PHYSIOLOGY OF SALT STRESS IN PLANTS

PERCEPTION, SIGNALLING, OMICS AND TOLERANCE MECHANISM

Edited By

Pratibha Singh | Madhulika Singh
Rajiv Kumar Singh | Sheo Mohan Prasad

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Physiology of Salt Stress in Plants

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Perception, Signalling, Omics and Tolerance Mechanism

Edited by

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Preface

This edited book entitled Physiology of Salt Stress in Plants: Perception, Signalling, Omics and Tolerance Mechanism is an important contribution to Plant Science containing information related to salt stress and its mitigation strategy by experimental techniques based on theoretical concepts. The salt-stress-related problems are rising in the soil and water due to natural and anthropogenic activities. Anthropogenic activities include repeated irrigation through canal system and heavy crop production practices which has led to enhanced salt level in crop/agricultural field, hence substantially declining the crop productivity. Therefore, study on salt toxicity is continued as an area of scientific interest in direction to understand their whole mechanism of its toxicity and their entry into crop plants.

In this book, the authors explain a number of approaches to ease the negative impact of salt stress in crop plants. These approaches include nutrients, antioxidants, osmolytes, phytohormones and extra cellular compounds, etc. They are endo as well as exogenous in nature. In this book, the adverse impact of salt ion toxicity on plants and implication of advance approaches in alleviating salt toxicity have briefly been reviewed. This work enables the scientific world to design strategies for reducing NaCl-mediated loss to crop by the application of different endo and exogenous substances in the farm soils. The governments and other organizations may design a holistic approach to reduce NaCl and other salt toxicity by different types of practices. Agriculturalists may be enlightened with several awareness programmers by the government and non-government actions wherein the content of this book may be used. It is widely useful for all post-graduate courses in the biological sciences. The idea of this work has a wide-ranging scientific and socio-economic utility.

All the editors thankfully acknowledge the contributions from all the scholars working across the Indian subcontinent and across the world. An authoritative book written by an individual that remains relevant over the coming years is rather cumbersome and instead requires the concerted effort of a team of expert scientists. All editors also gratefully acknowledge the team at John Wiley & Sons Limited which made possible the proposed book in its present form.

Editors
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1

An Introduction to Salt Stress Perception and Toxicity Level: Worldwide Report at a Glance

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1.1 Soil Salinity: An Introduction

The threat of global warming is not limited only to the earthen atmosphere but slowly progressing toward the lithosphere. Attenuation of vegetative health due to the assimilation of brine substances is referred to as saline toxicity. The destruction caused solely due to the elevated level of sodium chloride (NaCl) is characterized as sodicity and is rather attainable to reclaim. Contrarily, the assorted salt stress enforces salinity, which makes land barren(Gul et al. 2015). Since the Green Revolution, the salinity footprint is engulfing the terrestrial territory quite rampantly. Presently, around one-tenth of the earth's crust accounting nearly 46 M ha has turned non-fertile (Hossain 2019). Excessive groundwater abstraction in the high zones may lead to premature desertification. The Indian Council of Agricultural Research (ICAR) predicted in a geospatial study that the coastal districts will be left with no aquifer water by 2050 without any technical interference (ICAR 2015). This further booms the inland intrusion of saline water. Figures are even more agitating, precisely in coastal regions. The rising sea levels often cause waterlogging in different parts of the world, precisely places located at lower elevations (EL-Raey et al. 1995). India, with a coastline length of approximately 7516 km, is presently under immense risk of temporary submergence. Saline water logging abnormally elevates the sodicity and thereby turns the lands nonproductive or unfertile.

The other reason that may trigger the soil sodicity is extreme groundwater abstraction. The negative aquifer pressure in the coastal regions causes brackish water intrusion and vertical rise by capillary action (Dillon et al. 2009). Whereas, the increase in soil salinity is a complex phenomenon. Studies showcased the discharge of industrial effluents into the water bodies successively raising the dissolved salt content resulting in increased salinity

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while utilized in irrigation. The other foremost reason for soil salinity involves drying out. Overutilization has already caused drying of a significant chunk of sweet water resources. In the absence of the desired water quality, farmers are moving toward alternate sources with high saline concentration, leading to the salinity of agricultural lands (Staniforth and Davies 2018).

