



Biostimulants towards Soil Health Improvement: A Review

Nasir Bashir Naikoo¹, M.H. Chesti¹, M. Auyoub Bhat¹, Aamir Hassan Mir¹,
Owais Bashir¹, Tauseef A. Bhat², Mohd Salim Mir², Zakir Amin³, Audil Gull⁴, Liyaqat Ayoub⁵

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ABSTRACT

Biostimulants are organic products made up of peptides and amino acids which are readily available to plants. Changes in farming are being caused by agro-ecological practices that take into account biodiversity and the way soil works. In agriculture, biostimulants can be used to keep plant growth and productivity without use of chemicals. Biostimulants can be used to identify and enhance specific soil microorganisms and they can help them grow and thrive. Soil microbial activity and the activity of important plant growth hormones or enzymes are also considered to help crops grow and yield more. The words “soil health” and “soil tilth” aren’t new in the world of farming. Many factors, many of which are biological, affect the health of soil. With the application of biostimulants soil health gets improved by influencing soil health indicators. Chemical fertilizers affect soil environment, which ultimately affects the human and animal lives. Microbes in the soil called arbuscular mycorrhizal fungi (AMF) play an important role in maintaining long-term soil fertility by forming mutualistic relationships with the roots of food crops, which help them, grow and thrive. Plants thrive under biotic and abiotic stress, due to the activation of defense mechanisms through these substances. Biostimulants from seaweed extracts are very popular because they help plants to grow and be more resistant to stress. Repeated applications of biochar could make the soil more carbon-rich and productive, which could lead to more crop biomass and biological carbon sequestration over time. This review summarizes the description of biostimulants and their role in soil health.

Key words: Biostimulants, Soil health, Seaweed extracts.

Products like biostimulants are seen as an entirely new generation of agricultural tools for sustainable farming. The health of a country's soil is a critical and delicate resource because it determines the overall yield of a country's crops, which feeds their population. It's a serious problem when a country has to rely on outside sources to meet its population's demand for food and other agricultural products (Kapoor *et al.*, 2021). Agricultural productivity has enhanced in India as a result of the Green Revolution in order to meet public demand and to sell crop products commercially. With chemical inputs like fertilizers, pesticides, fungicides, insecticides, nematicides and weedicides as well as intensive irrigation practices of green Revolution helped achieve the goal to some extent. When crop yields start declining despite fertilizer application following the Green Revolution, this indicates that the soil has lost its fertility. Beneficial soil organisms can't live there if there are toxic chemicals in the soil. The pollution of groundwater and air, as well as the harm they caused to human and animal health, were all additional consequences of these chemicals. The need to restore soil health and the natural environment is therefore pressing. Soil and environment can be nourished by using natural fertilizers such as biofertilizers, vermicompost, farmyard and green manure and biopesticides, all of which can be used in a sustainable way to increase crop productivity (Srivastava *et al.*, 2020). An agroecosystem's viability and the services it provides to humanity depend on healthy soil, which must be managed in harmony with environment. Due to human activity, the soil ecosystem and its services have been adversely affected. Soil ecosystems do indeed serve as the basis for

¹Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology-Kashmir, Srinagar-190 001, Jammu and Kashmir, India.

²Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology-Kashmir, Srinagar-190 001, Jammu and Kashmir, India.

³Division of Plant Pathology, Sher-e-Kashmir University of Agricultural Sciences and Technology-Kashmir, Srinagar-190 001, Jammu and Kashmir, India.

⁴Division of Genetics and Plant Breeding, Sher-e-Kashmir University of Agricultural Sciences and Technology-Kashmir, Srinagar-190 001, Jammu and Kashmir, India.

⁵Division of Entomology, Sher-e-Kashmir University of Agricultural Sciences and Technology-Kashmir, Srinagar-190 001, Jammu and Kashmir, India.

Corresponding Author: Nasir Bashir Naikoo, Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology- Kashmir, Srinagar-190 001, Jammu and Kashmir, India. Email: nasirnaik3@gmail.com

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all life on Earth, providing food, shelter and oxygen. There are a wide variety of microorganisms that thrive and maintain nutrients in soil. Nutrients in soil are essential to the health of plants and the foundation of agriculture on which people's

livelihoods depend and the health of the soil is a determining factor in performance. Plant growth and yield are directly influenced by the quality of the soil in which they grow and are true regardless of how the soil is cultivated. To maintain soil health, it is important to consider everything from its depth to its texture and its porosity to its density and its ability to flow water. Soil health is the capacity of soil to sustain the living community which essentially depends on soil physical, chemical and biological environment. Soil health indicators given in (Fig 1) are frequently being benefitted due to application of biostimulants.

It is the aggregates (sand, silt, clay) that make up soil and their association that forms peds (larger units of structure). Aeration, water movement, heat conduction, resistance to erosion and the growth of plant roots are all influenced by the structure of the soil, which in turn is affected by soil water content. Biostimulants are classified into four categories viz., extracts, acids, microbials and other natural products (Fig 2).

