

**Role of Plant Growth Promoting Bacteria in  
Improving the Quality of Marginal Soil for Multiple  
Purposes**

Project submitted

**For the award of  
Master of Science**

In

**Life Sciences (Microbial Sciences)**

By

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**May, 2018**

## **Declaration**

I declare that the project entitled “Role of Plant Growth Promoting Bacteria in Improving the Quality of Marginal Soil for Multiple Purposes”, has been prepared by me under the guidance of Dr. Ramakrishna Wusirika, Professor and HOD, Department of Biochemistry and Microbial Sciences, Central University of Punjab. No part of project has formed the basis for the award of any degree or fellowship previously.

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## **CERTIFICATE**

I certify that Ritu Kumari has prepared her project entitled “Role of Plant Growth Promoting Bacteria in Improving the Quality of Marginal Soil for Multiple Purposes”, for the award of M.Sc Life Sciences with specialization in Microbial Sciences degree of Central University of Punjab, under my guidance. She carried out this work at the Department of Biochemistry and Microbial Sciences, school of Basic and Applied Sciences, Central University of Punjab.

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## ABSTRACT

### “Role of Plant Growth Promoting Bacteria in Improving the Quality of Marginal Soil for Multiple Purposes”

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**Key Words:** Marginal land, phytoremediation, PGPB, Biofuel, Sustainable food production.

Degrading quality of soil by the presence of xenobiotics or change in the natural environment of soil is of great concern. One of them is heavy metal pollution of soil. With increasing population, sustainable food production is a challenge in this climate changing and water deteriorating environment. Marginal soil has been defined from different perspectives. In general, marginal land can be defined as arid and inhospitable land that has low inherent productivity. Marginal land is a good source for the production of biofuels. This can be achieved with the help of Plant Growth Promoting Bacteria (PGPB). This project provides a review of marginal soil and how PGPB can be used to improve its quality, in phytoremediation, and in the production of bioenergy and food.

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## **ACKNOWLEDGEMENT**

First and foremost I extend gratitude to my revered advisor Prof. Ramakrishna Wusirika, Professor and HOD, Department of Biochemistry and Microbial Sciences, for instilling in me the confidence and drive for doing an arduous task and having faith in my abilities to accomplish any assignment which I set out to do. I thank him also for being a guardian, a friend as well as an erudite scientist to troubleshoot the problems encountered during the scientific report presentation and preparation.

I extend my heartfelt thanks to other faculty members of the department for their mature and scholarly guidance in making this study fruitful.

I wish to thank Mr. Radheysham (Ph.D. scholar) and my classmates for their kind cooperation and support.

At last, I am thankful to all people who have helped and inspired me during my seminar preparation and wishing for my bright future.

**Ritu Kumari**  
**Date**

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## LIST OF ABBREVIATIONS

Sr. No.	Full Form	Abbreviation
1.	1-aminocyclopropane-1-carboxylate	ACC
2.	Absciscic Acid	ABA
3.	Hectare	Ha
4.	Indole Acetic Acid	IAA
5.	Millennium Ecosystem Assessment	MEA
6.	Nitrogen, Phosphorous, Potassium	NPK
7.	Plant Growth Promoting Bacteria	PGPB
8.	Plant Growth Promoting Rhizosphere	PGPR
9.	Reactive Oxygen Species	ROS
10.	Superoxide Dismutase	SOD
11.	Total dry matter accumulation	TDMA

## **1. Introduction**

Marginal land has received great attention as it possesses potential to increase food security and support bioenergy production (Tilman *et al.*, 2006). Marginal land can be defined as land which is less fertile and can be used for cultivation again if it is feasible from an economic perspective. Marginal land is a broad term which includes areas with limited rainfall, extreme temperature, low quality, steep terrain, shallow depth (<50cm), imperfectly drained, poor fertility, coarse-textured, stony, heavy cracking clays, salt-affected, waterlogged, marshy lands, barren rocky soils, or other problems related to agriculture (Shahid and Al-Shankiti, 2013).

