

Salinization of Soil – A Consequent of Climate Change Threatens Food Security: A Review

Chaitali Bose^{1,*} and Imana Pal²

¹Assistant Professor, Department of Food and Nutrition, Government General Degree College, Narayangarh, Rathipur, West Midnapore, West Bengal, India.

²Assistant Professor, School of Health Sciences and Technology, UPES, Dehradun, India

*Correspondence author email: chaitali.bose85@gmail.com

Abstract. Food security and agricultural production are still a global challenge amidst the dramatic alterations in conventional farming technology. Deforestation and emission of Green House Gases (GHGs) from several sources play the pivotal role in global warming and succeeding climate change. Primary or natural salinization of soil is again a detrimental outcome of this climate change. Excessive accumulation of soluble salts in soil makes the soil saline and causes degradation of soil affecting the production of plants and crops. Excess salt accumulation in land not only hampers the growth and development of plants in all possible ways (e.g. osmotic stress, nutrient stress) but also destroy the biodiversity in soil (flora and fauna inside the soil) transforming it into barren dry land. Such land is expanding across all the climate zones and continents thus leads to environmental, social, economic burden and endangers global food security. Innovative technologies, certain agricultural practices, policies of stakeholders have been adopted either to reclaim the salt affected soil or to encourage alternative plant cultivation (like salt resistant plant by genetically modified technology) in such lands but still it is not feasible to manage or use all such lands in agricultural purposes as it imposes economical burden hence extensive research is needed to ensure food security and sustainability in the light of persistent climate change.

KEY WORDS: Climate change, salinity, soil degradation, food security

1. INTRODUCTION

Sustainable Development Goals (SDGs) was adopted by all the member states of United Nations (UN) in 2015 to envisage a better earth for future and set 17 goals encompassing ‘zero hunger’ and ‘food security’, preventive actions for ‘climate change’ and its vicious consequences and ‘equality’ and ‘prosperity’ for all by 2030 [1]. Food security as defined by World Food Summit (1996) is the ‘physical and economic access to sufficient, safe and nutritious food by all the people at all the time to meet their dietary needs and food preferences for an active, productive and healthy life’ [2].

Continuous supply of adequate food either from domestic yielding or from imports and this supply must be consistent over the years even during any catastrophic circumstances and physical/economical access to food at community or household levels by requisite resources and proper utilization of such foods midst of appropriate environment (such as safe potable water, sustainable green environment and all) can only bring food security for promoting good health and well being. Again, Food and Agricultural organization (FAO) has defined food insecurity as ‘lack of access of adequate, safe and nutritious foods by the individuals to support their normal growth and development for healthy, active and productive life’. FAO has also developed ‘Food Insecurity Experience Scale’ to measure the global

food insecurity which ultimately results hunger and under nutrition and the data accessed from World Food Programme (WFP) revealed that 343 million of people from 74 nations are facing off with food insecurity of acute level. And this climate change has immense effects on food availability hence in food security [4].

Climate Change and Food Security:

Emission of Green House Gases (GHS) occurs primarily by anthropogenic activity like incineration of fossil fuels, industrial production etc. contributes to global warming which results in low precipitation, change in the pattern of precipitation or seasonal variation of rain fall. Melting of glaciers is raising the sea level causes Salinization of both the soil and groundwater. Acidification of rain water and oceans; increase in ocean temperature; sudden flood, violent storms, drought and expansion of desert are some of the deleterious consequences of climate change. (Fig-1) [5].

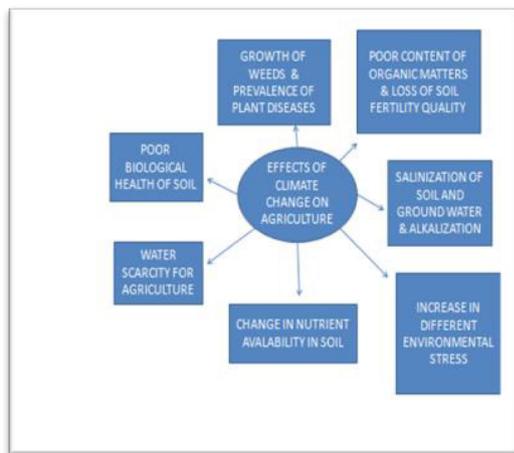


Fig-1: Effects of climate change on agriculture and food security

Climate change affects food security in many ways but in this article only the salinization of soil which is a consequent of climate change and its impact on food security with the possible ways to tackle such hurdles will only be discussed.

