The Role of Microbes to Improve Crop Productivity and Soil Health

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Abstract: *Soil microbes are the most important candidature for enhancing soil fertility and health. The plant growth promoting microbes and arbuscular mycor-rhizae (AM) are used for enhancing plant growth and yields of agricultural crops under normal and stress conditions. It improves plant growth on various physio-logical parameters of plant in response to external stimuli by a number of different mechanisms. The mechanisms involved in growth promotion include plant growth regulators, production of different metabolites, and conversion of atmospheric nitrogen into ammonia, etc., by direct and indirect ways. In addition, it also pro-vides resistance against biotic components (pathogens) through induced systemic resistance (ISR) and systemic acquired resistance (SAR). Plant microbe's interac-tion contributing in plant growth promotion and disease control under changing environment and enabling more sustainable agriculture without compromising ecosystem functioning. Plant growth regulators maintain beneficial plant–microbe interactions such as interaction between plant growth promoting rhizobacteria (PGPR) and arbuscular fungi. The microbial diversity in rhizospheric soil maintains soil health and productivity. Thus, the inclusive use of plant growth promoting rhizobacteria helps to get sustainable agriculture production under normal as well stress condition. This review highlights an overview of the beneficial effect of microbes for enhancing sustainable agricultural production.*
Keywords : Soil microbes Rhizobacteria Sustainability Soil health Mycorrhizae

1. Introduction

Due to continuous increase in global human population, urbanization and industrialization have reduced the arable agricultural land. These changes have been severely affected by the demand of food and supply ratio, whereas continuous increasing world population needs a substantial increase in agriculture produce to fulfill the present demand (Tilman et al. 2011).[1] However, the conventional agri-culture is facing reduction in production and increased in cost of input. In addition, loss of agriculture productivity due to natural and anthropogenic activity leads that land degradation and reduced crop yield. Land use pattern shift varies frequently due to modernization and urbanization, hence reduces arable land. Farmers are also leaving this practice because of low-cost benefits and introduction of different variety of seed and technology. The higher cost of agriculture input affects farmers' interest and takes them away from agriculture. Both of these factors severely affect the agriculture practices and produce since agriculture provides major share in our country income and grass domestic production (GDP). Above fifty percent Indian population depends on agriculture. Further, intensive use of chemical fertilizers and pesticides for higher crop production is also detrimental for soil and food quality (Kang et

[1] Tilman D, Balzer C, Hill J , Befort BL (2011) Global food demand and the sustainable intensification of agriculture. PNAS 108(50):20260–20264

al. 2016).[2] In spite of anthropogenic causes, climate change is another cause for crop productivity. Plants are exposed to various abiotic and biotic changes. As world's human population continues to increase, the demand for agriculture supply will be a challenging for agrarian country, including India. In order to fulfill the demand of population, farmers use inorganic chemical and pesticides to enhance yield. The successful implementation of green revolution in India has been result food security and plays a significant role in Indian economy. The chemical fertilizers have played a significant place in increasing agriculture productivity. However, these chemicals and pesticides have detrimental impact on soil fertility (Singh 2015).[3] The major challenge in agriculture science is to develop a technique which increases crop yield sustainably. In recent years, due to the major negative consequences of inorganic fertilizers and pesticides, many researchers are focusing their attention on finding solution for reducing these effects. And this is where concept of "ecological wisdom" comes to guide us to look for alternative to improve crop production and soil health. Using an ever-increasing information base and understanding human "needs" and interactions between humans and nature, some planners, managers, and scientists have developed guidance for managing social–ecological systems using the concept of ecological wisdom (Patten 2016).[4] Ecological wisdom can guide adaptive management, which then is applied to restoration or management of soil ecosystem. In ecologically meaningful engi-neering, projects are developed in harmony with the existing ecosystems for overall environmental benefit (Achal et al. 2016).[5] Similarly, microbial-based fertilizers can be developed for the benefits of soils while maintaining sustainability.

