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Biofertilizers in Sustainable Farming

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Current world population is 8.1 billion, and is projected to reach 9.0 billion by 2037 [1]. A continued increase in population has led to a higher demand for food. Meeting up this demand, as demonstrated by the Green Revolution in the 1960s, has necessitated the use of chemical fertilizers. However, heavy utilization of chemical fertilizers, such as urea (NH_2-CO-NH_2) and muriate of potash (KCl) has considerable deleterious effects on soil (acidification from urea and chloride toxicity from KCl), plant, and the environment. It also brings about increased cost and reduced profitability. Thus, there is a need for efficient and sustainable methods to manage natural resources and enhance food production. That comes the role of biofertilizers, which contain a variety of living microorganisms (microbes) that can make nutrients more available to crops or even directly supply plant nutrients as in the case of nitrogen (N) fixers. Some common biofertilizers are:

1. Nitrogen fixing biofertilizers.

1.1. Symbiotic N fixers. Crops always need N, which is a component of protein, DNA, and enzymes. Thus, N regulates vital biological processes, including photosynthesis, growth, and development. However, most N on earth is present as N_2 gas in the atmosphere and is not directly available to crops. Fortunately, some soil bacteria called Rhizobia can convert atmospheric and inert nitrogen (N_2) to biologically useful ammonia (NH_3) that plants can use. These bacteria live in the roots of legumes, such as beans, peas, and clovers. In legumes and a few other plants, the bacteria live in small growths on the roots called nodules (Figure 1). Within these nodules, nitrogen fixation is done by the bacteria (using the nitrogenase enzyme), and the NH_3 produced is absorbed by the plant. In return, the plant provides food (photosynthates) to the microbes. Nitrogen fixation by legumes can be in the range of 25-75 lbs of N per acre per year [3]. This plant-microbe association is called symbiosis. Notable symbiotic bacteria belong to the genera of Rhizobium, Sinorhizobium, Bradyrhizobium, and Mesorhizobium, which

Figure 1. Nodules on soybean roots. Adapted from [2]

interact with leguminous plants while Frankia with non-leguminous trees and shrubs [4].

1.2. Free-living N fixers. These bacteria can fix N in the soil without being associated with a specific plant. They have been used with crops like wheat, corn, rice, and some vegetables [5]. The quantities of N contributed by these free living bacteria, however, are rather small, usually less than 10 lbs of N/acre/year [5]. Common free living bacteria belong to the genera Azotobacter, Pseudomonas, Cyanobacteria (Anabaena and Nostoc), Azospririllum, Burkholderia, Enterobacter, and Gluconacetobacter [6]. Cyanobacteria (Anabaena and Nostoc) as free living or in symbiosis with Azolla (a small free floating fresh water fern) were found to fix N and to release N for rice uptake in the range of 15-30 lbs/acre [6].

2. Phosphorus (P) solubilizing microbes.

Along with N, P is important to crop growth and production [7]. P involves in many physiological processes, such as energy transfer, signal translocation, photosynthesis and respiration [8]. Soil P is present in both inorganic and organic forms, but mostly as insoluble (precipitated) and/or immobilized (adsorbed) forms [7]. Some microbes can directly solubilize inorganic P or mineralize organic P by secreting protons (H^+) and various organic acids (for example, gluconic, oxalic, citric acids), which lower the pH in the rhizosphere, and dissolve phosphatic minerals and/or chelate cationic partners of the P ions directly, thus releasing P into solution for plant uptake [7,9].

Common P solubilizing bacteria belong to the genera Bacillus, Pseudomonas, and Staphylococcus; whereas Aspergillus, Fusarium, Trichoderma, Penicillium are fungi. Among the fungi, Vesicular Arbuscular mycorrhiza (Figure 2) are the major group that contribute P uptake by solubilization of solid inorganic P and hydrolyzation of organic P [7].

