Sustainable Agriculture – The Contribution of Biostimulation

Supervisors:

Leslie Lavkulich,
Academic Director
MLWS, UBC

Stan Loewen,
Chief Executive Officer
TerraLink Horticulture Inc.

Submitted by:

Likhita Kiran Miriyapalli

Executive Summary:

Traditional agriculture has led to the degradation of fragile agro-ecosystems. Soil quality is gradually deteriorating and soils are becoming less fertile; thus, less productive for food production. Such agricultural practices pose potential threats to the environment causing land and water degradation risking global food security. To meet the growing demand for food production, due to the rapidly increasing population, there is a need for sustainable agricultural systems that are economically viable, environmentally safe and socially fair. Such systems must be congruent with improved quality foods and lower contaminants. Social concerns of conventional farming combined with the growing demand for sustainable agriculture and food safety have led to the emergence of alternative agricultural systems. Innovations and agricultural practices that are emerging play a crucial role in ensuring sustainable food production systems. One of such innovations is plant biostimulation, which may make existing practices more efficient and sustainable. "Plant biostimulants contain substance(s) and micro-organisms whose function, when applied to plants or the rhizosphere, is to stimulate natural processes to enhance/benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and crop quality." This paper presents an overview of plant biostimulation, its contribution to sustainable agriculture. Benefits and challenges of biostimulation are outlined, including uses, application in agricultural systems, public perception, global and market analysis.

Table of Contents

1. Context:

1.1. Conventional agriculture and the benefits:

The Ford Foundation and other organizations encouraged the international Green Revolution campaign in the 1960s to increase agriculture's productivity through the introduction of science-based technology in the cultivation of food grains such as rice, corn and wheat. Its purpose was to eradicate hunger by incorporating highly innovative technology into traditional agricultural societies (Oosterveer & Sonnenfeld, 2012). Worldwide increases in food production have helped millions of individuals escape poverty, decreased hunger and given the platform for economic development, both rural and urban in many countries. World agricultural production almost tripled between 1961 and 2007, while the population doubled. With new varieties, inputs, water management and rural infrastructure, the green revolution drove this production growth. During that period, most increases have been achieved in food production in the same area, with the net area growing only 11 percent (Rosin, Stock & Campbell, 2013). This type of intensive farming with the use of high-input technologies that boosted yields is known as Conventional Agriculture (Theocharopoulos et al., 2012).

2. Introduction to the issue:

2.1. Conventional agriculture and its ill effects:

The Green Revolution is recognized for its essential contribution towards increasing food production and reportedly had an adverse impact on the environment and society (Oosterveer & Sonnenfeld, 2012). Agrochemical products made it possible to more than substantially increased production in the last century, and the pressure for the extensive use of pesticide and fertilizer continues at present to meet the need to boost food production to feed a rapidly increasing population. However, the negative result of the pollution and impact of agrochemical residues on soils, terrestrial and aquatic ecosystems and their effects on humans and non-human biota have been reported globally (Carvalho, 2017). Food production has many direct consequences for human health and natural ecosystems. There are environmental impacts that are directly related to agro-industrial methods of primary food production, including soil erosion, intensive water use, pesticides, and fertilizer and emission of different pollutants into the natural ecosystem (Oosterveer & Sonnenfeld, 2012).

Conventional agriculture leads to considerable increases in water use. There are several environmental issues caused by extensive use of water in agriculture, such as salinization, diversion of watercourses creating scarcity for a range of socio-economic applications. Water contributes to soil erosion of agricultural land, leading to the loss of topsoil. Pesticides also attract considerable attention because they (may) directly affect human health and ecosystems. For example, the popular press on 15 October 2002, the *Toronto Globe & Mail* reported that "approximately 20% of food that we consume is contaminated with pesticides in trace amounts even those that have been banned for centuries". Chemical fertilizers may, primarily because of the large quantities of energy required to produce them, have adverse environmental effects (Carvalho, 2017). Leaching of unused and excess fertilizers through the soil profile into groundwater is a severe environmental concern caused by the use of chemical fertilizer (Oosterveer & Sonnenfeld, 2012).

To obtain higher productivity, industrial agriculture used contemporary techniques intensively, in which this intensive farming brought about an increase in the cultivation of single crops on large areas (monoculture) decreasing biodiversity and increasing vulnerability against pests and diseases. Modern agriculture, using 'high-input' technologies with fewer numbers in the workforce, has caused the displacement of traditional agriculture, a considerable shift from farming areas and rapid urbanization (Oosterveer & Sonnenfeld, 2012).

2.2. Present scenario threatening food security:

It's now understood that agriculture can harm the environment by overusing naturally occurring resource inputs, as they impose costs that are not reflected in the price of markets. Such impacts are called negative externalities (Rosin, Stock & Campbell, 2011). The evidence shows that an intensified agriculture system poses a potential threat to the environment causing land and water degradation risking global food security (Hurni et al., 2015). In the next few decades, population and income growth will further boost the demand for food.

Moreover, products from plants are increasingly used for unconventional purposes such as the generation of biofuels. To meet this increasing demand, world agricultural production is projected to increase by a minimum of 60% and potentially up to 100% by 2050 (Meemken & Qaim, 2018). At the same time, agricultural land is shrinking, and soil quality is deteriorating. Worldwide, topsoil is lost 10 to 40 times more rapidly than the soil regeneration rates. Organic matter is being lost in soil and soils become less fertile threatening future food safety. More than 52% of total fertile and food-producing soil is now classified as degraded (UNCCD, 2015). It is projected that there will be a 12% decline in global food production in the next 25 years (UNCCD, 2015). FAO (2015) has regarded that one of the significant reasons for land degradation is mainly through reducing soil health. Their definition of soil health considers "the capacity of soil to function as a living system. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots, recycle essential plant nutrients, improve soil structure with positive effects for soil water and nutrient holding capacity, and ultimately improve crop production. Healthy soil also contributes to mitigating climate change by maintaining or increasing its carbon content". Also, climate change is a major contributor to food security that threatens many parts of the world (Gomiero et al., 2008). This is a large challenge, as available land, water and other natural resources are becoming scarce.

3. Possible solution:

3.1. Need for sustainable agriculture systems:

The value of sustainable agricultural systems has increased, particularly because of the increased consumer concern regarding food safety and environmental pollutants (Theocharopoulos et al., 2012). Modern agriculture is therefore now facing the challenge of developing sustainable production technologies that reduce their ecological effects significantly (Henneron et al., 2015). The current and future growth in food production must be congruent with improved quality foods and lower contaminants (Carvalho, 2017).

"The agricultural systems are considered to be sustainable if they sustain themselves over a long period of time, that is, if they are economically viable, environmentally safe and socially fair" (Lichtfouse, 2009). "Sustainable agricultural intensification is defined as producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services" (Rosin, et al., 2011). The guiding principle for attaining sustainable objectives should be good farming practices, wherein producers strive at ecologically and economically sustainable utilization of resources. Sustainable farming should focus mainly on:

i. Maximizing the use of ecological processes such as plant-microbial interactions, biological pests and disease management (PMDs), crop-weed competition and organic matter / nutrient cycling (INMs) in agricultural system and agroecosystems (Spiertz, 2010).
ii. Optimal utilization of natural resources, such as soil fertility, soil water content, biodiversity above and below ground level and genetic diversity in plant traits (Spiertz, 2010).
iii. Limited use of external resources, including synthetic chemical products, fossil energy and freshwater (Spiertz, 2010).
iv. Quantifying and minimizing system management impacts on external aspects such as the emissions of greenhouse gases, clean water availability, carbon sequestration, biodiversity and dispersal of pests, pathogens and weeds (Rosin et al., 2011).

3.2. Building soil health for sustainable agriculture:

3.2.1. Definition of soil health:

"Soil Health also referred to as Soil Quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. This definition speaks to the importance of managing soils, so they are sustainable for future generations. To do this, we need to remember that soil contains living organisms that when provided the basic necessities of life - food, shelter, and water - perform functions required to produce food and Fiber"- (USDA).

