Biofertilizer as a tool for soil fertility management in changing climate

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Abstract. Many biotic and abiotic factors affect agriculture production worldwide. Biofertilisers of microbial origin can be a good option for sustaining productivity with more environment-friendly and integrated nutrient management approach. They have been advanced to use the naturally occurring nutrient mobility mechanisms, which promotes soil fertility and results in improved crop production.

1. Introduction

Many biotic and abiotic factors affect agriculture production worldwide [1–15]. The worldwide exponential growth of human population has boosted the urbanization and industrialization, as a result of which environment is being mutilated [16]. The present contest is to provide sufficient food to this increasing population [17]. Although, the large amount of chemical fertilizers has enabled the countries to provide enough food for their residing population but it has damaged the environment which affects the living of various organisms [18]. Mineral nutrients are considered very important factor that limits plant biomass and productivity in many ecosystems [19–36] The use of chemical fertilizers results in polluted soil, water and air. Use of chemical fertilizers has impacted the soil by increasing salinity, diminished soil fertility, loss of water holding potential and inconsistency in soil nutrients [37]. In order to counter the use of chemical fertilizers, organic farming has emerged as an alternative to provide safe food with improved shelf-life and to minimize the hazards to the environment [38]. In organic farming the use of biofertilizers came into picture, which contains living microbes and when used for the plants, seeds, soil and populate the rhizosphere and encourage the plant growth by enhancing nutrient flow to the plant [39]. These are employed to speed-up the microbial processes which elevate the accessibility of nutrients which can be absorbed by the plants comfortably [40]. Bio-fertilisers of microbial origin can be a good option for sustaining productivity with more environment-friendly and integrated nutrient management approach [41]. They have been advanced to use the naturally occurring nutrient mobility mechanisms, which promotes soil fertility
and results in improved crop production [10]. These biofertilizers in the form of PGPR (Plant Growth Promoting Rhizobacteria) possess direct mechanism, which has the immense potential to promote nitrogen fixation, solubilisation of potassium and phosphate, plant nodule formation, and production of phytohormones and siderophores in plants. The indirect mechanism of PGPR encourages induced system resistance, production of exo-polysaccharide and hydrolytic enzymes and promotes heavy-metals bioremediation. The most important factor is to find suitable plant microbe interaction, which results in improved crop yield. With the help of molecular biotechnology, the most suitable plant-microbe interaction can be well understood. The use of bio fertilizers in agriculture is at initial stage and the advances in genomics, technology-mediated microbial research, genetic engineering and plant pathogen interactions will definitely enhance the current protocols implement to use bio fertilizers. The use of bio fertilizer in agriculture can be extended to carry out research on evolving microbial strains, which are temperature resistant and effective. The key factors behind the utilization of bio fertilizers for sustainable agriculture lies in determining bio fertilizer strains, their properties and ongoing mechanisms which leads to enhanced properties of agricultural crops [3].

2. Biofertilizer and soil fertility
The farming practices with the use of non-chemical substances enhance the soil biodiversity and confirms the safety of food [42]. Organic farming relies on the use of soil microflora, which consists of various PGPR’s. The implication of biofertilizer retains the soil’s micro and macronutrients with the help of solubilisation of phosphate or potassium, fixation of nitrogen, antibiotic production, the liberation of plant growth regulating substances and performing biodegradation of organic matter present in soil [43]. The implication of biofertilizers, allows the mycorrhizal hyphae to keep the soil masses together and thus consolidate the soil structure and decreases soil erosion [44]. On applying biofertilizers as soil inoculant or seed, they proliferate and contributes to nutrient cycling and enhances crop yield [45].

3. Nitrogen fixation

![Diagrammatic overview of nitrogen fixation](image)

**Figure 1**: Diagrammatic overview of nitrogen fixation shows that the key nitrogenase complex consists of Dinitrogenase and Dinitrogenase reductase. The electrons shared by Dinitrogenase reductase were being utilized by Dinitrogenase, which results in the conversion of $N_2$ to $NH_3$. Oxygen molecule was the inhibitor of this enzyme complex. The enzyme couples with oxygen and gets deactivated. Figure 1 modified from [17].
4. Solubilization of phosphates

The process in figure 2 presents an overview of phosphorous solubilization mechanism by rhizobacteria. The hydroxy and carboxyl group of organic acids (low molecular weight like gluconic and citric acid) leads to chelation of cations coupled to phosphate. The chelation results in change of insoluble phosphorus to soluble organic one. With the help of hydrolysis by various phosphatases, mineralization of soluble phosphorous takes place.

