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Chapter 15: Considerations with biostimulants in turfgrass

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1 Introduction

The term “biostimulants” and biostimulant products have been misunderstood and often misused as potential “miracle cures” in the turfgrass industry, and these products were often dismissed as “snake oil”, “foo-foo juice” or “foo-foo dust” (e.g., sarcastic reference to the mythical foo-foo tree). Some biostimulant products make performance claims substantiated with scientific research conducted in turfgrass ecosystems, while other products lack direct evidence of their benefit within a turfgrass management program (Fidanza et al., 2019).

The Merrion-Webster Dictionary (Springfield, MA, USA) lists “biostimulant” as derived from “bio” (~life) and “stimulus” (~a thing that evokes a specific functional reaction in an organ or tissue, or a thing that arouses activity or energy in something, or an interesting or exciting quality). Dr. Richard Schmidt (Emeritus Professor; Virginia Polytechnic Institute and State University, Blacksburg, VA, USA) is considered the pioneer of biostimulant research in turfgrass science. Dr. Schmidt along with Dr. Xunzhong Zhang (Virginia Polytechnic Institute and State University, Blacksburg, VA, USA) studied and evaluated various substances that promoted plant growth without the plant’s response attributed to fertilizers, nutrients, or pesticides. Drs. Schmidt and Zhang’s concise definition is “*Biostimulants are organic materials that when applied in small or minute quantities enhance plant growth and development*” (Bigelow et al., 2021; Fidanza et al., 2015; Schmidt and Chalmers, 1993). The use of the word “minute” in this definition was important and intended to differentiate the fact that these substances, compared to traditional nutrients and/or soil amendments, elicited a measurable and beneficial response at much lower application rates (Bigelow et al., 2021). Drs. Schmidt and Zhang explained the plant biostimulant effect as attributed to a hormonal response and the plant protection effect against abiotic stress as attributed to antioxidant production, and both of those effects made possible from low concentrations of exogenous applications. Later, the term “metabolic enhancers” was used, but the important distinction was that something positive was happening to the plant beyond what mineral nutrition supplied (Zhang and Schmidt, 1997).

More recently, du Jardin (2015) defined a plant biostimulant as “any substance or microorganism applied to plants with the aim to enhance nutrition efficiency, abiotic stress tolerance, and/or crop quality traits, regardless of nutrient content”. Plant biostimulants also refer to commercial products containing mixtures of those aforementioned substances, compounds, and microorganisms (du Jardin, 2015). The term “plant biostimulant” often is used to describe the various categories of compounds and substances used in these products: plant growth hormones (e.g., abscisic acid, auxins, cytokinins, gibberellic acid, etc.), microorganisms (e.g., *Bacillus* spp., *Trichoderma* spp.., mycorrhizae, etc.), amino acids, humic and fulvic acids, plant defense-activating substances, plant growth-promoting compounds, vitamins, pigments and oils, soil amendments and soil conditioners, composts and compost teas, and more (Bigelow et al., 2021; Crouch and Van Staden, 1993; Ervin, 2013a, 2013b; Fidanza et al., 2015; Kostka and Fidanza, 2017).

The European Biostimulant Industry Council (EBIC; https://biostimulants.eu) defines biostimulants as: “Agricultural biostimulants include diverse formulations of compounds, substances, and other products that are applied to plants or soils to regulate and enhance the crop’s physiological processes, thus making them more efficient; biostimulants act on plant physiology through different pathways than nutrients to improve crop vigor, yields, quality and post harvest shelf life/conservation.” The EBIC also has a functional definition of plant biostimulants as follows: “A material which contains substance(s) and/or microorganisms whose function, when applied to plants or the rhizosphere, is to stimulate natural processes to benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and/or crop quality, independently of its nutrient content.” Of note, the EBIC’s functional definition expands beyond the ‘plant’ to also include the ‘soil’ (e.g., rhizosphere) (Fidanza et al., 2019). The Association of American Plant Food Control Officials (AAPFCO; https://aapfco.org) defines biostimulants as: “…any substance or compound other than primary (e.g., N, P, and K), secondary (e.g., Ca, Mg, S), and microplant nutrients (e.g., Fe, Cu, etc.), that can be demonstrated by scientific research to be beneficial to one or more plant species when applied exogenously; …a substance or material, with the exception of nutrients or pesticides, which has the capacity to beneficially modify plant growth.” Of note, the ASPFCO definition of biostimulants refers to the term “beneficial substance”.

Biostimulants are often categorized by “what they are” (e.g., how are these substances or compounds or component materials described chemically or physically?) and “what they do” (e.g., how do these substances or compounds benefit the turfgrass plant or the turfgrass soil/root zone?) (Fidanza et al., 2019). Therefore, a classification strategy is needed to organize and clarify helpful information for biostimulants utilized in the turfgrass industry. Also, the turfgrass practitioner and stakeholder would benefit from knowing not only what a biostimulant is composed of, but how those commercially available biostimulant products may benefit managed turfgrass ecosystems.

2 Classification of biostimulants for turfgrass

A proposed classification method or strategy for listing biostimulants in turfgrass is presented in Table 1. Overall, biostimulants are listed as primarily targeting the plant or soil/rhizosphere, then further organized by category to describe their composition, followed-by active or functional ingredients (e.g., compounds, substances, other descriptive terms) listed within each category. Examples of common names for biostimulant products are listed for each category.

Table 1. Proposed classification of biostimulants for turfgrass science and industry.

-- PLANT --			
Category[1]		Examples of active or functional ingredients	Examples of biostimulant products[2]
I	Phytohormones	Abscisic acid Auxins Cytokinins Ethylene Gibberellic acid Others	algae, indoleacetic acid, benzyl-adenine, gibberellins, kelp, seaplant, seaweed extracts, and more
II	Biopolymers, protein hydrolysates, and other N-containing compounds	Amino acids (e.g., proline, etc.) Antioxidants Betaines Chitin Enzymes Fatty acids Non-protein amino acids Peptides Polyamines Polysaccharides Vitamins Others	amino acids, chitosan, glycine betaine, and more
III	Other botanical or synthetic bioactive compounds	Elicitor compounds Induced systemic resistance compounds Plant defense activator compounds Others	acibenzolar-*S*-methyl, jasmonic acid, salicylic acid, and more

[1] Category based on chemical and/or physical composition.

[2] Broad or general name of a biostimulant product listed; no product trade name provided. Should an additional column list the specific biostimulant function of those biostimulant products, and/or should the manufacturer include that information on their product label?

Table 1. Proposed classification of biostimulants for turfgrass science and industry (continued).

-- SOIL/RHIZOSPHERE --			
	Category[1]	Examples of active or functional ingredients	Examples of biostimulant products[2]
IV	Humic substances	Fulvic acid Humic acid	leondardite, and more
V	Organics	Biochar Bio-extracts Bio-fertilizers Composts/compost extracts Soil amendments/supplements Others	biochar, composts, compost teas, kelp, seaplant, seaweed extracts, vermi/worm extracts, and more
VI	Inorganics/minerals	Al, Co, Na, Mo, Se, Si, etc. Phosphites Others	phosphite salts, and more
VII	Biologicals/microbials	Beneficial fungi - Arbuscular mycorrhizal fungi *Trichoderma* spp. Others Beneficial bacteria - *Bacillus* spp. and other species Plant growth promoting rhizobacteria Others Other beneficial organisms	Many
VIII	Soil surfactants[3]	--?--	--?--
IX	Other naturally derived or synthetic bioactive compounds	Elicitor compounds Induced systemic resistance compounds Plant defense activator compounds Others	--?--

[1] Category based on chemical and/or physical composition.

