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Smart agronomic practices for growing crops in salt-affected soil

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India, which occupies 2.4% of the world's land area, has to feed 17% of the world's population and 15% of its livestock. With a projected population of 1.43 billion in 2030 and 1.8 billion in 2050, demand for food is increasing. However, 146.8 million hectares of land is degraded, resulting in an annual soil loss of 5.3 billion tonnes, threatening food security. Saline soils in states like Gujarat, Uttar Pradesh, Maharashtra, West Bengal and Rajasthan are deteriorating agricultural productivity. Solutions include managing salt-polluted soils with gypsum, phosphogypsum, sulfonated press mud and biodrainage, besides salt-tolerant crops and biosaline agriculture. Promoting agroforestry with salt-tolerant trees and climate-smart practices is critical. A holistic approach that integrates technology, agriculture and environmental strategies is critical to food security.

Keywords: Bio-drainage, Bio-saline agriculture, CSR-BIO, Gypsum, Salt tolerant crops, Varieties

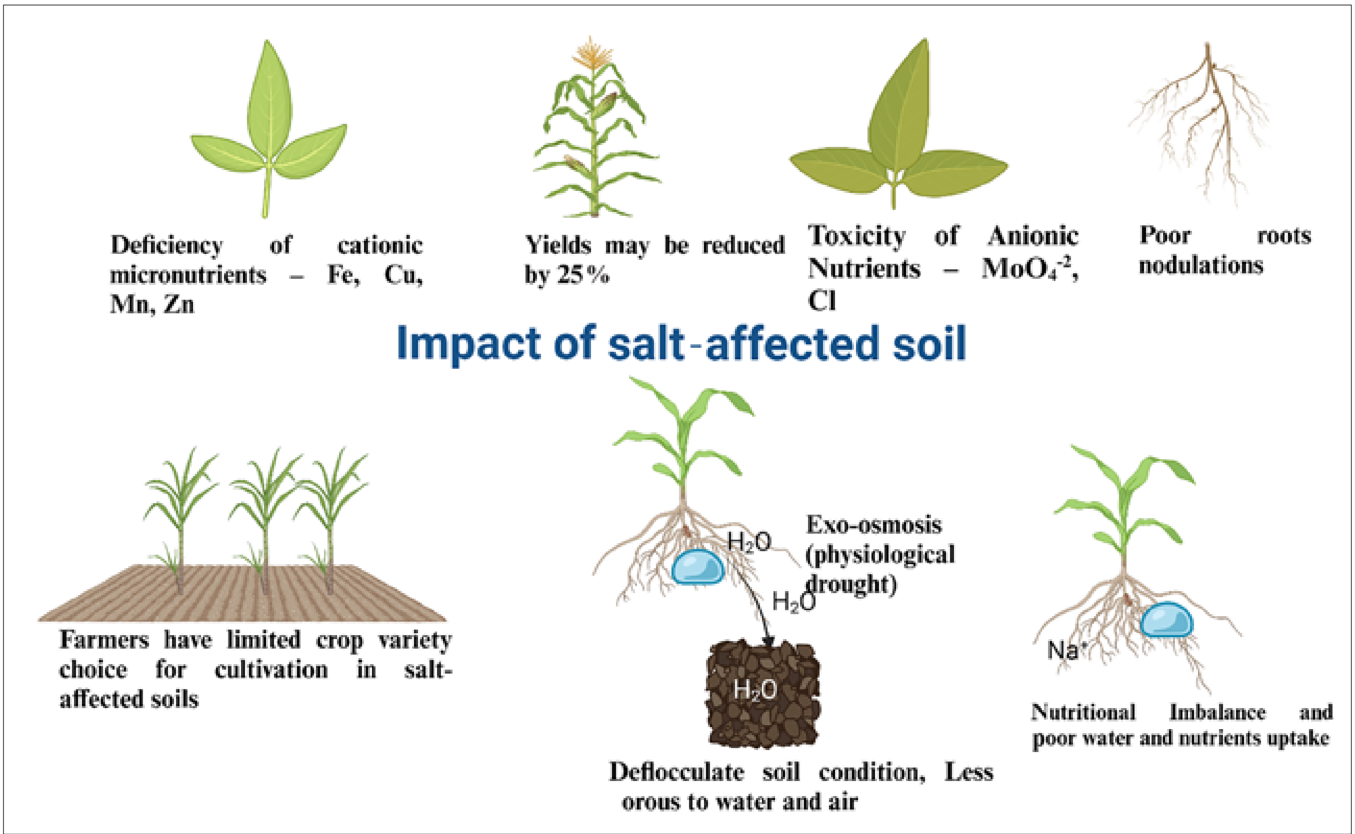
India covers 2.4% of the world's geographical area (328.73 million hectares), with 2% forest cover and 4% fresh-water resources. Despite these dimensions, it feeds 17% of the world population and 15% of livestock. To meet the food and nutritional needs of India's rapidly growing population, which is expected to reach 1.43 billion by 2030 and 1.8 billion by 2050, a significant increase in food grain production is required. An estimated 311 million tonnes of food grains, including cereals and pulses, will be required by 2030 and 350 million tonnes by 2050. To sustainably meet this need, efforts must focus on identifying areas of higher yield without expanding into forested regions. Land degradation affects 146.8 million hectares, with an annual soil loss of 5.3 billion tonnes, posing a serious threat to food security and environmental sustainability. Saline soils, characterized by pH <8.5, EC >4 dS/m, and ESP <15, are locally known as *Thur*, *Lona*, *Khar*, *Kari*, and *Pokhali*. Alkali soils, characterized by pH above 8.5, an EC below 4 dS/m, and an ESP >15%, have local names such as *Rakkar*, *Usar*, *Bari*, and *Chopan*. Saline-alkali soils, with a pH value below 8.5, an EC value >4 dS/m, and an ESP of more than 15%, are referred to as *Chopra* and *Rels* in local contexts. Salt-affected soil are widespread in various states of India, with notable affected areas being Gujarat (2.2 million hectares), Uttar Pradesh (1.37 million hectares), Maharashtra (0.6 million hectares), West Bengal (0.44 million hectares), and Rajasthan (0.38 million hectares). These regions struggle with challenges posed by soil salinity, which impact agricultural productivity and requires targeted interventions for sustainable land management. Salt-affected soils in India are due to primary or natural factors, including weathering of basic rocks and flat terrain, enhanced by high temperatures and low rainfall. In addition, secondary or anthropogenic salinization often occur due to poor irrigation water quality, discharge of salts near the soil surface, untreated industrial waste water. Targeted use of saline soil through improved agricultural practices represents a viable option to feed the growing global and Indian populations. Ensuring food security requires development of climate-smart practices for growing crops in saline conditions to achieve optimal productivity.