The impact of salt stress is found to be most severe on agricultural crops. The primary issues involve the non-germination of seeds, reduced leaf surface area, retarded plant growth, strength, hampered yield, etc. Elevated soil salinity hampers the plants in various ways such as osmotic stress (OS), ionic toxicity, retarded cell division, reduced photosynthesis, to name a few. The inclusive impact of all the above factors boosts the mortality rate (Lauchli and Grattan 1970).

Immediate exposure to higher saline medium primarily increases the OS, causing reduced leaf surface area (i.e. due to repressed cell division and growth). Whereas, prolonged exposure imparts ionic stress leading to stomatal closure, immature senescence of mature leaves, chlorosis, necrosis, etc. The reduced biomass negatively affects photosynthesis and plant growth (Darko et al. 2019). In contrast, exposure to elevated sodicity, especially NaCl,affects the enzymatic system and augments cell swelling. The mutual impact leads to suppressed energy synthesis. Furthermore, excess exposure hinders all the growth-oriented processes like metabolism and protein synthesis (Acosta-Motos et al. 2017).

Therefore, prolonged exposure provoked the development of a defense mechanism in some species against salt stress and toxicity either by excluding through cells or by enhancing the salt tolerance. Additionally, synthetic species with transgenic properties are also synthesized by genetic engineering by altering the levels of gene expression (Carillo et al. 2011).

1.2 Salt Stress Perception and Current Scenario

Accumulation of excessive salt content in the soil causing direct and indirect adverse effects on flora and fauna is termed as salt stress (Shrivastava and Kumar 2015). The above situation can inhibit plant growth, and prolonged exposure may lead to a decrease. Higher saline level impacts the plants in various ways such as genotoxicity, alteration of metabolic processes, oxidative stress, water stress, ion toxicity, nutritional disorders, reduction of cell division and expansion, and membrane disorganization (Hasegawa et al. 2000; Munns 2002). The preliminary exposure to salt stress causes leaf surface area reduction. The immediate impacts include suppressed cell expansion and cell division and closure of stomata due to osmotic influence (Munns 2002; Flowers 2004). Furthermore, prolonged exposure imparts ionic stress leading to early senescence of mature leaves and thereby reducing the leaf surface area responsible for photosynthesis and plant growth.

The severity of salt stress is most predominant in the case of agricultural crops from a food security perspective; impacts include retarded seed germination, reduced biomass, and small yield. Higher abscisic acid (ABA) concentration results in the formation of specific genes through the plant defense mechanism which leads to counteracting its generation cause (Godoy et al. 1990; Lodeyro and Carrillo 2015). Generally, the acute level of salt toxicity causes instantaneous death in various species, whereas, in selected species, limited stress influences defense mechanisms mimicking halophytes. For instance, conversion of C_3 to CAM, amendment in epidermal bladder cell to withhold excessive NaCl enabling better survivability over the saline condition. Significant parts of the coastal irrigated areas face salination issues majorly due to the seawater intrusion. More than 45 M ha of cultivable land distributed among hundreds of countries covering more than 10% of the global land surface area have already been sacrificed due to saline irrigation. Additionally, approximately 1.5 M ha of fertile land becomes nonproductive every annum due to soil salinity (Munns and Tester 2008). Presently, about 1150 M ha of productive land are under induced stress, while80 M ha are only affected due to the anthropogenic activities (Rasool et al. 2013; Hossain 2019).

1.3 Types of Salt Stress

Based on the origin and root cause, there are two different categories of salinity, namely, primary and secondary. Primary salinity is a natural phenomenon and mostly occurs due to the former presence of salt lakes, slat clads, tidal swamp, etc., at a particular location. It is majorly a kind of sodicity. At the same time, secondary salinity is imposed due to man-made activities such as urbanization, saline irrigation, etc. (Shahid and Rahman 2011). Detailed reasons are delineated below.

Primary salinity:

i) Spreading from the saline artesian well.
ii) Capillary rise from saline groundwater.
iii) Seawater intrusion.
iv) Canopy formation due to the movement of fine sea sand by the sea breeze.
v) Waterlogging.