[2] Broad or general name of a biostimulant product listed; no product trade name provided. Should an additional column list the specific biostimulant function of those biostimulant products, and/or should the manufacturer include that information on their product label?

[3] Proposed location of soil surfactants as a category if some of those soil surfactants are to be considered or included as biostimulants.

2.1 Phytohormones

Salisbury and Ross (1991) define a plant hormone as: "*an organic compound synthesized in one part of a plant and translocated to another part, where in very low concentrations it causes a physiological response*." Plant hormones or phytohormones are considered chemical messengers in plants. Phytohormones are often referred to as 'signal molecules' that occur in very low concentrations, and are vital to plant growth and development, and regulation and function of many physiological processes (Mauseth, 2019). Of note, each plant cell is capable of producing phytohormones, unlike animals which require specialized hormone-synthesizing glands. The most common phytohormones utilized as plant biostimulants are abscisic acid, auxins, cytokinins, ethylene, and gibberellic acid.

2.1.1 Abscisic acid

Abscisic acid (ABA) is associated with water regulation in plants as indicated by an increase in ABA concentration in leaves under drought stress (Swamy and Smith, 1999). ABA involvement with plant adaptation to drought stress includes regulation of stomatal aperture, transpiration, leaf senescence, and cellular osmotic conditions (Chen et al., 2018). ABA also is associated with the plant's ability to mitigate abiotic stress from salinity and temperature, and possible biotic stress tolerance by signaling plant pathogen defense mechanisms (Mauch-Mani and Mauch, 2005; Wilkinson and Davies, 2002). Some examples of ABA research in turfgrasses include: foliar application of ABA improved Kentucky bluegrass (*Poa pratensis* L.) growth under drought stress (Wang et al., 2003), and ABA's role in heat tolerance (Li et al., 2014), cold tolerance (Zhang et al., 2013a), salinity stress (Huang et al., 2021b), and photosynthesis (Chen et al., 2018).

2.1.2 Auxins

Auxins are produced in shoot and root tips and promote cell division and elongation and many aspects of plant growth and development (Salisbury and Ross, 1991). Auxin is responsible for phototropism (e.g., shoots growing upward, toward the light) and gravitropism (e.g., roots growing downward into the soil) (Mauseth, 2019). Indole-3-acetic acid (IAA) is the most common naturally occurring auxin and included as the auxin component of many biostimulant products (Sanderson et al., 1987). An example of auxin research in turfgrass is: foliar applications of IAA with the shoot absorbed plant growth regulator trinexapac-ethyl to creeping bentgrass (*Agrostis stolonifera* L.) maintained under water-deficit environmental conditions may promote root viability and drought tolerance resulting in improved turfgrass quality (Zhang et al., 2017).

2.1.3 Cytokinins

Cytokinins are involved with plant growth and development and stress-response processes, and in particular with cell division and delaying of leaf senescence (e.g., plant senescence is the process of aging in plants; plants have both stress-induced and age-related developmental aging) (Ervin, 2013b, Haberer and Kieber, 2002). This delay of leaf senescence or "stay green" effect is a plant stress response in which cytokinins inhibit the action of senescence-inducing enzymes, slowing the degradation of chlorophyll, and maintaining photosynthetic rates and root viability (Ervin, 2013a; Haberer and Keiber, 2002). In plants, cytokinins are produced in healthy, actively growing root tips and translocated to shoots via the transpiration stream (Ervin, 2013a; Haberer and Keiber, 2002). Consequently, as summer root decline proceeds in cool-season turfgrasses, leaf tissue cytokinin levels also decline (Ervin, 2013a).

An example of a commonly used biostimulant product in this category is seaweed extract (SWE), also referred to as seaplant or kelp. SWE is derived from brown, green, or red macroalgae and has been utilized in the turfgrass industry since the 1950s (du Jardin, 2015; Khan et al., 2009; Sanderson and Jameson, 1986; Sangha et al., 2014). SWE is widely used in turfgrass culture and management due to their positive effects on turfgrass growth and abiotic stress mitigation from drought, nutrient deficiency, soil salinity, and extreme temperatures (Bigelow et al., 2010; Fidanza et al., 2015; Kostka and Fidanza, 2017; Wang et al., 2012, 2013, 2014; Zhang and Ervin, 2008). SWE from the brown seaweed (*Ascophyllum nodosum* [L.] Le Jolis) has been shown to contain biologically active concentrations of natural cytokinins of trans-zeatin riboside and isopentenyl-adenine (Zhang and Schmidt, 1999). Although SWE is best known for containing cytokinins and cytokinin-like compounds, SWE potentially can contain many other beneficial and potentially biologically active compounds (e.g., polysaccharides, fatty acids, vitamins, mineral nutrients, and more) (Craigie, 2011; Khan et al., 2009). Some examples of cytokinin research in turfgrass are: benzyl-adenine increased gross CO_2 exchange rate, chlorophyll and nonstructural carbohydrate contents of Kentucky bluegrass, indicating antisenescence activity (Goatley and Schmidt, 1990; Kane and Smiley, 1983); foliar application of SWE has been shown to increase leaf cytokinin content and antioxidant activity while decreasing lipid peroxidation and delaying senescence in creeping bentgrass drought stress (Zhang and Schmidt, 1999, 2000), increase turfgrass tolerance to salinity stress (Nabati et al., 1994), to ultraviolet B irradiation (Ervin et al., 2004), and to heat stress (Liu et al., 2002; Zhang and Ervin, 2008).

2.1.4 Ethylene

While abscisic acid, auxin, cytokinin, and gibberellic acid exist in the plant in liquid form, ethylene is a gaseous phytohormone that regulates plant growth (e.g., the development of leaves, flowers, and fruits), senescence, response to environmental stresses (e.g., heat and freezing stresses), and often interacts with other phytohormones (Iqbal et al., 2017). Heat stress is a major contributor to leaf senescence and other physiological damage in cool-season grass species, and ethylene and cytokinins are two phytohormones associated with leaf senescence (Xu and Huang, 2009). Some examples of ethylene research in turfgrass are: foliar application of an ethylene synthesis inhibitor or a synthetic cytokinin was associated with suppressed leaf senescence and improved heat tolerance of creeping bentgrass (Xu and Huang, 2009), and the inhibition of ethylene production in annual bluegrass (*Poa annua* L.) may improve winter survival during environmental conditions associated with ice encasement (Laskowski and Merewitz, 2020). Foliar application of ethephon, which is converted to ethylene in leaf tissue, has been shown to reduce rooting and hasten chlorosis in cool and warm-season turfgrass species (Marcum and Jiang, 1997; McCullough et al., 2005a, 2005b). Ethephon, however, has been shown to be a very effective annual bluegrass seedhead inhibitor, given proper application timing (Patton et al., 2018; Peppers et al., 2021).