One of the reasons for turning fertile land into marginal land is contamination with heavy metals due to excessive use of chemical fertilisers. Heavy metals exist in soil for a long time as they are mostly non-biodegradable. They reduce soil health and are toxic to living organisms when they enter the food chain. Remediation of heavy metals is an important area of research which focuses on decreasing the negative impact of heavy metals on soil. Phytoremediation is one of the methods where hyperaccumulators are used to rehabilitate metal contaminated soil. PGPB not only help in enhancing plant growth but also enhance the quality of the soil. Marginal soil which is enriched by various methods is a good alternative for growing plants for biofuel production. This review deals with the multitasking of PGPB in improving soil quality, plant growth and bioenergy production.

### **1. Historical Perspective and Dynamic Properties of Marginal Soil**

The notion of marginal land was developed with time and space. The concept is often interchangeably used with other terms such as unproductive land, wasteland, under-utilized land, idle land, abandoned land, or degraded land (Sugrue, 2008). It was Ricardo (1817) who came up with the idea of marginal land in his land rent theory. Hollander (1895) described marginal lands as the poorest lands used above the margin of rent-paying land. Later, many theories were proposed. The three prefixes used for marginal lands are physical, production, and economical.

Marginal soils reflect dynamic state of land resources and are sensitive towards the natural processes. Land degradation is caused by poor management of productive land. Marginal land can be restored to fertile land by improving land function. A large area of land became of marginal in Europe and parts of Asia due to economic development and food demands. Transitional properties of marginal lands are crucial for explaining marginal soil dynamics. Restoration of unproductive lands can give rise to marginal land and by enhancing the quality of marginal land we can get productive land. Similarly, degradation of productive land gives marginal land and degradation of marginal land ultimately give rise to unproductive land.

The concept of marginal land has been developed into a comprehensive term with multiple needs and concerns. With current knowledge, the concept of marginal land can be further defined as the land that is physically inaccessible; it has soil and climate restrictions, or high environmental risk and fragile ecosystem with low production which is unprofitable. Following this concept, marginal lands are able to be assessed quantitatively and the most suitable management practices are applied. However, challenges of marginal land assessment and management remain to be addressed.

### **3. Importance and Advantages of PGPB in Agriculture**

Biofertilizers contain living microorganisms which promote plants growth when applied to seeds, plant surfaces, or soil, colonize the rhizosphere or interior of the plant. Biofertilizer products are usually based on plant growth-promoting rhizobacteria (PGPR). PGPR have been used worldwide as biofertilizers, contributing to increased crop yields and soil fertility without exerting any toxic effect on the environment like chemical fertilizers. Instead, they help to get the soil free from toxic heavy metals. Hence, the potential contribution of PGPR will lead to sustained agriculture and forestry. A healthy rhizosphere is created by the rhizobacteria at sufficient densities so that they help in promoting plant growth and converting nutritionally important elements through various biological processes. For example, increasing the availability of key elements, N, P, and K, as well as inhibiting pathogens. This higher availability of N, P, and K enhances soil fertility, improves antagonistic isolates' bio-control effects, and extend microbial survival

rates in soil (Vejan *et al.*, 2016). PGPR inoculation of wheat plants led to increased Zn, Fe and Cu content, thus showing their ability to promote translocation and mobilization of micronutrients (Rana *et al.*, 2012). PGPR treatment of rice helped in overcoming salt stress at the seedling stage. PGPR treated plants have shown a significant increase in shoot dry weight, root dry weight and total dry matter accumulation (TDMA) (Sen and Chandrasekhar, 2014). PGPR treatment of maize has shown a significant increase in seed germination, nutrient uptake and growth (Agbodjato *et al.*, 2016).