3.2.2. Importance of soil health:

Many ecosystem services rely directly on the functions of the soil. "Healthy soils are the basis for quality food production" (FAO, 2015). Soil is an integral part of agroecosystems and promotes numerous ecosystem services, including food supply, climate regulation, erosion regulation and water supply. Soil biota is an essential driver for soil function, as soil organisms play an important role in the soil, including nutrient cycling, maintenance of the soil structure, carbon transformation and regulating the biological population (Altieri, 1999). Soil microorganisms, nemato fauna and macrofauna are significant players in the soil food web and functioning of healthy soil. Micro-organisms are the primary decomposers of organic matter and drive the most significant biogeochemical cycles in soil. The interactions between soil fauna and micro-organism are of key significance in regulating soil processes. Trophic interactions among micro-organisms and nematodes in the soil micro food web play a vital role in the regulation of the microbial population and nutrient cycling (Henneron et al., 2015). The intensification of the agricultural paradigm of the green revolution has been shown to have significant harmful effects on soil biota (Postma-Blaauw et al., 2010). This includes many agricultural practices, including heavy tillage, harmful management of crop residues, lack of organic amendments and application of pesticides (Kibblewhite et al., 2008).

Soil health and human health are strongly related. In areas with the greatest degradation of the soil, as in Sub-Saharan Africa and South Asia, food insecurity continues (Singh et al., 2011). Also, the quantity of food production, soil health also has a significant impact on food quality. Concentrations of micronutrients, protein, and essential amino acids in agronomic products are important aspects that link soil health with human health by the quality of food produced. Soil health may affect human health by the deficiency, excess, or imbalance of these elements in soils (Singh et al., 2011).

Soil health also affects human health because of its impact on diet and the environment. Figure.1 illustrates the close interaction between soil health, human health and environmental quality. Environmental implications of soil health are linked to its interaction with the hydrosphere that alters the quality of water, the biosphere that moderates NPP (net primary product) and the uptake of nutrients/elements, the lithosphere which changes the stability of the landscape and the atmosphere which changes the concentration of greenhouse gases (GHG) and other airborne contaminants (Singh et al., 2011).

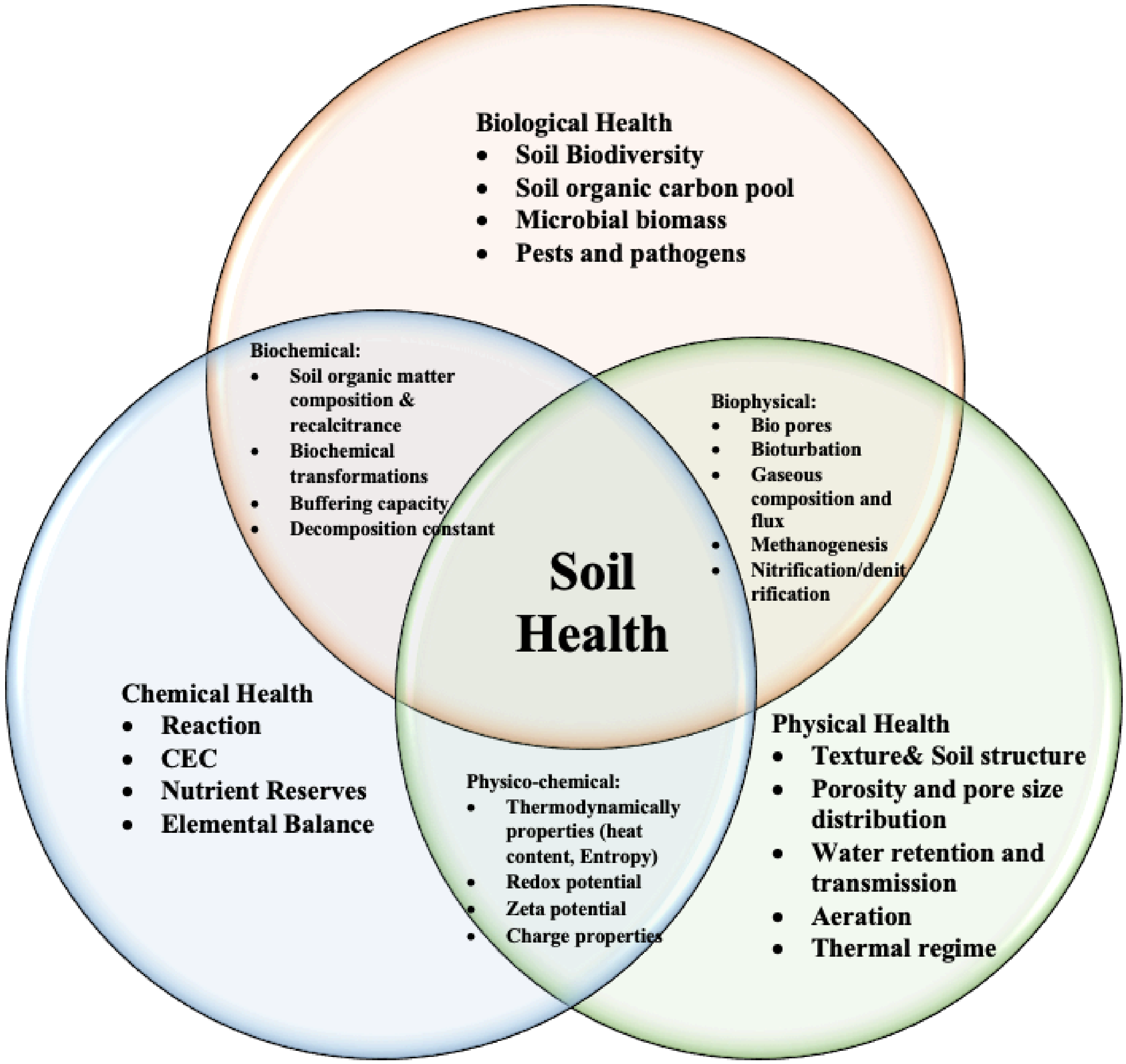


Figure 1 Source: Singh et al., 2011

3.3. Biostimulation, the sustainable alternative – Could it be the solution?

One of the sustainable alternatives that may be used in agricultural systems is "biostimulation." "The term biostimulation is often used to describe the addition of electron acceptors, electron donors, or nutrients to stimulate naturally occurring microbial populations." (Kanissery & Sims, 2011). Land and water degradation can be rolled back with biostimulation, which is one of the sustainable and innovative agroecological techniques that are capable of improving soil health

(Lichtfouse, 2018). Formulations used in biostimulation are called biostimulants. "Plant biostimulants contain substance(s) and micro-organisms whose function, when applied to plants or the rhizosphere, is to stimulate natural processes to enhance/benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and crop quality" (EBIC). It is an age-old practice that has been used for many centuries and not new to modern agriculture (Gu et al., 2014).

The Industry Council of European Biostimulants claims that biostimulants differ from crop inputs as they operate through various other mechanisms than commercial fertilizers, even though they have the presence of nutrients in their products (EBIC). They also differ from pesticides because they do not act directly against specific pests or diseases but act on plant vigour. Hence it can be complementary to crop nutrition and protection. Agricultural biostimulants include a diverse range of formulations of compounds, substances and micro-organisms, such as seaweed and plant extracts, amino and humic acids, salts and minerals and more (Figure. 2) (EBIC). Biostimulants are commonly applied to horticultural crops in greenhouse conditions or open field conditions to vegetable crops, fruit trees and ornamentals (EBIC).

