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BIO-STIMULANTS IN MODERN AGRICULTURE

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INTRODUCTION

Bio-stimulants function as advanced agricultural solutions which boost plant development through their ability to activate native biological systems instead of providing direct nutrient resources. The substance functions as a fertilizer which enables plants to metabolize better and take up nutrients more effectively while withstanding environmental pressures. Modern agriculture has seen increased use of bio-stimulants because environmental issues and soil degradation and sustainable crop production requirements have emerged as urgent problems. The natural substances derive from seaweed extracts and humic substances and beneficial microbes and amino acids to help plants grow throughout their development stages. Bio-stimulants serve an essential function which enhances soil health through their ability to boost microbial activity and improve the structural qualities of soil. The system enables farmers to reduce their usage of chemical fertilizers while achieving higher efficiency in resource management which fosters environmentally friendly agricultural practices that adapt to climate challenges. Bio-stimulants function as essential elements which support environmentally friendly agricultural techniques that utilize advanced technology across all regions of the globe.

2. Definition and Concept

Definition:

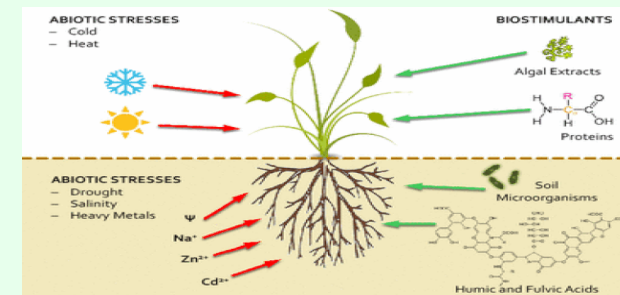
Bio-stimulants are substances that include beneficial microorganisms which get applied to plants and seeds and soil to boost plant growth and help plants absorb minerals and withstand environmental stress and improve their total agricultural production. The fertilizers supply essential nutrients to plants while these substances enhance the plants ability to use their existing resources through improved efficiency.

Concept:

Bio-stimulants function by influencing plant physiological and biochemical processes. They activate natural development pathways which proceed through normal plant growth and development processes.

Bio-stimulants activate plant metabolic functions which lead to increased plant growth. Bio-stimulants enable plants to absorb and use nutrients more effectively. Bio-stimulants help farmers achieve sustainable agricultural practices because they decrease the need for chemical fertilizers.

Modern farming systems benefit from Bio-stimulants because of their distinctive characteristics which include all these unique features. Bio-stimulants possess non-toxic qualities which make them safe for both human health and the environment. Bio-stimulants work together with organic farming methods. Bio-stimulants help plants withstand drought and salinity and extreme temperatures.



Source: <https://www.biobasedpress.eu/>

3. Historical Background and Development

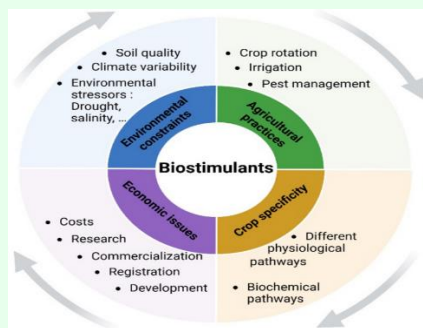
Farmers used natural materials like compost and farmyard manure and plant extracts to improve soil fertility and their crop yield which established the basis for bio-stimulant development. The practices which existed before scientific definitions arose served as the basis for modern bio-stimulant research because they demonstrated how natural materials help improve plant health and productivity.

The scientific field of agriculture developed through its research into bio-stimulants which scientists began developing. The 20th century brought a significant scientific advancement with the discovery of plant growth regulators that include auxins together with gibberellins and cytokinins because these hormones control plant development through their impact on plant growth. Scientists created products which could either produce or enhance the natural functions of plants.

Scientists during the late 20th century conducted research on marine resources which resulted in the discovery of seaweed extracts used as bio-stimulants. The extracts contain micronutrients and vitamins and natural hormones which make them powerful tools for enhancing plant health and their ability to withstand stress.

The 21st century has witnessed rapid progress in biotechnology and microbiology which resulted in the creation of microbial bio-stimulants that include plant growth-promoting rhizobacteria and mycorrhizal fungi. The development of nano-based bio-stimulants through nanotechnology innovations has created products that achieve better results because they deliver specific treatment benefits.