Application of beneficial microbes may be a potential alternative to harmful chemical fertilizers and pesticides. Microbes stand an important role in improving crop productivity and soil management. Plant-associated soil microbes play a crucial role in plant growth and development such as nutrient cycling and crop productivity (Yan et al. 2015)[6]. Soil microbial dynamics determine the potentiality of soil crop productivity. While the interaction of plant and microbes is major factor for controlling ecosystem functioning, these plant–microbes interactions vary greatly and depend upon availability of nutrient and. Plant growth promoting microbes mostly used for plant growth promotion through various means such as plant growth regulation and nitrogen fixation (Ahmad et al. 2008)[7]. In addition, it has also been reported that PGP microbes induce plant growth under stress con-dition such as drought and salinity. These microbes induce plant growth through

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[6] Yan N, Marschner P, Cao W, Zuo C, Qin W (2015) Influence of salinity and water content on soil microorganisms. Int Soil Water Conserv Res 3(4):316–323

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regulating cell division, enlargement, and differentiation. However, complex interactions at different level in plant involve such as genetics, physiological, ecological, and morphological events (Islam et al. 2014)[8]. These interactions vary and depend upon plant and microbes. Nowadays to make agriculture more sus-tainable and efficient, an alternative method is needed to introduce in agriculture system. To feed the increasing world population novel and potential approach should need to boot agriculture productivity sustainably. Food security is one of the serious challenges due to indiscriminate increase of human population worldwide. In spite, the advanced technology in agriculture practice and use of fertilizers and pesticides causes degradation of soil fertility. In addition, the pathogens cause detrimental impact on crop productivity. Therefore, now a biological control major is needed to advance our agriculture system to overcome or minimize above con-sequences. It is both sustainable and cost-effective approach for future. Improvement in agriculture is done through the application of Plant growth pro-moting bacteria which is sustainable and beneficial for soil health and farmers.

2. Beneficial Effects of Rhizobacteria

Sustainable agriculture is essential today's world to fulfill the agriculture need and future food security. Since our tradition agriculture method is unable to do so because of various concerns. We have an urgent need to develop sustainable and effective mechanism to do same. Sustainable agriculture has potential to meet our agriculture need that our convention methods were unable to do so. This types of agriculture practice use special farming technique wherein environmental resource fully utilized without compromising it. Biological methods, a component of special forming may be an important alternative to replenish gap created by traditional method. This type of agriculture is beneficial, and they use natural resources without harming future generation. Diversity of dense population of microbes including bacteria, fungi, and Actinomycetes colonizes the root of plants. These microorganisms are group of naturally occurring beneficial microbe applied as inoculant to enhance plant growth and development (Ahmad et al. 2008)[9]. These groups of microbes have several properties which attract modern scientist and policy makers. In addition, these microbial communities improve soil quality, soil health and crop quality. Organic matters, in form of root exudate, attract numerous microbes and habitat for variety of microbes. Rhizobacteria in response to root exudates by chemotactic mechanism and competent rhizobacteria reside the rhizospheric zone of plant root. Some microbes reside in close vicinity with plants and communicate through different method (Singh et al. 2011)[10]. The communication occurs at molecular level through particular signaling molecule. Depending on compatibility of plant and microbes, it may for root nodules which provide favorable condition for microbes to fix atmospheric molecular nitrogen (Masciarelli et al.

[8] Islam F, Yasmeen T, Ali Q, Ali S, Arif MS, Hussain S, Rizvi H (2014) Influence of Pseudomonas aeruginosa as PGPR on oxidative stress tolerance in wheat under Zn stress. Ecotoxicol Environ Saf 104:285–293

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2014)[11]. However, microbial community consists of selected groups of microbes which have plant growth promoting attributes. These microbes may reside in rhizosphere and promote plant growth. Soil microorganism also contributes to a wide range of application in sustainability of all ecosystems. These microbes reg-ulate nutrient cycling, regulation of dynamic of soil organic matter, and enhance efficiency of nutrient acquisition. The symbionts of microbes enhance the efficiency of nutrient acquisition of nutrient and water by plants. Decomposition, mineral-ization, and nutrient flow are also regulated by these microbial associations.

3. Soil Health and Crop Productivity

Earth crust is an important biological component for microbial activity. It is a natural habitat for diversity of microbes, and it is estimated that one gram of soil contains up to ten billion bacterial cells. Decline in soil fertility is major concern for food security. Soil microbes contribute to a wide range of function in controlling soil health and crop productivity (Sahoo et al. 2015)[12]. It managed soil fertility through the modification of soil properties either directly or indirectly. Plant–mi-crobe interaction is one of the important aspects for agriculture system. This association may help to achieve goal of future sustainable agriculture. Soil held variety of microbial species such as bacteria, fungi, mosses, and liverwort. Bacteria fungi and Actinomycetes are three groups of microbes that form major soil biomass of microbes. Among these, rhizospheric bacteria are to establish relationship with plants and promote nutrient uptake, water supply, and ameliorate various types of abiotic and biotic stresses. The presence of microbes is indicator of soil biological activities and regulates physical and chemical properties of soil. Microorganism is fundamental component of soil for all nutrient cycles and plant nutrient. Variation in temperature, low water content, anthropogenic, and grazing causes detrimental impact on microbial diversity and soil process. Soil–root–microbes form a com-paratively stable and beneficial association. Some microbes have negative impact also in rhizosphere zone and harmful for plant growth and development (Ahmad et al. 2008)[13]. Due to intensive cropping and unhealthy effect of fertilizers, this relation declines soil microbial diversity.