### **3.1 Nitrogen Fixation**

Nitrogen fixation is the conversion of atmospheric nitrogen into ammonia which is essential for all life forms. Biological nitrogen-fixation is brought about by nitrogen fixing microorganisms, using *actinomyces* enzyme to reduce  $N_2$  to  $NH_3$ . Nitrogenase is a complex enzyme encoded by nitrogenase gene (*nif*). Of the total nitrogen fixed biologically, 80% is done with the help of microbes associated symbiotically with the roots of the plants. Non-symbiotic nitrogen fixers are also important in nature as they help in the accumulation of a great amount of nitrogen (Gupta *et al.*, 2000). The nitrogen thus fixed by the microbes is present in the bacterial cytoplasm in the form of ammonium ions which are finally secreted into the host cytoplasm due to the concentration gradient (Mia and Shamsuddin, 2010).

### **3.2 Production of Indole Acetic Acid**

Phytohormones are growth regulators which affect seed growth, time of flowering, sex of flowers, senescence of leaves, and fruits. They also influence gene expression and transcription levels and, cellular division. In targeted cells, phytohormones also regulate cellular processes, pattern formation, vegetative and reproductive development and stress responses. The levels of these growth hormones are regulated in order to decrease the negative growth under limiting environmental conditions. PGPRs have been found to produce indole acetic acid (IAA), an auxin, regulating cell division, cell elongation, differentiation, and extension. By increasing osmotic content of the cell, increasing cell permeability for water, decreasing wall pressure, inducing cell wall synthesis IAA promotes cell

elongation. IAA also delays or inhibits leaf abscission, and induces flowering and fruiting (Mohite, 2013). IAA is the product of L-tryptophan metabolism by many microorganisms mainly by PGPR. PGPR release IAA that helps to increase size, weight, branching number of the root system, and its surface area in contact with soil. All these factors result in the increased ability of root to explore soil for nutrient availability thus having a positive effect on growth and nutrition pool of plants (Goswami *et al.*, 2016). PGPR have also been found to produce other growth hormones like gibberellins and cytokinins.

### **3.3 Phosphate Solubilisation**

Phosphorus is crucial for plant growth. It is required for photosynthesis, signal transduction, energy transfer, biosynthesis of macromolecules and respiration. The availability of P to the plant roots depends on the solubility of this element, which is influenced by the activity of plant roots and microorganisms in the soil. PGPR make the phosphorus available to plants by phosphate solubilization by releasing mineral-absorbing compounds- protons or hydroxyl ions, liberating extracellular enzymes for phosphate mineralization. Inorganic soil phosphates, such as  $\text{Ca}_3(\text{PO}_4)_2$ ,  $\text{FePO}_4$ , and  $\text{AlPO}_4$  can be solubilized by the production of siderophores, organic acids and hydroxyl ions (de Souza *et al.*, 2015). In the case of commercially important crops, phosphorus is provided by NPK fertilizers but this phosphorus reacts with many constituents of soil and becomes inaccessible to the plants. This phosphorus needs to be solubilized which is done by the microbes present in the rhizosphere (Ahemad and Kibret, 2013).

### **3.4 Production of Siderophores**

Siderophores are iron chelating agents produced by the rhizobacteria which make the inaccessible iron in soil available to the plants. In the aerobic environment, iron exists in phases such as hydroxides and iron oxides; this reduces the bioavailability of iron for the plants. Siderophores released by the rhizobacteria scavenge iron from the mineral phases. Thus, the plants are provided with soluble  $\text{Fe}^{3+}$  complexes which can be actively transported into the plant system. Another advantage of the siderophores production is that it deprives the other pathogenic bacteria of this metal thus indirectly promoting plant growth.

### **3.5 Biofilm Formation**

PGPRs colonize the root of the plant and multiply to form microcolonies or produce biofilms. Biofilms are microbial populations that have surface-adherent properties and are embedded within a self-produced matrix material (de Souza *et al.*, 2015). The biofilm also helps to increase crop yield and quality by providing protection from biotic stresses (microbial competitors) and abiotic stresses.

