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Importance and mechanisms of PGPR for sustainable crop production- A review

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ABSTRACT

Soil microflora play a very important role in nutrient cycle and their uses in crop production may prove a sustainable plant nutrient supply system. Moreover, beneficial microflora collectively known as Plant growth promoting rhizobacteria (PGPR) provide growth promotion by interacting with plant roots, producing plant growth hormones, antagonizing the harmful microflora. Nitrogen biofixation, increased phosphorous availability, cellulytic capacity, bioherbicidal, bioinsecticidal and biofungicidal properties have been used in crop production. PGPR have the potential to contribute to sustain-able plant growth promotion. Use of bio fertilizers not only improves the soil health towards sustainability in crop production but also reduce the amount of chemical fertilizers thus cutting down the inherent cost of production and soil degradation rate. Combined use of chemical fertilizers and biofertilizers is most preferred soil fertility management technology to improve the deteriorating soil health as well as to sustain the crop production at higher levels.

I. INTRODUCTION

Since some last decades, use of high yielding varieties and hybrid varieties while applying imbalanced rates and sources of nutrients (i.e. high analysis chemical fertilizers) only focused on more and more food production, has been leading to depletion of soil nutrients below their critical levels. Use of chemical fertilizers alone for a long period of time leaves unfavorable effects on soil physical, chemical and biological property and environment which adversely affects the crop production in long term. Aggravating micronutrient deficiency (ranging from 3% for Cu to 48 % for Zn) is one of the examples of this. Integrated use of different sources of nutrients including chemical fertilizers, organic manures, green manures, biofertilizers and crop residues is a better approach for sustaining the crop productivity and maintaining the soil health. This paper is aimed to review the importance of biofertilizers in crop production, their mechanism and effect on crop performace.

Importance of biofertilizer application in crop production

To combat the N and P deficiency use of chemical fertilizers is obviously the best mean but this also leads to the increase in cost of production. Besides, nutrient use efficiency is also low due to unavoidable losses of N via leaching, volatilization etc. and fixation of phosphorous. Plant available nitrogen i.e. nitrate-N is more susceptible to leaching in coarse-textured soils (Chaudhary and Katoch 1981). Loss of nitrogen leads to less proportion of applied N taken up by the crop i.e. lower N use efficiency. Generally 50% of the N applied is not taken up by the crop plants (Tilmanet al 2002; Dobermann and Cassman 2004). In case of P, a considerable amount is rapidly transformed into less available forms by forming a complex with Al or Fe in acid soils or with Ca in calcareous soils (Goldstein 1986)

Under these conditions, the utilization of symbiotic or non-symbiotic nitrogen fixing bacteria in fixing atmospheric nitrogen biologically in rhizospheric soil for use of plants and replacement of depleted soil nitrogen reserves is an appropriate approach. Francheet al (2009) estimated the contribution of nitrogen biofixation in supplying soil nitrogen as 44–200 kg ha^{-1} annually. Similarly, the process of mineralization/solubilization or immobilization affected by rhizosphere microbes, especially phosphate-solubilizing microorganisms (PSM), serves as an alternative to chemical phosphatic fertilizers and provides the available forms of P to plants.

Moreover, loss of biodiversity and soil organic matter (SOM) depletion are most important among all types of soil deterioration resulted from the recent development in agriculture during last few decades. Overall results of deterioration of soil health are loss of soil resilience capacity, essential functions of the ecosystem and agricultural

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production sustainability (Sanchez et al 1997) along with quality deterioration of products and gradual decline in the rate of responses to external inputs even with the best possible management practices. Doran and Parkin (1994) first time included soil biological properties in soil health indicators. Soil biodiversity helps to improve other soil health parameters viz. microbial biomass C and N, microbe mediated processes like decomposition, fixation, remediation and suppression of pathogen. Today's monoculture based intensively managed mechanized cropping systems result into decrease in belowground biodiversity. Good management of soils helps to flourish diverse range of microorganisms which perform various activities like synthesis of antibiotics, phytohormones, siderophores and growth regulators etc., affecting the crop productivity directly or indirectly. Smiley (1981) reported that the chemical fertilizers and other agrochemicals have inhibitory effect on bacterial growth thereby reduce the population of beneficial microorganisms. Strzeleowa (1970) recorded that Throton's agar medium containing 2.5 mg ml^{-1} urea led to abnormality in cell morphology of Rhizobium meliloti. Becking (1995) reported that generation time is increased and protein synthesis is disrupted in Acetobacterdiazotrophicusdue toexcessive nitrogenous fertilization. Population of G. diazotrophicus in rhizosphere was higher in a low fertilized soil than that in highly N-fertilized soil (Muthukumarasamyet al 2002).

Mechanism of action of different bioinoculants

According to Antoun and Prevost (2005), functional activities of biofertilizers can be classified into four main groups which include (a) an increased availability of nutrients to plants or biofertilizers (through biofixation or increased solubility/mobility of nutrients), (b) enhanced plant growth through phyto-based hormones or phytostimulators, (c) an abated rate in organic pollutants or rhizoremediators, and (d) the controlled capacity of disease through production of antifungal and/or antibacterial metabolites or pesticides.

