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Boosting Paddy Yields Naturally: The Role of Biofertilizers

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1. Introduction:

Rice (*Oryza sativa L.*) is Asia's staple food crop, cultivated extensively under diverse agro-ecological conditions. The intensive use of chemical fertilizers in paddy cultivation has led to nutrient imbalances, soil degradation, and declining input-use efficiency, raising serious concerns about long-term sustainability. Biofertilizers have emerged as an eco-friendly and cost-effective alternative to chemical fertilizers. Among the key biofertilizers used in rice cultivation are Azolla, Azospirillum, phosphate-solubilizing bacteria (PSB), and potassium-releasing bacteria (KRB). Azolla, an aquatic nitrogen-fixing fern, contributes significantly to biological nitrogen fixation when incorporated into rice fields. Azospirillum species are associative nitrogen-fixing bacteria that not only fix atmospheric nitrogen but also produce plant growth-promoting hormones, enhance root development, improve nutrient uptake, and help plants tolerate abiotic stresses such as drought and salinity. PSB mobilizes insoluble forms of phosphorus into plant-available forms, while KRB facilitates the release of potassium from mineral fractions of the soil. Collectively, these biofertilizers supplement major nutrients, improve soil microbial activity, reduce dependence on chemical fertilizers, and sustain higher productivity in rice-based systems.

2. Biofertilizers: Concept and Definition:

"Biofertilizers are preparations of living microorganisms which, when applied to seeds, soil, or plant surfaces, colonize the rhizosphere and promote plant growth by increasing the availability or supply of primary nutrients. In contrast to chemical fertilizers, biofertilizers enhance nutrient-use efficiency, improve soil health, and contribute to sustainable crop production. They naturally replenish or make available essential nutrients such as nitrogen, phosphorus, and potassium, making them particularly valuable in paddy cultivation as a sustainable and eco-friendly alternative to synthetic inputs."

3. Role of Key Biofertilizers in Paddy Cultivation:

Azolla:

Azolla is a free-floating aquatic fern that maintains a symbiotic association with the nitrogen-fixing cyanobacterium Anabaena azollae. This unique partnership allows Azolla to directly fix atmospheric nitrogen into forms readily available to rice plants, thereby significantly reducing the requirement for synthetic nitrogen fertilizers. When incorporated into paddy fields as a green manure, Azolla decomposes rapidly, releasing essential nutrients such as nitrogen, phosphorus, and organic matter, which enrich soil fertility and improve overall crop productivity.

Mechanisms of Action:

1. **Biological Nitrogen Fixation:** Anabaena azollae residing in Azolla leaf cavities converts atmospheric nitrogen (N_2) into ammonium (NH_4^+), which is accessible to rice plants. Nitrogen fixation by Azolla can contribute up to 40-60 kg N/ha per cropping season.

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2. Soil Fertility Enhancement: Decomposition of Azolla biomass adds organic matter, improves soil structure, and increases cation exchange capacity, facilitating better nutrient retention.
3. Microbial Activity Stimulation: Azolla incorporation promotes proliferation of beneficial soil microorganisms, which further aids nutrient cycling and soil health.
4. Weed Suppression: By forming a dense floating mat over water, Azolla reduces light penetration, inhibiting growth of aquatic weeds in rice fields.
5. Phosphorus Mobilization: Decomposing Azolla releases phosphorus in plant-available forms, enhancing nutrient uptake.

Benefits in Rice Cultivation:

- Provides significant quantities of biologically fixed nitrogen, reducing dependence on chemical fertilizers.
- Improves soil organic carbon and overall soil fertility.
- Enhances microbial diversity and activity in paddy soils.
- Suppresses weed growth, reducing labour and herbicide requirements.
- Acts as a cost-effective and eco-friendly component of integrated nutrient management (INM).
- Can be used both as a dual crop (grown alongside rice) or incorporated as green manure prior to transplanting.

Azospirillum:

Nitrogen is a critical nutrient for rice growth, affecting chlorophyll synthesis, protein formation, and vegetative development. While atmospheric nitrogen (N_2) constitutes about 78% of the air, rice plants cannot utilize it directly. Over-reliance on chemical fertilizers like urea increases input costs and can degrade soil and water quality. Azospirillum is a free-living, plant growth-promoting rhizobacterium (PGPR) that colonizes the rhizosphere and root surfaces of rice plants. Unlike symbiotic nitrogen fixers such as Rhizobium, it does not form nodules but associates closely with rice roots, partially supplying nitrogen and promoting growth in an eco-friendly manner

Mechanisms of Action in Paddy:

1. Biological Nitrogen Fixation

- Converts atmospheric nitrogen (N_2) into ammonium (NH4+), making it available to rice plants.

2. Phytohormone Production

- Produces indole-3-acetic acid (IAA), gibberellins, and cytokinins.
- Stimulates root initiation, branching, and root hair formation, improving water and nutrient uptake.

3. Enhanced Nutrient Uptake

- Increases absorption of nitrogen, phosphorus, and other essential nutrients through a well-developed root system.

4. Stress Tolerance

- Helps rice plants cope with drought, salinity, and nutrient-deficient soils.

Benefits of Azospirillum in Paddy:

- Improves nitrogen uptake by 20-30% in rice.
- Enhances root proliferation, improving water and nutrient absorption.

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- Field studies showed 10-30% yield increases in rice.
- Decreases urea requirement, lowering costs and environmental impact.