![Diagram of phosphorus solubilization](image)

Figure 2: General overview of phosphate solubilisation. Figure 2 modified from [17]. Now we will point out various biofertilizers, which were used to maintain the soil fertility.

| Impact on soil fertility | Biofertilizer name |
|-------------------------|-------------------|
| Nitrogen fixation       | Azocarbus, Azorhizobium, Burkholderia, Frankia |
| Phosphate solubilisation| R. leguminosarum, M. mediterraneum, B. japonicum, Bradyrhizobium sp. |
| Siderophore production  | Pseudomonas fluorescens, R. meliloti, Chryseobacterium |

5. Biofertilizer and environment

The growing population in India has put forward immense burden on agricultural lands and various other resources to produce sufficient food for the residing population [46]. The increased implication of chemical fertilizers in agriculture may lead to produce sufficient food for the country but on the other hand it declines the health of the environment and living organisms [47]. This increased use of chemical fertilizers on agriculture will result in poor soil quality and may lead to contaminated water resources [48]. The increased implication of soluble chemical fertilizers having phosphate and nitrate is among the principal contributors to water pollution [49]. To limit the use and negative impact of chemical fertilizers in agriculture, bio-fertilizers came into picture. With the help of actinorhizal plants and legumes, which have the potential of nitrogen fixation symbiotically, may limit the use of chemical nitrogen fertilizers. Implicating these practices, water and soil pollution arising from nitrates and associated contaminants by using chemical fertilizers, can be suppressed [50]. In 1990, a study concludes that vesicular-arbuscular endomycorrhizae, enhances fertilizer utilization coefficient by 2.7 to 5.6 times using rock phosphate as superphosphate in case of plants grown in phosphate-fixing, acidic soil. Vesicular-arbuscular fungi enhance phosphate fertilizer efficiency thereby decreasing their
input and using cost-effective, natural fertilizers [51]. Another study also suggests the role of this fungi in phosphate mobilization by plants using complex phosphates [52]. The above-mentioned work suggests ability of biofertilizers in minimizing fertilizers price and agriculture pollution. Considering the cost-effective and environment-competitive nature of biofertilizers, more research should be carried out to identify potential strains. Poor quality control and fickle supplies limit the use of this technology[46]. To attain sustainable agriculture, developing the biofertilizer which support growth of numerous-crops is the most crucial factor [40].

6. Biofertilizer and climate change
Climate change has led to alterations in temperature and rainfall patterns worldwide [53]. This alteration in rainfall pattern and temperature has a damaging impact on agriculture [54]. Elevation in liberation of greenhouse gases has resulted in temperature increase, droughts, floods, heatwaves and uncertainty of monsoons. The aforementioned biotic and abiotic pressures have intensive effect on the agricultural yield [55]. Conversion of habitable land into desert and soil erosion leads to deterioration and depletion of agricultural land. The reports of guesstimates suggest that abiotic factors such as salinity (10%), high temperature (20%), drought (9%), low temperature (7%) and other stress conditions (4%) lead to an average of 50% crop yield loss [56]. To overcome these unfavourable climatic conditions, it is necessary to implicate genetic engineering and plant breeding techniques to make crop cultivars which can bear the stress conditions. As these techniques are time consuming and expensive, the cost-effective and nature-friendly possibility is to implicate biofertilizers by inoculating microbes [57]. The microbes mostly used are free-living bacteria, fungi and arbuscular mycorrhizal fungi [58]. The studies have found that various microbial strain or species were able to make the plant bear abiotic stress conditions like drought, increased salinity and insufficiency of nutrients [59]. PGPR has immensely influenced the plant’s ability to bear biotic and abiotic stress conditions. PGPR reside concerning plant roots and impact their efficiency positively. PGPR significantly affect plant growth by various activities like by producing plant hormones (like cytokinin, auxin, gibberellin), enabling nutrient consumption from environment, by eliminating plant pathogens, mediating nitrogen fixation, phosphate solubilisation, iron sequestering and decreasing the concentration of plant ethylene[60,61]. “Induced Systematic Tolerance (IST)” was brought in knowledge to define action of PGPR in favour of plants. The IST triggers the chemical and physical alteration in plants which makes them bear abiotic stress conditions [55].

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