4. Microbial Mechanism of Plant Growth Promotion

Microbes can we use in different way for plant growth promotion required plant growth promoting rhizobacteria (PGPR). Two major ways to promote plant growth are direct and indirect mechanism. The indirect mechanism includes reduction of some of the negative impact of pathogens by different mechanism. For example, siderophore reduces availability of iron for pathogens and reduces their growth. In addition, it may increase resistance through mechanism called induced systemic resistance and provide protection

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against pathogens. Direct mechanism is providing by availability of different beneficial compound synthesized by microbes. Similarly, they facilitate host plant growth by solubilizing minerals, availability of nutrient, production of phytohormones and secreting siderophore (Złoch et al. 2016)[14]. Plant growth promoting microbes that enhance plant growth process includes (Table 1):

(1) increase availability of nutrient, (2) production of plant growth regulator (Auxin, Cytokine, and Gibberellins), (3) metabolites such as hydrogen cyanide (HCN), 1-amino cyclopropane-1-carboxylate (ACC) deaminase, siderophore, and antibi-otics, (5) induction of systemic resistance (Duan et al. 2013[15]; Contesto et al. 2010)[16]. For example, Pseudomonas aeruginosa LES4 strain of Tomato rhizosphere has plant growth promoting properties such as production of siderophore, hydrogen cyanide, indole acetic acid production, and phosphate solubilization (Kumar et al. 2009)[17]. Despite these properties, plant growth promoting microbes also enhance plant growth through production of ACC deaminase enzyme, exopolysaccharides, and antibiotic. ACC deaminase enzyme produced by microbes converts ethylene it into ammonia and a-ketobutyrate and protects host plant from deleterious effect of ethylene (Glick 2014[18]; Rashid et al. 2012; Bal et al. 2013)[19]. Exopolysaccharides protect host plant through biofilm formation and reduce uptake of unwanted elements.

Table 1 Plant growth promoting substances released by some microbes and their role in plant growth and development

Plant growth promoting microbes	Sources/Plant	Plant growth regulation	References
Burkholderia gladioli and Penicillium aculeatum	Oil Palm	Convert insoluble form of phosphorus to an available form of peat soil	Istina et al.
Erwinia species and P. chlorogaphis	Coffea arabica L.	Efficient uptake of insoluble phosphate from soil	Muleta et al.
Pseudomonas aeruginosa FP6	Chili	Siderophore Produced by biocontrol stain for Rhizoctonia solani and Colletotrichum gloeosporioides	Sasirekha and Srividya

[14] Sasirekha B, Srividya S (2016) Siderophore production by Pseudomonas aeruginosa FP6, a biocontrol strain for Rhizoctonia solani and Colletotrichum gloeosporioides causing diseases in chilli. Agric Nat Resour 50(4):250–256

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[19] Bal HB, Nayak L, Das S, Adhya TK (2013) Isolation of ACC deaminase producing PGPR from rice rhizosphere and evaluating their plant growth promoting activity under salt stress. Plant Soil 366(1–2):93–105

