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Magic Mantle of Microbes in Vegetable Production

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Vegetable is an essential part of a person's diet because they provide the body with vitamins, proteins, essential micro- and macronutrients, and more.They are always in contact with different phytopathogens, such as bacteria, fungi, viruses, nematodes, and herbivores, as well as environmental stressors, such as temperature, drought, and salinity, which negatively affect their quality and yield. Vegetables growers use chemical fertilizers and pesticides indiscriminately to increase growth and production and to counteract various stressors.

Extensive use threatens the environment, humans, and other living things. Given the harmful effects of these chemical fertilizers and pesticides, it has become necessary to reduce their use and shift to biological crop improvement techniques. This will improve the quantity and quality of vegetable crops. Arbuscular mycorrhizal fungi, plant growth promoting bacteria, and various entomopathogenic nematodes are microorganisms that fight various stresses and provide an environmentally friendly and sustainable alternative. This increases productivity and improves the quality of vegetables.

According to the **Food and Agriculture Organization (FAO) 2024**, about 33% of the world's soils are already degraded due to intensive chemical use, deforestation, and poor agricultural practices. Soil microbial solutions offer a sustainable way to reverse this trend.

The incorporation of microorganisms into carrier materials enables easy handling, long term storage, and effectiveness of the biofertilizer. Carrier material such as saw dust, talcum dust, manure, earthworm cast can be used. There is lot of work done by many researchers to know the effects of biofertilizers and they have achieved many successful results. Keeping in mind the above key points, narrating the potential key role biological fertilizers could play if incorporated towards vegetable productivity and sustainable agriculture, Microbial biofertilizers could help in safeguarding the environment and prove as an eco-friendly and cost-effective input for the farmers.

Nitrogen fixing microbes comprises of symbiotic nitrogen fixing biofertilizers (including Rhizobium, Azolla etc.), free living nitrogen fixing biofertilizers [Azotobacter, Cyanobacteria (blue green algae) etc.] and associative symbiotic nitrogen fixing biofertilizers (Azospirillum). Along with these there are microbes which fix phosphorus or solubilize the phosphorus like Phosphorus Solubilizing Bacteria (PSB). Various studies done regarding the application of microbial fertilizers among vegetables and their beneficial effect towards yield and quality parameters

Symbiotic nitrogen fixing biofertilizers

Rhizobium

These are the widely recognized symbiotic nitrogen fixers that belong to the Rhizobiaceae family and typically consist of various genera, such as Mesorhizobium, Sinorhizobium, Allorhizobium, Azorhizobium, Bradyrhizobium, and Rhizobium. Rhizobium are motile, gram-negative, non-sporulating rod type which tend to symbiotically fix atmospheric nitrogen. Rhizobium helps reduce the molecular N_2 to NH_3 in the root nodules, which is then readily absorbed by the plant roots. The N-fixation is carried out by a complex enzyme nitogenase consisting of dinitrogenase reductase with iron as its cofactor and dintrogenase with molybdenum and iron as its cofactor.Rhizobium can fix 50-200 kg N ha^{-1} which helps to meet up to 80 to 90% nitrogen need of the crop as their natural presence in nodulating legume crops makes them less dependent on inorganic nitrogen.

Azolla

It is a symbiotic diazotroph which has the capacity to fix nitrogen in the atmosphere found in temperate and tropical environments. There is a symbiotic relationship between Azolla and Anabaena cynobacteria. Azolla helps to provide the anabaena with a carbon source and its

nitrogen requirement is met by cyanobacteria's atmospheric nitrogen fixation. The benefit of growing Azolla as a biofertilizer helps provide N and K requirements to the plant. Anabaena azollae is considered to be the most dominant biofertilizers and commonly used for the wetland rice in South-east Asia and estimated to fix around 40-60 Kg N/ha in rice crop.

Free living nitrogen fixing biofertilizers

Azotobacter

Azotobacters are free living nitrogen fixing bacteria which belongs to azotobacteriaceae family and mostly found in alkaline and neutral soils. It does not require any

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host and fixes the atmospheric nitrogen especially in non-leguminous plants without any symbiotic. Application of Azotobacteras bio-inoculants may increase 10-12% crop productivity leading to synthesis of ample amount of biologically active substance like nicotinic acid, biotin, het-eroauxins, vitamin B and gibberellins etc, which increase root growth and uptake of the min-erals. Azotobacter sp. has the ability to produce antifungal antibiotics and fungi static comp-ounds against pathogens like Fusarium sp., Alternaria sp., Trichodermasp etc.

