Agronomic Measures to Enhance Productivity in Alkaline Soil

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ABSTRACT

Soil alkalinity has a detrimental effect on agricultural sustainability and soil health. Managing and maintaining agricultural productivity in saline–alkali soils is a major challenge. These soils have high salt levels, poor structure, and low fertility, which make crop growth difficult. As a result, they pose serious risks to soil health, long-term land sustainability, and global food security. Agronomic measures refer to crop and soil management practices designed to improve soil conditions and enhance crop productivity without major engineering interventions. Salt-affected soils are widespread in arid and semi-arid regions and have existed since ancient times. The global extent of saline and sodic soils has increased markedly, reaching approximately 424 million hectares in the topsoil (0–30 cm) and 833 million hectares in the subsoil (30–100 cm) by 2021, compared to about 800 million hectares reported in 2010. This notable expansion over the past decade underscores a persistent and escalating trend in soil salinization. Crop production loss due to salinity at the national level is 5.66 million tonnes (Mt), accounting for the annual monetary loss of 8,000 Crores, at prevailing Minimum Support Prices (MSP) of different crops during 2015. AICRP on Salt Affected Soils and Use Saline Water in Agriculture, established 1972. This review highlights effective agronomic measures to enhance productivity in alkaline soils, drawing on key practices and field-based outcomes.

INTRODUCTION

The term "saline–alkali soil" refers to soils characterized by excessively high concentrations of soluble salts, which adversely affect their physical, chemical, and biological properties, ultimately constraining plant growth and productivity. At national level around 6.73 million ha (Mha) area has been characterized as salt affected, out of which 3.77 M ha is sodic and the remaining 2.96 M ha is saline. A significant proportion of sodic soils is concentrated in states such as Uttar Pradesh, Gujarat, Maharashtra which together account for nearly 80% of the country's total sodic land. In addition, soil salinity poses a serious challenge in at least 13 states, with Gujarat having the largest affected area (1.68 million hectares), followed by West Bengal, Rajasthan, and Maharashtra. Key practices such as green manuring (e.g., *Sesbania*), incorporation of farmyard manure and compost, crop rotation, use of salt-tolerant varieties, mulching, and adoption of efficient irrigation and drainage management have proven effective in improving soil conditions and enhancing crop productivity. These interventions promote better nutrient cycling, improved soil aggregation, and enhanced root growth, while supporting the long-term sustainability of agro-ecosystems.

Agronomic Measures for Alkaline Soil Reclamation:

Agronomic measures involve targeted crop and soil management practices to improve soil quality and productivity without major engineering inputs. In alkaline (sodic) soils, these approaches mitigate sodicity, enhance soil structure, and improve nutrient availability. Key practices include salt-tolerant crops, crop rotation, green manuring (e.g., dhaincha), organic amendments (FYM, compost, biochar), and efficient irrigation, leaching, mulching, and balanced fertilization to sustain soil health and crop performance.

Followings are some measures adopted for reclaiming alkaline soils -

Organic Matter Incorporation: Boost Soil Fertility

The application of organic materials has been recognized as an effective strategy for ameliorating saline–alkali soils, and straw, biochar, manure, and vinegar residue are most commonly used which helps decrease pH, improve soil structure, and increase nutrient availability, especially when combined with gypsum. The other advantages of these materials in saline water irrigated soils are in terms of reducing the volatilization losses and enhancing nitrogen-use efficiency and the retention of nutrients in organic forms for longer periods also guards against their leaching and other losses. Biochar application 0–30 t ha^{-1} significantly improved soil properties over two years (Khan *et al*, 2024).

Bio Drainage: Enhancing Drainage in Alkaline Soils

The bio-drainage concept addresses the problem of excess groundwater by utilizing the evapotranspiration capacity of deep-rooted vegetation. In this system, selected plant species draw a significant portion of their water directly from the groundwater table or the capillary fringe above it. Tree species such as *Eucalyptus* and *Acacia*, along with certain grasses, bushes, and herbs, develop extensive root systems and exhibit high transpiration rates, thereby lowering the water table. It reduces waterlogging and salinity, improving soil conditions and crop growth in alkaline soils.