Secondary salinity:

i) Irrigation with impeded drainage
ii) Effluent discharge
iii) Excess fertilizer dosing
iv) Deforestation
v) Saline irrigation

Furthermore, based on the predominance of the type of anions present and the pH value, salt-affected soils are categorized as saline soil and sodic soil. Sodic soil typically comprises sodium carbonate and or bicarbonate ions with a pH value beyond 8.5, but contrarily, saline soil majorly incorporates chloride and sulphate ions with pH value below 8.5. Certain plant species manage to compensate the imparted stress through its metabolism and survive in the severe salt conditions known as halophytes. Remaining plant species are termed as glycophytes with a higher mortality rate overexposure to 10% or more concentration of saline water (Gorham 1995; Parida and Das 2005; Mane et al. 2011; Gupta and Huang 2014).

1.4 Origin of Problems

Primarily, hydro-geological activities contribute in escalating soil salinity and sodicity. Moreover, the soil is generated because of the weathering actions on intermediate and basic igneous rocks; sandstones already carry salt as a primary constituent. In the regions with moderate to low rainfall, a greater rate of evapotranspiration induces higher salinity and sodicity. Furthermore, coastal regions with tidal exposure may also develop salinity problems. A study conducted by Sultana et al. (2001) depicted that rice yield in coastal Asia gets often impaired due to the intrusion of saline Indian Ocean water. Inland precipitation also surprisingly elevates the soil sodicity. It is evidenced that rainwater can constitute up to a few milligrams of salt against each kilogram of a downpour with an electrical conductance (EC) value of 0.01 dS/m (Cucci et al. 2016; Corwin and Yemoto 2017; Hossain, 2019).

However, the deteriorating impacts of artificially induced salinity are more predominant. Over-irrigation or saline water irrigation is cited as one of the prima facie reason for human-induced salinity. Roughly, it is estimated that globally half of the irrigated lands are anyhow saltaffected. Other than irrigation, probable sources of inland salinity are the following:

i) Salt accumulation: Effluent and waste discharged into the surface water bodies from the industries and effluent treatment plants (ETPs) beyond absolute concentrations can accumulate and form salt films downstream to cause acute saline toxicity (Naidoo and Olaniran 2013).
ii) Reduction of greenbelt: Deforestation accelerates the salinization process by facilitating salt movement both through upper and lower soil layers. It further results in depleted annual precipitation and elevated soil temperature. Subsequent heating and cooling promote wear and tear, higher runoff, and substantial sedimentation to cause flooding and salt assimilation.
iii) Overdosing fertilizers: Post-Green Revolution, the usage of chemical fertilizers, herbicides, and pesticides has abruptly increased. Overdosing often results in underutilization and accumulation.
iv) Excessive grazing: Areas with scarce soil cover often suffer the root zone saline toxicity due to overgrazing. Surface waterlogging (i.e. either due to over-irrigation or riverbed sedimentation) in such areas can cause elevation of the water table and thereby facilitating salt migration from the deep aquifers.

1.5 Salt Toxicity Level: A Worldwide Report

Soil salinity and sodicity is a global issue faced by more than 115 nations with annual yield depletion of 7% or more (Yadav 2010). A total of 955 M ha of world surface area is either primarily or secondarily affected by salt pollution. Sodicity is predominant with impact over more than half of the land surface, e.g. Australia. Salinity issue dominates about 21% of comprehensive land footprint, especially arid regions of Asia and Pacific and areas with impeded drainage. Coming to India, the ambiguity of figures (salt-affected land) is quite a concern in the absence of liable evidence. The reported niche is found to be varying from

Table 1.1 Soil salinity/sodicity scenario in worst-affected partsof India.

State	Sodic soil (M ha)	Saline soil (M ha)	Total[a] (M ha)
Gujarat	0.54	1.7	2.24
Uttar Pradesh	1.35	0.02	1.37
Maharashtra	0.42	0.18	0.6
Rajasthan	0.18	0.195	0.375
Tamil Nadu	0.35	0.013	0.363

[a] 0.35 M ha: Threshold limit.
Source: Data from Mandal et al. (2018).

7 to 25 M ha (Rasool et al. 2013; Shahid et al. 2018; Isayenkov and Maathuis 2019). A location receiving low to moderate precipitation poses a tremendous threat to native agriculture.