2.1.5 Gibberellic acid

Gibberellic acid (GA) controls important plant growth functions such as cell elongation and stem growth, seed germination, flower development, and flowering time (Schwechheimer, 2008). The number of known gibberellins exceeds 100 and they are classified as GA_1, GA_2, GA_3, etc. (Salisbury and Ross, 1991). GA_3 was the first commercially available gibberellin (De Casto et al., 2020). Use of GA products is currently recommended to reverse the effects of an over-application of anti-GA plant growth regulators (Ervin, 2013b). In low light or shade conditions, GA can accumulate in turfgrass thus causing shoot elongation and leaf etiolation (Tan and Qian, 2003).

Some examples of gibberellic acid research in turfgrass are: annual bluegrass seed germination is accelerated with scarification plus exogenous application of GA (De Castro et al., 2020), increased stolon growth up to a certain concentration in bermudagrass (*Cynodon* sp.) and creeping bentgrass (Juska, 1958), and under shade, GA_3 reduced ultradwarf bermudagrass (*Cynodon dactylon* [L.] Pers. × *C. transvaalensis* Burtt-Davy) visual quality and chlorophyll levels, but did not affect lateral regrowth of stolons (Bunnell et al., 2005). In addition, there are examples of research which explored the use of plant growth regulators in turfgrasses and their relationship to gibberellic acid, other phytohormones, and plant physiological responses (Gaussoin and Branham, 1987; Gaussoin et al., 1997; Heckman et al., 2001a, 2001b, 2001c, 2001d; Li et al., 2020). Of note, commercially available PGRs for turfgrasses (e.g., flurprimidol, paclobutrazol, prohexadione calcium, trinexapac-ethyl, etc.) are synthetic chemicals that interact with the gibberellin biosynthesis pathway thus "regulating" a phytohormone response versus "eliciting" a biostimulant-induced phytohormonal response.

2.2 Biopolymers, protein hydrolysates, and other N-containing compounds

Examples of compounds in this category include amino acids (e.g., betaine and proline) and chitin.

2.2.1 Amino acids

Amino acids are the "building blocks" for proteins, enzymes, nucleic acids, antioxidants, and other secondary compounds (Guo et al., 2021; Salisbury and Ross, 1991). The L-form of amino acids are assimilated by plants, and these L-amino acids and short-chain peptides are reported to increase plant N uptake, increase root mass, activate natural defense mechanisms, and enhance photosynthesis (Salisbury and Ross, 1991). For example, L-proline has been shown to improve water stress tolerance in plants (Ashraf and Fooland, 2007), and lysine metabolism is related to abiotic and biotic stress response in plants (Yang et al., 2020). These amino acids and short-chain peptide compounds are derived by chemical or enzymatic hydrolysis of animal or plant by-products, fermentation metabolites by microorganisms, or chemical modification and synthesis (du Jardin, 2015). Glycine betaine (GB) is the amino acid betaine derived from glycine, and is synthesized in the chloroplast, and is associated with mitigation of abiotic stress from drought, salinity, extreme temperatures, ultraviolet radiation, and heavy metals (Ashraf and Fooland, 2007). Commercial production of glycine betaine is from sugar beet (*Beta vulgaris* L.), which is purified from molasses during the sugar extraction process (Ashraf and Fooland, 2007).

Other responses from amino acids applications, for example phenylalanine, include increased production of antioxidants, the key components in dealing with abiotic stress (Kauffman et al., 2007). Although primarily plant-directed, when applied to soil, microflora (e.g., bacteria and fungi) can readily access and assimilate amino acids, resulting in increased soil microbial biomass, which could be an important component of soil health (Moody et al., 2007). Amino acids can be a readily available N source for rapid root and foliar update in turfgrass, suggesting that they also have potential as fertility management options or to maximize plant use of existing soil nutrients (McCoy et al., 2020; Radkowski et al., 2020).

Some examples of documented amino acid research in turfgrasses include: increase in creeping bentgrass visual quality, chlorophyll content, and superoxide dismutase (antioxidant) content from amino acid applications thus indicating a potential role for foliar amino acids in a creeping bentgrass fertilization program (Zhang et al., 2013b), foliar applications of branched-chain amino acids to creeping bentgrass increased shoot density and root weight (Mertz et al., 2019), GB applications to creeping bentgrass was shown to ameliorate drought stress and this effect was related to maintenance of the antioxidant enzyme system (Gan et al., 2018), perennial ryegrass under high temperature stress and treated with hydrolyzed amino acids resulted in improved photosynthetic efficiency (Botta, 2013), foliar application of GB to perennial ryegrass under low temperature stress resulted in enhanced growth via osmotic adjustment (Mickelbart and Boine, 2020), and creeping bentgrass treated with tryptophan containing a fermentation byproduct or purified tryptophan plus urea ($46N\text{-}0P_2O_5\text{-}0K_2O$) resulted in improved leaf and root IAA content, root biomass, and overall turfgrass quality compared to applications of urea alone (Mertz et al., 2017).

2.2.2 Chitin

Chitin is the second most abundant natural biopolymer in the world, after cellulose (Shamshina et al., 2019). The main source of chitin is from shells of marine crustaceans, particularly crab and shrimp, but other living organisms biosynthesize chitin including algae, insects, and fungi (Yan and Chen, 2015). The chemical structure of chitin is a polysaccharide, and is reacted with an alkaline substance (e.g., sodium hydroxide) to produce chitosan. Therefore, chitosan is a linear polysaccharide composed of randomly distributed components of β(1→4)-linked D-glucosamine and *N*-acetyl-D-glucosamine (Shamshina et al., 2019).

Chitosan is used to stimulate plant growth and to induce a biological response to abiotic and biotic stresses (Hou et al., 2021). The plant's response to chitin is determined by species and growth stage of development, and by chitin structure and concentration (Hou et al., 2021). Research on chitosan has focused on it's use as an "elicitor" (e.g., an elicitor is a molecule that triggers a hypersensitivity response in plants) of stress response signaling (e.g., stomatal closure to manage transpiration and water use) (du Jardin, 2015). Chitosan interacts with many cellular components (e.g., DNA, plasma membranes, etc.) to bind to specific receptor sites that activate defensive genes which results in increased protection from plant pathogens and insect pests, but more broadly to enhance tolerance to abiotic stress (e.g., drought, salinity, nutrient deficiency or toxicity) (Hou et al., 2021).

Current research is exploring the metabolic mode of action of chitin and chitosan polysaccharides in plant abiotic stress tolerance, and also the suppression of plant pathogens (du Jardin, 2015). Of note, complex polysaccharides in SWE may have similar effects (Sun et al., 1997). An example of chitin research in turfgrass is: chitosan may be helpful to alleviate heat-induced leaf senescence in creeping bentgrass by regulating chlorophyll metabolism and influencing the production of antioxidants and heat shock proteins (Huang et al., 2021a).

