osmotic stress or Prevent ion imbalance or the resulting auxiliary effects these stresses. First, a water potential imbalance is caused by chemical potential of saline solution between apoplast and symplast which causes turgor is reduced causes a decrease in growth (Yokoi, *et al*., 2002). Plant survival under adverse conditions depends on the integration of stress adaptive metabolism and structural changes (Golldack *et al*.,2014).

Effects of salinity on vegetable crops

Salinity symptoms (salt stress) can look like water stress and nutrient deficiencies because salinity causes both. Usually, leaf margins yellow and die off because salts accumulate there due to transpiration. This makes the symptoms look similar to potassium deficiency. Plants are smaller and may die off early. Seedlings struggle to establish. The best way to confirm salt stress is via testing the soil, water and plant sap (NSW DPI, 2016).

Sodic soils

Sodicity is indicative of the amount of interchangeable Na to Ca and Mg in soil and a high sodicity suppresses plant growth due to Na toxicity and nutrient imbalance in plants, as well as low availability of mineral nutrients in the soil (Liluchli and Epstein 1996). Sodic soils are formed by negatively charged sites on soil particles for adsorption of sodium ions, usually clay solutions, salts liberated from soil solutions (Rengasamy, 2006). Sodic soils are the most widespread problem in the irrigated arid and semi-arid regions of the world. Together with this, presence of interchangeable sodium, soluble sodium carbonates and bicarbonates in irrigation water has a deleterious effect for raising salinity/ alkalinity in cultivated areas of these areas (Pal *et al.*, 2003). The degree of adverse effects depends on the type and amount of salts, soil texture, crop type, diversity, stage of development, cultural practices, and environmental factors (temperature, relative humidity, and rainfall) (Chhabra, 2004, Abrol and Bhumla, 1979). There are eleven states of the country seriously affected by sodicity. Among these, the largest area in Uttar Pradesh (1.35 M ha) is under sodic soil constituting about 36% of the total area. After Uttar Pradesh, Gujarat (14.36%), Maharashtra (11.21%), Tamil Nadu (9.41%), Haryana (4.86%) and Punjab (4.02%) have high sodicity problem and together represent about 80% of the total sodic lands in India. Asparagus and tomato growth were both more suppressed in sodic soils than saline soils, indicating that asparagus and tomato are sensitive to sodicity. The bean also died in sodic soils, indicating that bean was very sensitive to sodicity (Jumberi *et. al*, 2002).

Effects of sodicity

Soil sodicity can lead to:

- Reduced water flow through the soil - which limits leaching and can accumulate salt over time and cause salt water development.
- Dispersion in the soil surface, leading to crusting and sealing, which then prevents water infiltration.
- Spreading in the subsoil, accelerating corrosion, which can lead to the presence of lanes and tunnels
- It destroys aggregation in the form of dense, dense and structure-free soil.

Indicators of sodicity

Soil sodicity can be anticipated outwardly in the field in the accompanying ways

- Poorer vegetative development than ordinary, with a couple of plants enduring, or with many hindered plants or trees
- Variable statures of the plants
- Poor entrance of downpour water – surface ponding
- Raindrop sprinkle activity – surface fixing and crusting (hard setting)
- Cloudy or turbid water in puddles
- Plants show a shallow establishing profundity
- Soil is regularly dark in shading because of the development of a Na-humic substances intricate
- High power needed for culturing (particularly in fine finished soils)
- Difficult to get soil immersion extricates in research facility because of a channel blockage with scattered mud (Shahid *et. al*, 2018).

Effect of Alkalinity on Vegetables

Like salinity, wide genetic diversity exists between crops and them varieties in relation to their tolerance to alkalinity. Crop yields are generally not significantly reduced until the salt concentration and ESP in the soil solution exceed the specific values for each crop. Salt and no tolerance of winter crops are generally higher than those grown during the hot season. It is therefore suggested that (<400 mm) vegetable crops can be grown during the winter season (low ET) in areas with low rainfall, which fall under the arable crop during summer. The efficient strategy should choose crops that require less water for *rabi* and rainfed crops for *kharif* (Phogat et. al, 2010).

