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Seaweed Extract: Advancing Sustainable Agriculture through Biostimulation in Saline Vertisols

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Seaweed extract is a complex biostimulant containing bioactive compounds, essential nutrients, and natural growth regulators (Table 1). It is a potential driver of future agriculture as it addresses the urgent global need for sustainable, climate-resilient, and high-yield farming practices. Unlike traditional synthetic fertilizers that prioritize short-term nutrient supply, seaweed extracts function as biostimulants, enhancing various plant physiological processes thereby optimizing the quality as well as quantity of the produce.

Table 1. Composition of sea weed extract and their functions in plant growth

Components	Key Examples	Primary Functions
Phytohormones	Auxins, Cytokinins, Gibberellins	Regulates plant growth and development
Polysaccharides	Alginate, Laminarin, Fucoidan	Improves soil health and pest and disease resistance
Minerals	K, Mg, Ca, Fe, Zn, Iodine	Supports metabolic processes
Protective Solutes	Betaines, Proline, Amino Acids	Enhances abiotic stress tolerance

Common Formats and Application

The common formats of seaweed extract available in market are as follows:

- **Liquid Concentrate:** Often applied as a foliar spray or soil drench.
- **Soluble Powder/Crystals:** High-purity forms that dissolve instantly in water.
- **Granules:** Frequently mixed into potting soil or applied as a top dressing for slow-release nutrition.

Effect of seaweed extract on yield in various crops

The application of seaweed extract significantly increases yields in different crops (Table 2) according to large-scale meta-analyses. It acts as a biostimulant, enhancing nutrient uptake and providing natural growth hormones like auxins and cytokinins.

Table 2. Impact of Seaweed extract on crop yield

Crop	Yield Increase	Specific Research Finding	Author(s)
Grapes (Table)	28.0% – 47.0%	Enhanced cluster weight, berry diameter, and antioxidant levels.	Frioni <i>et al.</i> (2025)
Mung Bean	28.8% – 30.0%	Improved seed priming and shoot growth through biostimulation.	Zulfiqar <i>et al.</i> (2025)
Garlic	21.3%	Triggered defense genes and increased bulb dry matter weight.	El-Shabrawi <i>et al.</i> (2025)

Rice	7.6% – 12.1%	Maximized grain density using combined soil and foliar delivery.	Banjare et al. (2025)
General Crops	15.17%	Global meta-analysis showing consistent gains in 72 field trials.	Zhang et al.(2024)
Potato	21.2% – 26.0%	Significant expansion in tuber size and total marketable weight.	Ammar et al. (2022)
Sugarcane	9.0% – 9.2%	Boosted plant height and sucrose content under drought conditions.	Mahmoud et al. (2021)
Soybean	57.5%	Recorded highest pod count using a 15% sap concentration.	Rathore et al. (2009)

Strategic importance of seaweed extract in future farming

The importance of seaweed extract in future agriculture are as follows:

- **Climate Change Resilience:** It significantly improves the abiotic stresses (*viz.*, extreme heat, drought, salinity, and frost) tolerance capacity of plant. For instance, brown seaweed extracts help plants accumulate osmo-protectants like proline to maintain turgor pressure during water scarcity.
- **Reduced Chemical Dependency:** Seaweed serves as a viable, eco-friendly alternative to synthetic agrochemicals. It can enhance Nutrient Use Efficiency (NUE), allowing farmers to maintain yields while reducing the overall amount of chemical fertilizer used thereby reducing the chemical footprint of the farm.
- **Soil Health Restoration:** These extracts act as soil conditioners, with alginic acid improving soil structure, moisture retention, and aeration. They also stimulate the activity of beneficial soil microorganisms and assist in the bioremediation of heavy metals in polluted soils.
- **Economic Viability:** Global demand of sea weed extract is on rise as farmers seek higher marketable yields. In India, seaweed cultivation is being promoted as a sustainable livelihood, and is thus becoming a cornerstone of the "blue economy."

Beneficial effects of seaweed extract in saline Vertisols:

- **Mitigating Osmotic Stress:** High salinity in Vertisols makes it difficult for roots to absorb water due to physiological drought. Seaweed extracts contain betaines and proline, which help plants maintain internal water balance and cell turgidity even under hypertonic conditions.
- **Improving Soil Structure:** Vertisols are prone to compaction and poor aeration when wet. The alginic acid in seaweed acts as a soil conditioner, promoting the flocculation of clay particles to improve porosity and water infiltration.
- **Balancing Nutrient Uptake:** Salinity often causes higher levels of sodium (Na⁺) to accumulate. Seaweed biostimulants help plants selectively absorb beneficial ions like Potassium (K⁺) and Calcium (Ca²⁺), maintaining a healthier K⁺/Na⁺ ratio necessary for growth.
- **Boosting Antioxidant Defense:** Salt stress triggers the production of harmful reactive oxygen species (ROS). Seaweed extracts activate antioxidant enzymes such as catalase (CAT) and superoxide dismutase (SOD) to protect plant cells from oxidative damage.

Conclusion

Thus, seaweed extracts are expected to be a cornerstone of next-generation agriculture. By merging soil health restoration with crop stress mitigation, they act as a potential pathway toward a more resilient and productive global food system.

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