The scenario is quite predominant in the southern region of India. These semiarid zones experience more than 300 sunny days per annum with high solar radiation, causing elevated evaporation rate and thereby moisture loss. The soil resource maps published by the National Bureau of Soil Survey and Land Use Planning, Nagpur (NBBS and LUP) were considered as the baseline data for the present study. The salinity of the soil was subcategorized into six basic classes depending on the EC of the saturated extract. The categories (based on severity) are as follows: very severe, severe, strong, moderately strong, moderate, and slight. The soil extracts portraying EC values between 200 and 400 mS/m were neglected for the above study. Furthermore, the sodicity of the soil was categorized into three major classes, namely, strong, moderate, and high. The above classification was done based on the presence of exchangeable sodium percentage (ESP), and the scale ranges from <5 to >15. The soil samples with sodicity <5 were considered as nonsodic, whereas the black soil samples with sodicity more than five were considered as alkali or sodic (Rasool et al. 2013; Shrivastava and Kumar 2015). The Rann of Kutch, Gujarat, an area with a footprint of 7500 sq. km mostly comprising salt marshes was marked as a separate entity by NBBS and LUP (Table 1.1).

As per the statistics published by the Food and Agriculture Organization (FAO) in 2007, about 770 000 sq. km of the global land surface area is already salt affected, and approximately 430 000 sq. km is under secondary salinity threat. The study further estimated that around one-third of the world's irrigated lands are either already affected by higher salinity or will be affected in the recent future.The global share distribution (in percentage) of saline soil across the countries is portrayed in Figure 1.1.

Multiple studies highlighted that abnormal abstraction of groundwater and waterlogging due to excessive irrigation often lead to desertification of fertile land. Therefore, urban local bodies (ULBs) and concerned government authorities should spread awareness among the farmers against salinization and over usage of water. Also, imposing water cess for misuse/overuse can be a productive measure to combat the typical tendency instantly, especially in the water-scarce areas.

The overall salinity profile of India was first estimated in 1966 under the accountability of the Ministry of Agriculture. The raising concern developed due to uncontrolled usage of

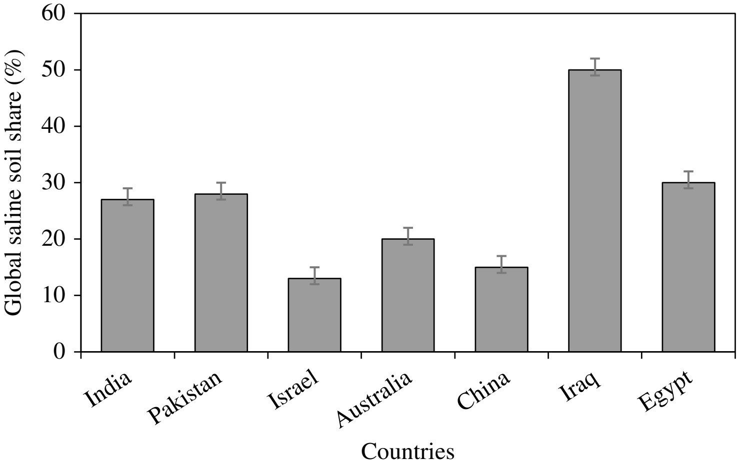

Figure 1.1 Worst-affected nations vs. salinity share. *Source:* Adopted from Rasool et al. (2013) and Mandal et al. (2018).

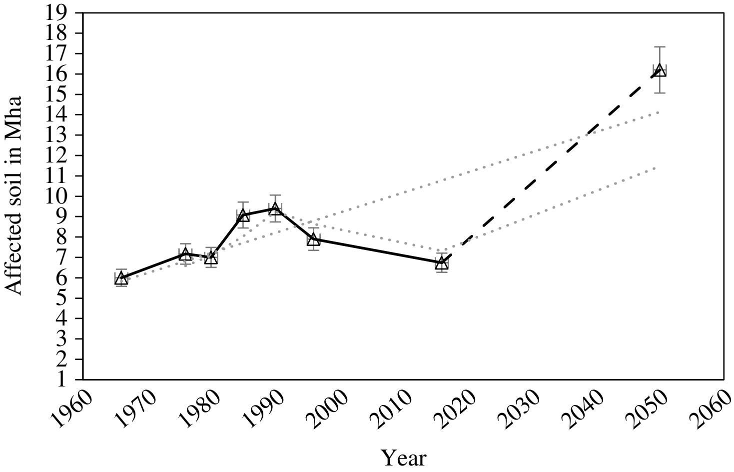

Figure 1.2 Salinity index and prediction for India since the Green Revolution. *Source:* Adopted from Sharma and Singh 2015.

the chemical fertilizer provoked the study. Furthermore, in the period of 1980–2015, a total saline footprint of approximately 2 Mha has been reclaimed under the effort of the ICAR. The retracted area presently yields around 16 MT of fodder grains per annum. The trajectory of the salinity footprint of the nation and foreseen values are portrayed in Figure 1.2.