## **4. Occurrence of Marginal Soil**

### **4.1 Occurrence of Marginal Soil Globally**

Drylands account for about 45% of world's land area. About 40% of the Earth's land covers dryland ecosystem, mostly Africa ( $13 \times 10^6$  km<sup>2</sup>) and Asia ( $11 \times 10^6$  km<sup>2</sup>). Many issues such as scanty rainfall, extremely high temperatures, poor fertility soils, salinity in soils, and, draughts are associated with dryland ecosystems. These features constrain the land for agriculture giving dryland its specific feature. Water stress lands are sensitive to land degradation. About 10-20% of drylands are known to be degraded (Millennium Ecosystem Assessment, 2005). 20% of land in Spain is desert or is seriously degraded.

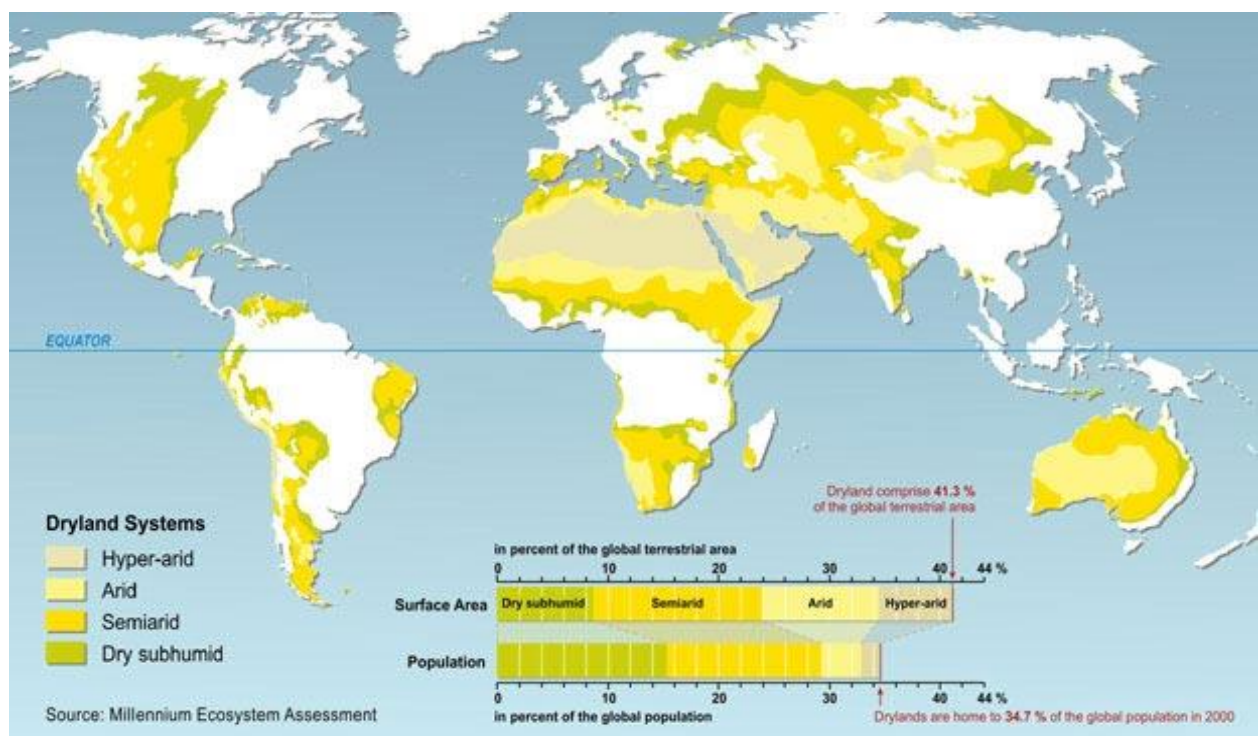
#### **4.1.1 The Concept of Dryland System**

Global dryland system is divided into four sub types: hyper-arid, arid, semiarid and dry sub-humid. Distribution of all these four subtypes is shown in figure 4.1. A land area where the average annual precipitation is below  $2/3^{\text{rd}}$  of potential evapotranspiration is referred as dryland system. Shortage of water in dryland system limits the production of crops, food, wood, forage etc. The ratio of precipitation/potential evapotranspiration of these four subtypes of dryland is shown in Table 4.1. All these subtypes show an increasing level of aridity or moisture deficiency. Management of one dryland system varies from the other. For instance, sub-humid dryland system with rainfall in the range of 200 mm – 800 mm requires different management than arid, hyper-arid or semiarid climates, where rainfall is much lower.