Today, bio-stimulants function as essential elements of precision agriculture which helps sustainable farming systems to achieve better productivity and improved resource efficiency and environmental protection.



Source: <https://link.springer.com/>

4. Classification of Bio-stimulants (Expanded)

Bio-stimulants are classified into three main categories which they originate from their composition and their functional mechanisms. The major categories are as follows:

1. Humic Substances

These substances consist of humic acid and fulvic acid which scientists extract from decomposed organic materials. The substances play an essential role to enhance soil structure since it increases cation exchange capacity and makes nutrients more accessible. Humic substances also stimulate root growth and improve water retention in the soil.

2. Seaweed Extracts

Bio-stimulants which come from seaweed are extracted from brown and red and green marine algae. The seaweed contains natural plant growth regulators which include auxins and cytokinins and gibberellins together with essential micronutrients and vitamins. The extracts of this product promote plant growth while they improve plants' ability to handle stress and they boost both crop quality and quantity.

3. Protein Hydrolysates and Amino Acids

These bio-stimulants are obtained from plant or animal proteins through the process of hydrolysis. The substances contain amino acids and peptides which enable metabolic processes to occur while they help plants absorb nitrogen and grow when they experience environmental stress. The products work effectively to help plants restore their health after they experience environmental stress.

4. Microbial Bio-stimulants

This group contains beneficial microorganisms which include plant growth-promoting rhizobacteria (PGPR) and

mycorrhizal fungi. The microorganisms provide three benefits to plants because they help plants access nutrients and develop better root systems while also making plants more resistant to both organic and environmental threats. The microorganisms help to maintain soil health by their ability to boost microbial diversity in the soil.

5. Biopolymers

Chitosan and alginates serve as biopolymers which function as natural substances to boost plant defense systems and support plant growth. The substances enhance seed germination rates while they activate plant protective systems and help plants cope with environmental challenges.

5. Mechanism of Action

Bio-stimulants create effects on plant growth and development through multiple linked physiological and biochemical and molecular pathways. Bio-stimulants differ from fertilizers because they do not provide direct nutrient delivery but instead improve plant growth through better internal operations which lead to enhanced productivity results.

Bio-stimulants create their main impact through their ability to boost root growth which produces roots that extend throughout the soil. This system enables plants to search for water resources and nutrient supplies throughout a wider area of soil. The process enhances nutrient absorption and movement because it boosts cell membrane permeability while it activates nutrient transport proteins which results in better nutrient absorption efficiency.

Bio-stimulants increase chlorophyll levels which boost photosynthetic efficiency and result in greater biomass production. The compounds activate different

enzymes that drive metabolic pathways which results in improved growth and development.

The mechanism functions through its ability to control plant hormones which include auxins and cytokinins and gibberellins. The balance of hormones enables the body to control biological functions which include cellular replication and growth and the process of flowering and fruiting.

Bio-stimulants help plants withstand abiotic stress conditions which include drought and salinity and extreme temperature conditions. They help in osmotic adjustment and antioxidant activity and protection of cellular structures under stress conditions. Bio-stimulants at the molecular level can affect gene expression which governs both growth processes and stress response mechanisms. The multi-dimensional action of these elements improves plant resilience and productivity and sustainable development of agricultural systems.

6. Role in Crop Production

Bio-stimulants play a significant role in enhancing crop production through their ability to improve all growth stages and physiological functions of plants. They serve as essential components that farmers use to achieve sustainable agricultural practices which result in increased productivity and improved crop quality.

Bio-stimulants serve to enhance seed germination rates together with the early growth strength of young plants. The seeds which received treatment showed a higher rate of germination because they developed with greater consistency which led to improved establishment of the crops. Bio-stimulants assist plants in their vegetative stage by enhancing their growth through the promotion of cell division and elongation together with root development which creates stronger and better plants.

Bio-stimulants enhance plant flowering and fruiting activities through their control of plant hormone levels and their ability to boost nutrient availability. This leads to better fruit set, reduced flower drop, and improved reproductive efficiency. The result leads to substantial improvements in both yield and quality, which includes superior product dimensions together with enhanced visual appeal and flavor and nutritional content.

Another important function enables plants to use applied fertilizers with greater efficiency, which leads to reduced fertilizer waste and lower expense for nutrient inputs.