Phosphate-Solubilizing Bacteria (PSB):

Phosphorus (P) is the second most important macronutrient for plant growth after nitrogen, playing a vital role in root development, energy transfer (ATP), photosynthesis, and grain formation. Although soils often hold large reserves of phosphorus, nearly 70-90% of applied chemical phosphorus fertilizers become unavailable to plants due to fixation with calcium in alkaline soils, and with iron and aluminium in acidic soils. This results in low phosphorus-use efficiency and necessitates repeated fertilizer applications, increasing cultivation costs and environmental concerns. Phosphate-Solubilizing Bacteria (PSB) are a group of beneficial microorganisms that can convert insoluble forms of soil phosphorus into plant-available forms through various mechanisms. They produce organic acids (citric, oxalic, lactic, gluconic acid) and enzymes (phosphatases, phytases) that chelate cations and release soluble orthophosphates. By doing so, PSB act as natural biofertilizers, enhancing phosphorus availability, crop growth, and yield while reducing dependency on costly chemical fertilizers.

Mechanisms of Phosphate Solubilization

1. Organic Acid Production - Acidifies the soil microzone, releasing bound P.
2. Enzyme Secretion - Phosphatases and phytases hydrolyze organic P compounds.
3. Chelation of Cations - Prevents precipitation of P with Ca^{2+}, Fe^{3+}, or Al^{3+}.
4. Mineral Weathering - PSB can mobilize P from rock phosphate and mineral complexes.

Benefits of PSB in Paddy:

- Improve phosphorus availability and uptake.
- Enhance root growth and biomass accumulation.
- Reduce requirement of chemical P fertilizers by 25-50%.
- Improve soil microbial activity and nutrient cycling.
- Cost-effective and eco-friendly approach for sustainable agriculture.

Important Genera of PSB:

- Bacteria: Pseudomonas, Bacillus, Rhizobium, Enterobacter, Burkholderia.
- Fungi with P-solubilizing ability: Aspergillus, Penicillium.

Potassium-Releasing Bacteria (KRB):

Potassium (K) is the third essential macronutrient required by plants after nitrogen and phosphorus. It plays a key role in enzyme activation, protein synthesis, stomatal regulation, osmoregulation, photosynthesis, and translocation of assimilates. Despite being abundant in soils, nearly 90-98% of potassium exists in insoluble mineral forms such as feldspar, mica, and illite, which are unavailable to plants. As a result, farmers often depend on chemical fertilizers like muriate of potash (MOP) to meet crop K requirements, leading to higher costs and imbalanced nutrient use.Potassium-Releasing Bacteria (KRB) are a group of beneficial microorganisms capable of mobilizing non-exchangeable and mineral-bound potassium into soluble forms that plants can absorb. They act as biofertilizers by improving potassium availability in the rhizosphere, thereby enhancing crop yield and reducing dependence on chemical fertilizers.

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Mechanisms of Potassium Mobilization:

1. Organic Acid Production - Bacteria such as Bacillus and Pseudomonas secrete citric, oxalic, tartaric, and gluconic acids that dissolve silicate minerals.
2. Enzymatic Activity - Production of polysaccharides and enzymes helps in weathering of K-bearing minerals.
3. Chelation - In clay soils containing 2:1 type clays (like illite and vermiculite), potassium ions(K+) are subject to fixation, becoming trapped in the interlayers and unavailable to plants. This fixation is often promoted by the interaction of metal ions like aluminium (Al3+and iron (Fe3+) with the clay surfaces, where they can block cation exchange sites. Chelation, the process where organic ligands (such as humic substances or root exudates) form stable complexes with these Al3+ and Fe3+ ions, effectively removes the metals from the clay surfaces. By preventing Al3+andFe3+ ions from blocking the exchange sites, chelation indirectly inhibits K fixation, thereby keeping potassium in a more exchangeable and plant-available form.
4. Bio-weathering - Direct mineral dissolution through microbial colonization of mineral surfaces.

Benefits of KRB in Paddy:

- Enhance potassium availability and uptake efficiency.
- Improve plant vigour, disease resistance, and drought tolerance.
- Reduce dependency on chemical K fertilizers.
- Promote balanced nutrient cycling and soil fertility.
- Cost-effective and eco-friendly solution for sustainable farming.

Important Genera of Potassium-Releasing Bacteria

- Bacillus spp.
- Pseudomonas spp.
- Burkholderia spp.
- Paenibacillus spp.

Some fungi (Aspergillus, Cladosporium) also exhibit potassium-releasing ability.

6. Integration with Nutrient Management Practices:

Biofertilizers are most effective when integrated with organic manures, green manures, and judicious chemical fertilizer use. Integrated nutrient management (INM) strategies combining Azolla, Azospirillum, PSB, KRB, and farmyard manure improve nutrient use efficiency, sustain soil fertility, and enhance paddy yield in an eco-friendly manner.

7. Constraints in Biofertilizer Use:

- Limited awareness among farmers.
- Short shelf-life and improper storage conditions.
- Low colonization efficiency under adverse soil and climatic conditions.
- Inconsistent field performance due to microbial competition.

8. Future Prospects and Research Needs:

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- Development of multi-strain, stress-tolerant biofertilizer formulations.
- Studies on synergistic effects of biofertilizers under different rice ecologies.
- Integration with precision farming and smart nutrient management.
- Enhancement of farmer awareness and extension services for wider adoption.

9. Conclusion:

Biofertilizers such as Azolla, Azospirillum, PSB, and KRB offer an eco-friendly and cost-effective approach to sustaining paddy productivity. Their application not only reduces chemical fertilizer dependence but also improves soil health, nutrient availability, and crop resilience. Integrating biofertilizers into nutrient management practices is key to achieving sustainable and high-yielding rice cultivation.


Method Demonstration onSeedling Root Dipping in Paddy Using Biofertilizers by Krishi Vigyan Kendra, Nellore

Distribution of Biofertilizers to Farmers by Krishi Vigyan Kendra, Nellore


Method Demonstration on Soil Application of Biofertilizers in Paddy by Krishi Vigyan Kendra, Nellore