**Table 4.1. Precipitation/Evaporation Ratio of Subtypes of Dryland System.**

Subtypes	Precipitation/Evapotranspiration Ratio
Dry sub-humid	0.5-0.65
Semi-arid	0.2-0.5
Arid	0.05-0.2
Hyper-arid	<0.05

(Source: Shahid and Al-Shankiti, 2013)



**Figure 4.1. Global Distribution of Drylands (Source: Millennium Ecosystem Assessment, 2005).**

#### 4.1.2 Stretch of Saline Lands

Soils affected by salts are considered as marginal because of high salinity and sodicity (Soil with high a concentration of sodium in their cation exchange complex). They may fall in dryland and other systems. If we summarize the global extent of marginal saline land, we conclude that out of total  $13.2 \times 10^9$  ha of the land surface area,  $7 \times 10^9$  ha of land is arable and  $1.5 \times 10^9$  ha is cultivated. Around 20-30% of irrigated lands is affected by salt and is unproductive. Of the

total cultivated lands,  $0.34 \times 10^9$  ha (i.e. 23%) and  $0.56 \times 10^9$  ha (i.e. 37%) are saline and sodic respectively. Szabolcs (1989) reported that about 10% of the total land is saline and sodic (which covers more than 100 countries and almost all continents). About 12.1% and 14.2% of the total area is salt-affected in Kuwait and Iran, respectively (Table 4.2). About 6.7 million ha ( $6.7 \times 10^6$ ) of soil is reported to be salt affected in India (Mandal, 2016). The total area of degraded land in Kurukshetra district in Haryana, India, was estimated to be 16,916 ha. Slightly sodic soil comprised 61% of the total degraded soil followed by moderately sodic soil (33.6%) and strongly sodic soil (0.2%). The upward movement of salt with the rising water table due to the introduction of canal irrigation has been cited as one of the reasons for salt enriched soil in parts of India (Singh *et al.*, 2010). Another reason attributed to secondary salt enrichment of soil is the use of salty ground water for irrigation purpose (Gupta, 2010).

**Table 4.2. Distribution of Saline Land Worldwide**

Country/Continent	Unproductive saline land (in ha)
Egypt	$1 \times 10^6$ ha
Iran	$25 \times 10^6$ ha
Africa	$80 \times 10^6$ ha
Pakistan	$10 \times 10^6$ ha
Bangladesh	$3 \times 10^6$ ha
Thailand	$3.58 \times 10^6$ ha
China	$26 \times 10^6$ ha
North America	$15.7 \times 10^6$ ha
Mexico and Central America	$2.0 \times 10^6$ ha
South America	$129.2 \times 10^6$ ha
South Asia	$87.6 \times 10^6$ ha
North and Central Asia	$211.7 \times 10^6$ ha
South East Asia	$20.0 \times 10^6$ ha
Australia	$357.3 \times 10^6$ ha
Europe	$50.8 \times 10^6$ ha

(Source: Shahid and Al-Shankiti, 2013)

## **5. Phytoremediation**

There are several physicochemical and biological techniques in practice for the remediation of soil. Out of these, remediation processes which are based on physicochemical parameters are expensive and also affect the properties of soil, soil fertility and biodiversity. These remediation processes include vitrification, land filling, chemical treatment, electro kinetics and phytoextraction. In comparison phytoremediation takes place at a marginal cost as it involves harvesting plants. Also, the biomass of plants used for phytoremediation can be utilized for heat and energy production (Peuke and Rennenbarg 2005). Phytoremediation is an emerging technology which includes the growth of plants on the impacted soil to degrade or sequester the contaminants. Phytoremediation of different types of marginal soil is described below.

