<u>Assessment of Regenerative Agriculture and Biostimulation as Forms of Alternative Agriculture: Potential Benefits to Soil Health and Agricultural Production</u>

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Executive Summary:

Globally, several management practices in Agriculture, such as the application of pesticides/chemicals, inorganic fertilizers, and monocultural practices have contributed to land/soil degradation. This resulted in a loss of soil fertility and ultimately, poor quality of our food crops/plants. As the population of people increases daily, there is a critical need to improve crop productivity (yields) of nutritious, economical, and culturally appropriate food crops and promote healthier soils in our agroecosystem. Recent studies and discoveries have shown that the basis for agriculture, crop production, and human security in the future is healthy soil. Evidence has shown that “alternative” agricultural practices may provide solutions to curb issues surrounding soil and water degradation (FAO, 2015). These practices are adopted to promote healthier soils and can result in increasing crop productivity, greater economic viability, and increased local food security. Major emphasis is placed on ‘regenerative agriculture’ and ‘biostimulation’ as conservation and alternative approaches/management practices improve soil health and agricultural productivity. This paper presents a review and an assessment of regenerative agriculture and plant biostimulation and their potential benefits to soil health and agricultural production. It will summarize and communicate the benefits of these two innovative alternative practices to agriculturists, government officials, and farmers.

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1.0 Introduction

As the world population is projected to exceed nine (9) billion by the year 2050, there is considerable concern about the increasing impact of anthropogenic activities amplified by the increasing competition for land and water resources, uncertainties from climate change leading to increasing rates of soil degradation through erosion, compaction, and contamination (Hurni et al., 2015). Thus, there is a critical need to improve crop productivity (yields) of nutritious, economical, and culturally appropriate food crops and promote healthier soils (FAO, 2015).

Healthy soils are the foundation for agricultural production (FAO, 2015) and according to the report published by the Food and Agriculture Organization (FAO, 2008), it has been stated that one major reason for land/soil degradation is through the deterioration of soil health. *These soils, when characterized as 'healthy', have been defined as being able to maintain a diverse community of soil organisms that help to mitigate plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots, recycle essential plant nutrients, enhance the structure of the soil with positive impacts for soil water and nutrient holding capacity, and ultimately improve crop production.*"

Globally, present-day agricultural management practices, such as the contribution of pesticides/chemicals and inorganic fertilizers and monocultural practices have contributed to land/soil degradation. Evidence has shown that "alternative" agricultural practices may provide solutions to curb issues affecting soil and water degradation (FAO, 2015). These alternate practices are adopted to promote healthier soils that result in increasing crop productivity, greater economic viability, and local food security.

Alternative agricultural systems that improve the health of our ecosystem that are considered economically and ecologically sustainable are vital to maintain our soils and enable farmers to facilitate the movement to global food security.

Alternative agriculture encompasses a range of different practices and production systems, including but not limited to organic agriculture, ‘zero-till’ practice, conservation agriculture, biostimulation, and bioremediation. These practices have been suggested to enhance sustainability in soil management with the aim of achieving high crop productivity (FAO, 2015).

1.1 Background

Alternative agricultural systems have been proposed to be indistinctly sustainable, unlike the conventional systems of agriculture, as they tend to be more protective of soil productivity and do not rely on exhaustible sources of energy such as coal, oil, and natural gases. These agricultural systems focus on minimal use and application of inputs obtained from the farm operations and the elimination of ‘synthetic or inorganic inputs’ or, in other words, chemicals in the form of pesticides and inorganic fertilizers, in the production of crops and growth regulators and other chemicals in livestock production (Crosson,& Ekey,1988). To achieve this goal, the management of insect pests, diseases, and growth of weeds is carried out through farming systems, such as crop rotation, cultivation practices, and various biological methods. Nutrients are supplied through rotation of leguminous crops with local major (cash) crops and by the return to the soil of residues of crops, animal wastes, sewage, and other forms of organic materials.

This project addresses recently published alternative agricultural management practices that focus on-preventing degradation of the physical and chemical properties of the soil, as well as eliminating the need for excessive addition of pesticides and inorganic chemicals through a combination of alternative agricultural systems practices. These practices have been shown to be ecologically less damaging, more profitable, and sustainable for the optimum yield of crops and production of ‘safer and healthier’ food crops by maintaining healthy soils, for the maximum benefit of humans and livestock.

For the purpose of this project, major emphasis is placed on ‘regenerative agriculture’ and ‘biostimulation’ as conservation and alternative approaches/management strategies for improving soil health and agricultural productivity.

1.1.1 Healthy soil

As stated in the introduction of this paper, healthy soils are the foundation for agricultural production (FAO, 2015). According to the report published by the Food and Agriculture Organization (FAO, 2008), one major reason for land/soil degradation is the deterioration of soil health. "*These soils when characterized as 'healthy' have been defined as being able to maintain a diverse community of soil organisms that help to mitigate plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots; recycle essential plant nutrients; enhance the structure of the soil with positive impacts for soil water and nutrient holding capacity, and ultimately improve crop production*".

Soil health has been discovered to be intrinsically linked to human health and well-being (Singh et al.,2011). The state of soil health is also noted to have a consequential impact on the quality of food. The amounts of micronutrients, essential amino acids, and proteins in crop production and soil management are vital areas that connect human health to soil health, based on the quality of food production. Soil health has an impact on human health because of dietary and environmental impacts and may affect human health either negatively or positively depending on the inadequacy, imbalance or excess of these nutrients in the soil. The environmental impacts of soil health are connected to the relationship with the hydrosphere, that results in an alteration of water quality, the atmosphere resulting in the alteration of greenhouse gases, the lithosphere altering the landscape stabilization, and the biosphere that abates net primary product (NPP) and the uptake of nutrients (Singh et al.,2011). Figure 1 shows the connection between soil health, human health and quality of the environment.