2. Soil Salinization:

Salinization which is a global environmental issue affecting the nutrient content, chemical composition and biotic components of both the water and soil hence harming the agricultural and fishery industries as well as imperiling the food security. It is a combination of certain processes like evaporation, precipitation of salt, dissolution, transportation of salt followed by ion exchange and so on.

According to the 'Soil Science Society of America' saline soil is considered as 'non-sodic soil' which carries 'soluble salt' in high amount having negative impact on plant growth. 'Non sodic soil' is the soil with less than 6% of ex-changeable sodium (Na^+) ion, good in water infiltration thus suitable for agriculture, and the term 'soluble salt' refers to those inorganic solutes (like calcium (Ca^+)/magnesium (Mg^+)/sodium (Na^+) as cations and sulphate/chloride/bicarbonate as anions) present in soil and has greater solubility than gypsum.[6]. Electrical Conductivity or EC for determining total soluble salts; Exchangeable Sodium Percentage or ESP for % of cation-exchange sites taken up by Na^+ and SAR or Sodium Adsorption Ratio to measure the ratio of Na^+ to Ca^+ and Mg^+ are some conventional ways to determine the concentration of total soluble salts or the type of salt prevalent in a particular soil. Salinization refers to an increase in soluble salts in soil whereas 'sodification' refers to an increase in exchangeable Na^+ concentration in soil. And the salt affected soil can be 3 types like sodic, saline and saline sodic. EC for sodic soil is $<4 \text{ dsm-1}$, ESP is $>15\%$ and SAR is >13 ; for saline soil the cut-off values are $>4 \text{ dsm-1}$, $<15\%$ and <13 respectively also such values for the saline-sodic soil are $>4 \text{ dsm-1}$, $>15\%$ and >13 respectively. On the other hand, the threshold values for soil use in agriculture purpose would likely to have EC $<4 \text{ dsm-1}$, ESP $<15\%$ and SAR <13 even EC $>2 \text{ dsm-1}$ can be dangerous for cultivation of certain crops, fruits or ornamental

plants. FAO presented the first report on 'Global assessment of salt affected soil in 50 years' at the 'International soil and water forum 2024' in Bangkok which was truly appalling as the report estimated almost 10.7% of land area is soil affected globally, furthermore salinity has sprawled into 10% irrigated and 10% rain-fed cropland and if such trend follows nearly 24%-32% of land area will be affected globally in near future. Recently ten countries like Afghanistan, China, Australia, US, Russian Federation, Sudan, Argentina, Iran, Kazakhstan and Uzbekistan contribute almost 70% of global salt affected soil. The research report as published by the CSSRI i.e. Central soil salinity research institute of ICAR (Indian Council of Agricultural Research) in February 2024 unveiled that 6.73 million ha land is saline and would become double by 2050 which is posing a threat to economy and food security. 12 states are struck by salinity where Gujarat is mostly affected [7].

Climate Change and soil salinization

Salinization can be caused by both nature (primary) and anthropogenic (secondary) drives. Climate change which is the result of both the natural and anthropogenic activities has potent effect on salinity. As the result of climate change, raise in average temperature, melting of glaciers leads to increased sea level hitting the costal agriculture. Flooding and intrusion of sea water causes salinization in coastal regions. In some areas in inlands, saline water remains beneath the fresh water aquifers. Discharge of such water on to the surface layers causes contamination with fresh water. Deposition of sea salts by wet (rain fall or aeolian sedimentation), erosion of parent rocks by different physical, mechanical and chemical processes; transportation of such particles through various water flows; evapo-transpiration, precipitation, decreased soil leaching competency, type and composition of aquifers; proximity to salt deposition of the aquifers or any leakage from geological depositions and mixing it with ground water- all are the natural events besides faulty agricultural practices, low quality water used in irrigation or using saline water, water logging, poor drainage in irrigation system, exhaustion of fresh water sources by over usage and excessive use of inorganic fertilizers are some the human activities behind land salinity [8]. Causes behind the salinization have been summarized below (Fig-2).

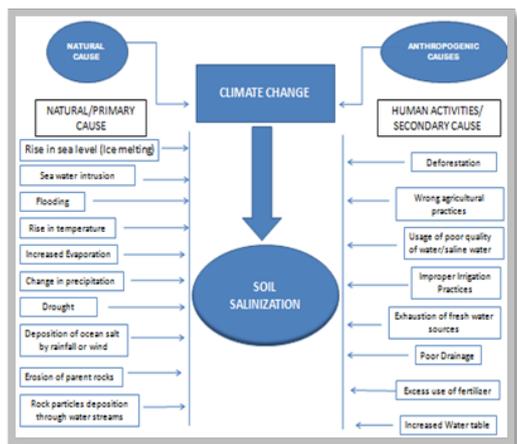


Fig-2: Causes of Salinization

3. Soil salinity and effect on agriculture production:

Soil salinity is a great threat to major crops for rice, wheat, and maize like staple grains. Salinity makes the land barren and unfertile as it causes changes in physical, chemical, microbiological properties of soil again it elevates stresses of the plants in many ways as summarized below.