Bacillus amyloliquefaciens 5113 and Azospirillum brasilense NO 40	Wheat	Promote plant growth under drought condition, increase enzyme activity in wheat plant	Kasim et al.
Bacillus mucilaginosus, Bacillus edaphicus, and Bacillus circulans	Panax	Solubilizes the insoluble potassium (K) to soluble forms of K for plant growth through acidolysis, chelation, exchange reactions, complexolysis and production of organic acid	Meena et. al
Bacillus amyloliquefaciens HK34	Panax	Induction of systemic resistance against Phytophthora cactorum	Lee et al
Bacillus licheniformis K11	Pepper	Higher Expression of stress genes, HSPs, and CaPR-10	Lim and Kim, Alizadeh et al.
Trichoderma hurzianum Tr6 and Pseudomonas sp. Ps14	Cucumber and Arabidopsis thaliana	Induced systemic resistance	
Bacillus thuringiensis AZP2	Wheat	Decrease volatile emissions and increase	Timmusk et al.
B. thuringiensis	Lavandula dentate	Higher content of potassium, proline and decrease the ascorbate and glutathiodne reductase due to IAA	Armada et al.
Bacillus thuringiensis GDB-1	Lavandula dentate	Enhanced phytoremediation of heavy metal (Pb, Zn, As, Cd. etc)	Armada et al.
P. fluorescens CHA0 and Pf1	Lavandula dentate	Enhane nutrient content and increase growth and yield	Babu et al.
Mesorhizobium spp.	Chickpea	Increase nodulation, Enhance and uptake of nutrient yield.	Verma et al.
Pseudomonas putida H-2-3	Soybean	Improve plant growth under saline and drought condition. Increase leaf length and chlorophyll content	Kang et. al.

Serratia nematodiphila PEJ1011	Capsicum annum L.	Plant growth enhancement and biocontrol management to control plant disease.	Praveen Kumar et al.
Bacillus and Pseudomonas spp.	Capsicum annum L.	Plant Growth enhancement and biocontrol management to control plant disease.	Praveen Kumar et al.

4.1. Direct Mechanism

4.1.1 Nitrogen Fixation

Nitrogen (N) is most essential for plant growth and development and constitutes 78 of atmosphere. Although it exists in molecular form and not directly available to plants use, it is available to plant through biological nitrogen fixation to in ammonia. The process of nitrogen fixation carried out by oxygen sensitive, nitrogenase enzyme complex. Nitrogenase enzymes convert atmospheric nitrogen into ammonia using ATP as energy source. Biological nitrogen fixation is an important growth parameter which affects plant growth and yield. Different microbial species from various genera have ability of nitrogen fixation such as Bacillus, Azospirillum, Pseudomonas, Enterobacter, Flavobacterium, Erwinia, and Rhizobium (Silva et al. 2016)[20]. Nitrogen-fixing microbes are categorized into (1) symbiotic nitrogen fixating bacteria and (2) non-symbiotic nitrogen-fixing bacteria. The symbiotic nitrogen-fixing microbes include members of rhizobia which form symbiotic association with leguminous plants. The non-symbiotic bacteria include Azospirillum, Azotobacter, Gluconacetobacter diazotrophicus, and cyanobacteria. Most of atmospheric nitro-gen is fixed by symbiotic association while non-symbiotic contributes only little. Some of these microbes for root nodule with their respective host plant root product play a significant role in communication between plant and microbes (Yan et al. 2008)[21]. Various stress conditions such as drought and salinity inhibit nodulation, hence nitrogen fixation. Microbes are more tolerant then host plant for drought and salinity. Nitrogenase enzymes responsible for nitrogen fixation are highly sensitive to salinity and its activity highly reduced under stress condition. The microorganism residing soil environment can cause a dramatic change in plant growth and pro-duction through various regulators. However, various free-living considers as plant growth promoting properties. Biological nitrogen fixation is environmentally sound and economically viable alternative of chemical fertilizers.

4.1.2 Phosphate Solubilization

Phosphorus is essential micronutrient and most vital element for plant growth and development. Plants acquire phosphorus in the form of phosphate ions from soil. Plant

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growth promoting rhizobacteria (PGPR) having phosphate solubilization ability, available phosphorus to plant through mineralization, and solubilization. Phosphorus solubilizing microbes govern biogeochemical cycle in natural agri-culture system. It is responsible for normal functioning of living organism. However, most of phosphorus present in soil in insoluble form and unavailable to plant. It plays a major role in sugar transport and stimulates root development and physiological process of plants and animals. The bioavailability of phosphate to plant depends on plants, microbes, and surrounding environment. The association of plant microbes could enhance the mobilization of phosphorus in soil and available to plants (Mehta et al. 2013)[22]. The phosphate solubilizing rhizobacteria are ubiquitous in nature and their numbers vary from soil to soil. Phosphate solubilizing microbes (PSM) such as bacteria and fungi mobilizes it by producing organic acid and phosphatase. Many genera of bacteria and fungi are described as phosphate solubilizing microbes (Yadav et al. 2014)[23]. The phosphate solubilizing bacteria are belonging to PGPR and have wide implication in plant growth and development (Naseem and Bano 2014)[24]. The solubilization of phosphate may result due to either decrease in P^H or cations chelation. The effects of phosphate solubilizing microbes vary according to soil properties. Majority of plant associated with rhizobacteria under phosphorus deficient condition improve phosphorus uptake from soil. Phosphate solubilizing microbes (PSM) as biofertilizer enhancing plant growth and provide phosphorus in sustainable way to plants (Meena et al. 2015[25]; Naseem and Bano 2014)[26].The principle mechanism involved in this includes lowering $p^{H,}$ pro-duction of organic acids acid phosphatase. The release of organic acids from PSB decreases the surrounding pH and release of phosphate ions from H^+. Oxalic acid, succinic acid, malic acid, etc., are important acid produced by plants. These organic acids compete with binding sites on soil and available phosphorus to plants. 2-ketogluconic acid is the most potent phosphate solubilizing acid produced by phosphate solubilizing microbes. A numbers of microbes have capacity to solubi-lize phosphate (Istina et al. 2015)[27]. Therefore, use of phosphate solubilizing microbes in agriculture system is may be cost-effective and sustainable approach.

