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Review: Salinity and Sodicity and their Management in Vegetable Crops

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ABSTRACT

Salinity is a major problem affecting crop production all over the world: 20% of cultivated land in the world, and 33% of irrigated land, are salt-affected and degraded. This process can be accentuated by climate change, excessive use of groundwater (mainly if close to the sea), increasing use of low-quality water in irrigation, and massive introduction of irrigation associated with intensive farming. Excessive soil salinity reduces the productivity of many agricultural crops, including most vegetables, which are particularly sensitive throughout the ontogeny of the plant. The salinity threshold (EC_t) of the majority of vegetable crops is low (ranging from 1 to 2.5 dS m^{-1} in saturated soil extracts) and vegetable salt tolerance decreases when saline water is used for irrigation. The objective of this review is to discuss the effects of salinity on vegetable growth and how management practices (irrigation, drainage, and fertilization) can prevent soil and water salinization and mitigate the adverse effects of salinity.

Keywords Vegetable crops, Salinity , Sodicity , Ion imbalance, Threshold.

INTRODUCTION

Salinity is one of the most common forms of land degradation results from soil salinization. Almost all of the continents have saline soils. However, salinity is predominantly a problem of arid and semiarid regions of the world, where the potential for evapotranspiration exceeds rainfall and there is insufficient rain to leach away soluble salts from the root zone . In India alone, 7 million hectares of land are salt affected. Tamil Nadu, which is one of the strong rice cultivation areas in India, are prone to salinity stress. The impact of salinity on the economic exploitation of land for agriculture and forestry is very severe . salt-affected soils occupy 7% of the world land area, and salinity is also a problem that is increasing rapidly.

Soil salinization is a major factor contributing to the loss of productivity of cultivated soils. Although

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difficult to estimate accurately, the area of salinized soils is increasing, and this phenomenon is especially intense in irrigated soils. It was estimated that about 20% (45 million ha) of irrigated land, producing one-third of the world's food, is salt-affected (Shrivastava and Kumar 2015). Salt affected soils have incredible environmental, agricultural, ecological, and social impacts through reducing crop production and soil quality, resulting in unstable livelihood security, low economic returns, and poor quality of life (Wondim *et al*. 2020).

The problems of soil salinity and sodicity can be tackled by adopting different technologies, such as increasing irrigation rate by leaching fraction, gypsum amendment for the sodic soils, introducing salt-tolerant crops for highly saline areas, managing poor quality irrigation water, and restoring salty lands using forestry species (Mandal 2018).

The plants can die from water stress or drought in moist soil if the salt concentration develops high enough in the field.(Nekir 2019).

A yield reduction of 5% for broad bean and 20% for lentils were observed at an ECe of 2.0 dS m^{-1}. When the salinity level was increased to 3.1 dS m^{-1}, the corresponding yield reductions were 15% and 95%, respectively . The high salinity causes reduction in the dry matter yield of Alfalfa and Rhodes grass while the leaf-to-stem ratio increases, affecting forage quality (Gelaye *et al*. 2019).

Salinization of soils has tremendous challenges for crop production and soil productivities, resulting in uncertain and unstable livelihood security, low economic returns, and poor quality of life (Kumar *et al*. 2020).

Salt affected soils have incredible environmental, agricultural, ecological, and social impacts through reducing crop production and soil quality, resulting in unstable livelihood security, low economic returns, and poor quality of life (Qureshi *et al*. 2020).

Overall rehabilitation and management of salt-affected soils depend on the classification of salt types , especially saline-sodic and sodic soils that need investment.(Mishra *et al*. 2019).

There are many constraints to salt tolerant gene identification in Ethiopia, such as high technologies and skilled human power limitations. Nonetheless, screening of salt susceptible genotypes through conventional selection. Such screening is an effective tool to exploit genetic variation among crop genotype (Mamo *et al*. 2021).

Differences between shortterm/temporary effects of salinization vs long-term effects (either single irrigation seasons or multiple years) are often overlooked (Maggio *et al*. 2011).