Seaweed extract as biostimulant

Overall, it is affirmed that algae are non - vascular plants with vulnerable reproductive structures which produce oxygen and photosynthesize. There are 30,000 to more than 1 million species of these “simple organisms,” according to various estimates (Kocira *et al.*, 2019). Algae can be divided into macro and micro varieties, this article, focuses on macro algae (also known as seaweed) and micro algae (phytoplanktons). Littoral zone seaweeds go by the names of greens, browns and reds, depending on their colour. From hot tropics to “icy polar regions,” these plants grow along the world’s coastlines in every climatic zone (Kaur I. 2020). Many people and businesses use and benefit from seaweed liquid fertilizer (SLF), such as dried seaweed mulch or dried seaweed meal. For millennia, seaweeds have been used for this purpose. The extracts were eventually accepted as liquid fertilizers and considered as a tonic due to their medicine-like properties that promoted plant growth.

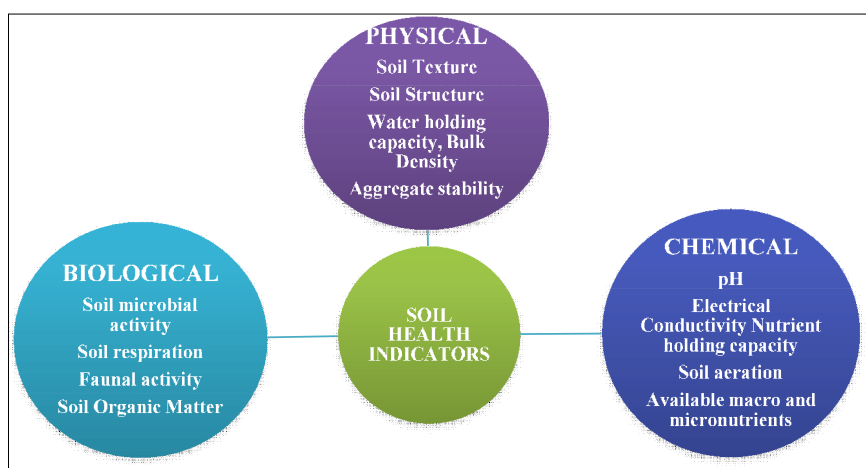


Fig 1: Soil health indicators.

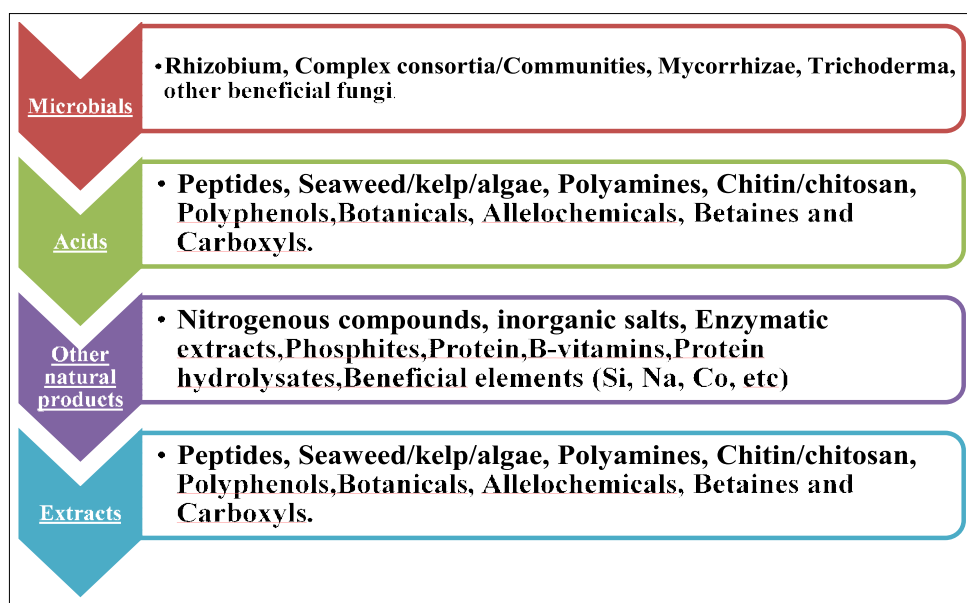


Fig 2: Classification of biostimulants.