4.1.3 Siderophore Production

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Iron (Fe) is a principle nutrient for almost all life form crucial for respiration, photosynthesis, nitrogen fixation, and DNA biosynthesis. Iron generally inacces-sible to plants because of very low solubility Fe^{3+}, and it forms hydroxides and oxyhydroxides. Almost all living organism require iron for physiological and enzymatic activity. Bacteria obtain iron secretion of iron chelating compound siderophore which available to microbes (Schalk et al. 2011)[28]. Siderophore is water soluble and has high oscillation constant for complexing with iron. Siderophore can be divided into two group extracellular and intracellular siderophore. Most of iron acquisition by plants occurs through microbial siderophore. The production of siderophore by microbes depends on immediate surrounding environment, and microbes may modulate the environment. Siderophore has higher affinity for iron (Mishra et al. 2011)[29]. Siderophore easily binds with iron and transport inside bac-terial cell. The transport of iron begins through the binding of siderophore–iron complex on material membrane. The transport of iron from through bacterial membrane involves different transporter. Once inside, the iron–siderophore com-plex reduced, ligand exchange to convert iron ($Fe^{3+)}$ complex on bacterial mem-brane reduced into soluble Fe^{2+} species (Rajkumar et al. 2010)[30]. ABC transporter (ATP-binding cassette) is involved in transport of siderophore–iron complex (Braun and Hantke, 2011)[31] Plant incorporates iron from the bacterial siderophore through different means either through direct uptake of iron–siderophore or ligand change reaction. The major effect of siderophore–iron includes chlorophyll a and chloro-phyll b content of plant leaves. Pseudochelin A, a new siderophore of Pseudoalteromonas piscicida S2040, shows siderophore activity against Aspergillus fumigatus.

4.1.4 Phytohormones Production

Abiotic stresses cause change in balance of phytohormones in plants which result growth inhibition. This change in hormones concentration also leads to suscepti-bility to disease occurrences. A major auxin, indole acetic acid (IAA), controls various physiological aspects such as plant development, cell signaling, and induction of disease resistance (Sukumar et al. 2013)[32]. Indole acetic acid acts as signaling molecule and affects expression of gene under different conditions (Egamberdieva et al. 2015[33], Cassán et al. 2014[34]; Li et al. 2016). The IAA production varies and depends on microbes and

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environmental conditions. The growth of plants depends on concentration gradient of IAA. This results in inhibition, stim-ulation, and tissue differentiation. The low level of IAA induces root elongation while higher level of causes laterals and adventitious root formation (Ghosh et al. 2013[35]; Tognetti et al. 2012)[36]. Phytohormones associated root colonizing rhizobacteria effectively colonized and supply additional IAA for plant growth and development (Sukumar et al. 2013)[37]. Ethylene is another ubiquitous phytohormones and plays a crucial role in biotic and abiotic stress tolerance. It causes cell elongation, root initiation and nodulation, leaf senescence, and fruit ripening. Under stress condi-tion, ethylene causes inhibition of root elongation and root hair formation. To overcome this, negative impact bacterial ACC deaminase hydrolyzes it into a-ketobutyrate and ammonia. It may be a source of nitrogen for microbes. In addition, physiological process and stress tolerance especially drought are regulated by another plant hormones abscisic acid. PGPR enhances the concentration of abscisic acid during drought stress and makes plant to tolerant stress (Meena et al. 2015[38]; Porcel et al. 2014;)[39]. From the above discussion, it is clear that the presence of phytohormones affects the endogenous mechanism of plants and stimulates plant growth. The major effects of these phytohormones include stimulation of lateral root and root hair formations which facilitate nutrient acquisition as well as water absorption (Belimov et al. 2014)[40].