Definition

Salinity is defined as the presence of excessive amounts of soluble salts that hinder or affect the normal functions of plant growth. It is measured in terms of electrical conductivity (ECe), with the exchangeable sodium percentage (ESP) or sodium adsorption ratio (SAR) and pH of a saturated soil paste extract. Therefore, saline soils are those that have saturated soil paste extracts with an ECe of more than 4 dS m^{-1}, ESP less than 15% and pH below 8.5 . Saline soils have a mixture of salts of Chloride, Sulfate, Sodium, Magnesium and Calcium ions with sodium chloride often dominant.

There are two main sources of salinity

Primary or natural sources

Resulting from weathering of minerals and the soils developed/derived from saline parent rocks.

Secondary salinization

Caused by human factors such as irrigation, deforestation, overgrazing, or intensive cropping.

Mechanism of salinity in plants

Effect of excess salinity on plant growth

Response of vegetables to the presence of increased amounts of salts is primarily stunted growth . The ultimate impact of excess salts is of course very dependent on the other environmental factors such as humidity, temperature, light and air pollution . In the more sensitive genotypes salts accumulate more rapidly and because cells are not able to isolate the salt ions in vacuoles to the same extent as more tolerant genotypes, the leaves of more sensitive genotypes usually die faster . In any case, yield losses due to osmotic stress can be very significant even before symptoms of toxicity on leaves become noticeable. Under the influence of salt stress growth of many species of vegetables is reduced, such as tomato pepper celery and peas (Maksimovic *et al.* 2010).

Soil salinity affects an estimated 1 million hectares in the European Union, mainly in the Mediterranean countries, and is a major cause of desertification. In Spain, 3% of the 3.5 million hectares of irrigated land is severely affected, markedly reducing its agricultural potential, while another 15% is under serious risk (Stolte *et al*. 2016).

Soil salinity reduces the productivity of many agricultural crops, including most vegetable crops, which present low tolerance to soil salinity. However, a substantial increase in production and consumption of vegetable crops that include edible portions of herbaceous species (roots, tubers, shoots, stems, leaves, fruits, and flowers) is a global priority. In fact, vegetables play an important role in human nutrition and health, particularly as sources of vitamin C, thiamine, niacin, pyridoxine, folic acid, minerals, and dietary fiber. Some of the world's most widespread and debilitating nutritional disorders, such as micronutrient deficiencies, are related to low vegetable intake.

A matrix plot of onion yield showed a reduced trend as the soil's pH, EC, and ESP increased (Kitila *et al*. 2020). A decrease in plant biomass, leaf area, and growth has been observed in different vegetable crops under salt stress (Giuffrida *et al*. 2012).

Salt stress effects on root architecture/morphology currently are poorly understood . However, root biomass has been reported to be generally less affected by excess salinity than aboveground organs. Salinity reduced root biomass has been reported in broccoli and cauliflower . (Giuffrida *et al*. 2012).
There are significant differences in salt tolerance between plant species and genotypes and similar goes for the ability to tolerate water deficiency , in parallel the classification of waters with respect to the total concentration of salts and tolerance of selected vegetable species to salts. In some other plant species were recorded adverse effects. In spinach leaves the presence of salt reduces the intercellular spaces , and stomatal density in tomato but it increases stomatal density in pea (Maksimović *et al*. 2010).

Effect of excess salinity on the water regime of plants

The vegetation period is shortened, water regime of plants is disrupted and the uptake and distribution of essential elements in both semi-controlled and field conditions is altered (Maksimovic *et al*. 2010).

Accumulation of compatible osmolites increases vegetable tolerance to osmotic stress

One of the ways plants can adapt to conditions of osmotic stress is the accumulation of salt ions, if these salts are isolated in individual cell compartments by which their involvement in metabolism is prevented. The ability to regulate the concentration of salts through compartmentation is an important aspect of tolerance to increased salt concentrations. These substances do not interfere with normal biochemical reactions in cells .Compatible osmolites are low molecular weight molecules such as proline and glycine betaine . It is believed that under conditions of stress, proline has a role in osmotic adjustment of cells, enzymes and membrane protection and also as a source of nitrogen for a moment when conditions of stress are over.

Their most important roles, beside in osmotic adjustment, is carbon storage and neutralization of free radicals. A similar role is attributed to the polyols that may accumulate under conditions of salt stress as well . Ionic status of plants is highly correlated with tolerance to salts so that it can serve as a selection criterion in breeding to help create genotypes more tolerant to excess salt.