Seaweed extracts, on the other hand, were argued to be plant biostimulants because of their high levels of nitrogen, phosphorus and potassium (Zhang and Schmidt, 1997). Based on their origin and content, biostimulants can be divided into three major categories: organic, inorganic and synthetic (Yakhin *et al.*, 2017). In addition to HS, HCP and amino acid-containing products, there are humic substances. Active components in seaweed extract are the most investigated among biostimulants from numerous sources. Now there is commercially available seaweed liquid extracts made from seaweed biomass using a variety of production methods, such as alkaline or acid hydrolysis, cellular disruption under pressure, or fermentation (Craigie, 2011). Horticulturists, farmers and orchardists use them as biostimulants to boost plant growth and fruit production. An extract of brown alga, *Ascophyllum nodosum* (L.), has been commercialized as Acadian to improve various plant growths attributes under normal and stressful conditions. It has been shown that Kelpak, a brown seaweed extract, can be used as a biological stimulant. Eckol, a new phlorotannin found in Kelpak, has auxin-like properties and has been shown to promote plant growth in a number of studies. Instead of toxic, polluting chemical fertilizers, seaweed extracts are biodegradable and contain nutrients essential to plant growth (Selvam and Sivakumar 2013, 2014). The efficiency of various liquid fertilizers is thought to be enhanced by additional plant-specific molecules found in seaweed extracts. When plants are exposed to seaweed extracts, bioinformatics studies have identified plant genes that are activated (Jannin *et al.*, 2013). Extracts can also enhance soil structure, water retention capacity and soil microbes, among other things (Nair *et al.*, 2012). Compounds that help plants cope environmental stress and improve their effectiveness are widely known. The extraction of various macro-algae species from seaweed yields seaweed extracts, which is based on extraction method, can yield a variety of biologically active compound mixtures. As a result, plant responses can be unpredictable, making it difficult to pin down the exact mechanism by which an effect occurs. There is a growing interest in uncovering these resources' untapped potential by employing multiple disciplines and high-throughput strategies, incorporating plant physiology with molecular biology and plant agronomy as well as multi-omics methodologies. New perspectives on the idea of seaweed extract (SE), based on existing scientific understanding and taking into account of both academic and industrial claims in accordance with market requirements, are the goal of this review. Analysis of extraction process and its impact on nutrient uptake and their role in biotic and inorganic stress tolerance are examined, with emphasis on the metabolic and genetic mechanisms. The possible impact of the recently implemented plant biostimulant regulation on the seaweed extract industry is acknowledged.

Humic acid as biostimulant

Humic substances extracted from various sources have been extensively found to boost iron nutrition of crop plants. In soil sediments, the existence of humified organic matter will further help to build up a supply of Fe for plants that exude metal ligands and provide Fe-HS complexes that can be used directly by plant Fe uptake. Research shows that HS can stimulate the transcriptional and post-transcriptional mechanisms that are involved in Fe acquisition. Fe-HS complexes, instead of other naturally or synthetically derived chelates, may have modified the distribution and allocation of Fe in the plant. Treatment with HS influenced root morphological characteristics and plant membrane activities related to primary and secondary metabolism, hormonal and reactive oxygen balance and nutrient acquisition. There are many ways in which soil- or exogenously supplied sulfonated Fe-HS complexes can influence iron uptake; including providing an easily accessible form of iron and directly affecting plant processes. It may also be considered eco-friendly to use Fe-HS from a variety of sources, sizes and solubilities for crop fertilization (Zanin *et al.*, 2019). Soil HS are generally thought to be the result of degradation and re-synthesis of organic material, particularly plant residues, in soil. From phenolic compounds that have been degraded by microbial activity, polymerization/polycondensation has resulted in them. Due to their aromatic nature, soil hydrocarbons have a high molecular weight (MW). Organic molecules, including amino acids and aliphatic chains, can be incorporated during condensation process to form substances of medium-high molecular weight. Hydrophobic interactions and hydrogen bonds between groups of small humic molecules may also contribute to soil HS (Piccolo, 2002). Depending on the pH, ion concentration and mineral content of soil solution, humic molecules of various molecular masses may form a supramolecular network (Esfahani *et al.*, 2015). All of these procedures imply the existence of a wide range of HS molecular sizes and solubilities in soil profile. It is because of this some fractions can have direct interactions with plant roots. The dissolvable HS is part of DOM. After extraction from soil with alkaline solutions, humic acids (HA) and fluvic acids (FA) can be functionally separated based on their water solubility (Stevenson, 1994). Since soil is so diverse, the molecular structure of soil HS is not known. However, a direct or indirect link between these compounds and measured effects on plant growth and nutrition is undeniable, however. Soil and rhizosphere properties, plasma membrane (PM)-bound activities and plant metabolic processes, are examples of indirect effects. Instead, it has been suggested that the extraction procedure used to extract them is to blame for their appearance in soils, rather than natural organic matter evolution itself (Lehmann and Kleber, 2015). Molecules resembling humic acids have been isolated from water, peat water extracts, as well as soil leachates which have been treated with mild extractants (Olk *et al.*, 2019). Even though humic molecules can form Fe complexes with each other,

organic materials from all across the world can provide plants with a significant amount of Fe, despite the fact that their chemical structures still seems to be controversial. Plants could also benefit from the formation of Fe-HS complexes, which are soluble and can be used directly. The capacity of HS to complex metals and impacts the mechanisms of nutrient uptake and plant metabolic activity provides evidence for a multidimensional interference of organic fractions in Fe nutrition. An emphasis is placed on water-soluble fractions of HS in plant Fe nutrition because of their chelating and biostimulant effects.