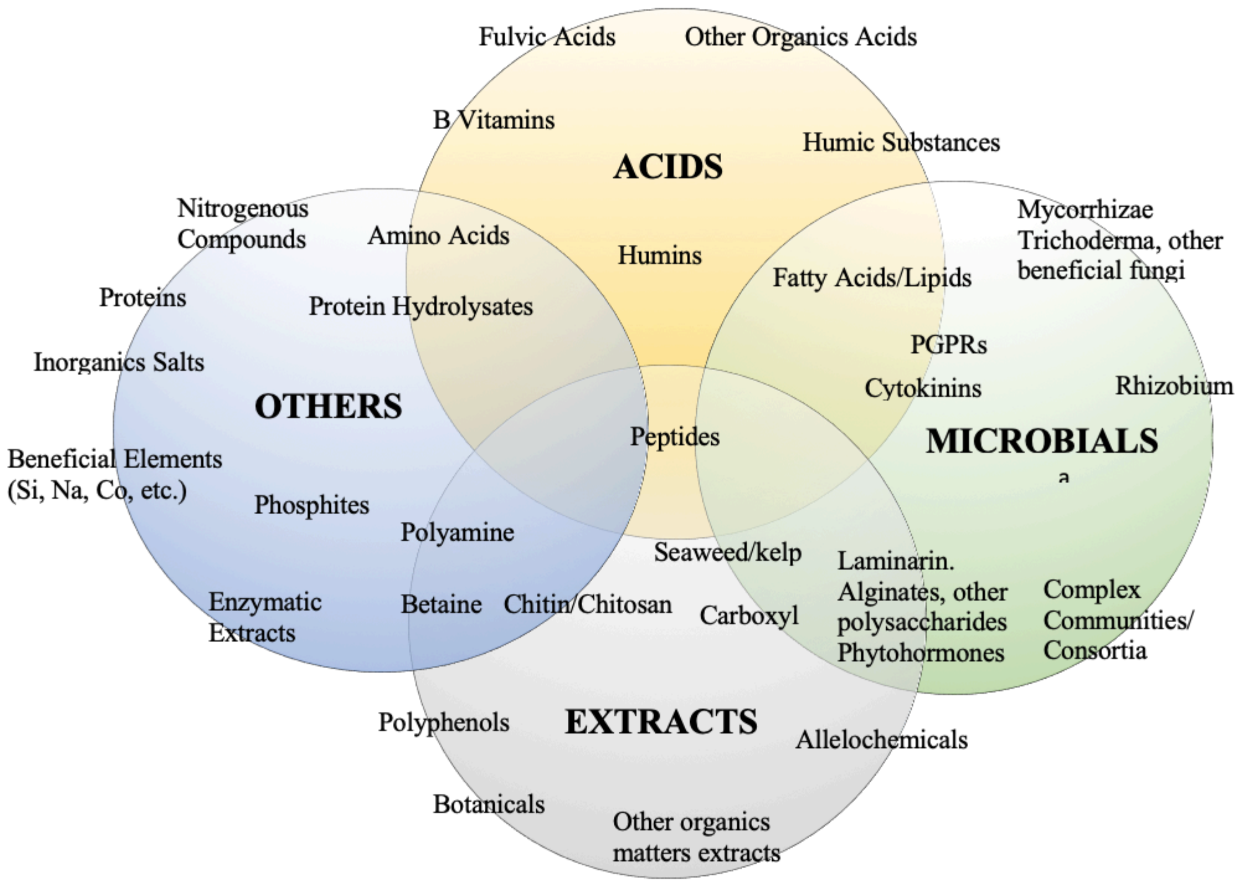


Figure 2, Source: Global Industry Perspective, 2017.

4. Project objectives:

This study focuses on an assessment of the utilization of biostimulation in agricultural systems and to:

i. Evaluate the range and properties of biostimulants.
ii. Identify the uses of biostimulants to increase the efficient use of a resource.
iii. Benefits and challenges of biostimulation in improving soil health.
iv. Determine the suitable crops for application of biostimulation.
v. Determine if it is useful for broad application.
vi. Analysis of the current understanding of biostimulation in terms of science and acceptance by the growers and public.

5. The study:

5.1. Agricultural systems:

Social concerns about the environment caused by conventional farming combined with the growing demand for sustainable agriculture and food safety have led to the emergence of alternative agriculture systems in recent years (Parra-López et al., 2007).

5.1.1. Zero Budget Natural Farming (ZBNF):

i. What is Zero Budget Natural Farming?

ZBNF is a natural method of agriculture that uses bio-pesticides rather than chemical fertilizers. Farmers use earthworms, cow dung, urine, plants, human excreta, and such fertilizers for crop protection. ZBNF is resource-efficient, minimizing the utilization of financial and natural resources while increasing crop yields. It decouples agricultural productivity and growth from the degradation of ecosystems and the loss of biodiversity by maintaining soil and water quality (Naresh et al., 2018). The income from intercrops compensates for the cost of production of the main crop. Furthermore, no agricultural inputs should be purchased from the market. All these inputs should be prepared and obtained from the farmer's farm. More importantly, inputs should not harm the soil and the environment as part of natural resources. No human interference should take place in plant growth. (Satish, 2018).

ii. The question may be raised why this practice?

In the last 20 years in India, almost three lakh farmers" have ended their lives due to debt traps. The average farmer in India with around 5 acres of land spends $770 annually on inputs like chemical fertilizers and pesticides which reduces investment returns (ZBNF, 2017). With excessive use of chemical fertilizers, the farmer's fields are more prone to insects and diseases thereby increasing the labour costs by around 40%. Over time, the soil using chemical fertilizers becomes harder and less fertile. Deteriorating farmer's health over time due to harmful fertilizers and pesticides in agriculture leads to increased health expenses and also financial burdens. Hence ZBNF a grassroots farming movement, has spread to different states in India with the support of government (ZBNF, 2017).

iii. Challenges in this system:

Recently in a policy brief, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Director-General reported that ZBNF's farming practices were not evaluated scientifically. To review its allegations, the Indian Council of Agricultural Research (ICAR) established a commission. At the Indian Institute for Farming Systems Research, trials on ZBNF are being performed. The committee intends to review ZBNF's results, to examine the merit and weaknesses, and to propose measures for the validation of results on research farms and in farmers ' fields. The committee also intends to assess the expected impact of ZBNF promotion on soil health, productivity, food production, livelihoods and agriculture sustainability in India (ICRISAT, 2019).

5.1.2. Organic Farming:

i. What is organic farming?

Organic farming is one approach to achieve sustainable methods in agriculture, and many of the techniques used in various agriculture systems are practiced. The process that makes organic farming unique is that: almost all synthetic inputs are prohibited and' soil-building ' crop rotations are mandated. The fundamental laws of organic production include the approval of natural inputs and the prohibition of synthetic inputs. However, in both instances, there are exceptions. Some natural inputs that are harmful to human health or the environment determined by the different certification programs (e.g. arsenic) are prohibited. In addition, specific synthetic inputs that are essential and in accordance with the philosophy of organic farming (e.g. insect pheromones) are permitted (FAO, 2019). It is different from ZBNF. Table .1 discussed the differences and similarities between organic and ZBNF.

Comparison between (Farming practices) Natural and Organic Farming

Characteristics	Organic Farming	Natural Farming (ZBNF)	Similarities
Manures	Organic manures are used	Neither chemical nor organic manures are used	Natural, organic-poison and Chemical free
Agricultural Practices	Basic agro-practices are followed. (Tillage, weeding and mixing of manures	Not practiced	Local breed of seeds
Environmental impacts	Ecological impacts on surrounding environment	Molding with local biodiversity	Eco friendly pest control
Economic point of view	Expensive bulk manures	Extremely low cost. Working models – Zero Budget Natural Farming. (ZBNF)	

Table 1, Source: (UGAOO, 2019)

ii. Perceptions of organic farming

Organic farming has been promoted as the most sustainable type of agriculture and the future paradigm of worldwide food production (Pandey et al., 2012). As a response to these degraded ecosystems, organic farming has emerged as a solution to improve health and sustainability issues (Pandey et al., 2012).

It is an apparent misconception that organic food is better by default or is an ideal way to minimize the environmental effect (Ritchie, 2017). Across various metrics, organic farming is proven to be more harmful than conventional agriculture for the world's environment (Ritchie, 2017). The discussion between organic and intensive farmers is often unnecessarily polarised. Some scenarios show one system better than the other and vice versa (Ritchie, 2017).

Many customers see organic foods as better because of reduced exposure to pesticides from a health perspective. In this respect, is organic food healthier and safer? Clark & Tilman (2017) in their study, did not show any health benefits of organic food. However, they note that there is evidence that organic foods typically record lower pesticide residue concentrations. This is perhaps not a surprising result because in traditional agriculture, the use of pesticides is generally high. The vital question, however, is: should we be concerned about the health impacts of pesticide residue? For nation-wide residue assessments from 2000 to 2008, Clark & Tilman (2017) searched USDA database results. All risk figures for pesticides were discovered to be well below the specified 'chronic reference doses' (RfDs). Only one product was residual in excess of 1% of RfDs. The majority (75%) of products were below RfD limits of 0.01%. This refers to residue levels 1 million times lower than the threshold for which there are observable effects to exposure.

However, the availability of nutrients is another limiting factor in many organic systems resulting in yield gaps between conventional and organic farming (Pandey et al., 2012). Therefore, the question remains whether organic farming alone can indeed feed the world with its 7.5 billion individuals now, and perhaps more than 9 billion by 2050 (Seufert & Ramankutty, 2017)? Today only 1% of farmland is organic, a complete conversion to organic farming does not seem to be a realistic situation in the foreseeable future, but it is an interesting experiment (Meemken & Qaim, 2018).