Management of salt affected soils

Management of salt-affected soils is necessary to optimize crop yield by improving soil structure, reducing the osmotic potential of soil water, and reducing the toxicity of anionic micronutrients.

Nutrient management under saline conditions

The 4R approach (right source, quantity, time and place) helps achieve sustainable nutrient management goals for saline soils. Choose fertilizers with a low salt index. Use a slow-release fertilizer to minimize salt effects. Use organic fertilizers to increase the availability of phosphorus and micronutrient through acidification and chelation. Add bio-fertilizers such as *mycorrhiza* to improve plant survival under stressful conditions and improve nutrient availability.



Impact of salt-affected soil

To prevent salt damage, reduce cost, increase profitability and reduce nutrients losses, the correct amount of fertilizers is required. Apply 25% more nitrogen fertilizer than the recommended dose. The timing of nutrient application should be synchronized with plant needs, to maximize uptake and reduce losses. In sandy soils (coarse textured), nutrients may be applied frequently in small doses to minimize leaching losses.

Microbial crop growth enhancers

ICAR-Central Soil Salinity Research Institute, Karnal has developed a low-cost microbial bio-formulation called 'CSR-BIO', which was developed on a consortium basis. It acts as a soil conditioner and nutrient mobilizer, increases the productivity of high value crops like banana, vegetables and gladiolus by 22 to 43% in sodic and normal soils.

