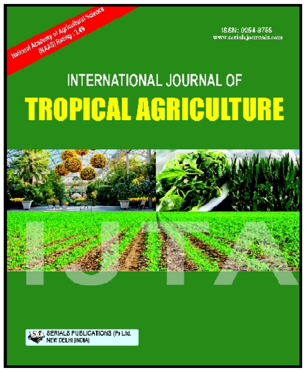

INTERNATIONAL JOURNAL OF TROPICAL AGRICULTURE

ISSN : 0254-8755

available at http: www.serialsjournal.com

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Volume 35 • Number 4 • 2017

Reviving Soil Biology and Crop Productivity through New Biofertilizer: Agroecological Performance of *Pseudomonas monteilii* in Tropical Environments

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Abstract: Traditionally, the soil biology was considered the most vital component of food production systems. However, excessive use of inorganic chemicals and toxic substances impaired the biological processes and ecological pathways in soils. So, because of a quest to extract maximum yields, the soil biology is spoiled to distress levels. Microbial biofertilizers are known to recover the soil biology and sustainability of agroecosystems. Having a forestry by-product carrier, Earth Alive Soil Activator® is an established biofertilizer suitable for tropical and temperate geoclimatic conditions. It contains three non-genetically modified bacteria (*Pseudomonas monteilii, Bacillus subtilis* and *Bacillus amyloliquefaciens*). Laboratory experiments ('mode of action' method) were conducted to gauge the agroecological performance of all three bacteria present in Soil Activator®. Phosphorus solubilization, nitrogen fixation, soil moisture retention, and plant nutrients uptake were tested as novel factors of *Pseudomonas monteilii* bacterium and as synergistic effects of all three bacteria. Based on largely a review, this paper discusses the agroecological performance of *Pseudomonas monteilii* bacterium. The results of the experiments demonstrate that level of phosphorus, nitrogen and various nutrients has increased following the application of the Soil Activator® containing *Pseudomonas monteilii*. Soil moisture retention has also increased up to 4.9 percent. In the soil, *P. monteilii* produces siderophores that chelate unavailable iron to increase iron uptake in plants. By using this bacterium through Soil Activator®, not only the yields of crops increase but the ecological functions of soil also recover, apart from safeguarding human health considerably.

Keywords: Biofertilizer; Soil Activator; Agroecology; Soil Biology

INTRODUCTION: CRITICALITY OF SOIL BIOLOGY

Conventionally, there is a perception that soil is an inorganic matter. But, the soil is living matter. It contains life. Neufeld (2017) argues that soil biology is still largely a mystery, and scientists have only identified somewhere between 5-10% of the microbial species living in soil.

Soil organisms can be divided into six groups: bacteria, fungi, protozoa, nematodes, arthropods, and earthworms. Each group of organisms plays important roles. Even within each group, there is great diversity in form and function. It is estimated that one cup of soil may hold as many bacteria as there are humans on Earth.[2] Because the bacteria and actinomycetes are exceedingly tiny, they make up half the living biomass in some soils. Interestingly, the weight of all bacteria in one acre of soil can equal the weight of a cow or two.[3] In addition to microorganisms, nematodes live in soil in huge number. Approximately 5000 soil nematode species have been described. Moreover, earthworms move soil from lower strata up to the surface and move organic matter from the soil surface to lower layers. Where earthworms are active, they can turn over the top 6 inches of soil in 10 to 20 years. We usually do not consider plant roots as part of soil, though the root system is an enormously complex living system interwoven with the soil. A mature tree can have as many as 5 million active root tips. The plants growing in a 2-acre wheat field can have more than 30,000 miles of roots, greater than the circumference of the Earth.[4] In fact, the rhizosphere is the interface between plant roots and the soil environment. It is the location of much soil biological activity and plant-microbe interactions including symbioses, pathogenic infection, and competition.