Tillage Practice: Improving Soil Tilth and Structural Stability

Tillage plays a critical role in regulating soil physical conditions and soil organic carbon

(SOC) dynamics. It is primarily used to break surface crusts, prepare a weed-free seedbed, and improve soil tilth. Subsoiling also enhances water infiltration, reduces salt accumulation in the root zone, and increases soil porosity and permeability, thereby creating favorable conditions for crop growth and improving productivity in alkaline soils. These practices also aid in salt redistribution and improve nutrient use efficiency. Using a chisel plough to break hardpan layers (up to 45 cm depth) enhances water infiltration and root development.

Bio-Growth Enhancers: Revitalizing Crops in Alkaline Soils

CSR-BIO is a low-cost multiplication technology of salt-tolerant bio-growth enhancers designed to improve productivity of agri-horticultural crops in normal and sodic soils. It involves microbial consortia of beneficial microbes with broad applicability, longer shelf life, and low production cost, which enhance plant growth, nutrient mobilization, and crop establishment. The biodegradable medium further improves photosynthetic and biochemical activity, making it an eco-friendly and cost-effective solution. The technology has been adopted across 10,800 ha in 7 states by about 18,400 farmers, resulting in an average yield increase of 19.75%. The bio-stimulant acts as a nutrient mobilizer and soil vitalizer, provides protection against soil-borne pathogens, and promotes plant growth in both normal and salt-affected soil conditions (ICAR-CSSRI).

Biofertilizers: Augmenting Soil Nutrient Dynamics

Bio-fertilizers play a vital role in enhancing productivity and facilitating reclamation of alkaline soils by improving nutrient availability and soil biological activity. Beneficial rhizosphere microorganisms, including plant growth-promoting rhizobacteria (PGPR) such as *Bacillus thuringiensis*, *Pseudomonas pseudoalcaligenes*, and *Enterobacter cloacae*, along with arbuscular mycorrhizal fungi like *Rhizophagus irregularis*, *Funneliformis mosseae*, and *Claroideoglomus etunicatum*, help convert essential nutrients (N, P, Zn, Fe) into plant-available forms (Yu *et al*, 2024). Elemental sulfur, when oxidized by sulfur-oxidizing bacteria like *Acidithiobacillus*, produces sulfuric acid, which lowers soil pH and enhances nutrient availability.

Green Manuring: Grow Green, Feed Soil Mean

The application of green manure is a traditional and valuable practice to improve the fertility of saline soil. The combined use of green manuring or FYM (10 Mg ha^{-1}) with 50% or 100% NPK significantly enhanced rice yield over the sole application of chemical fertilizers. Halophytes and green manure grasses with a certain salt tolerance, such as *Sesbania cannabina*, alfalfa (*Medicago*), *Suaeda salsa*, common vetch, etc., have been successfully used to improve saline soils (Liang 2021). The application of green manure can also produce a large number of organisms that can be returned to farmland, thus providing a large amount of soil organic matter, soil nitrogen, soil phosphorus and soil potassium, all of which contribute to enhanced agricultural productivity (Li *et al*,2024).

CONCLUSION

Saline–alkali soils significantly reduce agricultural productivity due to poor structure, high salinity, and low fertility. However, integrated agronomic practices such as green manuring, organic amendments, biofertilizers, improved tillage, and bio-growth enhancers effectively improve soil health and crop yield. These measures enhance nutrient availability, soil organic matter, and microbial activity while reducing salt stress. The combined use

of organic inputs with balanced fertilizers further improves productivity. Thus, integrated agronomic management is essential for restoring soil health, sustaining productivity, and ensuring food security in salt-affected soils.

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