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Impacts of Nitrogen Fixation in Crops

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Abstract: Although it is abundant in the environment, nitrogen is often the nutrient that limits plant growth the most. Because many agricultural plants, like cereals, are unable to directly use freely accessible atmospheric nitrogen gas, their development and output frequently depend largely on the use of chemical fertilisers, which causes greenhouse gas emissions and the eutrophication of water. Legumes, on the other hand, use their symbiotic relationships with rhizobia to acquire nitrogen. Symbiotic biological nitrogen fixation, a mechanism that these bacteria use to transform nitrogen gas into physiologically usable ammonia in nodules, is crucial to the operation of ecosystems.

An enzymatic "Nitrogenase" transformation of atmospheric nitrogen (N2) into ammonium that is quickly absorbed by roots is the basis of the biological nitrogen fixation (BNF) process, which involves microbial intervention. In association with plant roots, N2-fixing microorganisms collectively referred to as "diazotrophs" may fix N2 organically. N composts are used to meet a substantial portion of the nitrogen (N) demand in cereal cropping systems, but manufacturing costs are rising and there are environmental issues as well. This has led to a growing interest in researching other N sources, such as organic N2 fixation. Biofertilizers are additives that primarily fix atmospheric nitrogen, solubilize phosphorus, and create compounds that encourage plant development.

Keywords:Biological Nitrogen Fixation, Cereal Plants, Self-Fertilizing Crops, Microbiome

Introduction:

In the realm of agriculture, the availability of essential nutrients plays a crucial role in determining crop yield and overall productivity. Among these nutrients, nitrogen holds a special place due to its role in protein synthesis and overall plant growth. However, most plants cannot directly access molecular nitrogen (N2), which is mostly present in the environment. This is when nitrogen fixation enters the picture. Crops may use atmospheric nitrogen through a natural biological process called nitrogen fixation, which increases agricultural sustainability and decreases dependency on artificial fertilisers. In this article, we will delve into the significance of nitrogen fixation, its mechanisms, and its implications for crop production.

Nitrogen fixation is the process by which atmospheric nitrogen (N2) is converted into ammonia (NH3) or nitrate (NO3-) by certain microorganisms, primarily bacteria. These bacteria, which are often referred to as nitrogen-fixing microorganisms, have the extraordinary capacity to dissolve the tight triple binding between the nitrogen atoms in atmospheric nitrogen and transform it into a more reactive form that plants can use. This conversion process is essential because most plants can only absorb nitrogen in the form of ammonium (NH4+) or nitrate (NO3-).

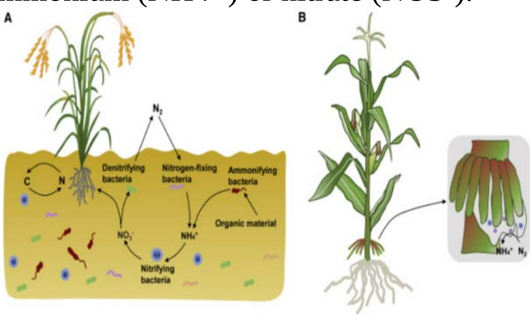

Fig. 1 Nitrogen-Cycling and Biological Nitrogen Fixation

There are two main types of nitrogen-fixing bacteria: free-living bacteria and symbiotic bacteria. Free-living bacteria, such as Azotobacter and Azospirillum, reside in the soil and fix nitrogen independently. They colonise the rhizosphere by forming connections with plant roots and giving the plants a direct supply of fixed nitrogen. On the other side, symbiotic bacteria form advantageous partnerships with particular plant species, most notably legumes. A type of bacteria called rhizobia develop nodules on the roots of legume plants including soybeans, peas, and clovers. Inside these nodules, the bacteria convert atmospheric nitrogen into ammonia, which is then utilized by the plant for its growth and development. In return, the plant provides the bacteria with carbohydrates and a suitable environment to thrive.