Bio-stimulants receive extensive usage across various crop categories which include cereals and pulses and oilseeds and fruits and vegetables. The essential role of these substances in contemporary agricultural systems stems from their ability to enhance crop yield while they help farmers obtain fewer chemical fertilizers and better soil quality through their use.

7. Methods of Application

The application of bio-stimulants requires multiple methods which depend on the specific crop, its current growth stage, and the intended results. The correct application method results in optimal performance while crops show improved response.

1. Seed Treatment

This method involves treating seeds with bio-stimulants before their actual planting. The process assists with seed germination improvement while it strengthens seedling growth and supports consistent agricultural output. Seed treatment also strengthens early root development and improves resistance to initial stress conditions.

2. Soil Application

Bio-stimulants get applied to soil through three methods which include broadcasting, fertilizer mixing, and irrigation water application. This method enhances soil structure while it boosts microbial activity and raises nutrient levels in the soil. The process enhances root development while it boosts the soil's capacity to retain water.

3. Foliar Spray

Bio-stimulants get applied through a spraying process which targets plant leaves. The method provides fast absorption which leads to immediate effects during the plant's crucial growth periods. The process effectively solves nutrient deficiencies while it boosts photosynthesis and stress resistance capabilities.

4. Fertigation

Bio-stimulants get applied through drip or sprinkler irrigation systems during the fertigation process. The system enables accurate delivery of bio-stimulants which targets the root area. The system provides consistent material distribution which decreases material loss while it boosts nutrient absorption success.

8. Advantages of Bio-stimulants

Bio-stimulants serve multiple beneficial functions for contemporary agricultural practices which make them essential elements of environmentally friendly farming methods. The practice of using these materials leads to enhanced agricultural output while safeguarding natural ecosystems.

The primary benefit of bio-stimulants lies in their environmentally safe and sustainable characteristics which result from their production through natural processes that create minimal environmental damage.

The products assist in decreasing environmental contamination which results from farmers applying excessive amounts of chemical fertilizers and pesticides.

Bio-stimulants enhance both soil structure and soil fertility through their ability to boost organic matter levels while they promote beneficial soil microorganisms to thrive. Soil properties such as aeration and water retention and nutrient availability improve through this process.

The primary advantage of this product is that it helps to improve both the quantity and quality of harvested crops. Bio-stimulant treatment results in better plant growth for crops which leads to more flowers and fruits and higher nutritional value.

Plants gain better protection against stressful conditions because of their improved ability to handle difficult situations which include drought and salinity and extreme temperature changes. The current situation requires this capability because of the ongoing climate transformations.

9. Constraints and Challenges

The use of bio-stimulants faces several challenges that limit their widespread adoption. A major issue exists because farmers lack awareness about the advantages and correct application techniques of these products. Inconsistent product quality which results from variations in raw materials and manufacturing processes decreases product reliability while increasing uncertainty for farmers. Scientists face obstacles which limit their ability to conduct effective research due to the lack of standardized scientific methods and untested agricultural methods. The high price of certain products creates financial barriers which prevent small-scale farmers from using them. There is also a need for proper guidelines and regulatory frameworks to ensure quality and safe usage.

Organizations need to resolve these obstacles because they need to implement solutions that will help their organization grow.

10. Future Prospects and Conclusion

Future Prospects:

Bio-stimulants possess essential capacity to create sustainable agriculture solutions which will determine upcoming agricultural methods. The development of nano bio-stimulants will create better results because these products deliver active compounds through specific methods and maintain control of their release. The system will utilize precision farming technologies which include sensors and drones and data-driven operational systems to achieve correct agricultural implementation which will boost efficiency. The increased adoption of these practices in organic farming will advance sustainable agricultural methods. Ongoing research on microbial consortia aims to develop more effective combinations of beneficial microorganisms for improved soil and plant health. Bio-stimulants will support climate-resilient agriculture by enabling crops to survive abiotic stresses which include drought and salinity and temperature extremes.

CONCLUSION

Bio-stimulants provide sustainable agricultural systems with an environmentally safe method to increase crop yield. The treatment promotes plant development while enhancing their ability to withstand stress and improving soil health through increased beneficial microbial activity. The system improves nutrient utilization because it enables users to decrease their chemical fertilizer consumption while reducing their harmful effects on the environment. The application of these practices enables farmers to build climate-resistant agricultural systems

that maintain soil health and productivity. Bio-stimulant adoption will become essential for food security because it will help develop efficient agricultural systems which protect the environment.