2.2.3 Polysaccharides

Algae (e.g., seaweed) produce a diversity of biologically active compounds that can enhance plant growth and resistance to abiotic and biotic stresses (Stadnik and Freitas, 2014). These compounds include polysaccharides which are essentially branched or unbranched chains of monosaccharides (~carbohydrate molecules). Some examples of polysaccharides are cellulose, glycogen, and starch. Similarly, microorganisms (e.g., bacteria, fungi, actinomycetes) also produce a diversity of polysaccharides that can influence how a microbe adsorbs onto surfaces, is protected from desiccation, and interacts with plants to trigger of plant's response to abiotic or biotic stresses. An example of a polysaccharide are ulvans. These water-soluble polysaccharides are obtained from cell walls of green macroalgae (*Ulva* spp.) commonly known as "sea lettuce" (Sangha et al., 2014). In plants, ulvans have been shown to signal a defense response to pathogen infection (Jaulneau et al., 2010). No specific research with ulvans or other seaweed polysaccharides and turfgrasses has been published, although this represents an opportunity to further explore biotic stress mitigation in amenity turfgrasses.

2.3 Other botanical or synthetic bioactive compounds

This is a "place-holder" category for plant-directed compounds not yet described or fully understood, or for compounds that do not fit the description of the other categories. Other naturally-derived plant compounds or synthetic materials may be listed in this biostimulant category (Table 1). An example of an organic compound in his category is acibenzolar-*S*-methyl (ASM), which is a synthetic analog of salicylic acid (Kessman et al., 1996). ASM is referred to as a "plant defense activator", because it is not directly toxic to fungal pathogens but produces an induced systemic resistance response and thus activates a plant's natural defense system (Cole, 1999). Of note, salicylic acid is involved in both abiotic and biotic stress defense due to its ability to signal for the activation of plant immune systems (Durner et al., 1997; Schmidt and Zhang, 2001). ASM is a component of commercial turfgrass fungicides that contain the active ingredients chlorothalonil and fluazinam (Clarke et al., 2020). Examples of ASM research in turfgrass are: ASM associated with improved turfgrass disease management (Hsiang et al., 2011; Lee et al., 2003), and also ASM associated with the ability to mitigate abiotic heat and drought stress in turfgrass (Jespersen et al., 2017).

2.4 Humic substances

Humic substances (e.g., humic and fulvic acids) are natural decomposition constituents of soil organic matter, typically derived from leonardite (a natural form of humates), associated with the surface layers of "brown coal" deposits. Leonardite describes the base material used in production of humic acids, and was named after A.G. Leonard, the first director of the North Dakota Geological Survey in recognition of his contributions in this field (Fidanza et al., 2015). Humic substances derived from leonardite are considered brown-black polymeric acids that exhibit both hydrophobic and hydrophilic characteristics and bind to soil mineral surfaces (Adani et al., 2006). Humic acid can be considered as a natural soil conditioner because it contains high concentrations of trace minerals and has a greater effect on soil with alkaline pH and lower cation exchange capacity (Chen, 1996; Wang et al., 1995).

Benefits of three active humic compounds (e.g., fulvic acid, humic acid, and humins) in humic substances include increased soil nutrient and water holding capacity (e.g., increased cation exchange capacity), prevention and reduction in leaching of soil nutrients, chelators of organic molecules and minerals facilitating increased plant root absorption, enhanced soil enzyme and metabolic activity, and more (Barrett, 2015; Liu et al., 1998; Schmidt and Zhang, 1998). Some examples of humics/humic acid research in turfgrasses include: applications of SWE plus humic acid to tall fescue (*Festuca arundinacea* Schreb.; syn. *Schedonorus arundinaceus* [Schreb.] Dumort., nom. cons.) sod increased canopy photosynthesis efficiency and recovery from post-harvest heat injury (Zhang et al., 2003), applications of humic acid were beneficial to creeping bentgrass shoot and root growth (Hunter and Anders, 2004), foliar application of leonardite humic acid prior to dry-down resulted in increased quality, photochemical efficiency, root mass, and leaf α-tocopherol levels during drought (Zhang and Erivn, 2004), and sequential foliar applications of leonardite- or peat-based humic acid during Kentucky bluegrass sod establishment resulted in greater root mass and root strength than the fertilizer control (Ervin and Roberts, 2007).

2.5 Organics

Many organic compounds, materials, and products can be placed into this category (Table 1). Bigelow and Soldat (2013) and Waddington (1992) provided recent reviews and considerations with chemical and physical soil amendments for turfgrass ecosystems. Traditionally, organic amendments such as peat moss, manures, biosolids, composts, and other materials have been added to sand-based turfgrass root zones to increase water and plant nutrient retention and availability, but these benefits can decline within a few years as those amendments decompose (Zhang et al., 2012; Waddington, 1992). Ideally, organic materials and substances applied to turfgrass soils should be sufficiently decayed and biologically stable and decompose very slowly so their benefits or positive impact can be expressed over a long time (Bigelow and Soldat, 2013). Thus, due to their stability and low cost, the peat mosses are the most frequently used organic amendment for synthetic sand-based root zones.

Another recent example of a stabilized organic material being utilized for turfgrass root zones is biochar (Brockhoff et al., 2010). Biochar represents a high carbon content, highly porous, and tremendously stable (e.g., extremely resistance to microbial degradation) substance produced from the pyrolysis (e.g., heating organic material > 500 ºC in the absence of oxygen) of various biomass feedstocks (e.g., wood chips, plant resides, animal manures, or other agricultural waste products) (Spokas et al., 2012). Some examples of organic materials/products research in turfgrasses include: beneficial use of biochar for water and nutrient retention for sand-based root zones and turfgrass establishment (Vaughn et al., 2015), beneficial inclusion of compost and biochar on soil biology of turfgrass subjected to deficit irrigation (Hale et al., 2021), benefits of compost-amended soil for nutrient availability of turfgrass (Wright et al., 2007), and benefits of compost and compost tea for turfgrass (Bero and Soldat, 2021). Another example of an organic biostimulant product applied to turfgrass is Worm Power® (AquaAid Solutions; Rocky Mount, NC; USA), which is vermicompost extract utilized to improve biological and physical health of the turfgrass root zone (for more information: https://tinyurl.com/2ch8ekmr).

2.6 Inorganics/minerals

Many inorganic/mineral compounds and products can be placed into this category (Table 1). Phosphite (PO_3^{3-}) of has become the most common inorganic compound incorporated into many turfgrass management programs, particularly with disease management and suppression (Havlin and Schlegel, 2021). In most products, phosphite is delivered as potassium phosphite in the form of either potassium dihydrogen phosphite (KH_2PO_3) or dipotassium hydrogen phosphite (K_2HPO_3) (Landschoot and Cook, 2005). Silicon in the form of silica (e.g., silicon dioxide [SiO_2]) is example of an inorganic mineral with potential benefits for abiotic and biotic stress reduction of turfgrasses (Guertal and Datnoff, 2021; Schmidt et al., 1999; Zeller et al., 2021). Some examples of inorganic/mineral products research in turfgrasses include: use of potassium phosphite to suppress snow mould disease (*Microdochium nivale* [Fr.] Samuels and Hallett) in cool-season turfgrass (Dempsey et al., 2012), the use of silica to enhance disease suppression in warm-season turfgrass (Datnoff and Rutherford, 2003), and foliar applications of potassium silicate to bermudagrass, tall fescue, and perennial ryegrass irrigated with saline water was helpful to alleviate sodium-induced stress (Esmaeili et al., 2015).