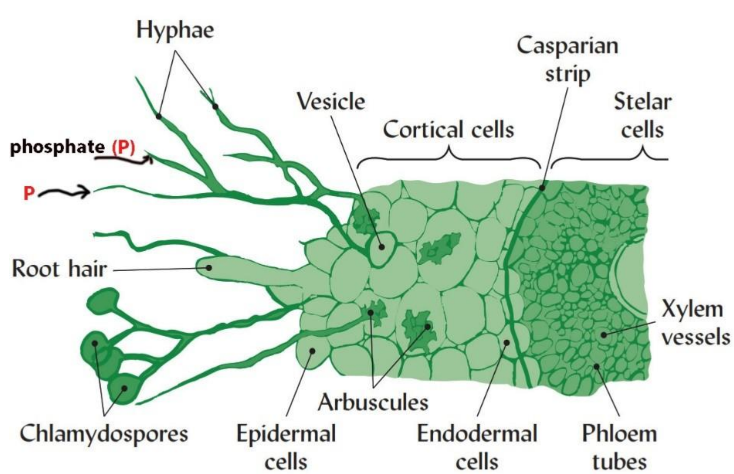

Figure 2. Vesicular Arbuscular mycorrhizal fungus on a root. Adapted from [7].

3. Potassium (K) solubilizing microbes.

Potassium is the third major nutrient that plants need. It is known to regulate water and nutrient transport, protein synthesis, among other biological functions [8]. A wide array of bacterial genera (e.g., Acidothiobacillus, Bacillus, Pseudomona; Table 1) can liberate K from minerals, such as mica, biotite, muscovite, and orthoclases [10], and can increase K availability up to 15% [11]. These microbes can release several small molecule, organic acids, such as citric, malic, oxalic acids (Table 1). Under a common pH range of 4 to 8 in most agricultural soils, these organic acids are present as their conjugated anions (citrate, malate, oxalate). These organic anions, in turn can dissolve K bearing minerals by chelating the structural Al and iron (Fe) of the minerals as shown below.

$KAlSi_3O_8$ (biotite) + citrate (3^-) + 8 H_2O ===? K^+ + (Al-citrate) + 3 $Si(OH)_4$ + 4 OH^-

Table 1. Common K solubilizing microorganisms and their organic acids produced.

Microbe species	Organic acids produced	References
Aspergillus terreus and	citric, oxalic	[6]
Bacillus megaterium	citric, oxalic, malic,	[12]
B. mucilaginosus	citric, oxalic, tartaric	[13]
Enterobacter	citric, oxalic	[14]
Pseudomonas	citric, oxalic, acetic	[15]

4. How are biofertilizers prepared and applied.

After selecting and cultivating the appropriate microbes that meet your crop's nutrient needs, the biofertilizers can be made by formulating/mixing the cultured microbes with a carrier. That carrier material can be powder, granule, liquid, or carrier-based inoculant. The carrier should provide a suitable environment for the microbes to survive and remain viable during storage and application. In some cases, fermentation may be employed to enhance the effectiveness of the biofertilizers. In other cases, biofertilizers can be mixed with compost or biochar before application.

Depending on the type of biofertilizers and the crop requirements, application methods can be:

4.1. Seed and seedling treatments. Seeds can be soaked in a liquid biofertilizer, or the biofertilizer can be applied directly to seeds before planting. Seedlings can also be dipped into a biofertilizer solution before transplanting. That would inoculate the young plants with beneficial microorganisms, promoting early and strong establishment and growth.

4.2. Root drench and soil application. Biofertilizers can be applied to the soil during or before planting. Alternatively, a biofertilizer solution can be drenched directly onto the plant roots, causing a close contact between the root system and the beneficial microbes for effective nutrient uptake.

4.3. Foliar spray and fertigation. With suitable formulations, biofertilizers can be sprayed directly onto plant leaves or mixed with water during irrigation.

5. Some commercial biofertilizers.

Several biofertilizers are currently available on the market, including: BioAct from Bayer, BioAG from Faust Bio-Agricultural Services, Inc., PrimAgo N from AgroLiquid, VaultIP PLUS from BASF, Utrisha N and Utrisha P from Corteva. The last two products are bacteria-containing biofertilizers that can fix N and solubilize P, respectively. According to Pivot Bio, which makes Proven 40, a biofertilizer labeled for corn, an application of 12.8 ounce (378 ml) of this product to an acre could replace up to 40 lbs/acre of N or 20% of an N budget in a corn field [2].

6. Conclusion.

In brief, biofertilizers that utilize beneficial microbes to provide nutrients, which normally would not be available to crops, can enhance soil fertility/health, and crop growth, save cost, and protect the environment. They work best as a complement to other nutrient sources, be it organic or chemical, in our complex systems of sustainable farming.

7. References

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