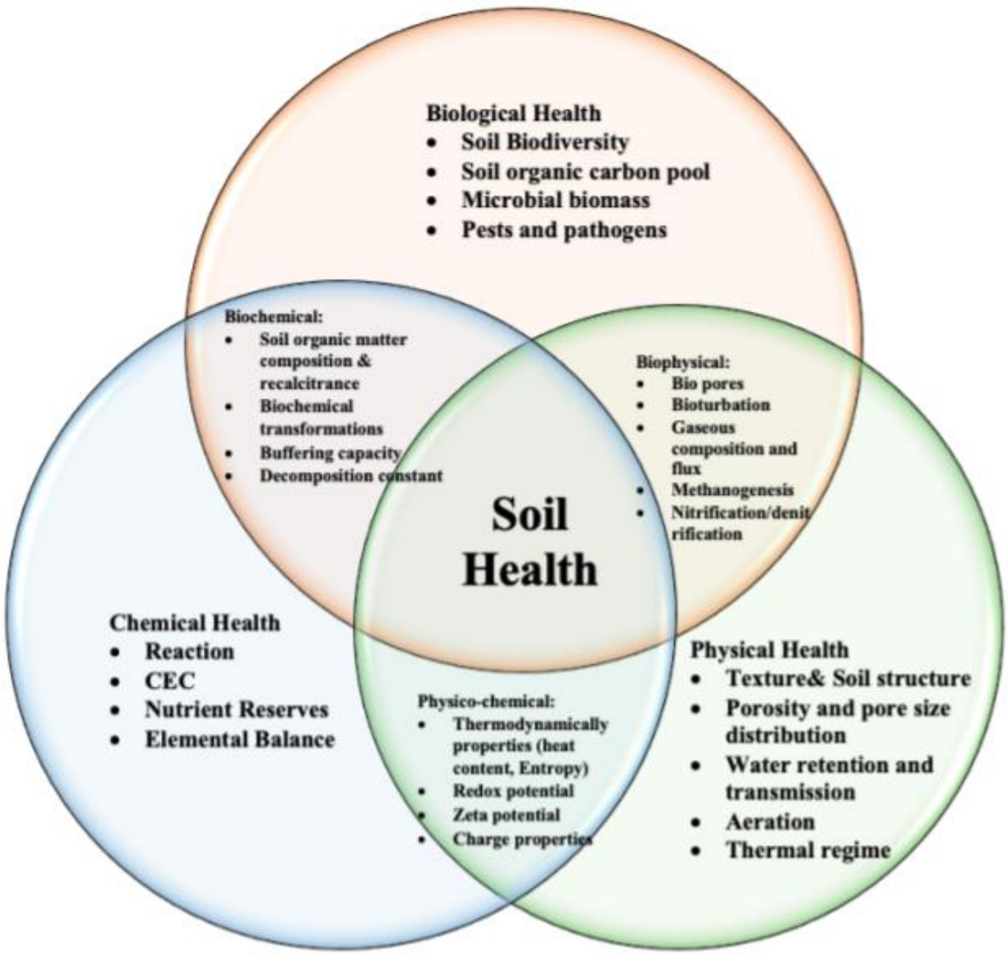

Figure 1: Diagram illustrating the connection between soil health, human health and quality of the environment (Picture credit- Singh et al.,2011).

1.1.2 Alternative approaches/management strategies for the improvement of soil health and agricultural productivity.

There is increasing research that concludes that sustainable forms of agriculture have shown to provide potential/possible solutions to enabling agricultural systems to feed the global (growing) population within the changing environmental conditions (Rockstrom, J. et. al., 2017).

1.2 Benefits of alternative agricultural practices

Research conducted by the National Research Council (NRC) shows that, as opposed to conventional farming systems, alternative agricultural systems of farming have decreased the costs of production to about twenty-five (25) percent with the elimination of the application of inorganic fertilizers and pesticides, minimal erosion of the soil and an increase in yields of crops (Faeth et al., 1991). The transition from conventional agriculture to alternative agriculture has shown that proper management and application of less synthetic fertilizers and pesticides have resulted in the reduced potential of agriculture to pose deleterious health and environmental challenges to the environment. The minimal use of chemicals and pesticides in agriculture has resulted in social, health and ecological benefits for both farmers and the public (National Research Council, 1989).

The United States Environmental Protection Agency (EPA) detected run-off from agricultural farms as the major source of pollution of water bodies the result of the use of large amounts of pesticides and fertilizers applied to crops, and the excess eventually run-off and contaminate the rivers and lakes. Lower application of these pesticides and fertilizers has resulted in cleaner drinking water for the public.

Alternative agricultural practices have also resulted in increased soil productivity. Scientists and researchers have concluded from recent long term studies that in their assessments of alternative agriculture and conventional farming systems, considering the environmental costs on the farm and off-farm without disruptions in agricultural regulations and policies, the alternative agricultural systems where crop rotations have been practiced and biological nutrients applied have been economically competitive, even where low costs exist and noticeably of a high quality where costs are high (Faeth et al., 1991).

The amounts of agricultural chemicals and pesticides applied in alternative farming systems have been identified to be closely linked to the farm management practices and expertise of the farmers. Major concerns that have been identified in the alternative farming systems include tillage of the soil, which may contribute to plant health positively or negatively and environmental concerns that result in the integrated strategies of managing agricultural pests. Healthier crops, proper management of the soil, and integrated pest control all result in the decreased need to apply fertilizers and pesticides on the farm. This ultimately results in a minimized incidence of pests and diseases reduced risks of diseases to the farmers and the public who consume the food crops.

"The fact that alternative agriculture would drastically reduce, if not eliminate, the human and economic costs associated with over-application of agricultural pesticides would seem to be its most important environmental advantage related to conventional farming systems"(Crosson & Ostrov, 1990).

Recent studies have also suggested that the practice of alternative agriculture systems has established the demand for improvement in new and suitable farming tools and equipment (*It's worth paying more : the benefits of alternative agriculture*, n.d.). This demand has, in turn, boosted the growth of the agricultural firm, creating room for innovations. This includes the establishment of farm equipment and machinery that can be used in alternative agricultural systems, production of beneficial soil organisms, production of pesticides that have reduced toxicity, production of alternative soil materials that are known to improve the health condition of the soil, as well as the establishment of pest and disease-resistant plant varieties that are suitable for a diverse range of cropping practices.