Biostimulants and remediation of polluted soils

Enzymatic hydrolysis has recently been used to obtain various biostimulants, including those derived from sewage sludge, chicken feathers, okra and rice bran. They are applied in bioremediation of soils contaminated by numerous pesticides such as chlorpyrifos, MCPA, oxyfluorfen, 2, 4-D, dicamba (Orts *et al.*, 2017). Crops are harmed by Imazamox soil application and it is also widely used to treat organisms other than those targeted by the drug Ortiz-Botella *et al.*, (2022). There was no more than a 25% decrease in soil microbial biomass-C when this herbicide was applied @ 2.5 L ha⁻¹, according to Vischetti *et al.* (2002). Subsequently, Vasic *et al.* (2019) estimated those 60 days after applying herbicide, total soil bacteria and amino heterotrophic microorganism contents decreased by 0.048 kg ha⁻¹. Because of lack of data on how imazamox affects soil biochemistry, more research is needed to better understand how this herbicide affects soil biochemical activity. Utilizing two enzymes (subtilisin and flavourzyme) in the bioremediation of soil that had been contaminated with imazamox, this paper set out to determine the behavior and impact on soil biological properties of a new biostimulant derived from okra. When compared to another biostimulant derived from okra, the results show that this is more effective (subtilisin). Carob germ enzymatic extract (CGEE) and wheat condensed distiller soluble enzymatic extract (WCDS-EE) were used as biostimulants to enhance dehydrogenase, phosphatase and glucosidase activities and to prevent

atrazine mineralization. The protein/carbohydrate ratio content of both extracts influences their extender capacity. Fertility and atrazine persistence, both of which are associated with increased soil activity, increased as a result of the increase in microbial availability. As an indicator of total metabolic activity of soil microflora, DHG is a group of intracellular enzymes found in active bacteria and other microorganisms in soil. Due to the fact that PHA and BGA are hydrolytic enzymes associated in P and C cycling, they are extremely sensitive predictors of stimulated changes in soil properties. In soils, microbial adaptation and C and N availability are known to influence atrazine biodegradation, which has been studied for years (Alvey *et al.*, 1995). Organic amendments can help speed up the breakdown of herbicides by promoting microbial activity (Entry *et al.*, 1995). It can be concluded from the data gathered that atrazine had no effect on enzyme activity over the time.

Arbuscular mycorrhiza and soil aggregation

Plants, numerous microflora communities and their interactions are all involved in the process of soil aggregation, which is governed by a variety of abiotic factors such as soil texture. For root development, plant emergence, water filtration and a diverse variety of soil characteristics as well as ecosystem process rates, soil aggregation is critical. In soil degradation and land restoration investigations, prior knowledge of soil aggregation is vital (Lehmann *et al.*, 2020). An iron-containing, thermo-stable glycoprotein, glomalin, is excreted from the hyphal exudate of AMF and acts as an aggregate binder material, which led to the aggregate stability (Fig 3). Glomalin is found in soil in large quantities, usually in the range from 1-10 mg g⁻¹ of soil (Bansal *et al.*, 2022). Soil organic matter is protected by aggregates from exposure to environmental factors.

The use of chitin as biostimulant

One of the most widely used and versatile polymers of β -1, 4-N-acetylglucosamine, chitin is primarily obtained commercially from prawn and crab shells (Sharp, 2013). Sucrose is the most abundant polysaccharide in living

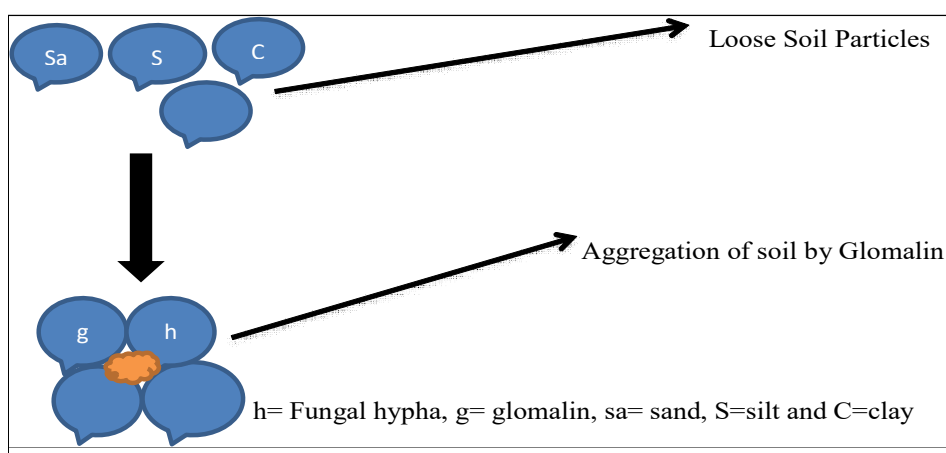


Fig 3: AMF and soil aggregation.

organisms and cellulose is the second most common. Chitosan's hydrophobic nature and reduced water solubility and a number of organic solvents limit its functional applications in agriculture and considerably influence the biological properties of chitin. As a result, chemical reactions and the derivatives they produce are critical to better utilization and commercialization of this biopolymer (Shahrajabian *et al.*, 2021). Vegetable crops have been

studied extensively for their biostimulating properties. Complex structures, including the protein/CaCO₃/chitin nanofiber complex, that enhanced plant growth in hydroponically grown tomatoes, or polymeric chitin nanofibers, that demonstrate eliciting activities, have been proposed to overcome the disadvantages of chitin (Dewang and Devi 2022). Tomato growth and nutrient use efficiency have improved. Increasing crop performance was

Table 1: Impact of biostimulants on soil health indicators.