Cyanobacteria

Cyanobacteria referred as "blue-green algae" or BGA, are free living, aquatic, small, zunicellular bacteria and possess photosynthetic property i.e. they can manufacture their own food. They are one of the largest bacterial species and the dominant nitrogen fixers among them are Calothrix, Nostoc, Anabaena and Aulosira. By building up soil fertility, they help to increase yield along with excretion of various substances that promote growth, e.g. amino acids, phytohormones, vitamins, soil salinity reduction, weed growth prevention, soil P content increase etc. When inoculated with cyanobacteria, vegetables such as chilli, spinach, radish, tomato have shown the beneficial effects.Nostoc and Anabaena are had been found to fix about 20–25 Kg of N/ha.

Associative symbiotic nitrogen fixing biofertilizers

Azospirillum

Azospirillum is a gram-negative motile bacteria belonging to order Rhodospirillales, with currently 17 species in use as biofertilizers, Azospirillum brasilense and Azospirillum lipoferum are most widely used species. It promotes plant growth enhancing IAA, gibberellins and cytokinins production and found to fix 20- 40kg/N/year when applied in non-leguminous plants. They can easily be isolated from the soil and from the aerial part of the plant. Azospirillum's key effects consist of modifications in root morphology that eventually stimulates plant growth. It was determined that by triggering cell wall modifications and osmotic adjustments, it can assist in plant survival under stressful conditions. The strains of Azospirillum are widely applied as biofertilizers in various vegetables.

Phosphorus Solubilizing Bacteria (PSB)

Phosphorus is a major nutrient that plays a crucial role in fostering crop growth and development. Its bioavailability is very poor and therefore not accessible to plants. It is available in two forms in the soil, i.e. organic and inorganic. Inorganic P is supplied in precipitated form by chemical fertilisers and plants cannot take up this form of Phosphorus. Phosphobacteria have the ability of converting the insoluble form of phosphorus to a soluble

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form and make it available to plant by releasing various organic acids (succinic acid, oxalic acid, glutamic acid, citric acid, malic acid and fumaric acid). Taking into account the exchange reaction, chelation and acidification these bacteria solubilize the insoluble phosphorus for plants. From soil, different species of Pseudomonas and Bacillus have been isolated which exhibit the P-solubilising attributes. PSB can applied in all vegetables through seed treatment, soil application or seedling dip. Plants with limited root systems would be the most benefitted by PSB application.

Vesicular Arbuscular Mycorrhiza (VAM)

VAM fungi are inter-cellular and obligatory endosymbiotics that have a beneficial relationship with plant roots since it extends and contaminates within the root zone. The root system transports nutrients to fungi and instead fungi tend to sustain plant roots with water and nutrients. Root length can expand through fungal hyphae and hyphae extend around 100 times in soils and enables plants to accumulate several nutrients. VAM fungi improve seedling tolerance to high temperature, drought and insect pest attack.

Factors imitating the use of biofertilizers

Lack of awareness among farmers. Biofertilizers are plant specific i.e. one biofertilizer which works on one crop does not helps in another crop. They have short shelf-life as compared to chemical fertilizer so the major problem is storage for long term. Unavailability of carrier material for specific biofertilizer. Biofertilizers requirement is more to fulfil the need of nutrient required by the plant.

Future prospects

It is essential to understand the value of biofertilizers and how they can be used in contemporary agriculture. Because biofertilizers increase soil productivity and fertility, more food will be produced to feed growing populations. Soil will gradually regain its fertility with biofertilizers, which will ensure its long-term health. Farmers will not have to pay more for chemical fertilizers if they use biofertilizers. They are environmentally friendly and reduce pollution। Biofertilizers are only the beginning, so more effort is needed to bring changes in contemporary agriculture. Microbial extraction, their colonization, production, marketing, application, and good farmer knowledge are all factors that require more and more use of biofertilizers in contemporary agriculture in order to reduce chemical fertilizer application in the field for high productivity. For more efficient technology to increase production without damaging the environment, more research on plant-microbial interaction is needed. Plants can benefit from biofertilizers like Azotobacter, Azospirillium, Phosphobacter, and Rhodobacter, among others, to survive and function under stress. When biofertilizers are used, they will not only help the agricultural ecosystem, but they will also lead to a more integrated and sustainable environment. Finally, in contemporary agriculture, the overuse of chemical pesticides and fertilizers is compromising the sustainability of our agricultural land.

Chemically produced food consumption causes dreadful diseases, making these chemicals dangerous for humans. These chemicals also have deadly effects on air, water, and soil, breaking down the ecological balance. To ensure food safety and environment protection, the use of biofertilizers is becoming a major challenge. Because of the harmful effects of chemical fertilizers, the focus is now on organic food production. Crop productivity is increasingly important with the use of beneficial microbes biofertilizers. These fertilizers can also help with the food shortage problem associated with the growing global population. India's soil fertility has diminished mainly due to soil erosion, water logging, and accumulation of toxic elements. Biofertilizers, which are naturally occurring and environmentally friendly, are useful in resolving these types of issues and making the soil more productive.

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