The benefits of alternative agricultural systems have also increased the need for extensive and focused research in agriculture that will execute and upgrade the farm tools and equipment used in this type of agriculture. This has resulted in an increased need to conduct advanced research from a systematic point of view in the area of agricultural ecology, the study of interrelationships among all the elements and factors comprising an agricultural ecosystem. This systematic point of view from which this research is conducted has enabled farmers to integrate a multidisciplinary approach in studying various agricultural systems.

2.0 Project Objectives

i.) To conduct a systematic review on the benefits of regenerative agriculture and biostimulation with respect to soil health and economic viability.

ii.) To assess potential barriers to implementation and adoption of regenerative agriculture and biostimulation practices.

iii.) To synthesize the results of the above review and assessment and provide recommendations on how to increase the viability of alternative agricultural practices.

3.0 Study review

3.1 Regenerative Agriculture

The word "regenerative" literally means "the ability to re-establish"; therefore, if an object or system is regenerative, it has the inherent capacity to reestablish itself (Christopher, 2015). The term 'regenerative' emanates from the fact that most of our agricultural soils have been degraded due to the different farming activities practiced on these soils. The transition to more sustainable agricultural systems remains crucial, as a variety of our present-day agricultural practices have severe negative effects, including land/soil degradation. However, despite the possibilities of agricultural systems to degrade the environment, they also have large potentials to improve it. Having realized this, several systems and agencies today are opting for regenerative agriculture as a sustainable approach to not just cultivate healthy food crops but also to improve the ecosystem, gradually. Typically, research suggests that on farms where regenerative agriculture is being practiced, yields are anticipated to increase over time.

Research shows that regenerative agriculture potentially offers a strategy to providing food on a small scale and to addressing the issues of carbon emissions and scarcity of land and water resources, on a larger scale, while strengthening the resilience of the environment. Regenerative agriculture is an alternative approach to food and farming systems that comprises a range of practices such as agroforestry, recycling of farm wastes, and the addition of composted materials (Rhodes, 2012). This approach targets the restoration of the topsoil, biodiversity enhancement, improvement of the water cycle, improvement of ecosystem services, an increase of resilience to climate change, support of biosequestration, and strengthening of the health and vitality of soils with a major emphasis on minimal soil disturbance and composting practices (Rhodes, 2012).

Research shows that regenerative agriculture can sequester large amounts of carbon from the atmosphere and help curb the challenges surrounding climate change. The sequestration of carbon by the soil through the practice of regenerative agriculture has been shown to not only produce more food for the world but also curb the issues surrounding global warming. Robert Rodale termed regenerative agriculture as a type of farming system that is not just limited to the concept of sustainability (Rodale & Instutute, 2014). This form of organic agriculture was defined by Robert as having the capacity to make use of the natural dispositions of the ecosystem to renew and revitalize when disturbed. He defined 'regenerative' as a holistic approach to agriculture that stimulates continual innovations and enhancement of not only environmental measures but also socio-economic measures. It can be differentiated from the other forms of agriculture that contend with or disregard the benefits of those natural inclinations. Regenerative agriculture has been strongly identified by inclinations towards increased biological diversity, greater numbers of perennials, smaller annuals, and higher dependence on internal resources compared to external ones. This type of agriculture is associated with methods of agroecology practiced by farmers whose major concern is predominantly the provision of food globally (Rodale & Instutute, 2014).

The majority of farmers and investors in the past decade have had several fluctuating definitions of the term 'regenerative' but in a broader view, it has recently been described to expand beyond conservation strategies or practices that simply 'manage', 'protect' or 'minimize/ natural resources (effects such as gases emissions, chemical fertilizers, and erosion and emphasizes the need to be in conjunction with natural systems to enhance and restore the biological vitality, capacity, and functional services in the ecosystem (Electris et al., 2019). This form of agriculture is also majorly centred on strengthening the resilience of the rural areas and broader value chains in which they are located (Electris et al., 2019). As Figure 2 indicates, regenerative agriculture goes beyond sustainability. Sustainability, as a result, is only possible if the system as an entirety is regenerative (Fullerton, n.d.). The story of regeneration begins with a single major concept which is: The universal patterns and principles the universe utilizes to establish healthy and sustainable systems throughout the real-life can and must be used as an idea for the economic-system design.

Figure 2: (Picture source: John Fullerton, "Regenerative Capitalism: How Universal Principles and Patterns Will Shape Our New Economy," Capital Institute, April 2015).

3.1.1 Principles and practices governing regenerative agriculture

According to Rodale & Institute, 2014, the major priority governing regenerative agriculture is soil health. The term 'regenerative agriculture' while prioritizing soil health concurrently includes high standards for social fairness and animal welfare. Rodale described the health of the soil to be inherently connected to the overall health of our food system and further stated that that soil health basically influences everything from soil/crop health to human health and the future of our ecosystem. He stated seven principles governing regenerative organic agriculture and they are as follows:

- Pluralism - This principle describes an overall increase in terms of plant diversity, human diversity (the people, their ways of life and what they do), and in the diversity of human experiences, capabilities, several opportunities and exposure and 'acceptance' to new innovations and experiences.

- Protection - This involves enhanced surface cover of plants and crops, thereby mitigating erosion and enhancing microbial populations that are considered as beneficial, increased resistance to cultural and economic changes that may occur due to the variations existing among people and their business which in turn, enhances stability in the environment and increases employment for the people. This also enhances tolerance to crises, followed by an improvement in the human system.
- Purity - This involves the discovery that a larger percentage of flora and fauna are obtainable in the soil when chemical fertilizers and pesticides are not applied to the soil. When the environment is not contaminated, greater numbers of people can thrive in improved health and by the cessation of certain practices that are considered deleterious such as smoking, the prospects for growth and success are enhanced in the community.
- Permanence - This principle involves the increased growth of more perennials and other crops with hardy root systems. As humans and what they are involved in continue to thrive and become more stable, they are in turn, able to contribute their own quota to the community and depth as regards life in general, is increased.
- Peace - In this principle, disruption of weeds and pests that normally intrude with growing crops occurs, the rates of crimes in the society are decreased, thereby enhancing the general well-being of the people and a greater level of security in the community.
- Potential - Nutrients become more available for plants uptake as they are inclined to move in an upward direction into the soil profile or are proliferated near the surface. This, in turn, enhances the availability of resources for the people and positivity in terms of personal qualities and resources are more accessible to others, generally.
- Progress - There is improvement generally in the structure of the soil, thereby enhancing water retention capacity. There is also improvement in the community, thereby enhancing the health and economic status of the people and an increase in the capacity of the people’s welfare (*Regenerative Organic Agriculture - Rodale Institute*, n.d.).