Table 3: Tolerance of vegetables to alkalinity

Sensitive Crops (ESP<20)	**Semi-tolerant (ESP 20-40)**	**Tolerant Crops (ESP > 40)**
Pea, cowpea, ginger, turmeric and cluster bean	Tomato, garlic, okra, radish, carrot, cauliflower, chilli, onion, potatoes, ash gourd, coriander, fenugreek and fennel	Brinjal, spinach and sugar beet

(Phogat *et. al*, 2010).

Table 4: Crop varieties tolerant to alkalinity

Crops	Varieties
Tomato	Angurlata, Azad T2
Spinach	K Hari Chikari
Garlic	Gattar gola, Hansa
Chillies	Jawala, Chaman

(Phogat *et. al*, 2010).

Table 5: Potential yield reduction from saline soils for selected crops

	Relative yield decrease (%)			
	100	**90**	**75**	**50**
Vegetables	**(EC_e ds/m)**			
Beans	1.0	1.5	2.3	3.6
Broccoli	2.8	4.9	5.5	8.2
Cucumber	2.5	3.3	4.4	6.3
Cantaloupe	2.2	3.6	5.7	9.1
Spinach	2.0	3.3	5.3	8.6
Tomato	2.5	3.5	5.0	7.6
Celery	1.8	3.4	5.8	9.9
Pepper	1.5	2.2	3.3	5.1
Radish	1.2	1.5	2.3	3.6
Cabbage	1.8	2.8	4.4	7.0

Potato	1.7	2.5	3.8	5.9
Lettuce	1.3	2.1	3.2	5.1
Onion	1.2	1.8	2.8	4.3
Carrot	1.0	1.7	2.8	4.6

(**Mass and Hoffman,1977 & Mass, 1984)**

Table 6. Soil salinity (dS/m) at which initial yield decline begins and percent yield increase in salinity

Name of the crop	**Soil salinity at which initial yield decline begins**	**Percent yield decline with per unit increase in salinity**
Bean	.0	19.0
Broad bean	.6	9.6
Broccoli	2.8	9.2
Cabbage	.8	6.2
Carrot	.0	14.0
Celery	.8	6.2
Cucumber	2.5	13.0
Lettuce	1.3	13.0
Onion	1.2	16.0
Pepper	1.5	14.0
Potato	1.7	12.0
Radish	1.2	13.0
Spinach	2.0	7.6
Sweet corn	1.7	12.0
Squash	3.2	16.0
Tomato	2.5	9.9
Turnip	0.9	9.0

Source: Technical Bulletin-1, Hisar Agricultural University (SRDI,2013)

Table 7. Salt tolerance induction in some vegetable crops

Name of the crop	Name of the chemical/growth substance	Concentration	Method of treatment	Time for treatment (Hours)
Cauliflower	Cycocel	250ppm	Root	2.0

			dipping for transplants	
Okra	Cycocel	5OOppm	Seed soaking	6.0
Onion	Cycocel	1.0%	Root dipping for transplants	8.0
Potato	Sodium salt solution or Cycocel	6.0 dS/m EC or 250ppm	Tuber soaking	2.0
Tomato	Sodium salt solution	8.0 dS/m EC	Root dipping for transplants	2.0

Source: Technical Bulletin-1, Hisar Agricultural University. (SRDI, 2013)