### **5.1 Phytoremediation of Metalliferous Soil Aided by PGPB**

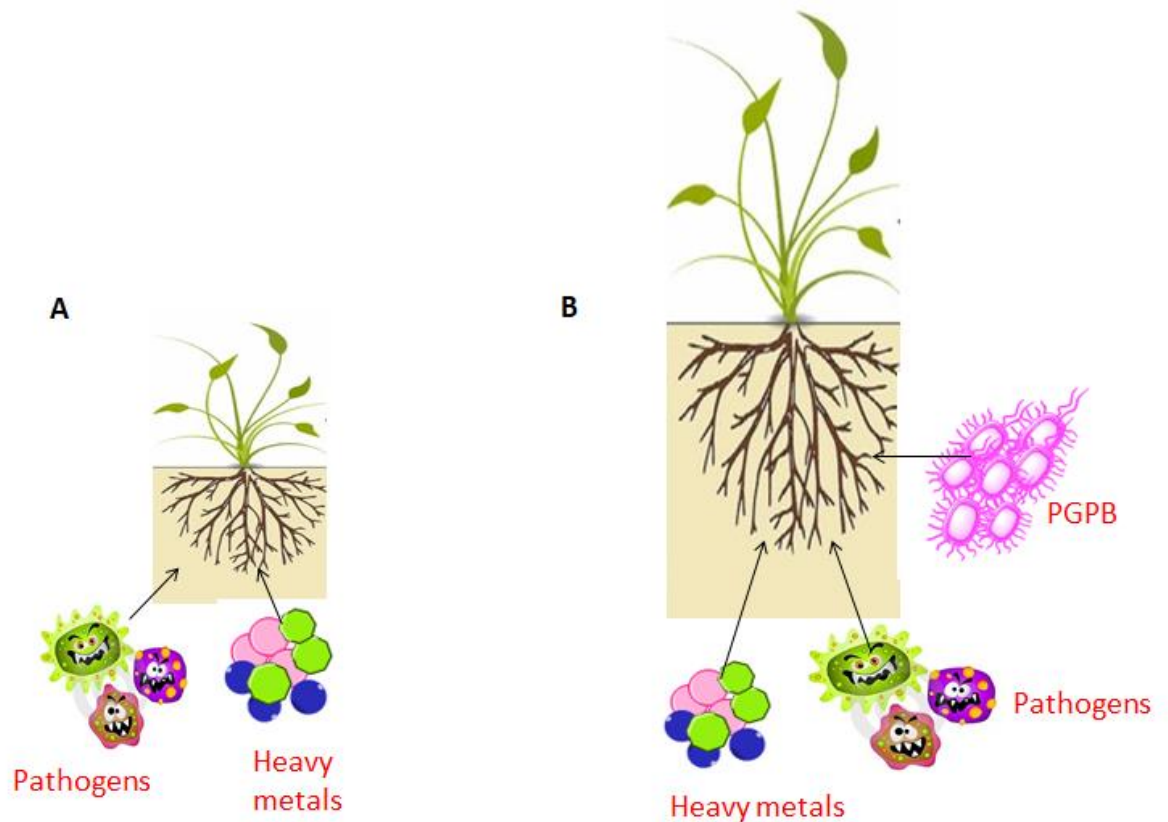
Contamination of water and soil by toxic metals is a threat to our ecosystem which results in decrease in soil fertility, water quality, agricultural production and human health. Rapid urbanization, industrialization and intensive agriculture are the causes of widespread pollution by heavy metals. Approximately 150 million km<sup>2</sup> of farmland is contaminated with heavy metals in China (Zhou and Feng 2014). These heavy metals persist for centuries once they are introduced into the soil as they cannot be degraded or destroyed by microbial or chemical processes (Bolan *et al.*, 2014). Inoculation with plant growth promoting bacteria (PGPB) can alleviate metal induced phytotoxicity and can enhance the production of biomass of the plants grown in soil contaminated with metals. These bacteria can interact with plants in one or more ways as discussed below.