Table 1 according to Gabe Brown illustrates the principles, practices and restrictions of the different versions of regenerative agriculture as compared to conservation agriculture.

Table 1: Table illustrating the principles, practices and restrictions of the different versions of regenerative agriculture as compared to conservation agriculture. Source: (*Regenerative Agriculture: Solid Principles, Extraordinary Claims | CSANR | Washington State University*, n.d.)

	Versions of Regenerative Agriculture				
Principles/Practices	Gabe Brown	Drawdown.org	Regenerative Organic	Chico State University	Conservation Agriculture
Limit tillage	✓	✓	✓	✓	✓
Protect the soil					
Plants or crop residues on soil surface	✓				✓
Controlled traffic					✓
Maintain living roots in the soil	✓			✓	
Increase biodiversity					
Diverse crop rotations	✓	✓	✓	✓	✓
Multi-species cover crops	✓	✓		✓	
Cover crops			✓		✓
Inoculation of soils				✓	
Integrate livestock	✓		✓	✓	
Restrictions					
Input limitations		On-farm fertility (no external nutrients)		Soil fertility through biological systems	
		No pesticides or synthetic fertilizers	No Synthetic Inputs		
			No GMOs or Gene Editing		
Other			No Soilless Systems		

3.1.2 Major findings on regenerative agriculture

Recent reports suggest that there is a deepened interest in regenerative food and agricultural systems and an increased need to keep capitalizing on this form of organic agriculture. Several methods have been identified as regards improving soil health, supporting rural communities, and alleviating climate change.

1. Stakeholders and investors in agriculture can establish 'soil wealth', termed as the prospects linked with improving soil health and enhancing rural wealth through regenerative agriculture, by investing in regenerative capital opportunities.
2. The positive impact of regenerative agriculture can be enhanced substantially by capitalizing on farms and industries that are related to regenerative agriculture.
3. There have been more than $320 billion (Figure 3) in investments to date that emphasizes on sustainable food and agriculture, with $47.5 billion (Figure 4) clearly targeting regenerative agriculture.
4. Recent studies identify sixty-seven (67) notable opportunities for further development capital in regenerative agriculture.
5. Some of the investments identified as most suitable for swift regenerative development, due in large part to the functions of financial institutions in obtaining funds and capital for farms and businesses in rural communities.

Overall, this research emphasizes the breadth of regenerative agriculture and its importance beyond the farming and food aspect. There have also been a variety of opportunities identified for those not included in the agricultural area to invest in the health of our ecosystem (Electris et al., 2019).

INVESTABLE STRATEGIES IDENTIFIED IN SUSTAINABLE FOOD AND AGRICULTURE	COUNT	ASSETS (Billions)
Cash and Cash Equivalents	5	$1.2
Fixed Income: Public Debt	5	$68.7
Fixed Income: Private Debt	25	$3.6
Public Equity	15	$84.1
Private Equity / Venture Capital	39	$74.4
Farmland / Real Assets	38	$89.1
Total	127	$321.1

Figure 3- Source: Croatan Institute (Electris, C., Humphreys, J., Lang, K., Lezaks, D., & Silverstein, J. (2019). ***SOIL WEALTH Investing in Regenerative Agriculture across Asset Classes*****. www.soilwealth.orgwww.soilwealth.orgwww.soilwealth.orgACKNOWLEDGMENTS)**

INVESTABLE STRATEGIES IDENTIFIED WITH REGENERATIVE AGRICULTURAL FEATURES

	COUNT	ASSETS (Billions)
Cash and Cash Equivalents	5	$1.2
Fixed Income: Public Debt	3	$5.3
Fixed Income: Private Debt	17	$2.8
Public Equity	4	$8.4
Private Equity / Venture Capital	12	$6.9
Farmland / Real Assets	29	$22.8
Total	70	$47.5

Figure 4- Source: Croatan Institute (Electris, C., Humphreys, J., Lang, K., Lezaks, D., & Silverstein, J. (2019). *SOIL WEALTH Investing in Regenerative Agriculture across Asset Classes*. [www.soilwealth.orgwww.soilwealth.orgwww.soilwealth.orgACKNOWLEDGMENTS](www.soilwealth.org)

3.2 Biostimulation

Biostimulation is a process that involves the addition of several forms of electron acceptors such as phosphorus, nitrogen, oxygen or restrictive nutrients to quicken/enhance naturally occurring microbial populations (Kanissery and Sims, 2011). This process involves the alteration of the environment to enhance existing bacteria capable of being bioremediated. The term ‘bioremediation’ refers to a process used for the treatment of polluted products, including water, soil, and subsurface material, by modifying environmental conditions to promote microorganisms' development and thereby, remove target contaminants. Recent research on bioremediation has shown that this process is less costly and more sustainable compared to other remediation processes (Ryan et al.,2011). This alternative form of agriculture can also be an alternative solution to conventional farming systems, which can result in promoting healthier soils and improved food security by enhancing the uptake of nutrients and improving crop quality. Research suggests that land and water deterioration can be refurbished with biostimulation, which is one of the productive and dynamic agroecological strategies shown to boost soil health (Lichtfouse, 2018). The European Biostimulants Industry Council (EBIC) has defined substances utilized in biostimulation practices as ‘biostimulants’. The Council has referred to biostimulants as comprising material(s), compound(s) and/or micro-organisms whose function, when applied to plants or the rhizosphere, is to enhance natural processes to stimulate the uptake of nutrients, improve the efficiency of nutrients, tolerance to abiotic stress, and crop quality.