Mechanism of increased P availability

P availability to plants is increased through mineralization and solubilization of organic and inorganic P. Khan et al (2009) analyzed many studies on phosphate solubilization and observed that organic acid production and extrusion of protons are main mechanisms for phosphate solubilization via microbial processes. Among the bacterial genera with this capacity are Pseudomonas, Bacillus, Rhizobium, Burkholderia, Achromobacter, Agrobacterium, Microccocus, Aereobacter, FlavobacteriumandErwinia (Rodriguez and Fraga 1999). Proton extrusion from root cell acidifies rhizosphere zone and it is the main mechanism proposed which enhances the minerals mobility (Bashan 1991; Marschneret al1986). The changes in root morphology and increase in root area due to inoculation with growth promoting bacteria increase the mineral element absorption by the plants. Soil pH is decreased due to the production of organic acids by both the plants and bacteria and causes more access to mineral elements such as P, Ca, Fe, and Mn (Ahemad and Kibret 2014). Low molecular weight organic acids like gluconic and keto gluconic acids produced by PSB are mainly responsible for solubilization of Ca-P (Goldstein1995). Increase in the root system extension, increased root numbers, thickness (fresh and dry weight), and root length are mainly attributed to increase in mineral absorption by plants (Biswas et al 2000).

Principle mechanism for mineralization of soil organic P is the production of acid phosphatases. Some PGPR such as Bacillus (Idrisset al2002), Pseudomonas and Rhizobium (Rodriguez and Fraga 1999) secrete phosphatase group of enzymes which hydrolyze phosphate ester bonds and anhydrides in the organic phosphorous (mostly present in the form of inositol phosphate) by converting it into inorganic or low-molecular weight organic acids.

N_2-biofixation

The most studied and longest exploited PGPR are the N_2-fixing bacteria (diazotrophs). For non-legume crops like cereals and oilseeds including rapeseed-mustard free living N_2 –fixing bacteria such as Azotobacter sp. and associative N_2-fixing bacteria such as Azospirillum sp. are used as biofertilzer.

Since Azotobacter species (Azotobacterchroococcum and Azotobactervinelandii) are heterotrophic, free living diazotrophs, need adequate supply of sugars and other reduced C compounds for the energy (Kennedy and Tchan 1992). Azotobacterutilizes carbon for its metabolism to improve plant growth and to increase soil nitrogen through nitrogen fixation (Monibet al 1979).

Diazotrophic bacteria fix atmospheric nitrogen by means of the enzyme nitrogenase, a two component metalloenzyme composed of (a) dinitrogenase reductase, a dimer of two identical subunits that contains the sites for MgATP binding and hydrolysis, and supplies the reducing power to the dinitrogenase, and (b) the dinitrogenase component that contains a metal cofactor (Dean and Jacobson 1992). The genes responsible for nitrogenase biosynthesis are nif genes having two factors NifA and NifL (approximately 20–24 kb). Oxidative phosphorylation is the major pathway of ATP generation so strains having more oxidative phosphorylation will fix more amount of N_2 as compared to those having storage of energy as glycogen since N fixation requires a large amount of ATP (16 ATP molecules to fix 2 moles of Ammonia) (Marroquiet al 2001; Kennedy and Tshan 1992).

Koval'skayaet al (2001) treated rape seeds with auxin like growth-promoting substance which caused some modification in root morphology i.e. formation of thickened lateral roots which they called paranodules. Inoculated Azotobacter cells were capable of colonize these paranodules and were detected both in the intercellular space and inside the cells of the paranodules of the rape roots. The nitrogen-fixing activity of the paranodulated plants was two times higher than that of the inoculated plants lacking paranodules and five times higher than that of the control (i.e., not inoculated) plants. The paranodulation led to a 40% increase in the crop yield of rape plants and provided for a statistically significant increase in the total nitrogen as well as protein nitrogen contents of the plants.

Mechanisms other than N_2-biofixation and Phosphorous solubilization

Plant growth promoting rhizobacteria (PGPR) exert direct or indirect positive influence on plant growth in various ways. Production of growth hormones, solubilization of insoluble phosphates or other mechanisms that improve plant nutrient uptake are included in direct effect; whereas indirect effects are generally are the metabolites production such as siderophores, antibiotics or HCN that decrease the growth of phytopathogens and other deleterious microorganisms (Andrews & Harris 2003).

Khan (2005) reviewed many studies and observed that inoculation with many PGPR such as Pseudomonasand Acinetobacter strains had resulted in enhanced uptake of Fe, Zn, Mg, Ca, K, and P by crop plants. Poonguzhaliet al(2008) reported that seed bacterization with PSB strains isolated and cultured from rhizosphere of Chinese cabbage, caused an increase in root elongation and biomass. They attributed the plant growth promotion by PSB to the production of phytohormones or mechanisms such as production of 1-aminocyclopropane-1-carboxylate (ACC) deaminase, indole-3-acetic acid and siderophores instead of solubilization of phosphate.

Azotobacter isolates have been reported to produce Gibberellins by several researchers (Althaf and Srinivas 2013; Mrkovac and Milic 2001). Brown &Burlingham (1968) found that treatment of tomato seeds and seedling roots with small quantity (0.5-0-01 pg.) of commercial gibberellins (GA3)**,** the plants response was the same as treated with 14-day cultures of Azotobacterchroococcumstrain A 6**.**

Azotobacter also producecytokinins, auxins, and GA-like substances, and these growth materials are the primary substance controlling the enhanced growth of tomato (Waniet al 2013). These hormonal substances, which originate from the rhizosphere or root surface, affect the growth of the closely associated higher plants. Eklund (1970) demonstrated correlated the increased germination and growth of seedlings with presence of Azotobacterchroococcum in the rhizosphere of tomato and cucumber.

II. CONCLUSION

Plant growth promotion by biofertilizers is through flourishing of the corresponding microflora in soil after their application. Increased N availability is through free living, associative and symbiotic N- fixation. Increased P availability is through increased phosphorous mineralization by bacteria and fungi. Other than that, secretion of plant growth hormones, cellulytic and proteolytic enzymes and suppression of plant pathogens by different microorganisms can also be exploited through application of related microbes.

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