We need soil organisms for the services they provide. They play critical roles in plant health and water dynamics. According to Soil For Life (2013), biological organisms are fundamentally important to cycle nutrients from organic and inorganic sources and make them soluble to support the production of plants and organic matter. These organisms include bacteria and fungi, but also larger creatures such as insects and earthworms. These natural processes are central to healthy, fertile soils and regeneration of productive resilient biosystems, delivering more nutritious crops and animal protein. Thus, soil is the base for all crop productions. Traditionally, the soil biology was considered most vital component of food production systems. Neufeld (2017) stresses that 'good' biology is crucial for agricultural production. Soil biology builds soil organic matter to store carbon, and breaks organic matter down to release carbon back into the atmosphere. The balance between these two processes determines whether a soil is a carbon source or a carbon sink, and the goal is to tip the scale in favour of building soil organic matter (Neufeld, 2017). In addition to nitrogen fixation and carbon sequestration, soil flora and fauna have been identified[5] that perform the following actions:

1. Mineralization: The protozoa and nematodes excrete excess nitrogen into the soil when they eat nitrogen-rich bacteria and fungi.
2. The microbes degrade pollutants before they reach groundwater or surface water.
3. Soil biological activity substantially affects soil structure including the size of soil pores, the stability of soil aggregates, and the existence of macropores. Soil structure impacts how water flows over, into, and through soil and how much water is held within reach of plant roots.
4. Large, burrowing invertebrates (e.g., earthworms, ants, termites, beetles) create macropores that allow rapid flow of water into or through soil.

5. Even tiny arthropods produce fecal pellets that are mixtures of soil and organic matter. These became stable soil aggregates.
6. Some organisms prey on or compete with disease-causing organisms. Some bacteria release plant growth factors that directly increase plant growth.
7. Resilience is the ability of a soil to recover its functions after a disturbance such as fire, compaction, tillage, etc. The mix of organisms in the soil partially determine a soil's resilience.

In the quest of maximizing crop yields, excessive use of inorganic nutrients and toxic substances have impaired the biological processes and ecological pathways in the soils. The use of excessive chemical fertilisers and pesticides (herbicides, pesticides, etc.) have decreased soil microbial life and destroyed the balance between soil microbes and plants, negatively impacting plant nutrition, production and soil health. Shiva (2014) articulates that contemporary societies across the world stand on the verge of collapse as soils are eroded, degraded, poisoned, buried under concrete and deprived of life. Industrial agriculture, based on a mechanistic paradigm and use of fossil fuels has created ignorance and blindness to the living processes that create a living soil. Instead of focusing on the Soil Food Web, it has been focused on external inputs of chemical fertilisers — what Sir Albert Howard called the NPK mentality. Biology and life have been replaced with chemistry (Shiva, 2014). Microbial biofertilizers have been developed as a way to recover the soil biology and sustainability of agroecosystems.

THE BIOFERTILIZERS AND BIOFERTILIZER TYPES

Biofertilizers are microbial compounds that enhance soil fertility by using microorganisms in symbiotic relationships with plants. Biofertilizers may further be defined as microbial inoculants containing cultures of certain soil microorganisms which are multiplied in controlled conditions, and that can improve soil fertility and crop productivity (Roychowdhury, Paul and Banerjee, 2014). Biofertilizer can be classified broadly into eight types: (i) Rhizobium, (ii) Azospirillum, (iii) Azotobacter, (iv) Blue Green Algae (Cyanobacteria) and Azolla, (v) Mycorrhiza (Phosphate absorbers), (vi) Plant Growth Promoting Rhizobacteria, (vii) Phosphate solubilizers, (viii) Zinc solubilizers.

Rhizobiums

Known for their ability to fix atmospheric nitrogen, the *Rhizobium* genera of bacteria function in symbiotic relationship with legume plants of Leguminoceae family, e.g. chickpea, red gram, pea, lentil, black gram, soybean, groundnut and forage legumes like berseem (*Trifolium alexandrium*) and lucerne (*Medicago sativa*). The bacterium colonizes the roots of specific legumes to form nodules, which act as factories of ammonia production. Each legume requires a specific species of *Rhizobium* to form effective nodules (Mishra *et al.*, 2012). Popular genera include *Azorhizobium* for stem nodulation (*Sesbania rostrata*), *Bradyrhizobium* for soybean, lupin, cowpea, green gram, red gram, chickpea and groundnut, *Rhizobium* for pea, lentil, bean, lathyrus, berseem and lotus (Arjjumend, 2006).