Biostimulants have been strategized to help farmers meet the increasing agricultural demands sustainably. They have been shown to enhance crop yield and quality, which positively affects farm profitability. These substances have also been noted to enhance the uptake and effective use of other necessary inputs, particularly fertilizers. This enables farmers to make optimal use of their investments with the additional advantage of reducing environmental impacts (EBIC, 2013).

Plant biostimulants comprise a distinct range of formulations of materials, compounds, and micro-organisms, such as seaweed and plant extracts, amino and humic acids, salts, and minerals. The different methods by which these biostimulants can be applied include foliar application, applying directly to the soil, through irrigation water and integrating into fertilizers or other products (Jones, 2018). Common biostimulants are as shown in Figure 5.

The European Biostimulants Industry Council claims that biostimulants vary from other crop inputs because they operate by various mechanisms other than commercial fertilizers, although nutrients are present in their products. They also vary from pesticides because they do not act specifically against particular pests or diseases but act on increasing the vigour of plants. Hence, the use of biostimulants is considered complementary to improving crop quality and enhancing soil health (EBIC, 2013).

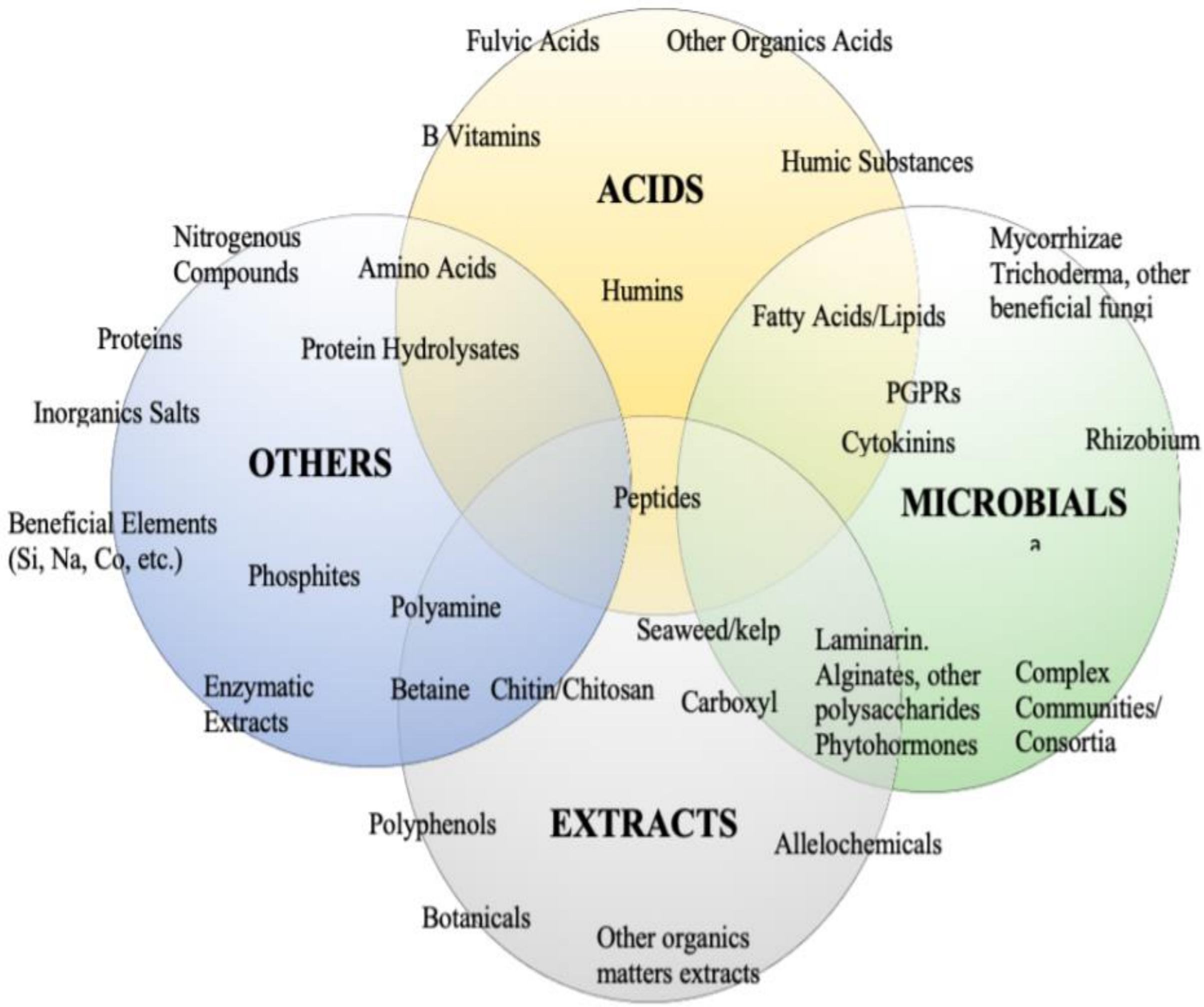

Figure 5: Image source- Global Industry Perspective, January 2017.

One of the roles of microorganisms includes the degradation of several organic pollutants by metabolic machinery and their ability to conform to antagonistic environments or hostile environments. The ability of microbial populations to degrade these organic pollutants within an environmental matrix such as the soil, sediments, or wastewater can be improved either by stimulation of the natural microorganisms or the addition of several forms of electron acceptors like phosphorus, nitrogen, oxygen, or restrictive nutrients (the process of biostimulation) or by the introduction of some particular microorganisms to the local population (the process of bioaugmentation). Research shows that the idea of the initiation of exotic or cultured microorganisms into indigenous or engineered environments is not a contemporary concept. It has been recently introduced in agriculture, in several wastewater treatment stages and in the bioremediation process of sites that are polluted. The indigenous practice of bioaugmentation has attained its highest results through repeatedly applying highly competent pollutants known to degrade bacteria by the use of appropriate microbial strain selection better adapted for specific functions and environments (Singh et al.,2011).

Several studies have also shown that prospects for a successful and viable process of biostimulation and bioaugmentation may be enhanced by using soil comprising non-exotic degrader populations that may have been exposed initially to contaminants.