4.2 Indirect Mechanism of Plant Growth Promotion

The indirect effect of plant growth promoting bacteria occurs when they either decrease or inhibit deleterious consequence of pathogen through various mecha-nisms. The application of microorganism to control disease in plants is known as biocontrol (Kumar et al. 2014). It is an environmentally sustainable and cost-effective approach to ameliorate deleterious effect of pathogens. Various types of antifungal and antimicrobial agent secreted by rhizobacteria help in disease resistance. The major indirect includes competition for nutrient, antifungal metabolites, induced systemic resistance(ISR) and niche exclusion. Rhizobacteria have been reported to secrete many metabolites such as 2,4-diacetylphloroglucinol, HCN, phenazines, pyrrolnitrin are important biocontroling agents.

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5. Biotic Stress

Plants have been evolved various sophisticated (physical and chemical) method to defense against pathogens. Chemical mechanism involved various chemical inter-actions at different steps. However, some plants lake have weak response to pathogen due to certain reasons. However, PGPR colonizes root surface and has been showing significant beneficial effect to plants (Salas-Marina et al. 2011)[41]. These PGPR activates plant defense response against pathogen and reduces crop losses. Plant growth promoting rhizobacteria possess various mechanism of defense against biotic stress. The mechanism defense against pathogen is trigger through chemical messengers. The induction of resistance against pathogen is generally of two kinds: systemic acquired resistance (SAR) and induced systemic resistance (ISR) (Fig. 1). SAR is induced by pathogenic bacteria and ISR by reducing disease rate (Nawrocka and Małolepsza 2013[42]; Choudhary and Johri 2009)[43]. Both SAR and ISR adopted different signaling mechanism to induced resistance. SAR involves accumulation of salicylic acid and pathogen-related (PR) protein while ISR consists of ethylene and jasmonic acid (Dimkpa et al. 2009)[44]. The synergistic effect of pathogen-related (PR) protein and oxidative enzyme causes high protection against pathogens. Salicylic acid is an essential component for development of systemic which acquires resistance. Non-pathogenic bacteria induced systemic resistance in plants and phenotypically similar to systemic acquired resistance (Wani et al. 2016)[45]. These colonizing bacteria cause an increase in concentration of Chitinase and peroxidase plants leaves and root.

The effectiveness of SAR and ISR is wide spectrum and includes bacterial, fungal, viral pathogens. The protection of plant to different pathogens includes inhibition of pathogen growth through competition for nutrient and reduction in disease symptoms (Ghazalibiglar et al. 2016)[46]. It is a highly beneficial, cost-effective, and sustainable approach to protect plant from pathogens. Once this system of defense activated increase the activity of enzyme such as peroxidase, catalase, superoxide dismutase and guaiacol, etc. These enzymes protect cells from oxidative damage due to reactive oxygen species and pathogen. In addition, several potential components of bacteria also induced ISR membrane lipopolysaccharides and iron-regulated siderophore. This defense mechanism provides resistance to pathogen above-ground part of plants. ISR induced various changes in plant parts including (1) change in epidermal and cortical cell wall (2) level of enzyme