Bio-drainage

Bio-drainage is an environment friendly and economically viable technique for overcoming the problems of waterlogging. It is a proven technology to prevent salinization in canal areas, where suitable tree species (e.g., *Eucalyptus, Poplar, and Bamboo*) are raised in the beginning to prevent waterlogging and salinization.

Application of amendments

***Gypsum*:** Gypsum serves as a versatile soil amendment, concurrently replacing exchangeable sodium with calcium in sodic soils. The recommended application is 1.1-10 tonnes per hectare, depending on soil type, slope, and climate. Typically applied after-*rabi* crops harvesting or in May-June, it benefits oilseed and pulse when used before sowing to provide sulphur and calcium. Broadcasting and incorporating gypsum into the soil to a depth of 15 cm, followed by adequate field flooding, facilitates the displacement of sodium into deeper soil zones. Be sure to follow soil testing recommendations, ensure uniform application throughout the field, and use finely ground, commercial grade gypsum with a particle size less than 2 mm

Recommended conditions for gypsum use

- ***Sodic soils***: Gypsum is most effective in sodic soils, which are high in sodium compared to calcium and magnesium. As calcium sulfate, gypsum provides calcium ions that replace sodium ions at the soil's cation exchange sites, improving soil structure and permeability.
- ***Saline-sodic soils***: In saline-sodic soils, gypsum can help reduce sodicity while managing salinity. The calcium from gypsum helps displace sodium ions, which can then be washed out through irrigation.
- ***Poor soil structure***: Gypsum can improve soil structure by flocculating clay particles, facilitating water penetration and root growth.

Table 1. Salt-tolerant grass and tree species

Grass/forage crop (Botanical name)	Trees (Botanical name)
Karnal grass (*Leptochloa fusca*), Rhodes grass (*Chloris* gayana), Dub grass (*Cynodon dactylon*), Para grass (*Brachiaria mutica*), Setaria grass (*Setaria anceps*), Anjan grass (*Cenchrus ciliaris*)	Vilayti babul (*Prosopis juliflora*), Babul (*Acacia nilotica*), Teak (*Tectona grandis*), Karanj (*Pongamia pinnata*),Shisham (*Dalbergia sissoo*), Arjun (*Terminalis arjuna*)

and a purity of approximately 70%.

Phosphogypsum: Phosphogypsum is a byproduct of the phosphorus industry widely used to remediate saline-contaminated soils. It supplies calcium sulfate ($CaSO_4·2H_2O$), which provides calcium ions (Ca^{2+}) that replace sodium ions (Na^+) bound to soil particles, thereby reducing the sodium content of the soil through ion exchange. The calcium ions also promote soil particle aggregation or flocculation, which improves soil structure and increases porosity. This improved structure allows for better water infiltration and drainage, which is critical for leaching excess sodium salts from the soil profile. In addition, phosphogypsum helps stabilize soil pH and lower it to a more neutral level in highly alkaline soils, improving the availability of essential nutrients for plants.

Sulphonated pressmud: Pressmud is a by-product of sugarcane industry. Pressmud in soil applied as both amendment and conditioner. When applied as amendment, it neutralize RSC of water, reduce salt build-up and increase crop productivity.