Soil health indicator	Biostimulant	Biostimulant influence	Impact on soil health	References
(a) Available N, P, K, Mg, Ca, Cu, Fe, Mn, Mo, Zn	Biochar	(a) ↑	+ Soil fertility	Anton Herrero <i>et al.</i> , (2022)
(b) Toxic elements As, Cd, Cr, Pb		(b) ↓	-Soil contamination	Hussien <i>et al.</i> , (2020)
Soil contamination by Petroleum hydrocarbons and pesticides	Biochar	↓	-Soil contamination	Dike <i>et al.</i> , (2021)
Soil aggregation	Chitosan	↑	+Soil structure stabilization	Ortiz-Botella <i>et al.</i> , (2022) Hataf <i>et al.</i> , (2018) Sharif <i>et al.</i> , (2018) Shahrajabian <i>et al.</i> , (2021)
Nutrient holding capacity	Seaweed extracts	↑	+ Soil fertility	EL Boukhari <i>et al.</i> , (2020) Nanda <i>et al.</i> , (2021) Mukherjee and Patel (2020)
(a) Soil organic matter, Microbial activity	Rhizogenic	↑	+ Soil fertility	Yousfi <i>et al.</i> , 2021 Garcia-Martinez <i>et al.</i> , (2010)
(b) Soil enzymatic activity (Phosphatase, Drhydrogenase and Catalase)	Enzymatic vegetable organic extracts		+ OM oxidation	
Available P, K, Total bacterial count, Phosphate solubilizers, Nitrogen fixers	Protein hydrolysates	↑	+N, P cycling	Kaur <i>et al.</i> , (2021) Colla <i>et al.</i> , (2015)
(a) Electrical conductivity, Exchangeable Na, Cl	Actwave	(a) ↓	(a) -Soil salinity	Karapouloutidou and Gasparatos (2019)
(b) Available N, P, K, Fe, Mn and Zn		(b) ↑	(b) +Soil fertility	Amato and Del (2021)
N fixation, P soilubilization, production of siderophores	AM fungi	↑	+Soil fertility	Giovannini <i>et al.</i> , (2020) Hage-Ahmed <i>et al.</i> , (2019) Ferrol <i>et al.</i> , (2019)
(a) Soil acidity and fungi	Physiostart	(a) ↓	+ Soil nutrient availability	Zielewicz <i>et al.</i> , (2021)
(b) Soil heterotrophic, oligotrophic, copiotrophic bacteria Dehydrogenase, Phosphatase, Urease,	N-14 1900	(b) ↑	+ C, P, N cycling	Tejada <i>et al.</i> , (2011) Hellequin <i>et al.</i> , (2020)
Soil microbial biomass Carbon and Nitrogen	Lemon waste watwer	↑	+ C and N regulation	Ioppolo <i>et al.</i> , (2020) Bhattacharyya <i>et al.</i> , (2001) Blagodatskaya and Kuzyakov (2008)
Total soil nitrogen, Phosphorus, Potassium, Available N,P,K and Organic matterSoil microbial activity, Urease	Humic Acid	↑	+ Soil fertility +N mineralization	Li <i>et al.</i> , (2019) Chen (2017) Wang <i>et al.</i> , (2011)
Biological nitrogen fixation	Tytanit, Rooter	↑	+ N cycling	Niewiadomska <i>et al.</i> , (2019) Nardi <i>et al.</i> , (2016)

↑ = Increase, ↓ = Decrease.

demonstrated by higher water use efficiency after betaine and chitin was applied to lettuce grown in a regulated water deficit irrigation system (Lin *et al.*, 2020). Several studies have been conducted on various biostimulants related to their influence on soil health indicators and their consequence on soil health. Chitosan aid in soil structure stabilization due to its positive charge it gets attracted between diffuse double layer of clay minerals leading to better soil aggregation which prevents soil erosion and accelerated mineralization of soil organic matter (Shahrajabian *et al.*, 2021). Biochar accelerates degradation of soil contaminants by stimulating soil microbial population which aid in reducing contaminants in soil (Table 1).

CONCLUSION

In climate-smart agriculture, biostimulants play an important role and improve the efficiency with which plants utilize nutrients. Soil health is improved, as is agricultural resilience to climate shocks. Circular plant biostimulants increase resource efficiencies and minimize nutrient losses. It is reasonable to assume that natural and synthetic plant biostimulants, as well as microbial inoculants, will play an increasingly important role in the development of environmental and economical viable crop production systems within more resourceful agro-ecosystems over the next few years, laying the groundwork for a bio-based industry-driven future of large-scale sustainable agriculture. This new category of agricultural inputs, known as biostimulants, has the potential to complement synthetic fertilizers in many ways, but there is a challenging need for researchers and fertilizer manufacturers to better understand the physiological and molecular mechanism underlying their effectiveness. There are now a lot of big players in the agroindustry who see plant biostimulants as a legitimate agri-input and a good business idea.