The figure portrays the sudden escalation in salinity footprint (i.e. up to 16.2 Mha) between 2020 and 2050 as per the prediction made by the ICAR (ICAR 2015). The prediction is highly likely with no scientific intervention. Moreover, the usage of inferior irrigation water and overconsumption, leading to negative pressure, may further accelerate the salinization process.

1.6 Effect of Salt Stress on Flora and Fauna of the Ecosystem

Salt stress induces a diverse range of metabolic and growth-oriented detrimental changes in plants. Furthermore, protracted exposure can also inhibit crop yield. Primarily, saline exposure incurs OS, and it ultimately leads to ionic toxicities (Bano and Fatima 2009). Induced OS negatively impacts the root absorption capacity and accelerates the stomatal evaporation loss. Saline exposure elicits hyperosmotic pressure, which causes an adverse situation like the above. Initially, OS provokes several physicochemical amendments, which include membrane disruption and disfunctionality, disproportionate nutritive levels, retarded detoxification mechanism, and impaired photosynthesis rate (Munns and James 2003). Particularly, sodicity incites ionic stress by assimilating excess sodium and chloride ions into the plant tissue. Surplus accumulation of the above ions triggers ionic inequity leading to several growths related to detrimental changes. Elevated cell sodium ion concentration limits the required level of other essential plant nutrients such as potassium, thereby causing reduced yield and, ultimately, senescence (Ashraf 2004; Zhu 2007).

The inherent countermeasures also destructively impact plant biology. The generation of reactive oxygen species (ROS) can cause potential oxidation injury to the interstitial components like DNA structure, cell protein, and cell walls. The other sets of nondestructive defense mechanisms include elevation of photosynthetic rate, re-exercising ion and water relation in the vesicular system, etc.

The saline balance of the terrestrial water sources is globally affected due to continual anthropogenic activities, for example, new England Marshes (Williams 2002). Perennial inland sweet water sources are worst affected due to the waste charging throughout the trajectory. Whereas, the salinity of global waters is also sacrificed due to the melting of glaciers. Territorial brackish streams such as arid estuaries and salt-marshes are as well reasonably affected by the artificial agricultural discharge. But, this sudden change caters to a tremendous threat to the aquatic ecosystem. It incorporates abridged survivability, inhibited fertility, metabolic disorder, and retarded physiology (Velasco et al. 2019). Any varied salinity can mainly disrupt the osmotic balance between the surrounding hydrosphere and organismic, cellular fluid. The severity of impact varies between a minor metabolic malfunction and decease. To counteract the above, marine organisms develop an osmoregulation defense mechanism and eliminate hypo and hyperstress conditions. But, severe salinity or attenuation majorly conquers over the internal defense. Moreover, the consequences of successful defense are also majorly anonymous.

Additionally, investigations were also pursued to recognize the impact of ancillary factors such as temperature, but it seemed to be relatively insignificant. For instance, a study performed on zooplanktons reported metabolic issues upon exposure to altered salinity, but no apparent influence of temperature (Garreta-Lara et al. 2018). Basic metabolic disfunctionalities elicited due to OS are addressed by spontaneous excretion. But, stress ascertained due to bioaccumulation of metals is far more complex, so the defense is required. Moreover, each metal is highly specific in terms of threat enforced.

An advantageous fact is that the combined stress imposed by the salinity and metal toxicity gets tackled by a common mechanism in case of catadromous and anadromous fishes during the migration, in and out from the oceanic environment. For instance, a study reported the secretion of carbonic anhydrase in sheepshead minnow, an estuarine variety while exposed to the combined stress evolved due to amended salinity and copper toxicity (Velasco et al. 2019). Furthermore, OS plays a protagonist role against metal stress for invertebrates residing in saline waters by incurring the ion transport system. Lack of free radicals and ions in the freshwaters facilitate metal uptake in the inhabitants. Therefore, the vulnerability of the sweet water species against the metal toxication is indeed more severe (Halse et al. 1998; Velasco et al. 2019).