Conditions where gypsum is not recommended

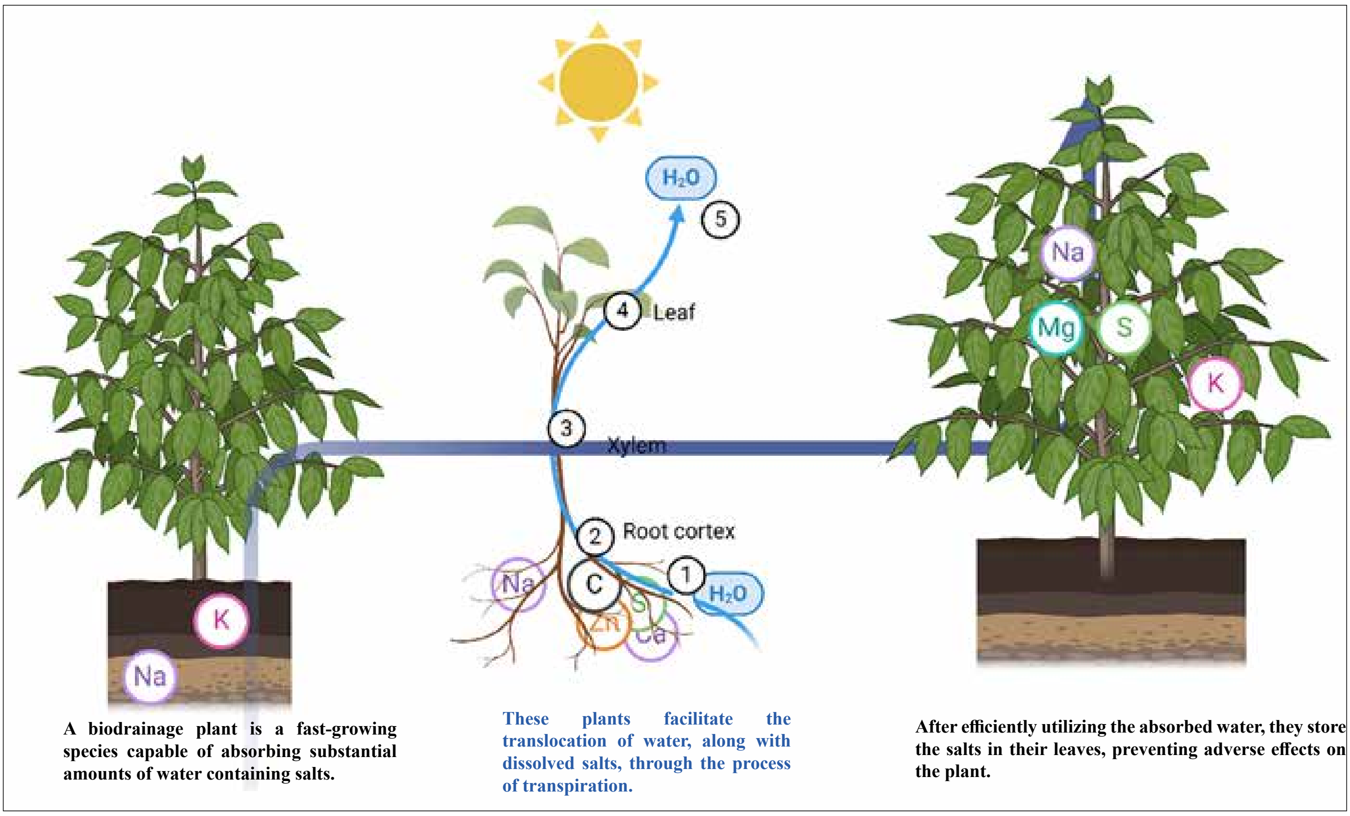
- ***Saline soils***: In purely saline soils (rich in soluble salts but not sodium), gypsum is not effective because the problem is not sodicity but total salt concentration. Leaching with good quality water is usually the preferred method for salinity control.
- ***Low-sodium soils***: If the soil does not have high sodium levels, adding gypsum may not be beneficial and may even cause an imbalance of calcium, potentially affecting plant growth.
- ***High gypsum content naturally***: In areas where soils already have high natural gypsum content, the addition of gypsum may not be necessary and may result in excessive calcium levels.
- ***Poor drainage***: If the soil is poorly drained, the application of gypsum may not be effective because the displaced sodium cannot be leached, potentially causing further salinity problems.

Agroforestry: Several trees and grass species have mechanism to tolerate high salt concentration in the root zone soil. Some of these highly salt tolerant species either exclude the absorption of salts from the soil and / or deposit the absorbed / translocated salts at points within the plant system (accumulator) which does not allow them to interfere in metabolic processes.