Table-1: effect of saline soil on soil properties and plant growth

Changes in properties of saline soil	Effect of plant growth due to salinity
<ul style="list-style-type: none"> Nutrient deficiencies Poor biodiversity Reduced organic contents Poor structural integrity Poor leaching capabilities Decreased water holding efficiency and rate of infiltration Poor availability of nitrogen (N) and carbon (C). 	<ul style="list-style-type: none"> Ionic & Salt Stress Hyper ionic concentration induced salt stress of plants As the iron (Fe) content is poor in such soil, plants experience Fe deficiency which acts as co-factor for many enzymes, resulting growth failure, conductance of stomata, chlorosis, reduce rate of transpiration. Most plants experience salt stress even at EC 2 $ds\ m^{-1}$. Excess chloride uptake by roots decreases nitrogen absorption. Salt stress causes morphological, biochemical, physiological and metabolic impairments of plant tissue.
<ul style="list-style-type: none"> Presence of high amount of cadmium Presence of ions of heavy metals Increased concentration of Na^+ Increased concentration of Cl^-, SO_4^{2-}, HCO_3^-. Lower concentration of potassium (K^+), calcium (Ca^{2+}) and Nitrate (NO_3^-) Poor content of iron (Fe) Extreme salinity also contains Boron, aluminium, silica, lithium which causes toxicity for plants and other biotic lives. 	<ul style="list-style-type: none"> Salt Stress Physiological effects include closure of stomata, limits stomatal conductance, poor carbon fixation, loss of catalytic activity of cellular enzymes, decrease photosynthesis. Morphological changes include chlorosis, senescence of leaves, reduction in fresh and dry weight of root and shoot
<ul style="list-style-type: none"> Salinity causes plasmolysis of soil microbes via osmotic stress Decreased availability of water Reduce microbial biomass, activities of microbes and the structure of their community. Reduced Carbon fixation and mineralization in the soil. As the oxidation, ammonification, nitrification occurs following the decomposition of organic matters in soil by microbes and nutrients are transformed and stored in soil which is reduced in saline soil 	<ul style="list-style-type: none"> Osmotic Stress: <ul style="list-style-type: none"> Increase uptake of ions like Na^+, Cl^- by the roots changes the osmotic potential in between the soil solution and within the root thus reduces water absorption. Oxidative Stress <ul style="list-style-type: none"> Generation of ROS (Reactive Oxygen Species) induced by salt stress As these are by-products of aerobic metabolism and mostly present in mitochondria, peroxisome and chloroplast of plant tissue. Elevates lipid peroxidation, reduce photosynthesis, damage to cell membrane and nucleic acids, cellular enzyme inhibition, apoptosis. Others <ul style="list-style-type: none"> High concentration of heavy metals interferes with and reduce nutrients uptake from soil solution. Reduction in endogenous phyto-hormones Poor germination of seeds in saline water Hinders seedlings to establish and to grow Sterility in spikelets Reduced weight of grain

4. Saline soil and Food security-A Challenge

According to ‘Global soil affected Soil Map’ FAO has revealed that more than 833 million ha land is affected by salt worldwide and 10% of crop land is already affected globally which is a huge burden on global food security. Regions of Asia, North Africa, Middle East, Southern part of America and the Pacific regions are the worst affected. Data confirmed from 118 nations have indicated that >4.4% topsoil and >8.7% sub soil is salt affected. Such soil is seen in arid and sub arid and coastal regions. Instead of innovative agricultural practices, salinization of soil which is a dynamic process, is not only reducing the total cultivatable land area but also raising an alarming condition for agricultural production and food availability and consequently putting burden on global economy.

The following table (Table-1) has shown the type of saline soil and its response to crop production [9].

Table-2: salinity and crop response.

