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Nutrient-Smart Oilseeds: Harnessing Organic Inputs and Biostimulants for a Golden Future

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Oilseeds support global edible-oil supply, nutritional security and farm incomes, yet productivity gains have often relied on rising doses of mineral fertilizers, leading to diminishing returns and concerns over soil health. This review examines a nutrient-smart approach that integrates organic amendments, biofertilizers, biostimulants and balanced mineral nutrition to improve oilseed yield, oil quality and resource-use efficiency. Farmyard manure, compost, vermicompost, crop residues and biochar enhance soil organic carbon, water retention and nutrient availability, while beneficial microorganisms improve nutrient uptake and cycling. Biostimulants such as seaweed extracts, humic and fulvic substances, amino acids and microbial consortia promote root growth, stress tolerance and reproductive development. Precision agriculture and Artificial intelligence-based tools can further optimize these inputs according to field specific requirements. Integrated nutrient management can reduce excessive dependence on chemical fertilizers while maintaining productivity and profitability. It also supports soil biodiversity, nutrient-use efficiency and resilience against drought and other climate stresses. Combining traditional organic resources with modern biological and precision technologies offers a practical pathway for sustainable intensification of oilseed production. Such nutrient smart strategies can strengthen farmer income, improve resource conservation and contribute to India's goal of greater edible-oil self-reliance.

Keywords: oilseeds, organic inputs, biostimulants, Integrated nutrient management, biofertilizers, soil health, precision agriculture

Introduction

Oilseed crops such as Groundnut, Soybean, Rapeseed-Mustard, Sunflower, Sesame and Safflower underpin the world's edible-oil supply and are central to food and nutritional security, rural incomes and agro-industrial value chains. Rising per-capita oil consumption and limited scope for area expansion mean that future gains must come chiefly from productivity improvement on existing land. Much of the historical yield growth in oilseeds has depended on progressively larger doses of nitrogen, phosphorus and potassium fertilizer, a trajectory associated with plateauing responses, secondary and micronutrient deficiencies, and gradual erosion of soil organic matter and biological activity (Rehman *et al.,* 2022). Continued reliance on this single-input model constrains long-term sustainability and profitability. "Nutrient-smart oilseed production" reframes the problem: rather than adding more of the same nutrients, it combines organic inputs, biological inoculants and targeted biostimulants with balanced mineral nutrition to improve nutrient availability, uptake efficiency and soil health simultaneously, while containing environmental losses.

Organic Inputs: Rebuilding the Soil Foundation

Farmyard manure (FYM), compost and vermicompost are key sources of organic nutrients in oilseed systems. They provide nutrients gradually while improving soil organic carbon, structure, water-holding capacity and microbial activity. Crop-residue recycling and green manuring further return carbon and nutrients to the soil. Biochar acts as a stable amendment that improves nutrient retention, soil porosity and nutrient-use efficiency, although its effectiveness depends on feedstock, application rate and soil type (Bana *et al.,* 2024).

Biofertilizers and Beneficial Microorganisms

Microbial inoculants such as *Rhizobium*, *Azotobacter*, *Azospirillum*, phosphate- and potassium-solubilizing bacteria, mycorrhizae and PGPR improve nutrient availability and uptake. They fix nitrogen, solubilize nutrients and promote root growth, thereby increasing nutrient-use efficiency. Combining these biofertilizers with organic amendments can further improve soil biological health and sustain productivity in oilseed-based systems (Aloo *et al.,* 2022).

Biostimulants: The New Nutrient Frontier

Biostimulants such as seaweed extracts, humic and fulvic substances, amino acids, protein hydrolysates and microbial consortia mainly enhance plant physiological processes rather than directly supplying nutrients. They can improve root growth, chlorophyll, nutrient uptake, stress tolerance and yield. In oilseeds, their application during flowering and pod/seed filling can support photosynthesis, reduce drought and heat stress, and promote oil accumulation (Li *et al.,* 2022).

Integrated nutrient Management

Productivity and profitability from organic inputs and biostimulants are greatest when combined with soil-test-based balanced fertilization rather than replacing mineral fertilizers. In Indian mustard, reduced NPK combined with vermicompost, zinc and *Azotobacter* can maintain or improve yield and economic returns. Since oilseeds are highly responsive to sulphur, integrated nutrient management should include S, Zn and B, with foliar micronutrients where needed. This approach improves nutrient-use efficiency, soil fertility, yield stability and oil quality under variable weather.

Crop Specific and climate - smart Considerations

Nutrient-smart packages must be tuned to crop and agro-climatic context. Groundnut and soybean, as legumes, benefit disproportionately from rhizobial inoculation and phosphorus management; rapeseed-mustard and sunflower are more sulphur- and boron-responsive, with direct consequences for oil yield and quality. Under drought, heat and salinity stress — conditions projected to intensify with climate change — organic matter build-up improves soil water-holding capacity, while biostimulants such as seaweed extracts and humic substances help maintain photosynthesis and membrane stability, translating into a more climate-resilient production system overall (Deolu-Ajayi *et al.,* 2022).

Precision Nutrient Management

Precision tools such as soil testing, remote sensing, sensors, GIS mapping and variable-rate application help optimize organic and biostimulant inputs according to field variability. These technologies improve nutrient-use efficiency and reduce input wastage, while AI-based decision support enables the right input, rate, time and place for efficient oilseed production (Cai *et al.,* 2025).

Economic and Environmental Benefits, and the Golden future

Economically, integrated nutrient management can lower unnecessary fertilizer expenditure, stabilise yields and improve oil quality, translating into higher and more resilient farm incomes. Environmentally, it builds soil organic matter and biological activity, reduces nutrient runoff and leaching, and supports broader ecosystem services central to sustainable

food production (Rehman *et al.,* 2022). For oilseed agriculture, a genuinely "golden future" is one in which higher productivity, reduced import dependence on edible oils, and long-term soil-health restoration advance together, rather than the first being achieved at the expense of the other two.

Challenges and Future Prospects

Variable quality and inconsistent availability of organic inputs and biofertilizers, limited farmer awareness, product standardisation gaps for biostimulants, and thin field-level validation across agro-climatic zones remain real constraints. Addressing them will require enforceable quality standards, region- and crop-specific recommendation packages, expanded farmer training and digital advisory services, and sustained long-term field trials linking research, extension and farmers.

Conclusion

Nutrient-smart oilseed production should move beyond fertilizer-centric farming toward an integrated system that combines balanced mineral nutrition, organic inputs, beneficial microorganisms, biostimulants, precision technologies and soil-health management. Evidence across groundnut, mustard and other oilseed systems shows that this integration delivers higher productivity, better oil quality, healthier soils and greater climate resilience while narrowing input losses and improving farmer profitability. Anchoring oilseed intensification in soil health rather than input volume is the more credible route to sustainable edible-oil security and a genuinely golden future for oilseed agriculture.

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