Effects on Vegetable Growth and Nutrition

Salts affect plant growth due to increasing osmotic pressure of the soil and interference with plant nutrition. A high salt concentration in the soil solution reduces the ability of plants to receive water, known as osmotic or water-deficit effects of salinity. Losses occur when concentrations begin high enough to reduce crop growth. The osmotic effect of salinity induces metabolic changes in the plant that are caused by water-induced stress shows wilting (Munns et. al, 2002) and some genotype differences (Lauchli and Grattan, 2007). In addition, salt stress reduces plant growth due to specific-ion toxicity and nutritional imbalance (Lauchli and Epstein, 1990) or a combination of these factors (Munnas and Tester, 2008). Indeed, the salinity effect on plant growth reduction is a time dependent process, and (Munns *et al*. 1995) proposed a two-stage model to characterize the salinity response of plant growth. The first phase is very rapid and the reduction in development is for the development of water scarcity. In the second phase, poisoning occurs due to the accumulation of salts in the shoot and is very slow. Despite the fact that this model has been featured in broccoli (Lopez *et. al*., 2006) the relative importance of the two mechanisms on yield reduction is difficult to assess with confidence because they overlap. Salinity affects photosynthesis due to reduced availability of CO_2 as a result of diffusion limits (Flexas *et. al*., 2007) and lack of content of photosynthetic pigment (Delfine *et. al*., 1999, Ashraf & Harris, 2013). The accumulation of salt in spinach prevents photosynthesis (Di martino *et. al*., 1999), mainly by reducing the stomatal and mesophyll conduction of CO_2 (Delfine *et. al*., 1998) and reducing chlorophyll content, which may affect light absorption (Delfine *et. al.*, 1999 and Alvino *et. al*., 2000). In radish, about 80% of the decrease in growth at high salinity can be attributed to a decrease in leaf area expansion and therefore to a decrease in light blocking. The remaining 20% effect of salinity on growth was most likely due to decreased abdominal conductance (Marcelis and Van., 1999). Salinity reduces the total photosynthetic capacity of the plant, reducing leaf growth and inhibiting photosynthesis, limiting its ability to grow (Yeo, 2007). Salt collection in the root zone causes the advancement of osmotic pressure and upsets cell ion homeostasis by instigating both the hindrance in take-up of fundamental components like K+, Ca$_2$+,and NO3- and the accumulation of Na+ and Cl- (Paranychianakis and Chartzoulakis, 2005). Specific ion toxicity occurs in tissues transporting leaves to transient levels due to the accumulation of sodium, chloride, and / or boron. The accumulation of harmful ions can inhibit photosynthesis and protein synthesis, inactivate enzymes, and damage chloroplasts and other organisms (Taiz and Zeiger, 2002). These effects are more significant in older leaves, as they are the longest transpiring, so they accumulate more ions (Munnas *et. al.*, 2002). Plant deficiencies of many nutrients and nutritional imbalances may be due to high concentrations of Na + and Cl- in soil solutions derived from ion competition (i.e., Na + / Ca2 +, Na + / K +, Ca2 + / Mg + +, and Cl- / NO3- in plant tissues) (Grattan and Grieve, 1992). When the Na + / Ca2 + ratio in soil water is high, calcium deficiency symptoms are common. However, low amounts of calcium uptake by tomato plants have been associated with reduced transpiration from the effects of competition with Na + (Adams and Ho, 1989). Reduction in plant biomass, leaf area, and growth has been observed in various vegetable crops under salt stress (Zribi *et. al*, 2009 and Giuffrida, 2013). Salt stress effects on root architecture/morphology are currently poorly understood (Maggio, 2011). However, root biomass has generally been reported to be less affected by higher salinity than above ground organs (Munnas and Tester, 2008). Salinity reduced root biomass has been reported in broccoli and cauliflower (Giuffrida, 2013) and root length density (RLD) in tomato (Snapp, 1991). Visible symptoms of salt injury appear progressively in plant growth. The first signs of salt stress are leaves, yellow leaves and increased growth. In the second stage the damage manifests as chlorosis of the green parts, burning of the tip of the leaf, and necrosis of the leaves, and the oldest leaves scorch (Shannon, 1998). Salt deficiency reduces marketable yields leading to reduced productivity and increases non-marketable yields of fruits, roots, tubers and leaves without commercial value. Irrigation with salt water has been shown to increase the occurrence of blight-end rot in tomatoes, chilli fruits, and brinjal, a nutritional disorder related to Ca^{2+} deficiency. However, salinity has some favourable effects, which is the quality of the edible portion of vegetable crops. In general, salt stress, with the exception of visual appearance (size, shape, and absence of defects), improves the quality of the edible portion of vegetable crops. In general, salinity increases the dry matter content of fruits, total soluble solids content (TSS) and acid content of watermelon, tomato, sweet chilli and cucumber. Salt stress increased carotenoid content and tomato antioxidant activity (De pascale *et al*., 2015). Overall, the nutritional quality (e.g., glucosinolate, polyphenol content, etc.) of edible florets of broccoli was improved under moderate saline stress (Lopez *et. al*., 2009). In romaine lettuce, the amount of carotenoids increased in salinity (Kim *et. al*., 2008). Salt pressure expanded polyphenol content and diminished nitrate particle and oxalic corrosive fixation in spinach (Shimomachi *et. al*., 2008). The effect of salinity on vegetable yield and quality was also affected by the timing of salt stress application, which may be important for improved irrigation (eg, deficit irrigation) and fertilization management strategies. In the two watermelons (Galia and Amarillo Oro), saline fruit yield did not decrease due to stresses ranging from fruiting to harvesting in the salt crop, and both increased fruit quality (TSS) and maturity index in cultivation (Botia *et. al*., 2005).