Dry farming also raises intricate contact interaction amid washed off pesticides and water salinity. These halogenated chemicals probably act as a neurotoxin and inhibit the counteract mechanisms of the nervous system. Remarkably, hypersalinity pivotally helps anadromous varieties such as Brown trout to subside the impacts of exposure efficaciously. The effective counter mechanism correlated with an interpretation of malfunctioning of the neural system upon instantaneous exposure to elevated salinity. Furthermore, collateral stress induced due to the combined effect of salinity and dehydration results in protraction of the osmoregulatory responses in some plants and marine bugs, thereby diminishing the moisture loss. It portrays the discordant individual stressors that abolish each other, while severe impacts were observed upon elementary exposure (Williams 1998; Kultz 2015; Cañedo-Argüelles et al. 2018).

1.7 Role in Sustainable Agriculture

The existence and survivability of the global population are mostly dependent on agriculture. It is estimated that about 99% or more consumable fodder sources are scattered across the lithosphere, whereas a hydrosphere contributes a negligible fraction of 0.5% or less. Thus, it is evident that a healthy and sufficient existence of earth crust is mandatory for the sustainable coexistence of the human being. Furthermore, soil erosion drastically impacts the agricultural yield. It is estimated that annually approximately 75 million tonnes of soil loss occurs only from the cultivable topographic regions worldwide. Other prominent effects of salinization include the erosion of the hilly terrains, which is probably less investigated (Aslam et al. 2017).

Saline soil mostly produces superficial seals due to two causes: (i) sodium pressure fragmentizes the soil structure and eliminates clay particles, resulting in clogging of interstitial voids and (ii) lean vegetative cover exposes the saline soil to precipitation compaction (Agassi et al. 1994, Singer and Lindquist 1998). Both the processes mainly decrease percolation and enhance surface runoff. Though the layer beneath gets safeguarded against vigorous erosion, the top layer gets severely imposed due to the disintegration caused by salinization (Agassi et al. 1994). Therefore, it is evident that soil salinity also can indirectly influence soil erosion up to a greater extent.

In this ever-raising context of fodder demand and versatile challenges, ensuring a hassle-free supply for the global population is a mammoth task. Amid eyeing for the alternate sources, existing challenges such as unavailability of the fertile land footprint, overconsumed natural resources, water and energy scarcity, and climate variance cannot be overlooked. Sustainability can only be achieved by compensating the need, not greed. Advanced issues need modern solutions, and indeed few are emerging as follows: reparation of sodicity with gypsum dosing, subsurface drainage of water-stagnant flood-planes, adaptation of agroforestry, and generating genetically engineered species and switching to them (ICAR 2015). The detailed pathway is delineated below:

i) The satellite-based remote-sensing approach with geographic information system (GIS) mapping and real-time ground truthing can provide an array of escalating salinity footprint (Singh et al. 2010).
ii) Gypsum-dosed alkali reparation techniques for soils affected with sodium toxicity.
iii) Reclamation of flooded wetlands through downward drainage– the method is quite useful in addressing multidimensional issues such as water stagnation and salinization.
iv) Chemical regeneration of saline soil with ameliorants is also practiced in some parts of the globe. The method is expensive and hence challenging to impose for more giant footprints.
v) Phytoremediation with salt-tolerant species is contrarily an inexpensive and eco-friendly mechanism.
vi) Multilayer agroforestry is a recent trend in the agricultural industry to mitigate rising demand. Anyhow, the method also assists in reclaiming saline soil by reducing the soil density and thereby causing an elevated percolation rate. Furthermore, the littered biomass improves soil fertility and yield (Kaur et al. 2000; Nosetto et al. 2007).
vii) Nonconventional techniques such as inland fishery have also gained limited popularity, majorly in the southern peninsula of the country. Flood-planes and wetlands near to the coastal regions are effectively serving as the source of alternate revenue generation.
viii) Microbialremediation: Desalination through microbial action is indeed rigorous. The inoculants are expensive and seek a suitable environment.