5.2. Biostimulation:

Biostimulation may be an alternative approach that may be used in both conventional and organic farming and contribute to healthy soils and increased food security. Most of the biostimulants are plant-based and hence may be used in organic systems (EBIC). Plant “Biostimulants” are prepared from compound, substance and microorganism that are applied for plants or soils to improve plant vigour, yields, quality and tolerance of physical stress (du Jardin, 2015). These include biological stimulants, metabolic enhancers, plant strengtheners, beneficial plant growth regulators, allelopathic preparations, plant conditioners, phyto biostimulators, and biofertilizer/biostimulant goods (du Jardin, 2015). These are supplements that are intended to promote plant health and to improve and encourage sustainable crop productivity. Biostimulants in tiny amounts increase and encourage plant growth and development, increase nutrient uptake and metabolism, enhance the ability of water retention and boost chlorophyll and antioxidant production. The active ingredient of biostimulants is naturally soil bacteria. Biostimulants are divided into two classes of acid biostimulants derived from the natural disintegration of organic matter in the soil, for example, from peat and coal and biostimulants extracted from seaweed. Biostimulants function by improving the uptake of essential chemicals and trace elements that encourage plant growth and also by enhancing plant processes like photosynthesis and nutrition. The additives which are normally used to promote and improve nutrients supply for plants are therefore not categorized as fertilizers (Craggs, 2017). Du Jardin included the following categories of biostimulants in his study:

i. Humic and Fluvic acids
ii. Protein hydrolysates and other N-containing compounds
iii. Seaweed extracts and botanicals
iv. Chitosan and other biopolymers
v. Inorganic compounds
vi. Beneficial fungi

vii. Beneficial bacteria

5.2.1. Humic and Fluvic acids:

Humic substances (HSs) results from the decomposition of plant, animal and microbial residue. They are also formed by the metabolic activity of the soil microbes using these substrates and are natural constituents of soil organic matter. HS are heterogeneous compounds originally classified in humins, humic acids and fulvic acids according to their molecular weights and solubility. Humic substances, which have acted on the physical, physio-chemical, chemical and biological properties of the soil have for a long time been recognized as an essential contribution to soil fertility (du Jardin, 2015). The most biostimulatory effects of HS are root nutrition amelioration through various mechanisms. One is the improved utilization of micro and micronutrients because of the increased cation exchange capacity of the soil. Apart from the absorption of nutrients, proton pumping of the ATPases plasma membrane also contributes loosen the cell wall, cell enlargement and organ growth. HS also refers to the stress protection proposed biostimulation activity. To produce phenolic compounds, phenylpropanoid metabolism is central and involved in secondary metabolism and a broad spectrum of stress responses.

5.2.2. Protein hydrolysates and other N-containing compounds:

The combination of amino acids and peptides is acquired from agro-industrial by-products of both plant and animal inputs through chemical and enzymatic protein hydrolysis. Chemical synthesis for single or mixed compounds may also be used. Other nitrogenous molecules include betaines, polyamines and non-protein amino acids, which are not well defined but diverse in higher plants as far as their physiological and ecological functions are concerned. Glycine betaine is a particular case of amino acid derivatives with prominent anti-stress characteristics.

These compounds have, case by case, been demonstrated to play multiple roles as plant growth biostimulants. The direct impacts on plants include the modulation of N intake and assimilation, regulating enzymes involved in the N-assimilation and their structural genes, acting on the root signalling pathway of N intake. In complex protein and tissue hydrolysates, hormonal activity is also reported. Some amino groups (such as proline) have chelating impacts that can protect plants against heavy metals and also contribute to mobility and acquisition of micronutrients.

In agricultural practice, indirect effects on plant nutrition and growth will also be crucial when protein hydrolysates are applied to plants and soil. Protein hydrolysates have been known to improve biomass and activity of microbes, soil respiration, and soil fertility in general. Specific amino acids and peptides are considered as contributing to root development and nutrients availability by chelating and complexing activities. Several commercial products derived from plant and animal protein hydrolysates have been marketed. Variable but substantial improvements in yield and quality in agricultural and horticultural crops in many cases have been observed.

5.2.3. Seaweed extracts and botanicals:

Fresh seaweeds have been used as a source of organic matter and fertilizer in ancient agriculture but only lately, biostimulating impacts have been reported. This leads to the commercial use of seaweed extracts and purified compounds, including laminarin, alginates and carrageenans, polysaccharides and their derivatives.

Seaweed can be applied to both soils and plants. It can be applied to soils, in hydroponic or foliar solutions. Their polysaccharides are used in soils to produce gel formation and increase water retention and soil aeration. The polyanionic compounds help in the fixation and exchange of cations, which are also important to fix heavy metals and soil remediation. Positive impacts through soil micro-flora, promoted by bacteria that promote plant growth, and pathogenic antagonists in suppressive plants, have also been identified. In addition to their other functions in plants, nutritional effects through the supply of micro-or macronutrients show that they function as fertilizers.

Hormonal impacts, which are seen as significant reasons for the bio-stimulation activities in crop crops, influence seed germination, plant development and further growth and development. There are also recorded anti-stress effects, with both protective compounds within the seaweed extracts, such as antioxidants and regulators of endogenous stress-responsive genes that could be involved. Botanical substances are extracted from plants that are used in pharmaceutical and cosmetic products, as food ingredients and plant protection products. In comparison to seaweeds, their biostimulants are much unknown, as their pesticide properties are the focus of attention.

5.2.4. Chitosan and other biopolymers:

Chitosan is a deacetylated, naturally and industrially developed form of biopolymer, chitin. In the meat, beauty, medical and agricultural industries, poly-and oligomers of variable regulated dimensions are used. The physiological effects of chitosan oligomers on plants are the result of this polycationic compound's ability to bind various cellular components, including DNA, plasma membrane and wall constituent, but also to attach to specific receptors engaged in the production of a defence gene similarly to defence elicitors for plants. Chitin and chitosan use particular receptors and signalling pathways.

As a result, agricultural applications of chitosan have been developed, concentrating on plant protection against fungal pathogens, but more general agricultural applications have to do with tolerance of abiotic stress (rainfall, salinity) and quality traits associated with both primary and secondary metabolisms. Chitosan inducing stomatal closure via an ABA-dependent mechanism participates in the protection against environmental stress by this biostimulant.

5.2.5. Inorganic compounds:

Chemical components that encourage crop development, but which are not needed by all crops, can be referred to as useful components for specific species. The five most beneficial elements are Al, Co, Na, Se and Si, and in soils and plants are present as different inorganic salts and as insoluble forms in graminaceous species of amorphous silica ($SiO2$-$nH2$ O). These beneficial functions can be constitutive, as strengthening cell walls by silica deposits of the cell walls or expressed in certain environmental conditions, such as pathogenic selenium attacks and sodium osmotic stresses. Therefore, the definition of beneficial elements is not restricted to their chemical nature but also to the specific situations where positive effects can be identified for plant growth and stress response. The bioactivity of a few complex biostimulants, such as seaweed, crop residues or waste, may involve the physiological functions of these beneficial elements.

The scientific literature reports many of the effects of beneficial elements that promotes plant growth, quality of plant products and tolerance of abiotic stress. This includes rigidification of the cell wall, osmoregulation, reduced transpiration by crystal deposits, radiation reflective thermal regulations, co-factor enzyme activity, plant nutrition via interaction with other parts during uptake and mobility, antioxidant protection, interactions with symbionts, pathogen and herbivore response, protection against heavy metals toxicity, plant hormone synthesis and signalling.

Inorganic salts–chlorides, phosphates, phosphites, silicates, and carbonates –of beneficial and essential elements have been used as fungicides. While these inorganic compounds have still not wholly developed methods of actions, they affect osmotic, pH and redox homeostasis, hormone signalling, and enzymes involved in stress response mechanisms. It needs more consideration to act as a bio-stimulant for plant growth, nutrient efficiency and abiotic stress tolerance which are therefore different from their fungicidal activity and fertilizer function as sources of nutrients.

5.2.6. Beneficial fungi:

Fungi interact in distinct ways with plant roots, ranging from mutualistic symbiosis (when both organisms live in direct contact with each other and establish mutually beneficial relationships) to parasitism. Mycorrhizal fungi are a heterogeneous taxonomic group that symbioses over 90% of all plant species. Among the different physical forms of interaction and the involved taxa, the Arbuscule-Forming Mycorrhiza (AMF) is a popular type of endomycorrhiza associated with horticultural and crop plants, where glomeromycotan species of fungal hyphae penetrate cortical root cells and form branch structures called arbuscules.