Conflict of interest: none.

REFERENCES

- Alvey, S. and Crowley, D.E. (1995). Influence of organic amendments on biodegradation of atrazine as a nitrogen source (Vol. 24, No. 6, pp. 1156-1162). American Society of Agronomy, Crop Science Society of America and Soil Science Society of America.
- Antón Herrero, R., Vega Jara, L., García Delgado, C., Mayans, B., Camacho Arévalo, R., Moreno Jiménez, E., Eymar, E. (2022). Synergistic effects of biochar and biostimulants on nutrient and toxic element uptake by pepper in contaminated soils. *Journal of the Science of Food and Agriculture*. 102(1): 167-174.
- Bansal, S., Chakraborty, P., Kumar, S. (2022). Crop-livestock integration enhanced soil aggregate-associated carbon and nitrogen and phospholipid fatty acid. *Scientific Reports*. 12(1): pp.1-13.
- Bhattacharyya, P., Pal, R., Chakraborty, A., Chakrabarti, K. (2001). Microbial biomass and activity in a laterite soil amended with municipal solid waste compost. *Journal of Agronomy and Crop Science*. 187(3): 207-211.
- Blagodatskaya, A. and Kuzyakov, Y. (2008). Mechanisms of real and apparent priming effects and their dependence on soil microbial biomass and community structure: critical review. *Biology and Fertility of Soils*. 45(2): 115-131.
- Chen, X., Kou, M., Tang, Z., Zhang, A., Li, H., Wei, M. (2017). Responses of root physiological characteristics and yield of sweet potato to humic acid urea fertilizer. *Plos one*. 12(12): e0189715.
- Colla, G., Nardi, S., Cardarelli, M., Ertani, A., Lucini, L., Canaguier, R. and Roupael, Y. (2015). Protein hydrolysates as biostimulants in horticulture. *Scientia Horticulturae*. 196: 28-38.
- Craigie, J.S. (2011). Seaweed extract stimuli in plant science and agriculture. *Journal of applied phycology*. 23(3): 371-393.
- D'Amato, R. and Del Buono, D. (2021). Use of a Biostimulant to Mitigate Salt Stress in Maize Plants. *Agronomy*. 11(9): 1755.
- Dewang, S.P. and Devi, C.U. (2022). Efficacy of organic biostimulant (fish protein hydrolyzate) on the growth and yield of tomato (*Solanum lycopersicum*). *Agricultural Science Digest-A Research Journal*. 42(1): 20-25.
- Dike, C.C., Shahsavari, E., Surapaneni, A., Shah, K., Ball, A.S. (2021). Can biochar be an effective and reliable biostimulating agent for the remediation of hydrocarbon-contaminated soils?. *Environment International*. 154: 106553.
- EL Boukhari, M.E., Barakate, M., Bouhia, Y., Lyamlouli, K. (2020). Trends in seaweed extract based biostimulants: Manufacturing process and beneficial effect on soil-plant systems. *Plants*. 9(3): 359.
- Entry, J.A. and Emmingham, W.H. (1995). The influence of dairy manure on atrazine and 2, 4-dichlorophenoxyacetic acid mineralization in pasture soils. *Canadian Journal of Soil Science*. 75(3): 379-383.
- Esfahani, M.R., Stretz, H.A., Wells, M.J. (2015). Abiotic reversible self-assembly of fulvic and humic acid aggregates in low electrolytic conductivity solutions by dynamic light scattering and zeta potential investigation. *Science of the Total Environment*. 537: 81-92.
- Ferrol, N., Azcón-Aguilar, C., Pérez-Tienda, J. (2019). Arbuscular mycorrhizas as key players in sustainable plant phosphorus acquisition: An overview on the mechanisms involved. *Plant Science*. 280: 441-447.
- García-Martínez, A.M., Tejada, M., Díaz, A.I., Rodríguez-Morgado, B., Bautista, J., Parrado, J. (2010). Enzymatic vegetable organic extracts as soil biochemical biostimulants and atrazine extenders. *Journal of agricultural and food chemistry*. 58(17): 9697-9704.
- Giovannini, L., Palla, M., Agnolucci, M., Avio, L., Sbrana, C., Turrini, A., Giovannetti, M. (2020). Arbuscular mycorrhizal fungi and associated microbiota as plant biostimulants: research strategies for the selection of the best performing inocula. *Agronomy*. 10(1): 106.
- Hage Ahmed, K., Rosner, K., Steinkellner, S. (2019). Arbuscular mycorrhizal fungi and their response to pesticides. *Pest management science*. 75(3): 583-590.
- Hataf, N., Ghadir, P., Ranjbar, N. (2018). Investigation of soil stabilization using chitosan biopolymer. *Journal of Cleaner Production*. 170: 1493-1500.