Azospirillum

Belonging to family Spirilaceae, the *Azospirillum* forms associative symbiosis with plants particularly with those having the C_4 dicarboxyliac pathway of photosynthesis. It is because they grow and fix nitrogen on salts of organic acids such as malic acid or aspartic acid. They do not produce any visible nodules or outgrowth on root tissue. It is mainly recommended for maize, sugarcane, sorghum, rice, wheat, millets, and other cereals. Although there are many species recorded (e.g. *A. amazonense, A. halopraeferens, A. brasilense*, etc.), the benefits of inoculation have been proved mainly from *A. lipoferum and A. brasilense* (Roychowdhury, Paul and Banerjee, 2014).

Azotobacter

Falling under *Azotobacteriaceae* family, the Azotobacters are aerobic, free living, and heterotrophic in nature. The *Azotobacters* are present in neutral or alkaline soils. Reported species of *Azotobacter* are *A. vinelandii, A. beijerinckii, A. insignis* and *A. macrocytogenes*. Commonly occurring species is *A. chroococcum*. The bacterium produces anti fungal antibiotics, which inhibit the growth of several pathogenic fungi in the root region, thereby, preventing seedling mortality to a certain extent (Roychowdhury, Paul and Banerjee, 2014). This bacterium is reported useful for rice, maize, sugarcane, pearl millet, vegetables and plantation crops. The crop plants are given phosphorus, calcium, copper, zinc etc., which are otherwise inaccessible to them in the soil. They also act to control plant disease by suppressing *Aspergillus*, *Fusarium* fungi.

Blue Green Algae (Cyanobacteria) and Azolla

The cyanobacteria are quite diverse. They belong to 8 different families, and are phototrophic with the characteristics of producing auxin, indole acetic acid and gibberellic acid. They fix nitrogen in submerged rice fields. According to Roychowdhury, Paul and Banerjee (2014), cyanobacteria form symbiotic association with fungi, liverworts, ferns and vascular plants, but the most common symbiotic association has been found between a free floating aquatic fern, the *Azolla* and *Anabaena azollae* (a cyanobacterium). Commonly known cyanobacteria belong to the genera like *Anabaena, Aulosira, Nostoc, Calothrix, Tolypothrix, Scytonema, Westelliopais, Anabaenopsis, Cylindrospermum, Plectonema, Gloecocapsa*. *Azolla* as a biofertilizer decomposes quickly in the soil and avails its nitrogen to rice plants. Besides N fixation, these biofertilizers also contribute significant amounts of P, K, S, Zn, Fe, Mb and other micronutrients. The commonly occurring species of *Azolla* include *A. caroliniana, A. filliculoides, A. mexicana, A. nilotica, A. azollae, A. microphylla, A. pinnata, A. rubra.*

Mycorrhiza (Phosphate absorbers)

The term mycorrhiza denotes "fungus roots". It is a symbiotic association between host plants and certain group of fungi. Therefore, inoculations of mycorrhizae with phosphate solubilizing bacteria (PSB) and other useful microbial inoculants restore and maintain the effective microbial populations in the soil for solubilization of chemically fixed phosphorus and availability of other macro and micronutrients (Mishra *et al*., 2012). Commonly occurring mycorrhiza are: *Glomus fasciculatum, Glomus mosseae, Gigaspora nigra, Acaulospora scrobiculata, Sclerocystis clavispora,* and *Endogone increseta.* They contribute the soil by enhancing uptake of P, Zn, S and water, by promoting more uniform crops, by increases growth and yield, by enhancing resistance to root disease and helping drought stressed plant, by improving hardiness of transplant stock, and by reducing stunting on fumigated soil.

Zinc Solubilizers

Zinc can be solubilized by certain microorganisms viz., *Bacillus subtilis, Thiobacillus thioxidans* and *Saccharomyces* sp. Such microorganisms can be used as biofertilizers for solubilization of fixed micronutrients like zinc. *Bacillus* sp. can also be used in soils where native zinc is higher or in conjunction with insoluble cheaper zinc compounds like zinc oxide (ZnO), zinc carbonate ($ZnCO_3$) and zinc sulphide (ZnS) instead of costly zinc sulphate ($ZnSO_4$) (Mahdi *et al*., 2010).