The use of mycorrhiza is increasingly in the interests of sustainable agriculture given the widely accepts advantages of symbiosis towards nutritional efficiency (for both macronutrients, in particular P and micronutrients), water balance, biotic and abiotic plant stress protection. New understanding also shows that hyphal networks are connecting not only fungal and plant associates, but individual plants within the plant community. This could have important ecological and agricultural effects since there is evidence that interplant signals are possible in the fungal conduit. AMF form a tripartite association of plants and rhizobacteria as a further region of study, which is important in practical field condition. Crop management and plant cultivar practices should be adapted to the interaction with microorganisms to harvest the benefits of mycorrhizal associations. Metagenomics is an interesting tool to monitor and study rhizospheric microbial associations. Inoculation of plants Fungal based plant products for the promotion of nutrition efficiencies, stress tolerance, crop yields and product quality and should be categorized under the concepts of biostimulants. Many plant responses, including increased tolerance to abiotic stress, effectiveness in nutrients use, organ growth and morphogenesis, are convincingly proven. These fungal endophytes may be regarded as bio-stimulants, based on these effects, although claims as biopesticides currently support their agricultural use.

5.2.7. Beneficial bacteria:

In every way feasible, bacteria communicate with crops (i). As to fungi, there is a continuum of mutualism with parasitism; I bacterial niches extending from soil to cell interiors, with the intermediate locations known as the rhizosphere and the rhizoplane ; (iii) transient or permanent associations, with certain bacteria being vertically transmitted through the seed ; (iv) Functions that influence plant life includes participation in biogeochemical cycles, nutrient supplies, increase in nutrient efficiency, disease resistance induction, increased abiotic stress tolerance and morphogenesis modulation by plant growth regulators (du Jardin, 2015).

Two major types in this taxonomic, function and ecological diversity are considered for agricultural use of biostimulants: (i) mutualistic endosymbiont type of Rhizobium and (ii) mutualistic rhizosphere PGPRs (plant growth-promoting rhizobacteria). Rhizobium and associated taxa are commercialized as biofertilizers., i.e. microbial inoculants facilitating nutrients acquisition by plants. The PGPRs has a multifunctional affect and influence all stages of plant: nutrition and growth, morphogenesis and development, reaction to biotic and abiotic stress, interactions in the agroecosystems with the other organisms.

Table 2. Biostimulant effects on plant production; cellular mechanism; agricultural, horticultural and physiological functions; and overall expected economic and social 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*)	*Ascophyllum nodosum* extracts stimulate expression of genes encoding transporters of micronutrients (*e.g.* Cu, Fe, Zn) in oilseed rape (*Brassica napus*)	Enzymatic hydrolysate from alfalfa (*Medicaco sativa*) stimulates phenylalanine ammonia-lyase (PAL) enzyme and gene expression, and production of flavonoids under salt stress	Protects photosystem II against salt- induced photodamage in quinoa (Shabala et al., 2012), likely via activation of scavengers of reactive oxygen	*Azospirillum brasilense* releases auxins and activates auxin- signalling pathways involved in root morphogenesis in winter wheat (*Triticum aestivum*)
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	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

Table:2, Source: Attained from du Jardin, 2015.

5.3. Benefits and challenges of biostimulants:

5.3.1. Advantages:

Biostimulants encourage plant growth and development throughout the crop's life cycle from seed germination to plant maturity in a number of ways (EBIC).

i. Improves the efficiency of the plant's metabolic process to increase yield and enhanced crop quality
ii. Increases improvement in plant tolerance and recovery from abiotic stresses
iii. Facilitates in modulation and assimilation of nutrients. They also increase the nutrient use efficiency of plants.
iv. Enhances the quality attributes of produce like improving sugar content, colour, fruit seeding etc.
v. Increases resource use efficiency and enhances soil fertility particularly by encouraging the development of complementary residential soil microbial population (EBIC).

5.3.2. Challenges:

As the concept of biostimulants is neither socially nor widely accepted and universally defined, market data is limited and less reliable. Some of the challenges include scientific, technical and regulatory challenges:

i. **Scientific challenges:** The complex nature of the physiological effects of biostimulant is one of the difficulties that require attention. The primary response of biostimulant is to induce physiological responses in a plant that bears primary metabolism, growth and development. These responses to fluctuating environmental are evolutionary changes and studies are still in progress.
ii. **Technical challenges:** They include the blending of this formulation with other fertilizing materials and plant protection products. Their rates and methods of application for different weather conditions still need to be explained. Delayed benefits to the farmers, including resource savings and ecosystem services, may be realized over the long term.
iii. **Regulatory Challenges:** As they are lack universal definition and lack of legal acceptance of this biostimulant concept, data and reliability are limited. Hence there is no specific regulatory framework by the regulatory bodies (du Jardin, 2015).

5.4. Suitable crops for application of biostimulation:

Many studies reported that each category of biostimulants shows that there is increasing scientific evidence to support the use of biostimulants as agricultural inputs for diverse plant species, including field crops, vegetables, fruits, and ornamentals. The literature also discloses certain commonalities in plant responses to different biostimulants, such as increased root growth, increased intake of nutrients and biotic and abiotic stress tolerance (Calvo et al., 2014).

5.5. Methods of application:

Plant biostimulants can be applied in different ways, such as direct application to the soil, foliar application, incorporation into fertilizer and other products, and through irrigation water (Jones, 2018).

5.6. Are biostimulants snake oils?

There is no specific method of action or known mechanism in many biostimulant products. Their impacts may be directly on crops or soils or indirectly through affecting the soil and plant microbiota with subsequent effects on the plant. Some products are simply pseudo-science and commercializing recycled waste products. A number of these products have been researched to show that they are inefficient or that they contain inactive or unstable properties (Wildman, 2017). Fake products like this limit the industry for all products and make it assumed that the majority of biostimulants are' snake oils.' However, the benefits of certain biostimulants are revealed in rigorous independent reports (Wildman, 2017).

Crop probiotics are bio-stimulants that have living microorganisms in them (Wildman, 2017). Although the concept of probiotics is sound, it is not easy to find and help establish the right strain(s). Wilman (2017) has itemized several questions regarding biostimulants. The expected advantages of the introduction of beneficial plant and soil microorganisms can be failing for probiotic products:

i. If they are probably false when they claim to be working on large crops or many soils.
ii. It is difficult to say how useful it can be under different conditions if a label or product data sheet does not list microbes in the product, contains microbes that are beneficial to particular plants but harmful to others.
iii. The majority of microbial products sold supply a mass of microbes that are a small proportion (i.e. fewer than one millionth) of that contained in the soil. The applied microbes then disappear at such a rate that only a few additional microbes will stay after a few days.

The efficacy of these products on plants and soils is anecdotal. However, researchers have demonstrated that they are of little importance as foliar apps for disease prevention and of no importance as soil apps for stimulating plant growth, soil or microbial population (Wildman, 2017).

5.7. Global analysis:

For many years synthesized fertilizers have been commonly used. Particularly poorer and less technologically developed nations still depend on the use of chemical compounds on a wide range of crops with very little access to agricultural advancements. However, in Europe and the US, dependence on chemically-driven fertilizers are being reduced, as research focuses on the use of biostimulants for the benefit of plants (Craggs, 2017).

Globally, agriculture is progressing towards the use of biostimulants because of their ability to enable plants more to tolerate stress from the changing environmental factors (Craggs, 2017). This includes the rising temperature and lower moisture levels caused by the climate change effect.

With the use of naturally derived biostimulants, farmers reduce their reliance on costly traditional synthetic chemical fertilizers (Craggs, 2017). Many ornamental plants, vegetable and fruit varieties have improved tolerance and recovery from physical stresses, nutrient assimilation and improvements in quality such as sugar content and colour (Craggs, 2017). For example, Research shows that biostimulants can enhance the development of root crops when applied to grasses, contributing to improved growth and plant vitality. In Europe, farmers use biostimulants as a fundamental component in their farm practices report greater levels of soil fertility and higher crop yields in cereal and oilseeds (Craggs, 2017).

Based on the recent market analyses in 2015, the European Union countries represented a major part of the research, development and use of biostimulants. In contrast, the Asia-Pacific area is projected to be the fastest-growing market for biostimulants from 2016 and 2021 as countries learn and adopt modern farming and agricultural practices that combine the use of organic substances and sustainable farming techniques. Increased awareness and preference for bio-stimulants in large agricultural countries like China, India and Australia will reinforce this. In North, Latin America as well as South Asia and the Middle East region, increased use of bio-based agricultural stimulants is also growing. The growing world demand for organic products seems to be a key driver (Craggs, 2017). Although there is increased evidence in favour of biostimulants, government action on policies to formally comply with the defined standards criteria has been mixed (Craggs, 2017). Action has been limited in the Asia-Pacific region.

In comparison, the EU has formed robust organizations, such as the European Biostimulants Industry Council and the United States Biostimulant Coalition, to advance a definition for biostimulant as part of a future piece of legislation. These and similar agencies are also engaged in a dialogue in the science to identify environmental considerations and safe use of products into crop management programmes. In Australia, little was achieved to establish and empower an appropriate legislative body to date. Therefore, Australia's primary producers and consumers are at risk without a framework responsible for the regulation of scientific testing, risk identifying and evaluating and responsible marketing enforcement (Craggs, 2017).