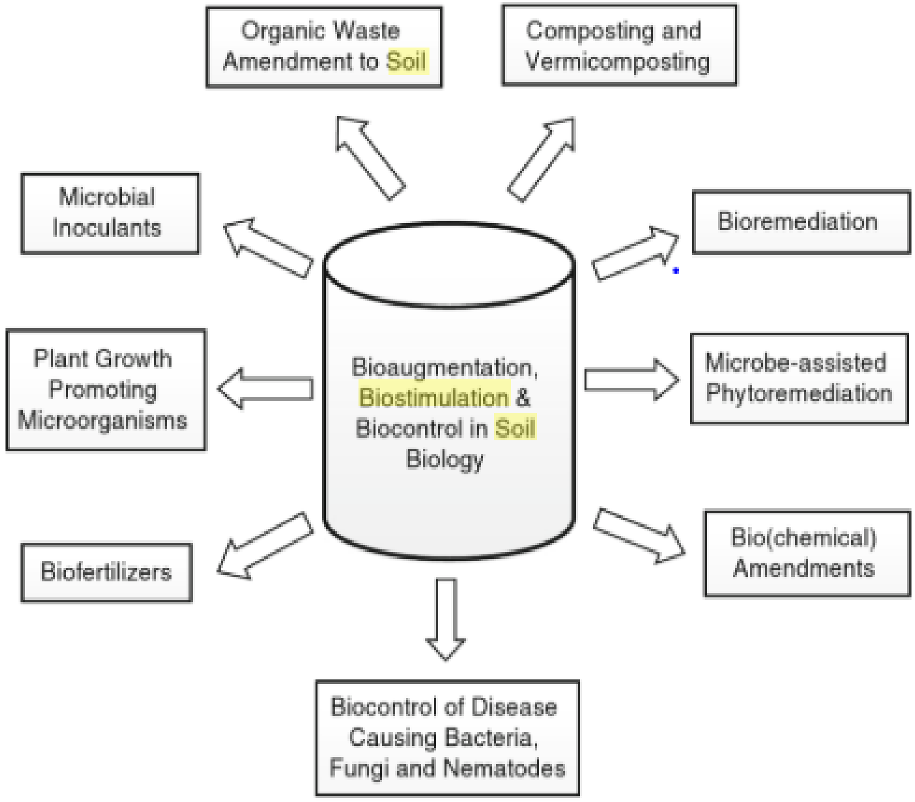

Figure 6: Functions of bioaugmentation, biostimulation and biocontrol in soil biology and in enhancing soil fertility (Source: Singh et al., 2011).

3.2.1 Why the application of biostimulants in agriculture?

Biostimulants have been classified into two major groups based on their reactions from orthodox crop inputs which are considered complementary to the health and nutrition of crops and crop security (EBIC, 2013). These two major ways include:

i.) The operation of agricultural biostimulants through various mechanisms, irrespective of the nutrients that are present in the products.

ii.) Biostimulants are distinguished from crop security products because they act only on the vigour of the plants and are do not act directly against pests and diseases.

3.2.2 Benefits of biostimulants in agriculture

The application of biostimulants nurtures and promotes the growth and development of plants throughout the lifecycle of crops from the stage of seed germination to the maturity of the plant in several ways that include:

i.) Enhancing the efficiency of the plant's metabolism to catalyze increases in yield and improved crop quality.

ii.) Proliferating plant tolerance to and recovery from abiotic stress

iii.) Enhancing the assimilation, translocation and use of nutrients

iv.) Improving efficiency in the use of water for plants

v.) Improving the quality characteristics of crop produce, including the colour, fruit seeding, content of sugar, e.t.c.

vi.) Improvement of soil fertility by promoting the growth and development of supplemental microorganisms in the soil (EBIC, 2013).

3.2.3 Challenges of the application of biostimulants

The challenges in the development and application of biostimulants can be majorly linked to scientific, technical and regulatory issues. These are:

i.) Scientific challenges - these are challenges related to the intricacy of the physiological outcome of biostimulants. Predominantly, the major effect of biostimulants is to catalyze physiological responses in plants that result in their (plants) primary metabolism, growth, and development. These processes are predisposed to firm homeostatic regulations that emanate from biological developments dating back several years and this can be attributed to the reason that some certain ecological habitats are occupied by plants and exhibit distinct phenotypic responses to fluctuations. Acting on these processes is a complex process that demands attention. Besides, the threefold relationship among the biostimulant, plant, and environment needs to be carefully handled for the application of biostimulants to be considered an overall successful process.

ii.) Technical challenges - The challenges associated with biostimulants include the combination and formulation of these biostimulants with other fertilizers and plant protection products. The major goal of several biostimulants that are applied is directed at the improvement of nutrient use efficiency so, effectiveness and functionality when these fertilizers and biostimulants are combined are usually aimed at. It is, however, a complex process when formulating and combining these products. The methods, different times and rates at which these biostimulants are to be applied considering the different climatic and weather conditions also, require extensive research and explanations which, in turn, has a major effect on the benefits for the farmers, including the long-term provision of ecosystem services and conservation of resources.

iii.) Regulatory challenges - These challenges have been linked to the classification, distinction, and assessment of biostimulants before they enter the market. The idea of biostimulation has not gained universal acceptance, or legal definition, hence limitations in terms of coherence and acceptance in the market have been observed resulting in the perception that they are not to be relied upon in agriculture. This has ultimately led to the lack of development in terms of molecular or particular approaches for regulation and authorization of these chemicals (du Jardin, 2015).

Table 2: Table showing the effects of biostimulants on the production of crops as regards their cellular mechanism, physiological roles of the crops, agricultural, horticultural functions and predominantly, their anticipated social and economic benefits.