2.7 Biologicals/microbials

Numerous biological/microbial organisms can be placed into this category (Table 1). Arbuscular mycorrhizal fungi form a mutually symbiotic relationship with plant roots, in which roots provide carbohydrates for the fungi and the fungi aid in access and transfer of nutrients and water to the plant roots, and also water balance, and abiotic and biotic stress tolerance or protection (du Jardin, 2015). *Trichoderma* spp. is another example of a fungal organism that has been studied for biopesticide (e.g., fungicide-like properties) and biocontrol (e.g., inducer of disease resistance) benefits and facilitating abiotic stress tolerance in plants (du Jardin, 2015). *Bacillus* spp. is the most common example of a bacterial organism utilized for biological control of plant pathogens, and this is achieved via direct suppression by the release of antipathogen compounds, or via indirect mechanism such as outcompeting the pathogen for space or food, or activating or inducing plant defense systems (Lugtenberg and Kamilova, 2009; Schlatter et al., 2017). Current research is exploring plant growth promoting rhizobacteria (PGPR) and their ability to confer beneficial effects on plant growth and development by increased nutrient uptake (e.g., nitrogen and phosphorus), synthesizing plant growth promoting compounds, activating abiotic and biotic stress tolerance mechanisms, and possibly more (Lugtenberg and Kamilova, 2009; Rosier et al., 2018).

Zuberer (2012) summarized 35 years of research in this area to conclude: (i) microbial function and growth in turfgrass soils are similar to agricultural soils or native grassland soils; (ii) soil microbial populations are resilient and changes to the community are most likely achieved through altering the soil environment towards a more favorable habitat; and (iii) best practices for managing the microbiology in the turfgrass root zone are those that adhere to well established agronomic principles and practices (e.g., healthy turfgrass will provide the necessary resources for soil microbes to thrive and function). Some examples of research on biologicals in turfgrasses include: synthetic fungicides applied at reduced label rates in combination with biological control agents (e.g., *Bacillus* spp.) provided an opportunity for dollar spot disease management in creeping bentgrass (Marvin et al., 2020), environmental factors and an actively growing turfgrass root system may have a greater influence and impact on soil microbial activity (Bigelow et al., 2002), and SWE can impart positive effects on soil microbial populations, especially PGPR that facilitate nutrient uptake or provide a source of biopesticidal metabolites or plant defense activators such as ulvans (Mueller and Kussow, 2005; Sangha et al., 2014).

2.8 Soil surfactants

Agriculture, horticulture, and turfgrass industry practitioners commonly refer to soil surfactant products as “wetting agents” (Fidanza et al., 2019; Kostka and Fidanza, 2019). The term “soil surfactant” is a more appropriate and descriptive label from a soil science perspective (Kostka and Fidanza 2018). Soil surfactant chemistries used in turfgrass management have been reviewed in Zontek and Kostka (2012). With over 300 soil surfactants commercially available globally, Fidanza et al. (2020) proposed a classification strategy for soil surfactants in the turfgrass industry, the majority of which in the global marketplace are of non-ionic chemical composition. Worthy of note, the first patent of a non-ionic soil surfactant was U.S. Patent #2,867,944, “Method of treating soil by non-ionic surface active agents” by L.W. Fletcher (Havertown, PA, USA) was first published in 1959 (https://patents.google.com/patent/US2867944). Should all or some specific soil surfactants be listed as a biostimulant? Can soil surfactants “behave as biostimulants”, or “facilitate a biostimulant effect” when applied to turfgrass root zones? Scientists and stakeholders in academia, government, and industry have begun to explore this question further (Fidanza et al., 2019; Kostka and Fidanza, 2019).

In managed amenity turfgrass ecosystems, soil surfactants are primarily and traditionally used for water conservation, improving irrigation use efficiency, and ameliorating soil water repellency (Kostka et al., 2007; Soldat et al., 2010). The utilization of soil surfactants is considered the number one water conservation strategy among golf course superintendents in the USA (Gelernter et al., 2015). Some examples of research on soil surfactants in turfgrasses include: use of soil surfactants to alleviate soil water repellency in sand-based turfgrass root zones (Cisar et al., 2000; Kostka, 2000; Dekker et al., 2019), beneficial use of soil surfactants with irrigation programs (Mitra et al., 2006; Moore et al., 2010), use of soil surfactants to improve delivery and efficacy of soil-directed fungicides (Fidanza, 2015; Fidanza et al., 2007) and nematicides (Webb, 2022), and use of soil surfactants to increase nitrogen uptake of bermudagrass and reduce nitrate leaching (Abagandura et al., 2021a, 2021b).

2.8.1 Soil surfactants and the turfgrass rhizosphere

In 1904, German agronomist and plant physiologist Lorenz Hiltner (1862-1923) first documented the term “rhizosphere” to describe the plant-root interface (Hiltner, 1904). “Rhiza” is a word of Greek origin that means “root” or “root-like”, and Hiltner (1904) first described the rhizosphere as that specific area surrounding a plant root that is inhabited by microorganisms, and these microorganisms are influenced by chemicals released from the roots. The rhizosphere is a concept that pertains to the soil-root interface, and recently has been described as the zone of biological, chemical, and physical influence generated by root growth and activity (Philippot et al., 2013; Pinton et al., 2007). The rhizosphere also has been defined as that zone of soil surrounding a plant root where the biology, chemistry, and physical properties and activities of the soil are influenced by the root and compounds exuded by the root (e.g., mucilage), and these influences change both radially and longitudinaly along the root (Figure 1), and the rhizosphere also facilitates communication between the plant and the microbiome (Bias et al., 2004; McNear, 2013).

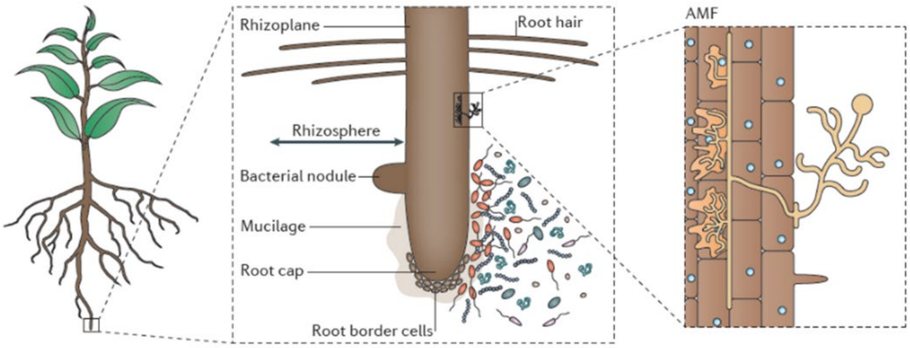

Figure 1. An example of a root section illustrating the rhizosphere (e.g., interface between plant roots and soil); AMF = arbuscular mycorrhizal fungi. Source: Philippot, L., Raaijmakers, J.M., Lemanceau, P., and van der Putten, W.H. 2013. Going back to the roots: the microbial ecology of the rhizosphere. Nature Reviews Microbiology 11(11):789-799.