1.8 Unintended Effects of Salt-Containing Substance Application in Agricultural Land

Salinity intervenes with plant nutrition and growth by exerting osmotic and ionic stress. Higher salinity level in soil hinders water absorption ability, referred to as the osmotic effect. The utmost concern is when elevated concentration can deter biomass growth. OS in plants influences metabolic amendments similar to wilting and sometimes depicts genotype changes. Furthermore, factors such as ion toxicity and nutritional inequity ensure impeded plant growth. Thus, it is evident that the impact of salinity on vegetative growth is a time-variant. Therefore, a bi-phase kinetic model proposed by Munns et al. (1995) is considered as a benchmark for the present work. The primary phase is exceptionally speedy. OS resulting from internal water scarcity leads to growth retardation. Whereas, the secondary phase is relatively much slower and happens because of acute assimilation of salts in the shoot. But, still differentiating amid both the phases is a difficult task due to smooth transition array. High salinity downgrades the photosynthetic rate by reducing the availability of CO_2 caused by limiting diffusion and decreased concentration of pigments. For instance, salt assimilation in spinach entirely impedes photosynthesis by reducing the conductivity of CO_2 both in mesophyll and stomata. Also, by decreasing the chlorophyll concentration, salt stress can inhibit light absorption, thereby reducing photosynthesis. Furthermore, salinity causing reduced leaf expansion had reported an 80% reduction in growth rate in radish, while reduced conductance only retards body growth by up to 20% (Savci 2012).

Root zone salt assimilation activates OS and interrupts cell ion homeostasis by replacing the uptake of essential salts such as calcium and potassium nitrate with NaCl. Stem and leaf zone assimilation causes reduced photosynthetic rates, damaged chloroplasts, degraded metabolism, enzymatic malfunction, and other organelles. The impacts are predominant in adult leaves due to the longer accumulation tenure. Furthermore, nutrient deficiency and inequality occur in plants due to ionic substitution. Cations such as K^+, Ca^{2+} responsible for principal nutritive balance get replaced by Na^+ while NO^{3-} as a major anion gets substituted by Cl^-, leading to significant imbalance. In the case of higher soil sodium–calcium ratio, deficiency symptoms appear as a first sign. Though, plants such as tomato minimize the calcium absorbance to lower the rate of transpiration, and sodium competency plays a dormant factor there (Yadav et al. 2011; Zhang et al. 2018).

Primarily, a reduction in vegetative biomass, leaf surface area, and retarded plant growth is encountered chronologically in almost all the vegetative crops due to external salinity issues. The understanding of the interaction between plant root and salt-imposed stress is still clumsy. Conversely, root biomass found to be nearly unaffected when compared with upper ground organs, except cauliflower, broccoli, and tomato. Biomass reduction is prevalent in cauliflower and broccoli, whereas in tomato, root length and density reduction are observed. The signs of salinity exposure appear gradually in plants. The primary symptoms include the transformation of green leaves, wilting, and hindered growth. Furthermore, advanced symptoms such as chlorosis, leaf burning, scorching, necrosis, etc., start manifesting after two weeks and prolonged exposure. The visuals of the above issues negatively influence sellability and affect economics. Commercial varieties such as roots, fruits, and tubers are the worse affected. Also, rotting of blossom-end has been detected in tomato, eggplants, etc., due to saline irrigation (Maas 1993; Chandna et al. 2013).

Nonetheless, exposure to limited salinity also exerts some beneficial impacts, especially on vegetative crops. It improves the quality of the edible parts despite impinging certain visual defects. For instance, it reduces water content in fruits, enhances soluble solids and acid concentration in tomato, cucumber, and watermelon. Additionally, salinity can also improve the concentration of antioxidants and carotenoids in tomato and romaine lettuce. Studies also depicted that the beneficial nutritional properties (i.e. polyphenol concentration) of broccoli and spinach also flourish under a controlled saline environment with a dip in oxalic acid and nitrate ion content. All the prior mentioned effects are timedependent and only visible when subjected to the stress at the right moment (Thomas and Bohnert 1993; Chandna et al. 2013).

1.9 Role of Salt Toxicity in the Operation of Green Revolution

The third agricultural revolution colloquially termed as the Green Revolution was a path-breaking exercise that occurred between the early 1950s and late 1960s in the twentieth century. Impacts were majorly widespread in developing nations. Beside positive, the