Management Practices

The key to producing vegetable crops is to control the level of salinity in the root zone which is equal to or less than the EC_t of the crop. To control salinity levels, management should include soil partitioning of saline and sodic soils, and fertilization and irrigation practices should prevent soil salinity and reduce the effects of soil salinity and / or increase the use of saline irrigation in the growth and development of vegetable crops.

Table 8: Management of salinity

Management methods	**Application in vegetables**	**Reference**
Salt leaching	Bell peppers-higher the salinity of the irrigation water the higher the leaching process	Ben *et al*., 2008
Primer and companion plants	Pepper- *Salsola soda* used as a companion plant	Colla *et al*., 2006
Soil mulching	Swiss chard-Mulching with gravel, rice straw improving crop yield	Zhang *et al*., 2008
Potassium	Potato -increased tuber yield	Elkhatib *et al*., 2004
Calcium	Tomato and Pepper-reduces blossom end rot	Rubio *et al*., 2009

	and increase fruit quality & yield.	
Nitrogen	1mM ammonium and 7mM nitrate -minimizing salinity effects on fruit yield	Ben-Oliel *et al*., 2004
Phosphorus	Radish-reduced the sensitivity to salinity up to a level of 3.5 dS m−1	De Oliveira *et al*., 2010
Sulfur	Brassica and legume crops- increased salinity stress-defense mechanisms	Rausch and Wachter. 2005
Zinc	Pepper-Zn reduced excess uptake of Na under saline conditions	Aktas *et al*., 2006
Biofertilizers	Lettuce-Phosphorine and Nitrobein increases proline and glycine contents	Hasaneen *et al*., 2009
Manures	Pepper -humic acid was dampen the deleterious effects of salt stress	Cimrin *et al*., 2010
Application of non-nutritional additives	Spinach under salinity increases the activities of SOD and CAT	Eraslan *et al*., 2008
Elevated CO2 concentrations	Tomato-increasing aerial CO2 concentration, Alleviate the negative salinity effects	Takagi *et al*., 2009
Relative humidity	Melons-cultivar grown in salt stress well at 70% than at 30% relative humidity	An *et al*., 2005
Inoculation with bacteria	Inoculation of artichoke -Bacillus subtilis alleviated the adverse effects of salinity and increased productivity	Saleh *et al*., 2005
Seed priming	Melon seeds with 18 dS m−1 NaCl solution decreases the negative effects of irrigation with saline water.	Sivritepe *et al*., 2005
Grafting to tolerant rootstocks	Combinations of melon & pumpkin rootstocks, pumpkin exclude 74% of available Na, while there is nearly no Na exclusion by melon rootstocks	Edelstein *et al*., 2011
Application of non-enzymatic antioxidants	In bean plants, found that addition of 100 mM ascorbic acid to the nutrient solution alleviates the adverse effects of salinity	Dolatabadian and Jouneghani. 2009
Application of plant	Tomato-Application of 0.5 mM Salicylic acid-	Tari *et al*., 2002

growth regulators	facilitates the accumulation of Na in the plant tissues to function as osmolytes	
Compatible solutes	Brinjal- Exogenous application of glycinebetaine (GB) leads to increased growth and yield	Abbas *et al.,* 2010
Foliar application of nutrients	Brinjal-K2HPO4 increased fruit yield	Elwan, 2010

Soil Reclamation

The problem of soil salinity and sodicity is very difficult to overcome, for this it is necessary to remove salt from the root zone (Reclamation). Reclamation of sodic soil, in addition to leaching, may require the application of modifications to increase soil permeability and reduce interchangeable sodium levels. Sodic Reclamation involves the replacement of sodium in the soil through calcium ions through increasing the amount of gypsum ($CaSO_4$). The released sodium ions are again leached deep beyond the root zone using more water and eventually run out of the field through drainage. Gypsum, when slowly mixed with water, releases calcium ions, which convert sodium ions into water moving downward from the soil. Sulfuric acid and elemental sulfur can also be used as an alternative to gypsum, as soil germs convert sulphur to sulphuric acid.