Biostimulants categories in different countries due to lack of definition:

OECD	Category	No defined Definition	Presumed function
Canada	Categorised as Plant signaling compounds	"substances other than fertilizers, manufactured, sold or represented for use in the improvement of the physical condition of the soil or to aid plant growth or crop yields".	Considered as “Supplements” under Fertilizers Act: and regulated by CFIA
EU	Biostimulants	“stimulate natural processes to benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and crop quality”	act independently of their nutrient content
Germany	Plant strengtheners	“maintain plant health in general, or protect plants against on-parasitic impairments, e.g.to reduce water evaporation, anti-freezing agents.”	Priority is NOT nutrition, trace elements or promoting growth (i.e. NOT plant growth improvers or soil improvers, which are considered as Fertilizers)
USA	No category of biostimulants	“biostimulants” proposed as new subcategories of “Beneficial Substances” in AAPFCO categories”	
Australia	No category found		

OECD: Organisation for Economic Co-operation and Development

CIFA: Canadian Food Inspection Agency

AAPFCO: The Association of American Plant Food Control Officials

Table. 3, Source: Attained from (Marshall, 2015).

5.8. Industrial analysis:

Interview with Mr. Stan Loewen (July 12th, Terralink Horticulture, Abbotsford, B.C):

In conversations with Mr. Loewen, he informed me about changes emerging in the private sector of agricultural crop input retailers. He stated that the private sector appreciates that the sustainability of crop farming is tied to the sustainability of the crop inputs industry and they are mutually dependent for their success.

The success of the crop production industry is dependent upon the agricultural retail industry delivering new applied science for inputs and equipment technology to farmers for them to be able to take advantage of technological advancements. The natural competition that emerges in the marketplace when multiple retailers compete for the customer's business is the best motivation for the retailer to deliver more and better goods and services to the farmer. Typically, the retailer with the best return on the farmers' invested capital wins the business. The natural result of this is for the retailer (or consultant) to try to outperform the competition by helping the farmer get more crop production with only the right amount and not more than necessary for the investment in nutrients, crop varietals, equipment, and so forth.

Crop production will increasingly be vulnerable to climate variability and climate change associated with an increase in temperature, CO_2 and change in precipitation patterns. The changes will cause a shift in how many and where the highly productive farms are located. If one looks back over the decades and centuries, it has always been the innovators and early adopters of technology that have succeeded first at farming. In a sense, nothing has changed. The same thing is still happening. The green revolution was famous for early innovators winning. Now, decades into the green revolution when negative consequences that result from certain long-term practises are becoming evident, we see greater effects of the resulting stress on crops from climate change showing up in productivity.

The challenges of preserving the future of farming by creating good soil health, higher organic matter levels, better water holding capacity to outlast the drought, and so forth are more relevant now than ever. The choices of what to use, where to put it, how much to apply and when to do it apply not only are relevant for application to any current year's crop but similarly, they apply to the preventative measures needed to combat soil degradation and reduction of productivity. Soil remediation takes wise investment just like good crop production. Thankfully more information is reality and the world's library of data is a working tool for any stakeholder wanting to use it

In the last centuries, there have been increases in extreme weather events such as droughts, severe heat waves, and heavy floods. These biotic and abiotic stresses are very real. The trade believes that new applied science technology including the use of biostimulants will be an important tool in dealing with such issues and will help maintain agriculture and food production at the core. The agriculture world is changing and is open to innovation as long as products are safe, efficacious, sustainable and economic (no specific order of importance). Following decades of using typical crop production technologies to push crop production to higher levels, the challenges of creating those improvements in a climate that may not be as forgiving as earlier years have brought on a new class of inputs called biostimulants. Biostimulants are current, relevant and seen as an important tool for the future. A selection of biostimulants and innovative products that are or may be important for crop production are listed in Appendix – A and B.

Below is a table of biostimulant products, suppliers and projected benefits (Table.3). This Table does not include **microfloral soil inoculants**. When used as root dips and seed treatments, such inoculants may act as phosphate solubilizers, root surface area increasers (mycorrhizae), root pathogen fighters and excluders, and nitrogen fixers. When applied as a drench to established crops, the dosage is usually vanishingly small (~0.2L a.i./acre) compared to the typical mass of microflora in the top 30cm of an acre (1-2MT of active or dormant microflora/acre). ~99% of all soil microflora remains unculturable.

This Table also does not include **biofungicides –** which are often specific strains of culturable soil microflora applied as either a foliar spray, for leaf diseases or as a dip or drench for root diseases. Examples are *Bacillus subtilis, B. amyloliquifaciens, B. licheniformis, Beauveria bassiana, Trichoderma harzianum* and *T. viride.*

Biostimulant	Supplier(s)	Supposed effect
Kelp (Ascophyllum nodosum)	Acadian Seaplants	Improved rooting, root branching (confirmed). Improved drought tolerance, recovery
Kelp (Sargassum sp.)	Chinese suppliers – various	Improved rooting, root branching (confirmed). Improved drought tolerance, recovery
Water-soluble amino acid powder – foliar	Various	Unspecified
Water-soluble amino acid powder - drench	Various	Increased growth of microflora in rhizosphere, therefore improved nutrient cycling etc.
Humic acid	Various	Increases soil CEC, water-holding capacity
Fulvic acid	Various	Chelates to micronutrient salts, improve foliar fertilizer uptake, root uptake
Blend of yeasts, molds, Lactobacillus etc.	Concentric Ag's 'Garden Solution'	"It interacts with the indigenous ecology—the phyto-microbiome—to act as a natural growth optimizer by improving both plant and soil quality. It also helps plants survive extreme weather conditions, including drought."
Brassinolide	Various	Improved stress tolerance – thermal, moisture, salts etc.
Chitosan	Various	Improved nitrogen uptake, plant growth and yield
Salicylic acid 10%	Various	Improved root formation; improved stress tolerance, improved flowering and fruiting
Potassium silicate solutions	Various	For crops that both do and don't absorb silica: protection from abiotic and biotic stresses
Jasmonic acid	Various	Improved stress tolerance – thermal, moisture, salts etc.
Haven (a.i.= Stearyl alcohol)	Morrone Bio Innovatios.	Heat stress and Blossom End Rot resistance in greenhouse tomato and pepper crops and other crops
Triacontanol	Various	Increased plant growth, water and mineral uptake, yield
Gibberellic acid 3 (GA3)	Various	Improved fruit set, internode elongation; overcomes certain seed dormancy mechanisms (all demonstrated)
Kinetin (cytokinin)	Various	A PGR with specific plant growth and development effects

Table.4, Source: Attained from Terralink, Abbotsford, B.C.

5.9. Market analysis:

As stated earlier, the global market in biostimulants will grow by USD 3,040 million at Compound annual growth rate (CAGR)12.7 percent between 2017 and 2022, driven by growing demand for crops and quality, growing organic farming and demand for organic food, and a range of benefits for biostimulants in crop production. In addition, increased awareness of environmental safety using biostimulants has further led to promote the growth of the global biostimulants market. However, a lack of education and knowledge among farmers, and various challenges facing new entrants and small players limit the growth of the market for bio-stimulants (Meticulous Market Research, 2017). Furthermore, the lack of a standardized regulatory framework for biostimulants and scientific and technical challenges in the development of biostimulants challenges to some extent the growth of this market (Meticulous Market Research, 2017).

The worldwide industry for biostimulants consists primarily of active ingredients (acid-based, extracts based, microbial amendments, trace minerals and vitamins, and others) by mode of application (foliar spray, soil treatment, and seed treatment), by formulation (liquid formulation and dry formulation), by crop type (row crops, fruits and vegetables, turfs and ornamental, and others), and by geography (North America, Europe, Asia-Pacific, Latin America, and Middle East & Africa) (Meticulous Market Research, 2017).

Europe holds a substantial share on the worldwide market in bio-stimulants, followed by North America and Asia-Pacific region. The great share of the European region is mainly attributed to the increasing concern about environmentally harmful chemicals, growing demand for organic food, rapid development and innovation in biostimulants, and the presence of several biostimulant providers. However, Asia-Pacific has a lucrative biostimulants market growth potential and is predicted to witness the fastest growth over the forecast period. Diverse strategies have been used by leading companies to expand their product range, to increase the global footprint, and market share. New product development, acquisitions and expansions were the main strategies followed by most companies on the global bio-stimulant market. Some of the key players in the global biostimulants market are 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, 2017).