Phos phate Solubilizing Bacteria (PSB) & Fungi

Some bacteria have ability to solubilize insoluble inorganic phosphate compounds, such as tricalcium phosphate, dicalcium phosphate, hydroxyapatite, and rock phosphate. These microorganisms possess the ability to bring insoluble soil phosphate into soluble forms by secreting several organic acids. Under favorable conditions they can solubilise 20-30% of insoluble phosphate and crop yield may increase by 10 to 20% (Khan, Zaidi and Ahmad, 2014). Examples of such microbes include the genera of *Pseudomonas, Bacillus, Rhizobium, Burkholderia, Achromobacter, Agrobacterium, Microccocus, Aereobacter, Aspergillus, Flavobacterium* and *Erwinia*. Species such as *Bacillus megaterium* var. phosphaticum, *B. circulans, B. subtilis, B. polymyxa*, *Pseudomonas striata, P. monteilii, P. liquifaciens* and *P. putida* are popular PSB. There are few fungi that also solubilize phosphates in the soil. Such examples include *Aspergillus awamori, A. fumigatus, A. flavus, Penicillium digitatum* and *P. lilacinum*. Normally PSB are present in soil and in plant rhizospheres. However, they should be added to the soil or seeds to increase the population to a requisite threshold level. Interestingly, majority of PSB are also considered to be plant growth promoting rhizobacteria (PGPR).

Plant Growth Promoting Rhizobacteria (PGPR)

Plant growth-promoting rhizobacteria (PGPR) are naturally-occurring soil bacteria able to benefit plants by improving their productivity and immunity. The plant growth-promoting rhizobacteria (mostly PSB) are associated with plant roots and augment plant productivity and immunity; however, recently it is proved that PGPR also elicit so called 'induced systemic tolerance' to salt and drought (Roychowdhury, Paul and Banerjee, 2014). The root colonizing bacteria (e.g. *Azospirillum*) and *Pseudomonas* sp. are known to produce growth hormones which often leads to increase root and shoot growth. Plants differ in the leaves and ration of the hormones required to maintain normal growth and development. Among them are strains from genera such as *Pseudomonas, Azospirillum, Burkholderia, Bacillus, Enterobacter, Rhizobium, Erwinia, Serratia, Alcaligenes, Arthrobacter, Acinetobacter* and *Flavobacterium*. Masunaka, Hyakumachi and Takenaka (2011) have reported that the solubilization of minerals in the soil is the main effect of a plant growth-promoting fungus (PGPF), *Trichoderma koningi*. Hyakumachi (1994) articulated that PGPF does not produce plant hormones and behaves like mycorrhizal fungi in the establishment of symbiotic associations. A lower production of an isoflavonoid (phytoalexin vesitol), a major defensive response of leguminous plants, was involved in their symbiotic associations (Hyakumachi, 1994).

ROLE OF BIOFERTILIZERS IN BIOLOGICAL SOILS

Mosttafiz, Rahman and Rahman (2012) exclaim that the broad application of microbes in sustainable agriculture is due to the genetic dependency of plants on the beneficial functions provided by symbiotic cohabitants (Noble and Ruaysoongnern, 2010). The agronomic potential of plant–microbial symbioses proceeds from the analysis of their ecological impacts, which have been best studied for N-fixing (Franche, Lindstrom and Elmerich, 2009). As Xiang *et al.* (2012) cite, the biofertilizers are substances which contains beneficial living microorganisms which, when applied to seed, plant surfaces, or soil, colonize the rhizosphere or the interior of the plant and promote growth by increasing the supply or availability of primary nutrients to the host plant (Weyens, 2009). In the soil or rhizosphere, biofertilizers generate plant nutrients like nitrogen and phosphorous through their activities or make them available to the plants (Rajendra, Singh and Sharma, 1998). These biofertilizers perform the following actions:

1) The biofertilizers fix atmospheric nitrogen in the soil and makes them available to the

plants. N-fixers reduce depletion of soil nutrients and provide sustainability to the farming system.

2) They solubilise the insoluble forms of phosphate like tricalcium, iron and aluminum phosphates into available forms.

3) They can add 20-200 kg N/ha (by fixation) under optimum conditions and solubilise/ mobilize 30-50 Kg P2O5/ha.

4) They produce hormones and anti metabolites which promote root growth. They also liberate growth-promoting substances and vitamins and help to maintain soil fertility.

5) They decompose organic matter and help in mineralization of soil.

6) When applied to the soils or seeds, the biofertilizers increase the availability of the nutrients and improves the yield by 10% to 50% without adversely affecting the soil and environment.