Fertilization

Crop fertilization is one of the well springs of soil salinization. To reduce this negative effect, fertilizer characteristics, method of fertilizer application, quality of irrigation water and fertilization scheduling *etc.* should be considered. Applications of excessive nutrients should be avoided, and high purity, chloride-free, low-saline fertilizers should be selected. In irrigated vegetable crops, the nutritional requirements of the crop must be supplied by nutrients in the soil, fertilization, and irrigation water. High nutrient levels (eg., nitrate-N, calcium, magnesium, sulphur, and boron) in irrigation water may be sufficient to partially or fully meet crop needs (Machado *et. al*., 2008). The response of plants to fertilizers depends on the severity of salt stress in the root zone, species, cultivar, nutrient source, and fertilizer application method. However, the use of fertilizers in brackish soil can also reduce soil salinity (Maas and Grattan, 1999). The use of bio fertilizer can reduce the effects of salinity on vegetables and reduce soil salinity. An organic fertilizer could be defined as a formulated product containing one or more microorganisms that enhance the nutrient status (and the growth and yield) of the plants by either replacing soil nutrients, by making nutrients more available to plants, and/or by increasing plant access to nutrients. Rhizobacteria that promote plant growth (PGPR), endo- and ectomycorrhizal fungi and many other useful micro-organisms improve nutrient uptake, plant growth, and plant tolerance to salt stress. Vaccination of seeds of various crop plants like tomato, black pepper, beans and lettuce with PGPR, can increase root growth and shoot growth, dry weight, yield of fruits and seeds, and tolerance to salt stress to plants. (Egamberdieva and Lugtenberg, 2014).

Irrigation

Preventing the effects of soil and water salinity by influencing irrigation method, management (irrigation determination and leaching fraction), and artificial drainage water-use efficiency (WUE) and nutrient-use efficiency, salt accumulation and distribution, and salt leaching and can do less. Where foliar damage by salts in irrigation water is a concern, irrigation methods such as surface drip irrigation (DI) and subsurface drip irrigation (SDI), furrow irrigation, and low energy precision application (LEPA) irrigation must be used. Compared to other irrigation methods, DI and SDI allow for better salinity management by increasing water-use efficiency and nutrient-use efficiency (Malash et al,2008, Hanson and Dey, 2011. Additionally, the soil inside the wet bulb, where root density is highest, is mostly leached of salt, creating an appropriate root-zone salinity (ECE < ECT). Under drip irrigation, water moves in a more or less radial pattern around the emitter and the ions eventually reflect this pattern.. Under SDI irrigation, water and ions flow in a circular manner and salts accumulate near the soil surface, which can become a significant barrier to sown vegetable crops and / or transplanted, as they are in the early juvenile development stage. Most crops are susceptible to soil salinity. This can lead to substandard levels to reduce plant population densities and consequently affect yields. With mulching, irrigation, soil-soluble salts concentrate with the wetting front, at its completion or convergence with another wetting front. When adjacent furrows are irrigated, the salts are concentrated in the middle places between the furrows. Bed sizing and planting arrangements are often used strategies to ensure that areas of salt accumulation stay away from germinating seeds and plant roots. Sprinkler irrigation and a suitable leaching fraction usually transfer salts below the core area. However, when saltwater is used with irrigation, crops are potentially subject to additional loss from salt dissipation in the leaves, and burn by spray contact with the leaves. The degree of injury depends on the weather conditions: it is the driest hot state, because evaporation concentrates salts on the leaf surface. Therefore, sprinkling irrigation with saline water should be done when the temperature is the coldest (Kirda *et. al*, 2004).

Maintenance Leaching

To ensure long-term land use with irrigated vegetable crops, maintenance leaching is necessary. The amount of water to be applied with irrigation should include a quantity of water that degrades the root zone, which is in addition to the amount required for general irrigation. This excess water is defined as the leaching fraction. Leaching is absolutely necessary to achieve long-term successful irrigation (Letey *et. al*., 2011).