- Hellequin, E., Monard, C., Chorin, M., Daburon, V., Klarzynski, O., Binet, F. (2020). Responses of active soil microorganisms facing to a soil biostimulant input compared to plant legacy effects. *Scientific Reports*. 10(1): 1-15.
- Hussien Ibrahim, M.E., Adam Ali, A.Y., Zhou, G., Ibrahim Elsidig, A.M., Zhu, G., Ahmed Nimir, N.E. and Ahmad, I. (2020). Biochar application affects forage sorghum under salinity stress. *Chilean journal of agricultural research*. 80(3): 317-325.
- Ioppolo, A., Laudicina, V.A., Badalucco, L., Saiano, F., Palazzolo, E. (2020). Wastewaters from citrus processing industry as natural biostimulants for soil microbial community. *Journal of Environmental Management*. 273: 111137.
- Jannin, L., Arkoun, M., Etienne, P., Laîné, P., Goux, D., Garnica, M., Ourry, A. (2013). Brassica napus growth is promoted by *Ascophyllum nodosum* (L.) Le Jol. seaweed extract: microarray analysis and physiological characterization of N, C and S metabolisms. *Journal of plant growth regulation*. 32(1): 31-52.
- Kapoor, R.V., Wood, E.E., Llewellyn, C.A. (2021). Algae biostimulants: A critical look at microalgal biostimulants for sustainable agricultural practices. *Biotechnology Advances*. 49: 107754.
- Karapoulidou, S. and Gasparatos, D. (2019). Effects of biostimulant and organic amendment on soil properties and nutrient status of *Lactuca sativa* in a calcareous saline-sodic soil. *Agriculture*. 9(8): 164.
- Kaur, I. (2020). Seaweeds: Soil health boosters for sustainable agriculture. In *Soil Health* (pp. 163-182). Springer, Cham.
- Kaur, M., Bhari, R. and Singh, R.S. (2021). Chicken feather waste-derived protein hydrolysate as a potential biostimulant for cultivation of mung beans. *Biologia*. 76(6): 1807-1815.
- Kocira, S., Szparaga, A., Kocira, A., Czerwińska, E., Depo, K., Erlichowska, B. and Deszcz, E. (2019). Effect of applying a biostimulant containing seaweed and amino acids on the content of fiber fractions in three soybean cultivars. *Legume Research-An International Journal*. 42(3): 341-347.
- Lehmann, A., Zheng, W., Ryo, M., Soutschek, K., Roy, J., Rongstock, R., Maass, S., Rillig, M. C. (2020). Fungal traits important for soil aggregation. *Frontiers in microbiology*. 2904.
- Lehmann, J. and Kleber, M. (2015). The contentious nature of soil organic matter. *Nature*. 528(7580): 60-68.
- Li, Y., Fang, F., Wei, J., Wu, X., Cui, R., Li, G., Zheng, F. Tan, D. (2019). Humic acid fertilizer improved soil properties and soil microbial diversity of continuous cropping peanut: a three-year experiment. *Scientific reports*. 9(1): pp.1-9.
- Lin, F.W.; Lin, K.H.; Wu, C.W.; Chang, Y.S. (2020). Effects of betaine and chitin on water use efficiency in lettuce (*lactuca sativa* var. capitata). *HortScience*. 55: 89-95.
- Mukherjee, A. and Patel, J.S. (2020). Seaweed extract: biostimulator of plant defense and plant productivity. *International Journal of Environmental Science and Technology*. 17(1): 553-558.
- Nair, P., Kandasamy, S., Zhang, J., Ji, X., Kirby, C., Benkel, B., Prithiviraj, B. (2012). Transcriptional and metabolomic analysis of *Ascophyllum nodosum* mediated freezing tolerance in *Arabidopsis thaliana*. *BMC genomics*. 13(1): 1-23.
- Nanda, S., Kumar, G. and Hussain, S. (2021). Utilization of seaweed-based biostimulants in improving plant and soil health: current updates and future prospective. *International Journal of Environmental Science and Technology*. pp. 1-14.
- Nardi, S., Pizzeghello, D., Schiavon, M., Ertani, A. (2016). Plant biostimulants: physiological responses induced by protein hydrolyzed-based products and humic substances in plant metabolism. *Scientia Agricola*. 73(1): 18-23.
- Niewiadomska, A., Sulewska, H., Wolna-Maruwka, A., Ratajczak, K., Waraczewska, Z., Budka, A., G³uchowska, K. (2019). The influence of biostimulants and foliar fertilisers on the process of biological nitrogen fixation and the level of soil biochemical activity in soybean (*Glycine max* L.) cultivation. *Applied Ecology and Environmental Research*. 17: 12649-12666.
- Olk, D.C., Bloom, P.R., Perdue, E.M., McKnight, D.M., Chen, Y., Fahrenhorst, A. (2019). Environmental and agricultural relevance of humic fractions extracted by alkali from soils and natural waters. *Journal of Environmental Quality*. 48: 217-232.
- Ortiz-Botella, M., Gómez, I., Paneque, P., Caballero, P., Parrado, J., Vera, A., Bastida, F., García, C. Tejada, M. (2022). Use of biostimulants obtained from okara in the bioremediation of soils polluted by imazamox. *Bioremediation Journal*. 26(1): 53-63.
- Orts, A., Cabrera, S., Gómez, I., Parrado, J., Rodriguez-Morgado, B., Tejada, M. (2017). Use of okara in the bioremediation of chlorpyrifos in soil: Effects on soil biochemical properties. *Applied Soil Ecology*. 121: 172-176.
- Piccolo, A. (2002). The supramolecular structure of humic substances: a novel understanding of humus chemistry and implications in soil science. *Advances in Agronomy*. 75: 57-134.
- Selvam, G.G. and Sivakumar, K. (2013). Effect of foliar spray from seaweed liquid fertilizer of *Ulva reticulata* (Forsk.) on *Vigna mungo* L. and their elemental composition using SEM-energy dispersive spectroscopic analysis. *Asian Pacific Journal of Reproduction*. 2(2): 119-125.
- Selvam, G.G. and Sivakumar, K. (2014). Influence of seaweed extract as an organic fertilizer on the growth and yield of *Arachis hypogea* L. and their elemental composition using SEM-Energy Dispersive Spectroscopic analysis. *Asian Pacific Journal of Reproduction*. 3(1): 18-22.
- Shahrajabian, M.H., Chaski, C., Polyzos, N., Tzortzakis, N., Petropoulos, S.A. (2021). Sustainable agriculture systems in vegetable production using chitin and chitosan as plant biostimulants. *Biomolecules*. 11(6): 819.
- Sharif, R., Mujtaba, M., Ur Rahman, M., Shalmani, A., Ahmad, H., Anwar, T., Tianchan, D. Wang, X. (2018). The multifunctional role of chitosan in horticultural crops; a review. *Molecules*. 23(4): 872.
- Sharp, R.G. (2013). A review of the applications of chitin and its derivatives in agriculture to modify plant-microbial interactions and improve crop yields. *Agronomy*. 3(4): 757-793.
- Srivastava, P., Balhara, M., Giri, B. (2020). Soil health in India: past history and future perspective. In *Soil Health* (pp. 1-19). Springer, Cham.
- Stevenson, F.J. (1994). Humus chemistry: genesis, composition, reactions. John Wiley and Sons.