Biosaline agriculture: Biosaline agriculture is an innovative agricultural approach that harness

Table 2. Salt-tolerant crops

Tolerant ESP 35-50	Moderately tolerant ESP 15-35	Sensitive ESP < 15
Karnal grass (*Leptochloa fusca*) Rhodes grass (*Chloris gayana*) Para grass (*Brachiaria mutica*) Bermuda grass (*C.dactylon*) Rice (*Oryza sativa*) Dhaincha (*Sesbania aculeate*) Sugarbeet (*Beta vulgaris*)	Wheat *(Triticum aestivum)* Barley *(Hordeum vulgare)* Oat *(Avena sativa)* Lucerne *(Medicago sativa)* Turnip *(Brassica rapa)* Sunflower *(Helianthus anus)* Berseen *(T. alexandrinum)*	Gram *(Cicer arietium)* Chickpea *(Cicer arietinum)* Lentil *(Lens esculenta)* Soybean *(Glycine max)* Groundnut *(A. hypogea)* Mung *(Phaseolus aureus)* Pea *(Pisum sativum)*



Principle of salinity management by Biodrainage the ability of certain plants (salicornia, quinoa, barley) to thrive in saline conditions, allowing crops to be grown in areas with marginal groundwater. This method is particularly valuable in regions where freshwater resources are scarce or where soil salinity is high. Careful management is crucial to ensure that the introduction of salt-tolerant species does not lead to the spread of invasive species.

Salt tolerant crops

The salt tolerance of crops is a crucial factor in the management and cultivation of saline soils. Exchangeable sodium percentage (ESP) serves as an indicator of soil sodicity, influences plant performance and determines appropriate plant selection. Crops are classified into different levels of tolerance based on their ability to thrive in soils with different ESP levels. Tolerant plants with an ESP range of 35-50 can withstand high levels of caustic soda in the soil and are often used in the reclamation and management of saline soils. Moderately tolerant plants with an ESP range of 15-35 can grow in moderately sodium soils but may require special management practices to achieve optimal yields. These practices may include the use of soil amendments, appropriate irrigation techniques, and crop rotation to maintain soil health. Sensitive crops with an ESP <15 require well-managed soils with low ESP values to produce good yields. These crops such as chickpea (*Cicer arietinum*) are very sensitive to sodium and require careful soil management to ensure healthy growth and productivity.

Role of gypsum in alkali soil management

Table 3. Salt tolerant varieties of crops under different sodicity and salinity classes

Crop	Variety	Classes	
		Sodic (pH)	Saline (EC, dS/m)
Rice	CSR 10, CSR11, CSR 12, CSR13	9.8-10.2	6-11
	CSR19, CSR23, CSR27, CSR30, CSR36	9.4-9.8	6.11
	CSR1, CSR2, CSR3, CSR4, CST7-1, SR26B, Sumati	-	6-9
Wheat	KRL 1-4, WHI57	<9.3	6-10
	Raj 3077, KRL19	<9.3	6-10
Barley	DL200, Ratna, BH97, DL348	8.8-9.3	-
Indian mustard	Pusa Bold, Varuna	8.8-9.2	6-8
	Kranti, CS52, CSTR330-1	8.8-9.3	6-9
	CST609-B 10, CS54	8.8-9.3	6-9
Gram	Karnal Chana 1	<9.0	<6.0
Sugar beet	Ramonskaaya 06, Maribo Resistapoly	9.5-10	<6.5
Sugarcane	Co 453, C01341	<9.0	10

SUMMARY

India faces challenges in feeding its growing population due to land degradation and salt-affected soils. Bio-drainage and bio-saline agriculture offer solutions by using salt-tolerant plants and trees to manage waterlogging and salinity. Effective nutrient management through the 4R approach and microbial enhancements like CSR-BIO can improve crop yields. Gypsum and other amendments help reclaim sodic soils, while agroforestry with salt-tolerant species supports sustainable agriculture. These strategies are crucial for enhancing productivity on marginal lands, ensuring food security, and maintaining environmental sustainability amidst increasing demands and limited resources.

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