Hallett et al. (2022) provided a review of plant roots and their capacity to improve soil, and in particular the importance of root hairs: "...just as dabbing paint with a brush allows it to penetrate into nooks and crannies on surfaces, root hair can aid the influence of plant roots by penetrating into soil pores too small for roots and distributing rhizodeposits into a greater soil volume”. Root hairs are single cell outgrowths from the root epidermis that increase root surface area and explore the bulk soil. Rhizodeposits are materials exchanged from plant to soil and dominated by root exudates, mucilage, and sloughed cells. Root exudates are substances excreted by roots and composted of sugars, amino acids, organic acids, and other carbon compounds. Mucilage typically composed of viscous polysaccharide (e.g., sugar) compounds secreted at the root tip, and is needed to lubricate soil particles as the root pushes through that abrasive soil environment. Mucilage also represents a significant food source for soil microorganisms and can influence soil-water relations (Carminati et al., 2016). The rhizosheath is defined as the soil that adheres strongly to the root through action of root hairs and rhizodeposists. Overall, root hairs not only help the plant access localized resources (e.g., air, nutrients, and water), but they also sequester carbon (e.g., deposits of exudates, mucilage, rhizosheaths) and this ultimately improves the soil and root zone environment (e.g., binding soil particles, improving soil structure, etc.). (Bigelow et al., 2022; Hallett et al., 2022).

Plants invest in improving their root zone environment at the root-soil interface (e.g., the rhizosphere) (Gregory et al., 2022). By exuding materials such as mucilage, a high molecular weight biopolymer that absorbs and retains water, plants can remain hydrated for longer periods. Once dry-down cycles occur, however, water retention and rewetting are compromised due the presence of small quantities of amphiphilic compounds that render the mucilage hydrophobic thus impeding rehydration and access to water and nutrients in a diversity of species (Hallett et al., 2003; Carminati et al., 2010; Ahmed et al., 2016). Their work indicates that soil treated with a surfactant modifies mucilage behavior (e.g., reducing swelling, increasing mucilage viscosity, and increasing the speed of wetting while resulting in a reduced rate of plant transpiration). Their work also suggests that in surfactant treated soil, applied irrigation results in faster root rehydration and a larger proportion of that applied water is plant available. While the rate of plant transpiration was slowed, turgidity duration was markedly increased with a concomitant maintenance of plant performance and tolerance to water stress. Soil surfactants may play an important role with modifying the turfgrass rhizosphere and thus influence the diversity of hydraulic processes and functions at the rhizosphere level (Figures 2 and 3) (Bigelow, 2022; Carminati and Vetterlein, 2013; Carminati et al., 2011, 2016; Fidanza et al., 2019, 2020; Kostka and Fidanza, 2018, 2019; Singh et al., 2018).

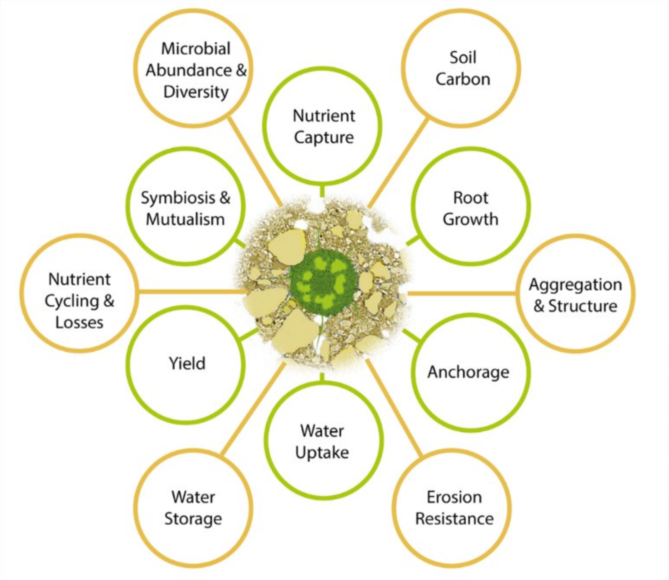

Figure 2. Illustration indicating processes and functions of the rhizosphere, and that *everything from the soil which passes through the plant passes through the rhizosphere.* Of note, “Yield” pertains to crop production, but could be substituted for “Quality and Resilience” when pertaining to amenity turfgrass. Source: Hallett, P.D., Marin, M., Bending, G.D., George, T.S., Collins, C.D., and Otten, W. 2022. Building soil sustainability from root-soil interface traits. Trends in Plant Science 27:688-698.

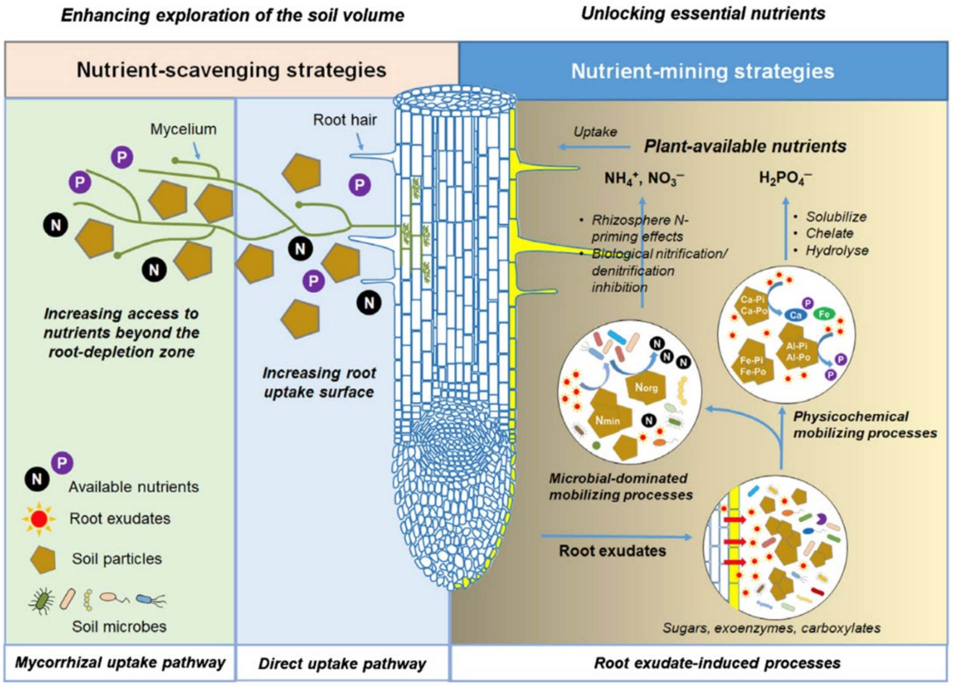

Figure 3. Illustration of root exudates functioning to enhance or influence nutrient acquisition with the rhizosphere. Soil surfactant applications in turfgrass root zones may play a beneficial role in this process. Source: Wen, Z., White, P.J., Shen, J., and Lambers, H. 2022. Linking root exudation to belowground economic traits for resource acquisition. New Phytologist 233:1620-1635.

In recent studies, Ahmadi et al. (2017) built on these earlier observations noting that not only did surfactant treatment increase and maintain access to water, but that surfactant modification of mucilage increased microbial activity in the rhizosphere, increased nutrient uptake efficiency, and resulted in increased rooting and development of rhizosheaths. Moreover, the production and distribution of a range of plant and microbial enzymes in the rhizosphere were associated with soil health and suppression of soil-borne pests and pathogens (Ahmadi et al., 2018). As Hallett et al. (2022) so obviously state: *everything from the soil which passes through the plant passes through the rhizosphere* (Figures 2 and 3). It is becoming apparent that strategies to" engineer" the rhizosphere may have profound effects normally associated with biostimulants.