Saline Soil (Types)	EC $ds\ m^{-1}$	Response to Crop Yield	Examples
Non-Saline	0-2	No loss	Rice, maize
Saline slightly	2-4	Sensitive crops production is reduced	Peanuts
Saline moderately	4-8	Most crops fail to produce	Sorghums
High salinity	8-16	Tolerant crops can be yielded	Rye
Excessive salinity	>16	Only halophytes are yielded	Various halophytes

5. Possible way out to support food security and attain SDGs

As estimated, data revealed that 27.3 billion US dollar is the annual economic loss from salinization of irrigated land degradation and simultaneous failure in crop yielding. Keeping the pace with population explosion it has become a major global challenge to ensure per capita food availability. To attain SD goals like ‘zero hunger’ and ‘food for all’, salinity of soil must be mitigated with incorporation of innovative technologies to increase agricultural production globally.

FAO in global symposium on salt affected soil raise the slogan “Halt soil salinization, boost soil productivity” and to address the threat of salinization in arid semi-arid and the coastal regions promises were taken which includes:

1. Raising awareness about the impact of salt affected soils on agriculture and economy and the effect of unsustainable agricultural practices on it

2. Encouraging and promoting sustainable practices those are effective in saline or sodic soil

3. Promotion of various technological strategies to reclaim or manage saline or sodic soil agricultural practices

4. Development of policies by stakeholders and implementing effective action for sustainable practices for soil management based on research reports.

Strategies to tackle saline soil involve two approaches which include reclamation and management without reclamation. Approaches to be chosen depend on the soil properties, possibilities to reclaim and the cost effectiveness. For e.g. sodic and alkali soil can be reclaimed through proper amendments whereas coastal soil and black soil affected with salt cannot be reclaimed completely.

Soil reclamation and management strategies:

Mechanical Amendments:

As the surface soil is covered by salt it can be removed by heavy machines like tractor-scraper but it is quite expensive.

Flushing off the salt crust by heavy amount of high-quality water and provision of appropriate drainage system to take it away from land.

Mulching by crop residue to remove salt and reduce rate of evaporation from soil

Levelling of land, 'Bunding' to retain moisture, efficient nutrient management use of good quality water source for irrigation, prevent water logging and removal of excess water

Minimum to no tillage for preparing seed bed that helps in salt leaching.

Raising of sunken bed in sodic soil for establishing fruit trees have proven to be beneficial.

Adaptation of modern irrigation practice – like 'partial root-zone drying', micro irrigation like 'micro jet' or drip method for better usage of water.

Chemical Amendments:

- The chemical amendments to reclaim sodic soil are taken depending on the EC, ESP, and PH of that soil

- Either soluble calcium like gypsum, phosphor-gypsum or calcium chloride and or acid formers or acids like sulfers, sulphates, sulphuric acid to replace the predominant cation Na^+ by Ca^+ and Cl^- by sulphates.

- Such amendments require moisture as precipitation or irrigation to remove salt from root zones.

Organic Amendments:

- Organic matters like farm manure, compost, vermicompost increase the C content i.e. Dissolve Organic Carbon (DOC) of the soil.

- Increases nutrient availability from the soil

- It also helps to improve the soil physical properties like porosity, water holding capacity, leaching of salt from rhizosphere and lessen evaporation rate.

- Chemical properties like EC, ESP, and PH of the soil also get improved.

- Activates enzymes like phosphatase, catalase etc.

Phyto Remedies [16, 32]:

- Plantation of salt tolerant plants like tree shrubs or grass (like alfa alfa)

- They remove excess salt from soil by root absorption which then get accumulated in their biomass, known as phyto-extraction or phyto removal.

- These plants are deep rooted and reduce water table.

- Improves physical and chemical properties as well as organic and nutrient content of the soil.

Microbial remedies [33-35]:

- Microbes can adopt themselves to the different environmental stress and has unique role to maintain sustainable eco-system. PGPB includes the strain of Rhizobium Pseudomonas Achromobacter, Microbacterium, Enterobacter, bacillus etc

- They have the potentiality to tolerate the stress induced by salt, osmotic pressure, diversity in genetic materials, ability to synthesize plant growth promoting hormone (PGPH) e.g enhance nutrients uptake, and can also synthesize various compatible bio solutes effective to support crop production

- Microbiomes residing in the rhizosphere have proven to stimulate growth and production plants in direct or indirect ways. Like rhizobacteria can fix nitrogen, produce phyto hormones, exhibit Fe sequestering activity participate directly whereas others protect the crops from pathogenic diseases (like certain fungal diseases) by synthesizing certain chemicals and protein for plant defense mechanisms.

- Salt resistant bacteria or halophytes can remove Na^+ from soil and promote plant growth by escalating enzymatic and metabolic activities in plant cells.