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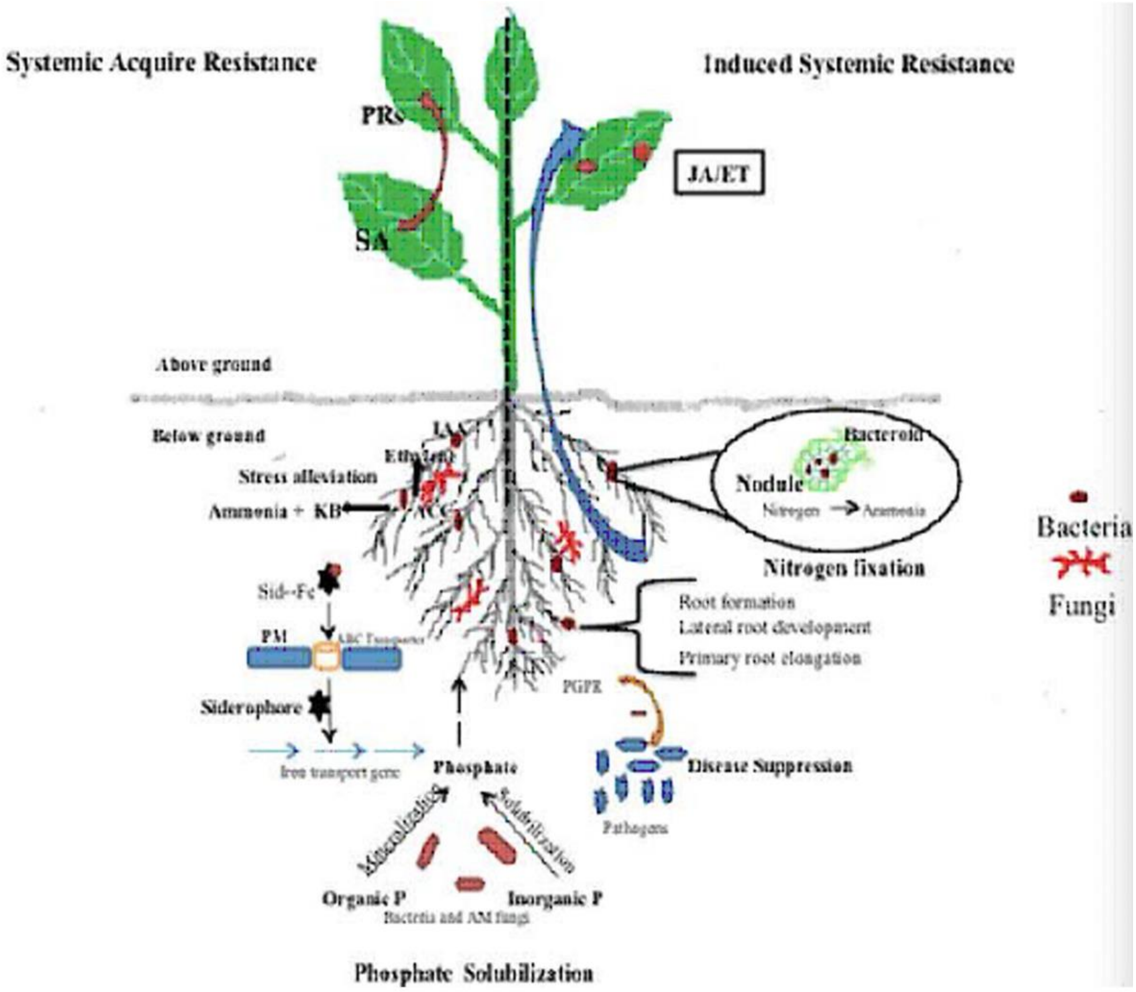
peroxidase, chitinase and phenylalanine ammonia lyase, and (3) expression of stress-related gene (Choudhary and Johri). The effect of ISR and SAR varies from plant to plant and depends on level of plant and microbes interaction. The combined effect of ISR and SAR enhances the defense level of protection against specific pathogens. Chithrashree et al. (2011) reported that PGPR mediate-induced systemic resistance in rice against bacterial leaf blight caused by Xanthomonas oryzae pv. oryzae. PGPR causes suppression of disease in plants by various mechanisms such as competition for space and nutrient, antagonism and induced systemic resistance (Beneduzi et al. 2012)[47]. Pseudomonas and Bacillus are acted as biocontroling agent and well known for their antagonistic and induced systemic properties. Bacteriocins, siderophore, and antibiotics are potential molecule and have antago-nistic properties. Application of PGPR to seed and seedling also results induced systemic resistance (ISR). So plant growth promoting rhizobacteria play an important role in defense against various disease-causing agents (Choudhary and johri 2009)[48]. It is a sustainable approach to overcome disease-causing agents in economic and sustainable way.



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6. Plant Growth Stress Condition

Global climate change is a major concern for agriculture productivity worldwide. Climate change will cause detrimental impact on agriculture system. Stress causes direct or indirect negative impacts on plants. For example, drought stresses con-dition increasing ethylene production, inhibit photosynthesis and damage photo-synthesis apparatus and decrease chlorophyll content. Similarly, salinity increases ion concentration especially ions which cause injurious effect on plant growth and development. In addition, the general impact of bacteria causes hormonal and nutritional imbalance and changes in physiology of plants. Many microbial genera have been reported that has ability to survive under stress condition and improve crop productivity. Soil is a complex and dynamic system which provide habitat for microbes. In soil, the growth of microbes depends on soil environmental and their impact on plants. Under environmental stress condition such as drought, salinity heavy metal, and heat stress, etc, PGPM is effective in alleviating these negative stresses. These microbes use number of mechanisms to alleviate negative impact. The application of PGPR reduced level of ethylene overcomes the ion toxicity which caused due to salinity.