Reclamation and Management of Sodic Soils

Gypsum: A wide variety of chemicals, such as soluble calcium salts (e.g., gypsum and calcium chloride), acids or acid-forming substances (e.g. sulfuric acid, iron sulfate, sulfur and pyrite) and low-solubility calcium salts (e.g. ground limestone) can. Can be used to reduce soil ESP to less than 15 However, factors such as low cost, easy availability, ease of application and better efficacy compared to other chemicals have shifted the balance in favour of gypsum (CaSO4.2H2O) making it the amendment of choice to overcome sodicity-induced anomalies in soil physical conditions. Gypsum application improves the availability of interchangeable Ca^{2+} to remove surplus Na^{+} from the soil exchange complex. Gypsum has long been used on agricultural land; Serves as an ameliorant and also as a fertilizer source of Ca and S. Gypsum as soil conditioner to reduce run-off induced soil erosion and nutrient depletion (Chen and Dick, 2011).

Gypsum-bed technology: In residual sodium carbonate water-fed areas, the use of gypsum becomes necessary to reduce sodicity risk. The gypsum can either be incorporated into the soil or dumped into the irrigation channel (in a gunny bag) so that the falling tube well water will slowly dissolve the gypsum. However, the use of gypsum dissolving beds specially made for this purpose gives far better results (Tyagi, 2003). In the gypsum-bed method, the irrigation water is passed through a brick-cement chamber containing a gypsum clod. The size of the chamber depends on the discharge of irrigation water tube wells and the rate of residual sodium carbonate. This chamber is connected to the water fall box on one side and the water channel on the other side. A mesh of iron bars covered with a wire net (2 mm x 2 mm) is placed at a height of 10 cm from the bottom of the chamber. With suitable modifications, farmers can also convert their tube wells into gypsum rooms. Sodic water flowing from the bottom dissolves the gypsum placed in the chamber and replenishes it (Sharma *et al*., 2016b). Notwithstanding the strategy for application, the reason for ascertaining the gypsum prerequisite remaining parts as before. However, the application time varies with the method adopted. In the case of soil application, the entire volume of gypsum is applied as a single basal dose. In the case of water-applied gypsum, neutralization occurs before its application and therefore, no build up occurs in the soil (Tyagi, 2003).

The application of organic materials such as heavy dressing of organic manures, regular incorporation of crop residues, rice hull, sawdust, sugar factory waste, etc. have all been found useful. Maintaining and improving soil physical properties and combating the adverse effects of high levels of interchangeable sodium. Wherever possible, if there is a risk of alkalinity in organic waters, the application of organic matter is recommended. However, the addition of organic modification alone without gypsum is not able to reduce the harmful effects of alkali water. FYM increased yields under water with potato, tomato, eggplant, broccoli, cluster bean, cauliflower, cabbage, knol-khol, bottle gourd, ridge gourd and bitter gourd with gypsum (Phogat *et. al*, 2010). The adverse effects of alkaline water with the addition of gypsum and FYM showed a significant increase in crop growth and yield parameters. They suggested that the delayed emergence of tubers under alkalinity may be due to the high alkalinity with high pH that disturbed the physicochemical environment of the rhizosphere. The toxic effects of sodium in the soil solution are also responsible to a large extent due to the low levels of potato. The formation of hard crusts on the soil surface due to precipitated carbonate and bicarbonate further delayed the emergence of germ tubers (Yadav *et al*., 2002).

Conclusion

Vegetable crop production requires high input of fertilizers and water, possibly increasing soil salinity. Fertilization and irrigation management strategies should consider vegetable development, crop salt tolerance, soil ownership and water use efficiency and impact on soil diversity. Biofertilizers have the potential to increase salt tolerance of vegetable crops and reduce soil salinity. FYM increased yields under alkali water with potato, tomato, eggplant, broccoli, cluster bean, cauliflower, cabbage, knol-khol, bottle gourd, ridge gourd and bitter gourd with gypsum. Among crops, vegetables have a central place in the human diet because of their nutritional value providing vitamins, carbohydrates, proteins and minerals. Nowadays salinity is one of the major abiotic stresses that reduce the growth and yield of plants. Salinity affects every aspect of vegetable crop development including their morphology, physiological function and yield. Where efforts have been made to improve the salt tolerance of vegetables, strategies range from developing a salt tolerant variety, generally following conventional breeding methods, so biotechnological approaches can be used as well. Salt affected area can be brought under cultivation by cultivating salt. Tolerant varieties, grafting of tolerant root stock to relieve salt stress.

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