- Tejada, M., Garcia-Martinez, A.M., Gomez, I., Parrado, J. (2011). Response of Biological Properties to the Application of Banvel (2, 4-D, Mcpa, Dicamba) Herbicide in Soils Amended with Biostimulants. In Soil enzymology in the recycling of organic wastes and environmental restoration, ed. C. Trasar-Cepeda, T. Hernandez, C. Garcia, C. Rad and S. Gonzalez-Carcedo, 241-53. Berlin: springer.
- Vasic, V., Djuric, S., Jafari-Hajnal, T., Orlovic, S., Vasic, S., Poljakovic Pajnik, L., Galović, V. (2019). The microbiological response of forest soils after application of nicosulfuron, imazamox and cycloxydim. International Journal of Environmental Science and Technology. 16(5): 2305-2312.
- Vischetti, C., Casucci, C., Perucci, P. (2002). Relationship between changes of soil microbial biomass content and imazamox and benfluralin degradation. Biology and Fertility of Soils. 35(1): 13-17
- Vishwanatha, S., Ramarao, B.N., Koppalkar, B.G., Ashoka, N., Ananda, N., Umesh, M.R., Vinaykumar, M. and Naik, V.S. (2022). Response of Black Gram (*Vigna mungo* L.) and Soybean (*Glycine max* L.) to Novel Bio Stimulants in North Eastern Dry Zone of Karnataka. Legume Research- An International Journal. pp: 1-7. DOI: 10.18805/LR-4858.
- Wang, L.B. and Wang, Y.X. (2011). Effects of humic acid fertilizer on soil nutrients and microbial activity. Humic Acid (in China). 4: 6-9.
- Yakhin, O.I., Lubyantsev, A.A., Yakhin, I.A., Brown, P.H. (2017). Biostimulants in plant science: a global perspective. Frontiers in plant science. 7: 2049.
- Yousfi, S., Marín, J., Parra, L., Lloret, J., Mauri, P.V. (2021). A rhizogenic biostimulant effect on soil fertility and roots growth of turfgrass. Agronomy. 11(3): 573.
- Zanin, L., Tomasi, N., Cesco, S., Varanini, Z., Pinton, R. (2019). Humic substances contribute to plant iron nutrition acting as chelators and biostimulants. Frontiers in Plant Science. 10: 675.
- Zhang, X. and Schmidt, R.E. (1997). The impact of growth regulators on the α -tocopherol status in water-stressed *Poa pratensis*. International Turfgrass Society Research Journal. 8: 1364-2137.
- Zielewicz, W., Swędryński, A., Dobrzyński, J., Swędryńska, D., Kulkova, I., Wierchowski, P. S., Wróbel, B. (2021). Effect of forage plant mixture and biostimulants application on the yield, changes of botanical composition and microbiological soil activity. Agronomy. 11(9): 1786.