	Humic acids	Seaweed extracts	Protein hydrolysate	Glycine betaine	Plant Growth-promoting Rhizobacteria
Cellular mechanism (*i.e.* interaction with cellular components and processes) ↓	Activate plasma membrane proton-pumping ATPases, promote cell wall loosening and cell elongation in maize roots (*Zea mays*) (Jindo et al., 2012)	*Ascophyllum nodosum* extracts stimulate expression of genes encoding transporters of micronutrients (*e.g.* Cu, Fe, Zn) in oilseed rape (*Brassica napus*) (Billard et al., 2014)	Enzymatic hydrolysate from alfalfa (*Medicaco sativa*) stimulates phenylalanine ammonia-lyase (PAL) enzyme and gene expression, and production of flavonoids under salt stress (Ertani et al., 2013)	Protects photosystem II against salt-induced photodamage in quinoa (Shabala et al., 2012), likely via activation of scavengers of reactive oxygen (Chen & Murata , 2011)	*Azospirillum brasilense* releases auxins and activates auxin-signalling pathways involved in root morphogenesis in winter wheat (*Triticum aestivum*) (Dobbelaere et al., 1999)
Physiological function (*i.e.* action on whole-plant processes) ↓	Increased linear growth of roots, root biomass	Increased tissue concentrations and root to shoot transport of micronutrients	Protection by flavonoids against UV and oxidative damage (Huang et al., 2010)	Maintenance of leaf photosynthetic activity under salt stress	Increased lateral root density and surface of root hairs
Agricultural/horticultural function (*i.e.* output traits relevant for crop performance) ↓	Increased root foraging capacity, enhanced nutrient use efficiency	Improved mineral composition of plant tissues	Increased crop tolerance to abiotic (*e.g.* salt) stress	Increased crop tolerance to abiotic (*e.g.* high salinity) stress	Increased root foraging capacity, enhanced nutrient use efficiency
Economic and environmental benefits (*i.e.* changes in yield, products quality, ecosystem services)	Higher crop yield, savings of fertilisers and reduced losses to the environment	Enhanced nutritional value, 'biofortification' of plant tissues (increased contents in S, Fe, Zn, Mg, Cu)	Higher crop yield under stress conditions (*e.g.* high salinity)	Higher crop yield under stress conditions (*e.g.* high salinity)	Higher crop yield, savings of fertilisers and reduced losses to the environment

Source: (Retrieved from du Jardin, 2015).

3.2.4 Global Opportunity (market) Analyses and Major findings of biostimulants.

As the awareness of chemical substances utilized in food production and the potential threats posed by chemical residues on foods and crops are increased as perceived by the public consensus, there is a heightened need to support alternatives; products that are free from chemical substances, driving the growers for organic agriculture and increasing the demand for biostimulants.

For several years, synthetic fertilizers have been widely used in agriculture to accelerate or substitute for naturally occurring nutrients. Especially poorer and less technologically advanced nations, with restricted access to advancements in agriculture, keep relying on the use of chemical compounds on a wide range of crops. There has been a shift, however, in Europe and the United States, from dependence on chemical fertilizers as research has constantly emphasized the use of biostimulants for the benefits of crops. These take the shape of supplements that are intended to aid in plant health, thereby resulting in enhanced and sustainable crop productivity (Craggs, 2017).

Progress in agriculture has been observed in recent studies as regards the application of biostimulants because of their ability to enable plants to withstand stress from varying external factors. These stressors include an increase in temperature and decreased levels of moisture caused by climate change (Craggs, 2017).

Research also shows that biostimulants, when applied to crops, provide enhanced development in the root biomass, leading to plant vitality and increased growth. Farmers in Europe, by using biostimulants that are naturally derived, have also been able to minimize their reliance on expensive synthetic fertilizers, that when constantly applied, can result in a build-up of chemical residues, decreasing the soil fertility. In 2015, based on recent market analyses, the European Union countries are contributing to the major part in the research, establishment and application of biostimulants. Comparatively, projections in the Asia-Pacific area have revealed this region to be the largest-growing market for biostimulants (from 2016-2021), as nations are open to accepting several new farming practices that include the application of organic additives in synthesis with sustainable agricultural strategies. In addition, trends are increasing in North and Latin America and South Africa and Middle Eastern regions as regards enhanced use of agricultural biostimulants. A major factor is a reinforcing demand for organic agricultural substances in the world today in opposition to crops that are cultivated by applying chemical fertilizers (Craggs, 2017).

Reports from FiBL-IFOAM-SOEL-Surveys show that organic farming is practiced in about one hundred and eighty-one (181) countries. In the year 2017, the largest growth was recorded in which 69.8 million hectares of farmland were being managed organically, amounting to about 11.7 million hectares and a growth of 20 percent. Reports from this survey also indicated that sales amounting to USD 97 billion were attained in 2017 from initial sales of USD 81.6 in the year 2015. This has over the recent years, increased the demand for organic food and the need to keep investing in organic agriculture globally, thereby increasing the demand for biostimulants and the overall growth of the market for biostimulants (Meticulous Market Research, 2020).

Globally, the value in marketing biostimulants is anticipated to increase between the years 2019-2025 at a Compound Annual Growth Rate (CAGR) of 13.4%, thereby reaching about $4.47 billion by the year 2025, while with regards to volume, the market for biostimulants is anticipated to reach 4,46,651.3 metric tons at a CAGR OF 12.4 percent by 2025, influenced by increasing demand for healthy crops, investing in the organic form of agriculture, demand for organic crops, and several benefits for biostimulants in crop production. To promote the growth of biostimulants in the market globally, there has also been a record of increased knowledge of environmental safety with the use of biostimulants (Meticulous Market Research, 2020).

Some barriers that have hindered the growth of biostimulants include inadequate education, inadequate technical knowledge, and other concerns that farmers, new entrants, and small players are faced with. Besides, in developing biostimulants, there is a lack of a standardized regulatory framework (regulatory challenges) as well as technical and scientific challenges. Globally, the biostimulants industry comprises majorly active ingredients (acid-based biostimulants, extracts based, microbial amendments, trace minerals, and vitamins. Their mode of application includes application by foliar spraying, treatment involving the soil, and treatment involving the seeds. They can be formulated either by liquid or by dry formulation and specifically by the type of crops such as fruits, vegetables, row crops, turfs, and ornamentals. The industry for biostimulants is located mainly in America, Europe, Asia-Pacific, Latin America, Middle East, and Africa (Meticulous Market Research, 2020).