5.10. Public perception:

Customers want food that is safe, healthy, and nutritious, but they are not clear how these characteristics are affected by technological inputs. There is a general concern about some of the technologies used in food production. Thus, there is a gap between the scientific basis of the technology and public perception. This 'gap' should be filled with the facts of agricultural production technology. The evidence suggests that the shared values are important to the development of trust, and it would be necessary for improving communication to understand the values that the producers and the broader community share in food production (Bray, 2015).

5.11. Transdisciplinary approach:

There is an emerging paradigm that sustainability challenges require new ways of producing knowledge and making decisions. The participation of stakeholders including growers, proponents, private sector and the general public from outside the academia in the research process to integrate the best available information and to reconcile values and preferences and to create ownership of problems and solution options is, therefore, one of the key elements of sustainability. Transdisciplinary, interactive, or participatory research approaches are often suggested to meet the demands of the real-world problems and the goals of sustainability as it attempts to integrate science and public concerns to address contentious concerns (Lang et al., 2012).

6. Conclusion:

Biostimulants are used in agriculture and horticulture crops as effective substances, environmentally friendly products and safe for humans. The use of biostimulants in plants reduces fertilizers to use and environmental concerns while increasing plant tolerance for abiotic and biotic stresses enhancing internal and external quality. Biostimulants are complex blends of highly different raw materials that utilize a wide array of processes and can, therefore, expect to have a broad range of possible biological activity and safety. The scientific evidence show the impact of applications for biostimulants on plants but few studies have focused on their impact on plant physiology and biochemistry. We know plant physiology deeper today than ever before, but most of these accomplishments use a limited amount in controlled environments of model organisms. The effect of biostimulants among plant species is also not always consistent. It is now a challenge to use that knowledge and tools to characterize biostimulants and their impact on many crops. It is also challenging and important to bridge the gap between laboratory data on single biostimulants and field data on mixtures (often combined with fertilizer).

Although biostimulation is applicable for both conventional and organic farming, the simple application of biostimulants still requires fertilizer inputs. Several scientific studies in the field of plant biostimulants have documented the benefits of its use in growth, crop productivity, quality and tolerance of chemical soil stresses, especially the nutrient deficiency of several vegetable crops in conventional farming. However, there is absolutely no data on the potential benefits of the application of plant biostimulants in organic systems.

Since sustainability science is a problem-driven and solution-orientated area that maintains a transformative agenda and transdisciplinary approach is a promising choice to bridge the gap between public problem-solving and scientific innovation. With any new technology or practise, there are always criticisms. To address the debate of which is better organic or conventional farming, as a transdisciplinary approach where all stakeholders including proponents, growers, the public and private sector should be involved right from the beginning. This approach focuses on real problems looking for the right questions, where options like biostimulation can be made credible to all stakeholders including the general public.

7. Recommendations:

i. Biostimulants must be distinguished from existing categories of legislative products, including essential nutrients, pesticides or plant hormones.
ii. The biostimulant should be characterized based on plant responses indicating physiological targets and the metabolic network involved.
iii. More in-depth knowledge of the effects and functions of the components of biostimulant products, both known and unknown, can, therefore, be obtained and used in the classification of new commercial formulations and the evaluation of their effectiveness.
iv. More research is needed to clarify the way biostimulants operate to overcome the nutrient limitation while improving the availability of and use of nutrients, thereby reducing the gap between organic and conventional yields. Further trials are also necessary to determine the optimal dose, application time and method for each species and environmental conditions.
v. Research on the mode of action of biostimulants and their interactions between environmental stressors and plant genotypes should be conducted.
vi. There is a need for a transdisciplinary approach for more effective communications among growers, the general public and suppliers of biostimualnts.

8. Acknowledgements:

It is a wonderful opportunity for me to study and write about "Plant Biostimulation". I want to extend my deepest gratitude to the key person—Program Director and Supervisor, Mr. Leslie Lavkulich for his support and impetus for carrying out my research. I thank him for proofreading the manuscript of my white paper. I want to express my deepest appreciation to Mr. Stan Loewen, CEO of Terralink Horticulture Inc. my Co-Supervisor, who shared his expert knowledge and provided continuous support throughout my research. I also thank representatives of Terralink Horticulture, Mr. Geoff Lewis from Research and Development for sharing valuable information useful for my study. I want to extend my heartfelt thanks to Ms. Julie Wilson, Academic Coordinator for her support throughout my project. During my research, I have gone through many research papers which helped me a lot to carry forward my meta-analysis. I acknowledge my gratitude to all scientists who contributed their research on plant biostimulation which helped for my study.

9. Reference:

1. Altieri MA (1999) The ecological role of biodiversity in agroecosystems. Agric Ecosystem Environ 74(1–3):19–31. doi:10.1016/s0167- 8809(99)00028-6

2. Bray, H. (2015). Public perceptions of agriculture: What influences consumer choice? Retrieved from https://blogs.adelaide.edu.au/food-values/2015/09/28/public-perceptions-of-agriculture-what-influences-consumer-choice/

3. Calvo, P., Nelson, L. & Kloepper, J.W. Plant Soil (2014) 383: 3. https://doi.org/10.1007/s11104-014-2131-8

4. Carvalho, F. P. (2017). Pesticides, environment, and food safety. Food and Energy Security, 6(2), 48-60. doi:10.1002/fes3.108

5. Clark, M., & Tilman, D. (2017). Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environmental Research Letters*, *12*(6).

6. Craggs, G. (2017). There is an Agricultural Trend Toward Soil Biostimulants but are Farmers and Consumers Adequately Protected? Retrieved from http://www.futuredirections.org.au/publication/agricultural-trend-toward-soil-biostimulants-farmers-consumers-adequately-protected/

7. du Jardin, P. (2015). Plant biostimulants: Definition, concept, main categories and regulation. Scientia Horticulturae, 196, 3-14. doi:10.1016/j.scienta.2015.09.021

8. EBIC. Sustainable agriculture | European Biostimulants Industry Council. Retrieved from http://www.biostimulants.eu/benefits-of-biostimulants/sustainable-agriculture/

9. FAO. (2015) News detail. Retrieved from http://www.fao.org/soils-2015/news/news-detail/en/c/277682/

10. FAO. (2019). Table of Contents. Retrieved from http://www.fao.org/3/X0075e/X0075e.htm#P86_4004

11. Global Industry Perspective, Comprehensive Analysis and Forecast, 2015 – 2021", by Zion Market Research; "Biostimulants Market: Global Trends & Forecasts to 2021" by Markets and Markets; and "Global Biostimulants Market Analysis (2016 – 2022), January 2017", by Merkle & Sears

12. Gomiero. T, Paoletti M. G. & Pimentel. D (2008) Energy and Environmental Issues in Organic and Conventional Agriculture, Critical Reviews in Plant Sciences, 27:4, 239-254, DOI: 10.1080/07352680802225456

13. Gu, Duanyin & Wang, Xiu-Feng & Fang-Jun, Ding. (2014). Plant biostimulants: a review on categories, effects and application.

14. Ritchie, H. (2017). Is organic really better for the environment than conventional agriculture? Retrieved from https://ourworldindata.org/is-organic-agriculture-better-for-the-environment

15. Henneron, L., Bernard, L., Hedde, M., Pelosi, C., Villenave, C., Chenu, C., . . . Blanchart, E. (2015). Fourteen years of evidence for positive effects of conservation agriculture and organic farming on soil life. Agronomy for Sustainable Development, 35(1), 169-181. doi:10.1007/s13593-014-0215-8

16. Hurni H, Giger M, Liniger H, Studer RM, Messerli P, Portner B, Schwilch G, Wolfgramm B, Breu T (2015) Soils, agriculture and food security: the interplay between ecosystem functioning and human well-being. Curr Opin Environ Sustain 15:25–34. doi: 10.1016/j.cosust.2015.07.009

17. ICRISAT. (2019). Agriculture Policy Briefing. Retrieved from https://www.smartindianagriculture.com/icrisats-dg-takes-a-swipe-at-subhash-palekars-zero-budget-natural-farming-at-naas-lecture/

18. Jones, R. (2018). So You Think You Know Something About Biostimulants. Retrieved from https://www.growingproduce.com/fruits/think-you-know-biostimulants/

19. Kanissery R. G., and G K. Sims, (2011) “Biostimulation for the Enhanced Degradation of Herbicides in Soil,” Applied and Environmental Soil Science, vol. 2011, Article ID 843450, 10 pages, https://doi.org/10.1155/2011/843450.