7) They suppress the incidence of pathogens and control diseases.

8) They improve soil physical properties, tilth, and soil health in general.

EARTH ALIVE SOIL ACTIVATOR® AS A NEW BREED OF BIOFERTILIZER

Earth Alive Soil Activator® is a patent-pending soil inoculant designed for organic and conventional agriculture.[6] Suitable for tropical and temperate geoclimatic conditions, Earth Alive Soil Activator® is a biofertilizer that contains three non-genetically modified bacterial strains, specifically *Bacillus subtilis*, *Bacillus amyloliquefaciens*, and *Pseudomonas monteilii* (also classified as *P. putida*). It has a forestry by-product as carrier. These ingredients were chosen for their individual abilities to enhance soil fertility in a number of ways. In the case of some functions, the effect of Soil Activator® results from the synergy of the ingredient blend rather than a specific strain (Neufeld and Yargeau, undated). When applied to soil, preferably at plant establishment, the beneficial microorganisms of Earth Alive Soil Activator® (strains of *Bacillus* and *Pseudomonas*) come to life, multiplying and colonizing the rhizosphere – the narrow region of soil around the roots of the plant.[7] The beneficial microbial population works in tandem with other active ingredients and improves plant nutrient uptake by converting the soil minerals into easily absorbable nutrients, thus promoting the plant's health and growth. The multiple modes of action offered by Earth Alive Soil Activator® produce more vigorous growth and higher yields, resulting in more sustainable agricultural practices and increased profitability for growers.[8] Experiments demonstrate that Earth Alive Soil Activator® performs equally effectively with and without simultaneous application of chemical fertilizers. Following observations were made:

- 36% yield increase when Soil Activator® is used as stand-alone product compared to untreated crops;
- 32% yield increase when Soil Activator® is used in combination with fertilizers, compared to standard fertilization;
- Soil Activator® improves water retention in the soil; and
- 25% to 66% reduction in chemical fertilizers is required to achieve similar yields.

The experiments on wheat and carrot were carried out by Canada-based independent laboratory, A&L Biologicals, by using different doses of Soil Activator® in order to gauge the cumulative agroecological performance of all three bacteria present in Soil Activator (Yargeau, Neufeld and Warren, 2017). The growth chamber experiment has demonstrated that wheat biomass increased significantly on 2kg/ha, 4 kg/ha, 6kg/ha, 8 kg/ha doses of Earth Alive Soil Activator®. Increased chlorophyll content was also observed to be significant over the same range of Soil Activator®, suggesting the enhanced capacity to generate energy, which eventually results in yield gain of wheat crop. A parallel test indicated that Soil Activator® contributing to increased water retention capacity of soil (Yargeau, Neufeld and Warren, 2017). In presence of Soil Activator®, the rate of drying in soils was slowed by up to 5% (Yargeau, Neufeld and Warren, 2017). Similarly, carrots that received Soil Activator® plus standard fertilization showed a yield increased by 63% versus the un-fertilized control, and by 32% versus the carrots treated with fertilizer only (Yargeau, Neufeld and Warren, 2017). Likewise, an analysis of tissue nutrients in wheat seedlings grown indoors using soil collected from conventional farm fields showed an increase in uptake for several nutrients, including nitrogen, sulfur, manganese, and iron (Neufeld and Yargeau, undated).

Agroecological Performance of PSB/PGPR *Pseudomonas monteilii*

This particular strain of *Pseudomonas monteilii* is very closely related to *Pseudomonas putida*. In registering Soil Activator® in Canada the Canadian Food Inspection Agency classified the strain as *P. monteilii*, while the Canadian Domestic Substances List classifies this strain as *P. putida*. For this reason, the references of both species are included in this section. The agroecological performance of *Pseudomonas monteilii* bacterium has been reviewed in this section. The results of the experiments mentioned in previous section demonstrate that level of phosphorus, nitrogen and various nutrients has increased remarkably following the application of the Soil Activator® containing *Pseudomonas monteilii*. Based on the characteristics of *Pseudomonas monteilii* or *Pseudomonas putida* the bacterium is considered both phosphate solubilizing bacterium (PSB) and plant growth promoting rhizobacterium (PGPR).