The benefits of nitrogen fixation in crops are numerous. Firstly, it reduces the reliance on synthetic nitrogen fertilizers. Producing synthetic fertilisers requires a lot of energy and can have negative environmental implications, such as greenhouse gas emissions and water contamination. Farmers may use less of these fertilisers by utilising nitrogen fixation, reducing the environmental effect. Additionally, nitrogen fixation improves soil fertility and structure. The bacteria associated with nitrogen fixation enhance soil health by increasing organic matter content, nutrient availability, and overall soil structure. This, in turn, improves the water-holding capacity of the soil and reduces the risk of erosion.

Table.1 Types of Fertilizers

Sr.No.	Types	Defination + Examples
1.	Organic fertilizer	Fertilizers derived from living or formerly living materials. e.g., animal wastes, plant wastes from agriculture, compost, and treated sewage sludge. Beyond manures, animal sources can include products from the slaughter of animals-blood meal and bone meal.
2.	Inorganic fertilizer	These include industrially synthesized fertilizers. e.g., $CO (NH_2)_2$ (Urea) 45-46% nitrogen, chile saltpetre with 15% nitrogen.
3.	Biofertilizer	Fuentes-Ramirez and Caballero-Mellado (2005) defined a biofertilizer as "a product that contains living microorganisms, which exert direct or indirect beneficial effect on plant growth and crop yield through different mechanisms". E.g., AM fungi, N-fixer, P solubilizer and K solubilizer

Increasing the connection of crops with N-fixing bacteria through the use of first-generation self-fertilizing cereal crops:

Cereal crops that make their own N nutrients or get them from their interaction partners are known as N-self-fertilizing plants. A significant portion of the total N required for cereal crops is provided by N-fixing organisms that are free-living in the rhizosphere or that are endophytic in plants. The growth and development of cereal crops, however, cannot be fully supported by the fixed N produced by associative bacteria. Thus, we suggest that the first generation of N-self-fertilizing crops be developed by enhancing associative relationships between N-fixing bacteria and cereal crops through the use of synthetic biology methods. Rhizopines, secondary small-molecular natural products, are secreted by a synthetic form of barley, as shown in Fig.2.

Furthermore, nitrogen fixation contributes to sustainable agriculture by promoting crop rotation and diversification. Leguminous plants can be used in crop rotations since they naturally fix nitrogen. These crops help future crops that require large nitrogen inputs when planted in rotation with other non-leguminous crops because they replenish the soil with fixed nitrogen. This practice reduces the need for external nitrogen inputs, promotes nutrient cycling, and helps break pest and disease cycles. In essence, nitrogen fixation supports a more balanced and resilient agricultural system.

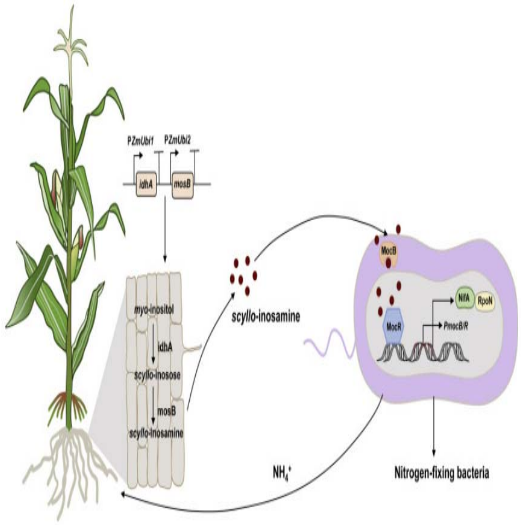

Fig. 2 Associative Nitrogen Fixation

However, there are challenges associated with nitrogen fixation in crops. First, for the nitrogen-fixing bacteria to function at their peak, the process needs a set of certain environmental parameters, such as the right temperature, pH balance, and moisture. Inadequate circumstances may restrict the fixation of nitrogen, requiring more nitrogen inputs. Second, various crop species and bacterial strains have varied rates of nitrogen fixatio. Scientists are actively researching ways to enhance the symbiotic relationship between crops and nitrogen-fixing bacteria to maximize nitrogen fixation potential.