Effect of excess salinity on mineral nutrition of plants

Salinity affects nutrient availability to plants in many ways. In the presence of increasing concentrations of salts some species-specific symptoms may be present, such as necrosis and burns of leaf edges due to the accumulation of Na+ and Cl- ions.

The high concentration of ions can disrupt the structure and function of cell membranes. Mineral nutrition of plants depends on the activity of membrane transporters which participate in the transfer of ions from the soil into the plant and regulate their distribution within and between cells . Changes in membranes may finally lead to disturbances in chemical composition of cells and can therefore be displayed as symptoms of deficiency of some essential elements, similarly as it happens in the absence of salts.

The use of arbuscular mycorrhiza (AM) has been shown to be able to alleviate salt stress in tomato, onion, and lettuce (Bargaz *et al*. 2016).

Effect of excess salinity on nitrogen, phosphorus and potassium uptake and metabolism

Nitrogen fertilization on saline soils is often necessary because in such soils there is a lack of accessible nitrogen and also because losses of nitrogen due to leaching typical for nitrate form (Abdelgadir *et al*. 2010). In addition, rate of nitrification of ammonia is often significantly reduced due to the large direct toxic effects of Cl- and the total amount of salt on the activity of nitrifying bacteria.

Inhibitory effect of Na+ on transport of K+ through channels in the membranes is probably more important in the phase of uptake of K+ from the soil solution than in the phase of K+ transport to the xylem .The degree of tolerance of plants to the salinity is higher if they have a more efficient system for the selective uptake of K+ instead of N+ .

Effect of excess salinity on photosynthesis

Since plant growth directly depends on photosynthesis, stress factors that affect plant growth, affect the photosynthesis as well .The effect of irrigation on production of organic matter and yield of vegetables is irreplaceable, as illustrated in table. The capacity of the photosynthetic apparatus is reduced in the presence of excess salts . However, the intensity of photosynthesis and yield are not correlated in the same way in different plant species. In asparagus and cotton a positive correlation was found.

Some plants can adapt to higher salinity by biochemical changes in the photosynthetic pathway. For example, facultative halophyte Mesembryanthemum crystalline instead of the usual C3 uses CAM pathway ,while another species is tolerant of salts due to property that photosynthetic path runs along the C4 instead of C3 biochemical pathway.

Effect of excess salinity on amino acid composition, hormonal balance, antioxidant system and quality of vegetables

Salts affect the level of hormones in plants. The responses of tomato to salt stress conditions are largely determined by the concentration of endogenous ABA. However ABA is only one component of composite hormonal control . It was found that the concentration of ABA and cytokinins increase with increasing in salt concentration.

Irrigation with treated municipal wastewaters in vegetable production

Treated municipal wastewaters, in addition to being a source of water, are a source of nutrients for plants and heavy metals . The concentration of metals in plants is affected by many factors and one of the most important is the genetic basis of plants, i.e., genotype. Heavy metals can affect the anatomy and uptake and distribution of essential elements in plants (Maksimovic *et al*. 2010).

An appropriate irrigation scheduling with DI and SDI methods can also reduce the effects of salinity by continuously maintaining moist soil around plant roots and providing steady leaching of salt to the edge of the wetted zone. SDI, in comparison with DI, increased water use-efficiency in tomato (Lamm 2016 and Kahlaoui *et al*. 2011).

Mechanism of tolerance to salinity in vegetable crops

Excessive amounts of soluble salt sins soil in any regions of the world, particularly in arid and semi-arid areas, limit production of most crops including . Like other crops, considerable crop to crop variation in vegetable crop salinity tolerance has been reported. For example, broccoli, cabbage, cauliflower, tomato, eggplant, potato, turnip, radish, lettuce, pumpkin, cucumber, and pepper have been reported to be moderately sensitive, red beet (*Beta vulgaris*) is moderately tolerant, whereas okra, pea, onion, and carrot are highly sensitive to salt.

Okra (*Abelmoschus esculentus* L.)