Nitrogen

The microorganisms with phosphate solubilizing potential increase the availability of soluble phosphate and enhance the plant growth by improving biological nitrogen fixation (Mohammadi, 2012). *Pseudomonas* spp. enhanced the number of nodules, dry weight of nodules, yield components, grain yield, nutrient availability and uptake in soybean crop (Son, Diep and Giang, 2006; Mohammadi, 2011). A study of nitrogen fixation by *P. putida* in soil growing sugar beets showed that the species was able to increase soil nitrogen through nitrogen fixation. Nitrogen uptake by sugar beet plants and the final beet yield had also increased (Shabayev, 2010). *P. putida* in combination of mycorrhiza increased leaf chlorophyll content in barley (Mehrvarz, Chaichi and Alikhani, 2008).

Phosphorus

Like several other bacteria, *P. monteilli* is capable of solubilizing insoluble inorganic phosphate compounds such as tricalcium phosphate [Ca3(PO4)2], dicalcium phosphate [CaHPO4], hydroxyapatite [Ca5(PO4)3(OH)] and rock phosphate (Goldstein, 1986). Rodriguez and Fraga (1999) articulate that physiology of phosphate solubilization has not been studied thoroughly. Unlike other genera of bacteria, *Pseudomonas* strains are reported not to require other mineral elements play a role in solubilization process, (Illmer and Schinner, 1992). Available scientific evidences suggest that *Pseudomonas, Bacillus* and *Rhizobium* are among the most powerful solubilizers, while tricalcium phosphate and hydroxyapatite to be more degradable substrates than rock phosphate (Illmer and Schinner, 1992; Arora and Gaur, 1979; Halder and Chakrabartty, 1993). An analysis of 443 different *Pseudomonas* strains, including *P. monteilii* and *P. putida*, found that 18% of the strains tested positive for phosphorus solubilization – 36 strains belonging to *P. monteilii* and 12 strains belonging to *P. putida* (Naik *et al.*, 2008). Premono, Moawad and Vlek (1996) concluded that *P. putida* was able to solubilize phosphorus, leading to an increase in growth of maize crop. Mohammadi (2012) too found that *Pseudomonas putida* was able to release 51% of the phosphorus contained in phosphate rock. *P. putida* was able to liberate upto 81% of the phosphate held in soil phytate (Richardson and Hadobas, 1997). The production of organic acids by phosphate solubilizing bacteria has been well documented. The production organic acids results in acidification of the microbial cell and its surroundings (Rodriguez and Fraga, 1999). Consequently, phosphorus may be released from a mineral phosphate by proton substitution for Ca^{++} (Goldstein, 1986). Phosphorus solubilization by *P. putida* was also confirmed by Ghaderi *et al.* (2008), who concluded that the production of H^+ is the main mechanism leading to the release of phosphorus from minerals.

Solubilization of organic phosphates consists of mineralization of organic phosphorus compounds that is carried out by means of phosphatase enzymes. The presence of phosphatase activity has been reported by various studies (Lynch, 1990; El-Sawah, Hauka and El-Rafy, 1993; Bishop, Chang and Lee, 1994; Feller, Frossard and Brossard, 1994; Kremer, 1994; Sarapatka and Kraskova, 1997; Kirchner, Wollum and King, 1993; Kucharski *et al.*, 1996; Garcia *et al.*, 1992; Xu and Johnson, 1995; Abd-Alla, 1994). Burns (1983) studied the activity of various phosphates in the rhizosphere of maize, barley and wheat. Bacterial strains that show acid phosphatases include the genera of *Pseudomonas* (Gügi *et al.*, 1981), *Bacillus* (Skrary and Camero, 1998), *Rhizobium* (Abd-Alla, 1994) and many others (Thaller *et al.*, 1995). Rodriguez and Fraga (1999) have recorded that several phosphatases (also called as phosphohydrolases) involve hydrolysis of phosphoester or phosphoanhydride bonds. The phosphohydrolases are clustered in acid or alkaline (Rodriguez and Fraga, 1999). The specific phosphohydrolases with different activities include 32 -nucleotidases and 52 -nucleotidases (Burns and Beacham, 1986), hexose phosphatases (Pradel and Boquet, 1988), and phytases (Cosgrove, Irving and Bromfield, 1970). Mohammadi (2012) documents that release of root exudates such as organic ligands can also alter the concentration of phosphorus in soil solution.