In 2019, overall the acid-based stimulants portion was evaluated to dominate the largest part of the biostimulants market. The large portion of this section of biostimulants is majorly accredited to their several benefits to the crops, higher efficiency, and easy availability. However, during the forecast period, the extract-based biostimulants segment is anticipated to witness an increase in terms of growth. Application through the foliar spray method is anticipated to command the largest portion of the biostimulants market in 2019. This is majorly attributed to its higher efficiency, as compared to other modes of applying biostimulants. However, during the forecast period, an application involving seed treatment is anticipated to experience the fastest growth, as it supplies several benefits including increased uptake of nutrients, protection from pathogens, enhanced availability of nutrients in the rhizosphere, enhanced growth of the roots and shoot, and more efficient utilization of nutrients (Meticulous Market Research, 2020).

Biostimulants are applied mostly on row crops, and this portion is evaluated to command the largest share of the biostimulants market in the year 2019. This high demand for row crops is majorly influenced by the huge area under cultivation of row crops globally, the increasing rate of organic agriculture, and the growing usage of biostimulants by farmers instead of pesticides or chemical fertilizers. Liquid biostimulants recorded the largest share of the biostimulants market based on formulations in 2019. This large portion is majorly accredited to a more effective duration (up to six months) when compared to the dry formulation (up to three months) and they also perform better than dry formulations (Meticulous Market Research, 2020).

Europe was considered the largest market for biostimulants in terms of geographic location. This was followed by North America and then, Asia. The large share of this segment is majorly attributed to the increasing concerns over chemicals that are deleterious to the environment, growing demand for organic foods, increasing research and development activities on biostimulants, and many biostimulants suppliers. However, during the forecast period, the Asia-Pacific area is anticipated to register the fastest growth, majorly due to the large area under agriculture, rising need to enhance the yield and quality of crops, growing demand for organic foods, increasing awareness among growers about the benefits of biostimulants, and several initiatives by the Government to establish and enhance the application of biologicals in the area. Some of the key players that are profiled in the global biostimulants market report include BASF SE, Valagro SpA, Biolchim S.p.A., Marrone Bio Innovation, Monsanto Company (Part of Bayer), Trade Corporation International (Part of Sapec Group), Plant Health Care PLC, Syngenta (Subsidiary of ChemChina), Biostadt India Limited, Andermatt Biocontrol AG, BioWorks, Inc., Novozymes, Inc., Koppert B.V., Italpollina S.p.A., Micromix Plant Health Ltd., Arysta Life Science Corporation (Subsidiary of Platform Specialty Products Corporation), FMC Corporation, Bioatlantis Ltd, Omex Agruifluids Limited (Subsidiary of Omex Group), Haifa Chemicals Ltd., Agrinos AS, Camson Bio Technologies Limited, Som Phytopharma India Limited, EuroChem Group AG, and SICIT 2000 SpA (Meticulous Market Research, 2020).

4.0 Conclusion

Agriculture is a vital aspect of the world today and the future of agricultural production still depends on healthy soil. Innovations in agriculture are being analyzed and closely examined to determine how they address our food production systems, how they are being perceived by consumers, and how suitable they are to the environment. As a whole, for instance, the quality of water is directly connected to soil management. Regenerative agriculture or biostimulation is more than a set of different agricultural practices or operations. These are more of our approaches and mindset, our perceptions of these practices, and what we are constantly working on to enhance soil health. As the tastes and likes of humans differ, there is a general notion that consumers demand the production of food that is carried out in an environmentally responsible manner. While the use of biostimulants in crops have been stated to be environmentally friendly, minimize environmental concerns, increase crop resistance for biotic and abiotic stresses and minimize the use of synthetic fertilizers and several published articles state that ‘Regenerative agriculture shifts the paradigm’ as its major focus is on enhancing soil health by following basic principles, putting into consideration the societal and environmental effects of our food production system, there is no data or research that conclusively states that regenerative agriculture and biostimulation can be practiced simultaneously.

It is, however, necessary in this context that limitations and barriers surrounding these agricultural practices be identified independently and that feasible, practical solutions established as these practices will differ depending on several factors, including the type of soil, type of farm, different production concepts and management, different perceptions of farmers, etc.

The concepts, practices, and principles that have been discussed in this report will take some effort and time in ensuring they 'work' but they may also serve as applicable references to farmers and the government as they work on enhancing their agricultural operations, regenerating their rural communities and planning towards ensuring sustainable ecosystems. Farmers that are willing to embrace regenerative agriculture and biostimulation in economically profitable ways should be able to thrive as the years go by provided the principles and management strategies governing each practice are judiciously combined to result in greater benefits.

5.0 Recommendations

- There is a need to approach regenerative agriculture and biostimulation with greater optimism and positivity.
- More efficient communication of these aspects of agriculture should be made available for all stakeholders involved; the farmers, the scientists, and the public.
- A standard framework for the scientific regulation of testing biostimulants, identifying and assessing risks should be formulated and properly established to minimize risks or potential hazards that may be involved in the application of biostimulants for agricultural production.
- The Government should establish well-defined policies regarding biostimulants that will enable suitable regulatory compliance and ensure this is strictly adhered to.
- More extensive research on the soil and ecosystem for making sound decisions regarding the implementation of regenerative agriculture or biostimulation to cultivate healthier crops and establish both economic and environmental strength into agricultural operations.

- The different underlying principles and strategies regarding regenerative agriculture and biostimulation that are proven to offer potential benefits both economically and environmentally should be investigated and followed, and outcomes are duly communicated to the public.
- Extensive research is required to construe the way regenerative agriculture and biostimulation individually operate, their interactions between external stressors, and if they can be practiced simultaneously in the environment.
- Expansion of farms with regenerative agriculture should be greatly encouraged as this often results in more employment opportunities, newer streams of income increasing economic resilience in rural communities.

6.0 Challenges to be addressed

- Limitations of extensive information, primary data, and research of both regenerative agriculture and biostimulation.
- Limitations of research regarding the effects of biostimulants on the biochemistry and morphology of the crops.

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