Salinity effects and crop responses

Although salinity stress has been reported to adversely affect the growth and productivity of okra, it is considered a semi tolerant or moderately tolerant crop compared with many other vegetable crops. Salinity (NaCl) had a considerable inhibitory effect on seed germination of okra with Na+, sugar, and phenols increased, and K+, starch, and amylase activity decreased significantly in the cotyledons of germinating seeds. Observed that rooting medium salinity significantly reduced shoot and root fresh and dry weights, to plant, shoot length, and fresh pod yield of different cultivars of okra.

The mechanism of ion home ostasishas also was reported to okra. For example, concentration sand uptake of Na+ and Cl− increased, while those of K+ and Ca^2+ decreased in okra in response to NaCl-induced salt stress Further more, shoot and root K+/Na+ and Ca^2+/Na+ratios were reported to be markedly decreased in okra under saline conditions.

Strategies to improve salinity tolerance

Very little work has been reported on the improvement of salt tolerance of okra. Only (Paksoy *et al*. 2010) have reported that addition of K and humic acid to the saline medium are very effective in enhancing the salt tolerance of okra particularly at the seedling stage.

Egg plant (*Solanum melongena* L.)

Salinity effects and crop response

Eggplant is considered to be moderately sensitive to salt stress. Salt stress also adversely affects the plants at later stages including shoot and root fresh and dry weights, shoot and root length sand the gas exchange characteristics, net CO^2 assimilation rate, transpiration rate, stomata conductance, and internal CO^2 concentration. In contrast, water use efficiency of eggplant is not affected by salt stress (Abbas *et al*. 2010). Salinity also markedly reduces both fruit weight and number of fruits per plant.

Strategies to improve salinity tolerance

Very few strategies have been reported in the literature to overcome the salinity-induced losses in eggplant production under saline conditions. Exogenous application of inorganic fertilizers, compatible solutes, and plant growth promote in bacteria has been found to be viable approaches to enhance salt tolerance (Abbas *et al.* 2010). For example, reported that foliar-applied di-potassium hydrogen orthophosphate (K_2HPO_4) ameliorated the adverse effects of NaCl on plant growth and development, crop fruit yield, and total soluble sugar contents.

Pepper (*Capsicum annuum* L.)

Salinity effects and crop response

Growth response of pepper to saline conditions varies with the stage at which salts are applied . Salinity effect observer when seeds are sown directly under saline conditions, but this adverse effect can be mitigated when established plants are transplanted to a saline medium.

Carrot (*Daucus carota* L.)

Salinity effects and crop responses

Carrot is considered to be a salt sensitive vegetable although a wide range of salt tolerance is reported. Research on the effect of salt on carrot response to salinity stress is scarce. For example, shoot and root fresh and dry weights of carrot have been reported to be reduced markedly under saline conditions . In storage roots, Na+,K +, Ca ^{2}+, and Cl− concentrations were considerably lower than those in the shoots under saline conditions . Salinity of the root growing medium reduces Br, S, and Si and increases Mg, Cu, Fe, Al, Cs, and Ni concentrations in carrot.

Potato (*Solanum tuberosum* L.)

Salinity effects and crop responses

Potato is a moderately salt sensitive to moderately salt tolerant crop whose growth and yield is considerably affected by salt stress Salt stress affected seedling fresh and dry biomass accumulation more seriously in salt-sensitive cultivars than in salt-tolerant ones. Root medium salt stress was reported to reduce shoot and root lengths with more reduction in salt-sensitive cultivars than in tolerant ones. Salt stress significantly alters the molecular responses of the potato plant.

Strategies to improve crop salt tolerance

Various strategies have been employed to enhance salt tolerance in potato including exogenous application of inorganic or organic fertilizers , 5-amino in air humidity and through genetic engineering Pre-treatment of potato tuber with NaCl and CaCl2 salts or a combination of these is an effective remedy against salt stress.

Application of potassium to the rooting medium is very effective in mitigating the adverse effects of salinity on potato. That adverse effects of salinity are more prominent under K deficiency conditions. They suggested the use of optimal doses of K to alleviate the problem of K deficiency; however, application of K beyond the recommended fertilizer level is not effective for alleviating the adverse effects of salt stress.

Area prone to salinity and sodicity in India

Area distribution of salt-affected soils

Globally, more than 800 million hectares (Mha) of land are estimated to be salt-affected .These soils cover a range of soils defined as saline, saline–sodic and sodic.