The Nitrogen Fixation Process:

Nitrogenase, an oxygen labile catalyst complex that is remarkably conserved in free-living and beneficial diazotrophs, catalyses the enzymatic transformation of ammonia from sub-molecular nitrogen. The most well-known form of nitrogenase, sometimes referred to as Mo-nitrogenase or classic nitrogenase, has an iron-molybdenum-cobalt bunch (FeMoCo) prosthetic group containing molybdenum. Some microbes, like Azatobacter and a few photosynthetic nitrogen fixers (including some cyanobacteria), produce other forms of nitrogenases that have iron (Fe-nitrogenase) or vanadium (V-nitrogenase) as their only cofactor.

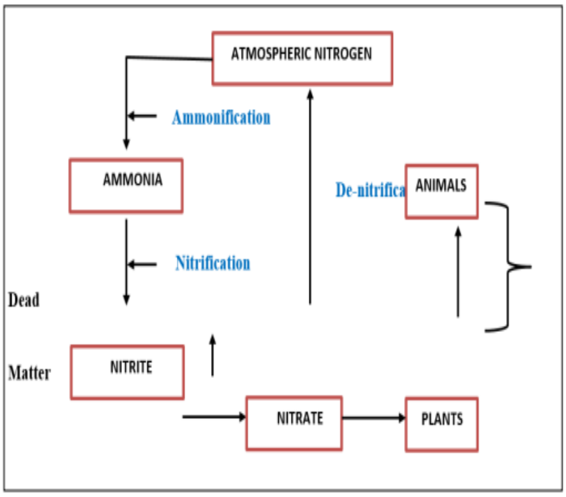

Fig. 3 Nitrogen Fixation Cycle

The Role of N Fixation in the N Cycle:

An essential component of the N cycle is the fixation of atmospheric dinitrogen into ammonia and subsequently into organic compounds (Figure 4). Around the world, BNF contributes 50–200 megatons of nitrogen (N) annually to terrestrial ecosystems, making roughly 80% of the total N fixed; the remaining 20% comes from other physical processes like lightning. Although it is generally accepted that the majority of terrestrial BNF contributions result from the legume-rhizobial symbiosis (both naturally occurring and cultivated), it is very difficult to assess BNF by legumes in the field. The only approach that is practicable in a natural forest or savannah is based on selective discrimination of the heavy stable isotope of N,15N, which is how most field methods for determining BNF operate.

However, the quantities vary widely from species to species and location to site. A few delta 15N investigations have been successful in measuring the amounts of N fixed by nodulated legumes in tropical forests despite the difficulties in employing this approach.

Conclusion& Research Needs:

Nitrogen fixation in crops plays a vital role in enhancing agricultural sustainability. By converting atmospheric nitrogen into a usable form, nitrogen-fixing bacteria contribute to improved soil fertility, reduced reliance on synthetic fertilizers, and increased crop productivity. Legumes in particular are excellent nitrogen-fixing crops that may be included into agricultural systems to encourage crop rotation, diversity, and resilience. Harnessing the potential of nitrogen fixation will surely continue to be an important element in our agricultural arsenal as we work towards more environmentally friendly and sustainable farming practises.

Through biological nitrogen fixation (BNF), the use of legumes in agricultural systems can improve sustainability. After the seeds and other crop parts are harvested, the non-dilated roots and crop leftovers are important sources of organic inputs for the replenishment of soil organic nitrogen (N). Whether planted as monocrops, intercrops, green manures, or tree crops, many agricultural systems in developing nations rely heavily on BNF associated with legumes as their supply of N for forage and grain crops.

It is commonly known that legumes may increase soil fertility. However, there is a propensity to believe that legumes are good for you already, so their effects have been overstated far too frequently and blindly. It is important to emphasise that the residual impacts of legumes are due to non-nitrogen effects as well, such as the disruption of pest and disease cycles and better physical and chemical soil characteristics. Additionally, a large portion of the apparent advantage of legumes in crop rotation could simply be attributable to the fact that legumes fix the bulk of the nitrogen lost at harvest rather than directly adding nitrogen to the soil.

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