7. PGPR and Sustainable Agriculture

A fundamental shift will need to shift our conventional agriculture in toward sus-tainable agriculture. Plant growth promoting (PGP) microbes regarded as alterna-tive to replace conventional agriculture practice. Plant growth promoting rhizobacteria Plant growth promoting rhizobacteria (PGPR) were first defined by Kloepper and Schroth (1978) for bacteria that colonize roots of plant after inocu-lation and enhance plant growth and development. PGPR includes wide range of microbes, including nitrogen fixation (Peix et al. 2015)[49] and phosphate solubilizing bacteria useful soil microbiota important for plant growth and development. These microbes form association with microbes such as nodule formation. These microbes enhance plant growth and development through different activity, for example, enhance availability of soil nutrients, production of plant growth regulator, con-trolling plant growth properties, and maintain soil health. The effect of biofertilizer on growing crop in different climate region varies from neutral, positive, and negative depending upon plant microbes' interaction. The successful colonization microbes facilitate plant growth by providing major and minor nutrient to plant. This association also involves biological nitrogen fixation, phosphate solubilization, and potassium, which help in plant growth and development. Plants required phytohormones for root morphogenesis and shoot development, such as phyto-hormones are indole acetic acid (IAA), gibberellin, and cytokine. These hormones play an accountable role in different stage of plant during growth and development. For example, IAA affects the root development, tissues differentiation in plants. IAA-induced root growth and enhanced root hair formation help in water and nutrient absorption due to increase surface area. This

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result profound growth and high yield of crop. Gibberellins are an important plant growth regulator which affects seed germination, stem elongation and development, flowering and fruit setting of plants. It also control ethylene level during stress condition by 1-aminocyclopropane-1-carboxylate (ACC) deaminase synthesized by PGPR and reduce the ethylene production (Saleem et al. 2007[50]; Glick 2014)[51].

8. Mycorrhizae

Mycorrhizae are mutual association between root of higher plant and fungi. Arbuscular mycorrhizae (AM) are most common fungi present in agriculture field. About 80 percent of higher plant form association with fungi. It plays in crucial role in nutrient cycling in agriculture field. Mycorrhizae are also important for improving physical properties of soil and maintain nutrient availability to plants and help in aggregation of soil (Garg and Pandey 2016[52]; Miransari 2011[53]; Chen et al. 2013)[54]. Mycorrhizae produce various metabolites under stress condition such as amino acid, vitamins, phytohormones and mineralization. The association with PGPR and mycorrhizae fungi supposed to cause effect on rhizospheric microbes, soil types, nutrient, moisture content, and temperature. The cumulative effects of this association also include assistance in plant growth and development in normal as well as under stress condition (Calvo-Polanco et al. 2016[55]; Kohler et al. 2010)[56]. In addition, some study reported the mycorrhizal fungi also affect physiology process of plant through osmoregulator under stress condition. This process includes osmoregulation, such as increase proline, efficiency of water use and carbon dioxide exchange. It also enhances sugar and electrolyte concentration under drought condition. The function of mycorrhizae varies on types of stress. For example, nitrogen availability under droughts and variation in Na^+ and K^+ uptake under salinity stress (Hashem et al. 2016)[57].

9. Conclusion

An ideal agriculture system maintains and improved soil health, benefit producer and consumer, protect human health and environment. In addition, produce enough food to feed world population and food security. Sustainable agriculture approach may fulfill these aspirations of farmers at low cost. Due to high cost of chemical fertilizers and

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pesticides, farmers are severely affected and compel to leave these practices. Application of biological approach decreases dependency on pest and fertilizers. This method is sustainable, cost-effective, and increase crop yield.

The application of microbial consortium reduced depletion of soil organic material and environment pollution. So plant growth promoting rhizobacteria offers an environmentally sustainable and cost-effective technology for increasing crop production. A number of studies have reported the effectiveness of PGM rhi-zobacteria under normal as well as in stress condition. In spite of the better per-formance achieved through dual inoculation of PGP rhizobacteria and mycorrhizae. PGP rhizobacteria and mycorrhizae show different response under different envi-ronmental condition. Such properties enable them to be applying as a potential alternative to traditional agriculture practices.