According to one estimate an area of 6.74 Mha in India suffers from salt accumulation out of which 3.78 Mha are sodic while 2.96 Mha are saline soils. The extent and distribution of salt-affected soils in different states of India is given in Table. The states of Gujarat (2.20 Mha) and Uttar Pradesh (1.37 Mha) in India have the largest area under salt-affected soils.

Sources of salinity and sodicity

The main sources and causes of salt accumulation include:

Geo-chemical weathering of rocks and parent materials and the salts brought down from the upstream to the plains by rivers and subsequent deposition along with alluvial materials.

Derived directly from sea water by flooding or intrusion into ground water resources.

Salt-laden sand blown by sea winds.

Indiscriminate and injudicious use of irrigation waters of different qualities.

Capillary rise from subsoil salt beds or from shallow brackish ground water.

Lack of natural leaching due to topographic situation and economic activities in arid and semi-arid regions.

Mitigation of salt stress

The mitigation approaches (e.g. the addition of amendments, plantation of salt-tolerant crops, appropriate irrigation and drainage management, phytoremediation, and bioremediation) have successfully tackled soil salinity and sodicity problems in many parts of the world. These approaches have further improved the socioe-conomic conditions of farming communities in salt-affected areas (Daba and Qureshi 2021).

The following mitigation strategies of salt stress

Seed hardening with NaCl (10 mM concentration).
Application of gypsum @ 50% gypsum requirement (GR).

Incorporation of daincha (6.25 t/ha) in soil before planting.

Foliar spray of 0.5 ppm brassinolode for increasing photosyntheticactivity.

Foliar spray of 2% DAP + 1% KCl (MOP) during critical stages.

Spray of 100 ppm salicylic acid.

Spray of 40 ppm of NAA for arresting pre-mature fall of flowers / buds / fruits.

Extra dose of nitrogen (25%) in excess of the recommended.

Split application of N and K fertilizers.

Foliar application of ascorbic acid alone increased number of leaves and leaf area, while in combination with zinc sulfate increased the plant height and total plant biomass.

The exogenous application of PGRs, auxins, gibberellins and cytokinins produces some benefit in alleviating the adverse effects of salt stress and also improves germination, growth, development and seed yields and yield quality.

Exogenous application of ABA reduces the release of ethylene and leaf abscission under salt stress in plants, probably by decreasing the accumulation of toxic Cl- ions in leaves.

Post-application with exogenous Jasmonic Acid can ameliorate saltstress, especially the salt-sensitive rather than the salt-tolerant cultivar.

4 mM ascorbic acid and 4 mM gibberellin could increase transpiration rate, relative water content, chlorophyll b, total chlorophyll and xanthophyll content. In general, it was concluded that synergistic interaction between ascorbic and gibberellin could alleviate the adverse effects of salinity on plants.
Maintenance of high K/Na ratio by applying potash and Cafertilization.
Application of PGRs likecytokinin,GA3, IAA, cycocel, thiourea and polyamines (putrescine, spermidine and spermine) either as seed treatment or foliar spray.

The application of fertilizers through irrigation water (fertigation) can reduce soil salinization and mitigate salt stress effects because it improves the efficiency of fertilizer use, increases nutrient availability and timing of application, and the concentration of fertilizers are easily controlled. Fertigation allows frequent applications of very low fertilizer rates which adjusts nutrient supply to plant requirements. Nutrient supply rate must take into account the rates of nutrient uptake and of evapotranspiration and irrigation water quality. The solutions applied in fertigation should generate low additions of EC_w and should not exceed the EC_t (electrical conductivity threshold) tolerated by the crops, which varies with the irrigation water and with the fertilizer used.

CONCLUSION

The stress provoked by excess salts in the soil solution has similarities with the stress caused by lack of water, although there are differences. Excess salt has an osmotic effect, which means that the amount of water accessible for plants is reduced.The threshold salinity level at which most of vegetable crops are affected is poorly documented. For example, okra is considered to be semi or moderately salt tolerant, tomato sensitive to moderately sensitive, eggplant moderately sensitive to salt sensitive, and potato moderately sensitive to moderately salt tolerant. Similarly, carrot is considered a salt sensitive crop but many authors are of contradictory views about its degree of tolerance. Further studies are required to classify these vegetables and their common varieties with respect to their degree of salt tolerance.

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