Roots are essential for the acquisition of water and nutrients/minerals from soils (Salisbury and Ross, 1991). Root exudates are important for the belowground, interspecies communication between plants and other plants, and/or microorganisms, and thus modifications to roots and the rhizosphere can result in improved plant performance and increased stress tolerance (Ahmed et al., 2016; Bias et al., 2004; Rosier et al., 2018). Therefore, strategies to manipulate the rhizosphere to maintain or enhance connectivity of roots and root hairs to soil particle surfaces can be expected to stimulate the rhizosphere microbiome to influence soil and plant health (Duddek et al., 2020, 2022). If root and root hair connectivity can be maintained, plant resilience should be optimized. Enhanced rhizosheath development has been documented in turfgrass grown in surfactant treated soils (Ahmadi, personal communication). Preliminary, unpublished studies show that certain surfactants increase rooting in cool- and warm-season turfgrasses under greenhouse and field conditions (personal communications: T. Malehorn [iGin Research, Westminster, MD, USA], X. Zhang [Virginia Polytechnic Institute and State University, Blacksburg, VA, USA], S.B. Martin [S.B. Martin Turf Research, Florence, SC, USA], P. Kirby [Indigo Specialty Products, Rocklea, Australia]). Further, turfgrass remains turgid even as soil water deficits increase suggesting that better root/root hair connectivity is being maintained (Figure 4). A body of evidence is building that certain diverse root zone processes can be "engineered" by surfactants to optimize rhizosphere and soil biophysical, microbiological, and chemical properties (Figure 4) (Ahmadi et al., 2017, 2018; Bias et al., 2006; Duddek et al., 2020, 2022**).**

Figure 4. An example of a beneficial application of a soil surfactant to improve the volumetric water content status of the root zone and possibly optimize the function of the rhizosphere of this creeping bentgrass fairway and putting green. A: left side of fairway was untreated. D: right side of fairway and putting green treated with soil surfactant (ProWet Evolve®; TurfCare; Kildare, Ireland). B: drought stress visible in the turfgrass sward, indicating root with compromised physiological function. C: illustration depicting poor root-to-soil contact. E: healthy and dense turfgrass visible on right side, indicating that roots in the soil surfactant-treated turfgrass root zones maintain root to soil contact and access to water and nutrients. F: illustration depicting good or optimum root-to-soil contact. Photo by D. Jones. Images in C and F from: Weil and Brady, 2022. Images in B and E from: Duddek et al., 2020, 2022.

2.9 Other naturally derived or synthetic bioactive compounds

This category is a "place-holder" for soil-directed compounds not yet described or fully understood, or for compounds that do not fit the description of the other categories. To date, no compounds are placed into this category.

3 Considerations with the use of biostimulants for sustainable turfgrass management

When asked to consider using a biostimulant product, a prudent and responsible turfgrass manager would ask "*What is in it?*" and "*What does it do?*", among other questions (Fidanza et al., 2019). Carrow (1993) published an inciteful list of eight questions to ask when evaluating a soil amendment or other product for turfgrass use and management (Table 2).

Table 2. Should I use this product on my turf? Eight questions to ask when evaluating a soil amendment or other turf product to help you make sound, fact-guided agronomic decisions.[1]

1. Is this product needed in my situation?
2. Are independent test results available?
3. What is the magnitude of response?
4. Does this product provide consistent results?
5. What is the duration of response?
6. Are there better alternatives?
7. Do benefits justify the costs?
8. Should I try this product on a trial area?

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[1] Source: Carrow, R.N. 1993. Eight questions to ask: Evaluating soil and turf conditioners. Golf Course Management 61(10):56, 58, 60, 64, 70.

The purpose of asking those questions is to help guide the turfgrass manager towards making the best fact-based agronomic decision. Fidanza et al. (2019) further expanded on those important questions to ask when a turfgrass manager is considering a biostimulant product (Table 3). These questions further explore a biostimulant's intended use (e.g., abiotic or biotic stress, plant nutrient efficiency, etc.) and ability to produce or facilitate the desired turfgrass response.

Table 3. What are key questions golf course superintendents, greenkeepers, course care managers, sports field managers, and lawn and landscape professionals should ask when considering a biostimulant product?[1]

- What's in it? What is the product's composition or active ingredient(s) or component(s)?
- What is its' function? How does the product claim to benefit turfgrass?
- Will the product function in all climates, soil types, turfgrass species, and turfgrass cultural practices and management programs?
- Does the product function best to help with abiotic (e.g., drought, heat, salt) or biotic (e.g., insects, pathogens, traffic) stresses?
- Where's the data? What does the research-based data show that the product does when the product is applied to turfgrass? Were the effects both qualitative and quantitative in replicated field and/or controlled greenhouse research?
- Does the manufacturer have clear research-based data showing that all or most of the product's active ingredients are essential to its function? Does the data show how individual ingredients, when tested against the formulated product, no longer provide the functional benefit?

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[1] Adapted from: Fidanza, M., Kostka, S., Ervin, E., and Bigelow, C. 2019. The European Union's view on biostimulants: What may be coming our way. Golf Course Management 87(9):58-62.

Products that contain a biostimulant or combinations of biostimulants may provide turfgrass management options to maintain or improve turfgrass quality and function during abiotic and/or biotic stress conditions. Moderating and mitigating these stresses are an important strategy to establishing and maintaining a healthy, resilient, and sustainable turfgrass sward. As these stresses increase, a number of plant physiological processes may be compromised: decline in efficiency of light capture (photosynthesis) and carbon utilization (respiration); increase in amount of destructive reactive oxygen species (free radicals) in leaves, shoots, and roots; leaves and shoots stop allocating energy to roots and draw energy and resources from the roots; and root decline which precedes shoot decline and is often coupled with root infection from secondary plant pathogens (Yakhin et al., 2017). Therefore, should a biostimulant product or program become a valuable part of sustainable turfgrass management? The answer to that question may depend on what exactly the turfgrass practitioner wants to accomplish (e.g., better rooting, better tolerance of heat or drought stress, improved recovery from heat or drought stress, traffic tolerance, turf recovery, disease prevention, turf recovery from disease, better color or visual quality, better playability, etc.).