Other Elements

Many species of bacteria, including *P. putida*, have been shown to produce siderophores with varying affinities to iron (Vandenberg *et al.*, 1983). Jurkevitch, Chen and Hadar (1988) measured the ability of *P. putida* to produce siderophores that chelate unavailable iron (Fe_3^+) when plant-available iron (Fe_2^+) is limiting in the soil. This resulted in increased plant uptake of iron. Mohammadi (2012) articulate that solubilization of Fe and Al occurs via proton release by PSB by decreasing the negative charge of adsorbing surfaces. Root colonizing *Pseudomonas* have high affinity iron uptake system based on the release of Fe^{+++} chelating molecules i.e. siderophores.

Plant Growth Promotion

Field trials conducted on *Pseudomonas putida* have demonstrated the increase in root and shoot elongation in canola, lettuce and carrot (Hall *et al.*, 1996; Glick *et al.*, 1997), and in crop yields in potato, radish, rice, sugar beet, tomato, apple, citrus, beans, wheat and ornamental plants (Suslov, 1982; Lemanceau, 1992; Kloepper, 1994; Kloepper, Lifshitz and Schroth, 1988). *Pseudomonas* strains have been recorded with process of ACC deaminase synthesis in mung beans and wheat (Ahmad, Zahir and Khalid, 2013; Shaharoona, Naveed and Arshad, 2008). Induction of plant stress resistance was recorded in common and maize by *Pseudomonas putida* (Yao, Wu and Zheng, 2010; Egamberdiyeva, 2007). Similarly, the plant growth is promoted by *Pseudomonas* spp. in wheat when the bacteria produces the antibiotic (Mazzola, Fujimoto and Thomashow, 1995). Kumar, Bajpai and Dubey (2010) noticed the release of chitinase and β-glucanases in pigeon pea by *Pseudomonas* spp. Normally, *Pseudomonas* bacterium produces siderophore in many crops such as potato, maize, etc. (Beneduzi, Ambrosini and Passaglia, 2012).

CONCLUSIONS

Industrial agriculture has disturbed both soil biology and biochemistry. Excessive extraction of soil for maximization of crop production has been shown to deform or obstruct the web of microflora and microfauna in the soil. As a result, the crop yields have either declined or been stagnant despite high doses of mineral and synthetic fertilizers. Biofertilizers offer a solution for reversing the increasing infertility of the soil as well as the degrading soil biology. Various biofertilizers, such as *Rhizobium*, *Azospirillum*, *Azotobacter*, Blue Green Algae (Cyanobacteria) and Azolla, Mycorrhiza (Phosphate Absorbers), Plant Growth Promoting Rhizobacteria, Phosphate solubilizers, and Zinc solubilizers, are recorded benefiting numerous cereal, vegetable, sugarcane, bean, pulse, oilseed and fodder crops. Earth Alive Soil Activator® is a biofertilizer product that contains three bacterial strains that work in tandem to improve plant nutrient uptake by fixing nitrogen and converting soil minerals into plant-available forms. Independent research trials demonstrated that Earth Alive Soil Activator® improves plant vigor and yield, resulting in more sustainable agricultural practices and increased profitability for growers. The results of the experiments demonstrate that levels of various nutrients have been improved following the application of the *Pseudomonas monteilii*-containing Soil Activator®. A significant increase in chlorophyll content, soil moisture, and crop yield has also been reported. Applying this bacterium, for example with Soil Activator®, can offer an opportunity to increase the ecological functions of soil. As one of the constituent bacterium of Soil Activator®, the *Pseudomonas monteilii* or *putida* strain has been studied vigorously. The agroecological performance of this bacterium is assessed to be most acceptable among majority of PSB and PGPR strains. This particular strain is also reported effective in fixing atmospheric nitrogen in soybean, sugar beet, etc. Conclusively, it is recommended that Earth Alive Soil Activator® be popularized in tropical geoclimatic zones.

NOTES

2. *https://extension.illinois.edu/soil/sb_mesg/sb_mesg.htm*
3. Ibid.
4. Ibid.
5. *https://extension.illinois.edu/soil/sb_mesg/sb_mesg.htm*
6. *http://earthalivect.com/business-units/soil-activator/*
7. Ibid.
8. Ibid.

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