20. Kibblewhite MG, Ritz K, Swift MJ (2008) Soil health in agricultural systems. Philos Trans R Soc B-Biol Sci 363(1492):685–701

21. Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P.,Thomas, C. J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. Retrieved from https://link.springer.com/article/10.1007/s11625-011-0149-x

22. Lichtfouse, E., SpringerLink ebooks - Biomedical and Life Sciences, & Ebook Central (2009). Sustainable agriculture. New York: Dordrecht; Springer Verlage

23. Lichtfouse, E., SpringerLink ebooks - Biomedical and Life Sciences, & SpringerLink (Online service). (2018). Sustainable agriculture reviews 31 biocontrol. Cham: Springer International Publishing.

24. Marshall, P. (2015). Agricultural Biologicals today and tomorrow: Potential and regulations.

25. Meticulous Market Research Pvt. Ltd. (2017). Biostimulants Market - Global Opportunity Analysis and Industry Forecasts to 2022. Retrieved from https://www.researchandmarkets.com/reports/4392231/biostimulants-market-global-opportunity

26. Meemken, E., & Qaim, M. (2018). Organic agriculture, food security, and the environment. Annual Review of Resource Economics, 10(1), 39-63. doi:10.1146/annurev-resource-100517-023252

27. Naresh, Rk & Kumar, Mukesh & Vallabhbhai Patel, Sardar & Kumar, Sunil & Kumar, Yogesh & Malik, Minaxi & Singh, Satyaveer & C Rathi, R & Beghra, Kvk & Vallabhbhai, Sardar & Vivek, Mukesh & Kumar, Udita & Chowdhary, Yogesh & C Kumar, N & Mahajan, Minaxi & Malik, Satyaveer & C Singh, R & S Rathi, S & , Tomar. (2018). Zero budget natural farming viable for small farmers to empower food and nutritional security and improve soil health: A review.

28. Oosterveer, P., & Sonnenfeld, D. A. (2011;2012;). Food, globalization and sustainability. London: Routledge. doi:10.4324/9781849776790

29. Parra-Lopez, C., Calatrava-Requena, J. & de-Haro-Gimenez, T. (2007). "A multi-criteria evaluation of environmental performances of conventional, organic and integrated olive-growing systems in the south Spain based on expert's knowledge". Renewable Agriculture and Food Systems 22 (3), 189-203.

30. Pandey, Prof. Jitendra & Singh, Ashima. (2012). Opportunities and constraints in organic farming: An Indian perspective. Journal of Scientific Research Banaras Hindu University. 56. 47-72.

31. Postma-Blaauw MB, de Goede RGM, Bloem J, Faber JH, Brussaard L (2010) Soil biota community structure and abundance under agricultural intensification and extensification. Ecology 91(2):460–473. doi:10.1890/09-0666.1

32. Pradhan, A. (2015). Effect of conservation agriculture production systems (CAPS) on system productivity, soil quality and sustainability under rainfed uplands of India

33. Rosin, C., Stock, P., & Campbell, H. (2011;2013;). Food systems failure: The global food crisis and the future of agriculture. London: Routledge. doi:10.4324/9781849776820

34. Satish Kumar (2018). ZBNF is suitable for all of State's agro – climatic zones. The Hindu

35. Singh, B. P., Cowie, A. L., Chan, K. Y., & SpringerLink ebooks - Biomedical and Life Sciences. (2011). Soil health and climate change. Heidelberg; New York; Springer. doi:10.1007/978-3-642-20256-8

36. Seufert V, Ramankutty N. (2017). Many shades of gray—the context-dependent performance of organic agriculture. Sci. Adv. 3: e1602638

37. Spiertz, J. H. J. (2010). Nitrogen, sustainable agriculture and food security. A review. Agronomy for Sustainable Development, 30(1), 43-55. doi:10.1051/agro:2008064

38. Theocharopoulos, Athanasios & Aggelopoulos, Stamatis & Papanagiotou, Panoraia & Melfou, Katerina & Papanagiotou, E. (2012). Sustainable Farming Systems vs Conventional Agriculture: A Socioeconomic Approach. 10.5772/27537

39. UGAOO. (2019). What is Natural farming? How is it different from Organic farming? Retrieved from http://www.ugaoo.com/knowledge-center/what-is-natural-farming-how-is-it-different-from-organic-farming/

40. UNCCD, (2015). Desertification, Land Degradation & Drought (DLDD): some global facts and figures. United Nations Conventions to Combat Desertification. Available from: http://www.unccd.int/Lists/SiteDocumentLibrary/WDCD/DLDD%20Facts.pdf (Accessed 17/11/2015).

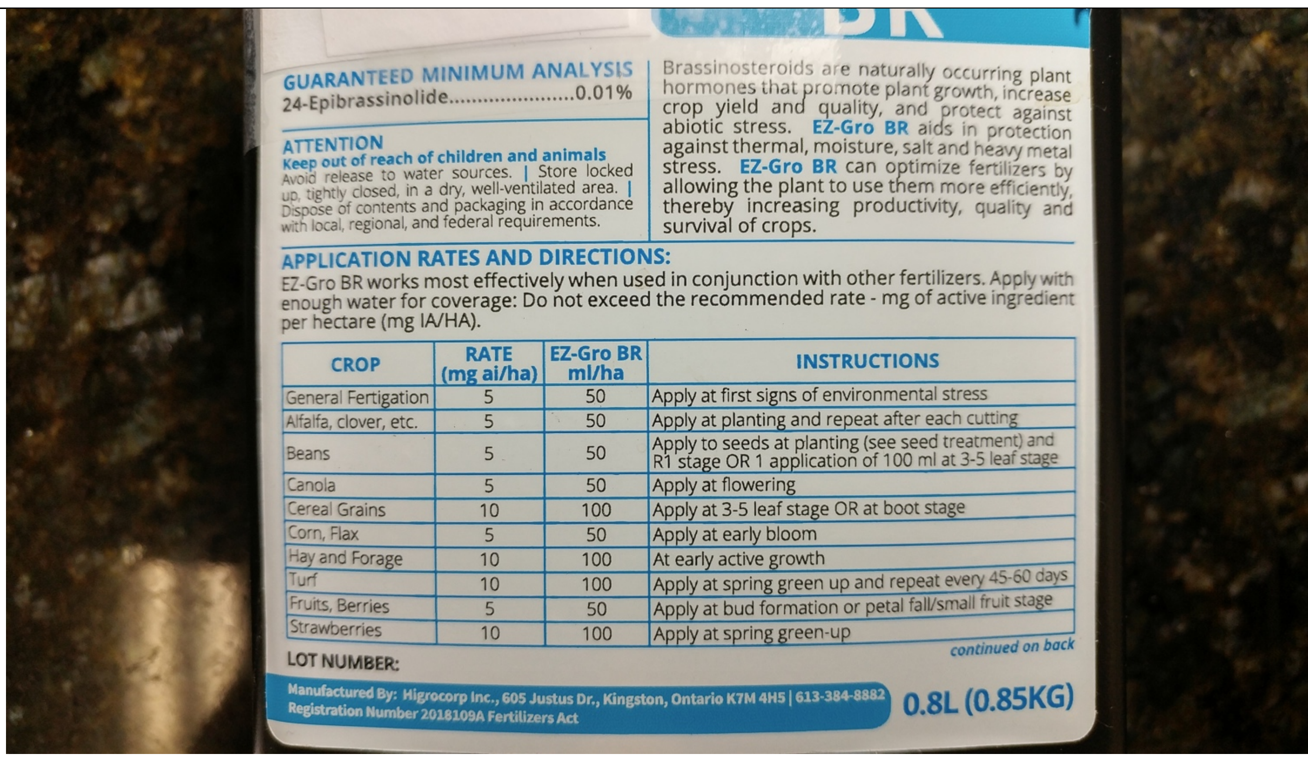
41. USDA, Natural Resources Conservation Service. Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/

42. Wildman, Howard. (2017). Agricultural biostimulants. Are they bio boosters or snake oils?. 10.13140/RG.2.2.36705.20328.

43. ZBNF (2017). Zero budget natural farming. Retrieved from https://zerobudgetnaturalfarmings.blogspot.com/

10. <u>Appendix</u>:

<u>Appendix – A:</u> Below are the two products Chitosan and Brassinolide which are under field trails in Terralink Horticulture.



Appendix – B: Below is Stella Maris which is commonly used Biostimulant on Blueberries which is produced by Acadian Sea Plants in Nova Scotia. Newer biostimulants are compared and assessed against Stella Maris which is used as Benchmark product.

Appendix – C: Illustration of effects of Biostimulants on Greenhouse Vegetables