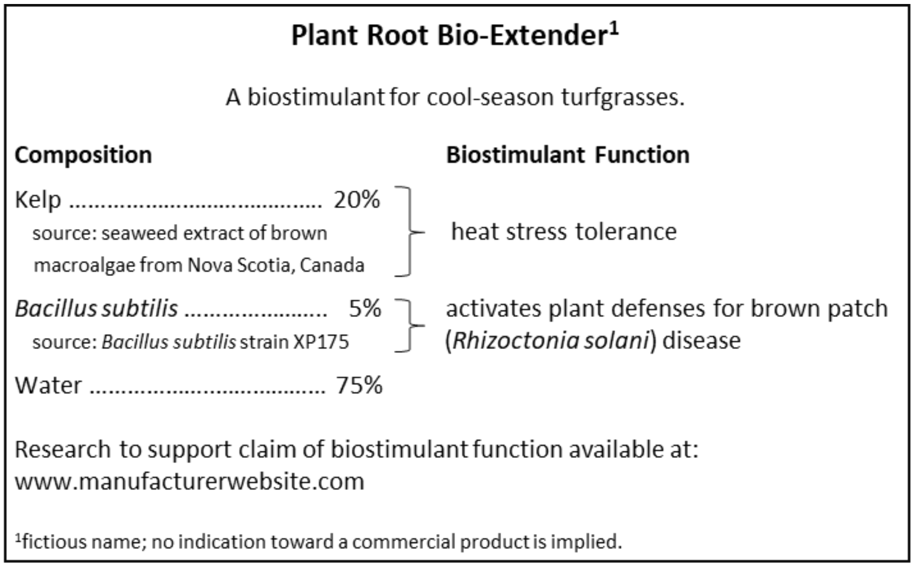
Many biostimulant products are formulated from multiple components and/or are of undefined or vaguely-defined composition (e.g., as components in fertilizer formulations or as soil amendments). While biostimulant activity may be measured from such formulations, is the observed plant or soil response a consequence of a single biostimulant component or from multiple components in the formulation or product? In studies conducted in growth chambers and in the greenhouse, effects of single components can be measured. However, measuring such effects in the field is often more challenging. One or more complex formulations may need to be applied to observe a visual plant response. The challenge then becomes explaining which components were responsible for the observed effects.

Turfgrass practitioners should critically evaluate turf for the response desired. If a turf manager decides to include a biostimulant product as a component of their turf management program, it would be important to make many observations and measurements throughout the year and document what you are seeing so that you can make informed decisions going forward. Also be sure to review all available information and consider that the use of a biostimulant or any product should be predicated on results from independent and replicated third-party research.

5 Summary and future trends

Why should there be a functional definition of plant biostimulants? The European Union's view is that biostimulants should support ecology-based agricultural and food production systems. The EBIC's last part of their biostimulant definition: "…to stimulate natural processes ... independently of its nutrient content" indicates that although a biostimulant product may contain a fertilizer component (e.g., N or Fe), the observed demonstrated plant response is due to the biostimulant and not the fertilizer effect. Therefore, the European Union has proposed regulations to support and enforce a claims-based definition of plant biostimulants (e.g., biostimulant products should be defined by their function, not by the ingredients inside the product container) (Fidanza et al., 2019). The European Union also proposed that biostimulant products should have credible demonstrated effects to support the product claims (e.g., documented research to support product label statements for the crops and markets targeted). For example, if a biostimulant product contains a microorganism that induces a plant defense response to a plant pathogen, then the manufacturer must provide data supporting that claim for that particular crop and use. Therefore, the manufacturer would have to prove the biostimulant inside the product performs the function for that particular crop or use as stated on the label (Fidanza et al., 2019; Ricci et al., 2019; Yakin et al., 2017).

Currently the EBIC is collaborating with government, academia, and industry to develop guidelines for compiling data and information obtained from consistent and reliable research results. The guidelines contain two main points: (i) data must be generated to support the biostimulant claim (e.g., biostimulant function), and (ii) data must be used to place biostimulant product into the European Union market and/or support commercial product claims. Of note, the data required will depend on the biostimulant's claim or declared function (Fidanza et al., 2019). Would biostimulant product manufacturers be required to include the specific biostimulant function or claim on the product label (Figure 5)?



Plant Root Bio-Extender[1]

A biostimulant for cool-season turfgrasses.

Composition	**Biostimulant Function**
Kelp .... 20% source: seaweed extract of brown macroalgae from Nova Scotia, Canada	heat stress tolerance
Bacillus subtilis .... 5% source: *Bacillus subtilis* strain XP175	activates plant defenses for brown patch (*Rhizoctonia solani*) disease
Water 75%	

Research to support claim of biostimulant function available at:
www.manufacturerwebsite.com

[1] fictious name; no indication toward a commercial product is implied.

Figure 5. Example of an ideal biostimulant product label that would include information on both composition (e.g., active ingredients and sources) and biostimulant functions or claims.

Regarding the required research-based data needed to support biostimulant claims, the European Union has proposed guidelines and criteria for laboratory, greenhouse, and growth chamber studies that include proper data analysis and interpretation (e.g., the use of a 90% probability statistic) and field trials conducted under real-world conditions and under various environmental and geographic conditions. Of note, peer-reviewed scientific journal publications can be used to support a biostimulant claim if it is of acceptable quality under the European Union guidelines (Fidanza et al., 2019).

Should the U.S. Department of Agriculture (USDA; Washington, DC, USA) adopt the European Union's claims-based definition of biostimulants for use in the United States? Recently, the U.S. Environmental Protection Agency (USEPA; Washington, DC, USA) has assembled a draft document of guidelines for clarifying which biostimulants, biological substances, mixtures, and associated product label claims should be considered as plant growth regulators (source: https://www.epa.gov/pesticides/draft-guidance-plant-regulators-and-claims-including-plant-biostimulants). Those compounds identified as plant growth regulators will be subject to regulation under the Federal Insecticide, Fungicide and Rodenticide Act as pesticides. Of note, the USDA's proposed definition of biostimulant is: *"...plant biostimulant is a substance(s), microorganism(s), or mixtures thereof, that, when applied to seeds, plants, the rhizosphere, soil or other growth media, act to support a plant's natural nutrition processes independently of the biostimulant's nutrient content. The plant biostimulant thereby improves nutrient availability, uptake or use efficiency, tolerance to abiotic stress, and consequent growth, development, quality or yield*." (source: https://www.epa.gov/pesticides/draft-guidance-plant-regulators-and-claims-including-plant-biostimulants).

In the USA, however, a structured regulatory path to register biostimulants has not been established, thus precluding validation afforded by regulatory oversight and its value to developers and users of the technology. Therefore, the Biostimulant Industry Workgroup (BIW) was established in 2020 as a collaboration of the Biological Products Industry Alliance (BPIA; Oakton, VA, USA) and The Fertilizer Institute (TFI; Arlington, VA, USA). In response to U.S. Department of Agriculture (USDA; Washington, DC, USA) and U.S. Environmental Protection Agency (USEPA; Washington, DC, USA) reports on biostimulants submitted to congress in 2019, BWI prepared and released a draft document: "United States Biostimulant Industry Recommended Guidelines to Support Efficacy, Composition, and Safety of Plant Biostimulant Products" (www.bpia.org). This draft document was developed by BIW representatives with input from a wide range of stakeholders and reviewers and released in 2022. The document offers clarification of terminology and a suggested framework for a regulatory process requiring scientifically sound data in support of product label claims and safety of biostimulant products. The biostimulant industry awaits the outcome of those interactions among the USDA, USEPA, BPIA, and TFI.

Regardless of the biostimulant product or strategy it is important to note that biostimulants are not a substitute for essential mineral nutrients and a sound agronomic-based turfgrass management program. If the goal is to include or incorporate biostimulants as part of an overall plant and soil health program, then the research in turfgrass ecosystems has demonstrated that they must be applied in advance of those abiotic and biotic stresses to optimize their benefits. There are many exciting innovations on the nearby horizon and evidence-based efforts will lead the way toward a better understanding of how biostimulants will help maintain and improve plant and soil health (Yakhin et al., 2017). Today, much more scientific research is focused on the development, evaluation, use, function, and benefits of biostimulants for sustainable agronomic practices in intensively managed amenity turfgrass ecosystems.

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