- Arbuscular mycorrhizal or AM fungi has also shown excellent beneficial effect in salt stress.

Change in agricultural practices for cultivation in saline soil [10]:

- Mono crop cultivation like cultivation of Rabi in coastal region.
- Crop cultivation by rotation like tolerant crops can be harvested in dry season and sensible ones in rainy season as rain would wash away the top soil salt crust
- Development of genetically modified crops with salt, drought resistant traits e.g. rice.
- Harvesting the rainwater in farm dug outs as source of fresh water.
- Integrated agriculture practices like cultivation of shrimp, fish, cattle, poultry along with plantation has been found to be beneficial.
- Saline aquaculture is gaining popularity as the degraded land with saline water even inland can be profitable through cultivation of shrimp and fish. Like other countries states like Punjab and Haryana in India are applying such practices.
- Addition of required nutrients (K, Ca, Mg etc); organic bio stimulus like proline; biochar, organic fertilizers.
- Application of nano management technologies like incorporation of nano Si (Silicon), nano Se (selenium) carbon nano dots have proven to improve crop production etc.

Modern Innovative Strategies:

Development of climate based smart agriculture

Climate smart management practices (CSMPs) involve soil based - reclamation strategies (like certain amendments, improved irrigation and drainage), conservation agriculture (CA) and use of stress-tolerant genotypes. Such practices help to reduce emission of GHG, improve carbon sequestration in soil and sustainable ecosystem [11].

GIS (Geographic Information Systems)

It is difficult to determine the distribution of salt affected areas by traditional ways which now has been replaced by geographic information systems (GIS) with advanced proximal sensor-based techniques which not only detect the soil properties but the associated opportunities in those soils.

Recent approaches involve crystallization inhibitor casting on soil surface leads salt crystal growth and then their removal and wicking materials also help to remove salts though more scientific evidences are needed to apply practically [12].

6. Conclusion:

Climate change and its adverse effects are affecting the eco system and human lives in many

ways. Salinization of soil is a deleterious output of climate change though anthropogenic reasons also play vital roles. Increased salinity is a dynamic process and a serious issue especially in arid, sub arid and coastal regions of the countries and is already posing threat on food production and per capita food availability hence hammering the food security and global economy. Various technological practices have been evolved to either reclaim the saline soil or to adapt management strategies to make such land economically profitable. But many of such methods are expensive. Strategies must be implemented by involving all the stakeholders and the respective policies are to be developed. And still more scientific research is to be done to develop cost effective easy ways to tackle such problems. Raising awareness among people about such issues and adopting effective measures not only helps to halt salinization but also to protect the climate at least to some extent which will make our earth greener.

REFERENCES

1. M. Thakur. *Sustainable Food Systems (Volume II)*. World Sustainability Series, Springer, Cham (2024). https://doi.org/10.1007/978-3-031-46046-3_1.
2. P. Pinstrup-Andersen. *Food security: Definition and measurement*. *Food Security* **1**, 5–7 (2009).
3. M. Thakur. *Sustainable Food Systems (Volume I)*. World Sustainability Series, Springer, Cham (2024). https://doi.org/10.1007/978-3-031-47122-3_1.
4. D.I. Stern & R.K. Kaufmann. *Anthropogenic and natural causes of climate change*. *Climatic Change* **122**, 257–269 (2014).
5. K.K. Tanji. *Nature and extent of agricultural salinity*. *Agricultural Salinity Assessment and Management*, 71–92 (1990).
6. S. Arora & V. Sharma. *Reclamation and management of salt-affected soils for safeguarding agricultural productivity*. *J. Safe Agric.* **1(1)**, 1–10 (2017).
7. A. Hassani, A. Azapagic, & N. Shokri. *Global predictions of primary soil salinization under changing climate in the 21st century*. *Nat. Commun.* **12**, 6663 (2021).
8. A. Tedeschi & X. Xue. *Crop response to soil and water salinity*. *Soil Syst.* **9(1)**, 27 (2025).
9. I. Stavi, N. Thevs, & S. Priori. *Soil salinity and sodicity in drylands: A review of causes, effects, monitoring, and restoration measures*. *Front. Environ. Sci.* **9**, 712831 (2021).
10. F. Visconti & J.M. de Paz. *Field comparison of electrical resistance, electromagnetic induction, and frequency domain reflectometry for soil salinity appraisal*. *Soil Syst.* **4(4)**, 61 (2020).
11. E.C. Brevik et al. *Soil mapping, classification, and pedologic modeling: History and future directions*. *Geoderma* **264**, 256–274 (2016).