#### **5.1.1 Mechanism used by PGPB for Phytoremediation of Soil Contaminated with Heavy Metals**

Soil bacteria interact with the host plant and are responsible for enhancing the efficiency of phytoremediation by promoting plant growth, alleviating metal phytotoxicity, altering metal bioavailability in soil and increasing metal translocation within the plant. There are different mechanisms by which PGPB promote the

phytoremediation process which includes improvement of plant metal tolerance and increased plant growth, as well as alteration of metal accumulation in plants (Figure 5.1). In addition to this, PGPB can also alter the metal accumulation capacity and its translocation in plants due to their metal resistance, detoxification, accumulation, transformation and sequestration, thereby diminishing the metal phytotoxicity and altering the phytoavailability of heavy metals in contaminated soils (Ma *et al.*, 2010). Metal phytotoxicity may inhibit the success of phytoremediation. PGPB can also enhance metal and mineral mobilization by producing organic acids and metal-specific ligands like siderophores, thus increasing nutrient levels and heavy metal uptake, which ultimately result in enhancing metal phytoextraction potential of host plants (Chen *et al.*, 2014). PGPB resistant to different metals have different plant growth promoting traits which include ACC deaminase, siderophore synthesis, IAA production, and phosphate solubilisation (Ma *et al.*, 2011). *Arthrobacter nicotinovorans* SA40 promoted plant growth and phytoextraction of Ni in *Alyssum pintodasilvae* (Cabello-Conejo *et al.*, 2014). *Sinorhizobium meliloti* CCNWSX0020 enhanced plant growth and Cu uptake and improved the responses of plant antioxidant defense to excess Cu stress in *Medicago lupulina* (Kong *et al.*, 2015). Increased root and shoot length, plant biomass and Cd uptake and Zn accumulation were observed in *Sedum plumbizincicola* upon high levels of colonization of *Bacillus pumilus* E2S2 and *Bacillus sp.* E1S2 respectively in rhizosphere and plant tissues (Ma *et al.*, 2015). *Pseudomonas sp.* TLC 6-6.5-4 increased total biomass of maize and increased Cu accumulation in maize and sunflower (Li and Ramakrishna, 2011).

PGPB can also be used to reduce metal accumulation food crops. A recent study showed that two metal-resistant bacteria, *B. megaterius* H3 and *Neorhizobium huautlense* T1-17 decreased cadmium bioavailability in rhizosphere soils which resulted in low cadmium accumulation in polished rice (Li *et al.*, 2017). Two rhizobacterial strains were shown to promote growth in maize by producing phytohormones and antioxidants enzymes that decreased the deleterious effects of lead (Hasan *et al.*, 2014). *Acinetobacter Sp.* nbri05 increased the growth and yield of chick pea and at the same time reduced the arsenic uptake by shoots (Srivastava and Singh, 2014).



**Figure 5.1.** Beneficial effects of PGPB on plants: A) control plant B) Plant treated with PGPB shows better growth.

## 5.2 Phytoremediation of Drylands

Climate change has significantly implicated crop production globally. There are predictions that warmer climate will increase the occurrence of prolonged drought and flood. Drought not only alters plant responses to pathogens but also microbial communities adapted to drought have been shown to be beneficial for the overall plant fitness under drought stress.

*Paenibacillus polymyxa* is a plant growth promoting rhizobacterium (PGPR) which can protect *Arabidopsis* against drought stress by upregulation of drought-stress response gene (Timmusk and Wagner, 1999). Furthermore, several bacterial strains (eg. *Bacillus* sp., *Pseudomonas* sp., *Acinetobacter* sp., *Sphingobacterium* sp., *Enterobacter* sp., and *Delftia* sp.) isolated from drought treated grapevine rootstocks improved grapevine resistance to drought by increasing the overall fitness of plant (Salomen *et al.*, 2014). Of these bacteria, *Bacillus licheniformis* Rt4m10 and *Pseudomonas fluorescens* Rt6M10 were shown

to produce a number of plant hormones, which include abscisic acid (ABA), IAA and gibberellin. ABA is responsible for inducing stomatal closure which reduces water consumption in plants, thus, improving drought tolerance (Helander *et al.*, 2016). Inoculation of plants with two ABA producing bacterial strains increased ABA level in plants, thus protecting the plants from drought (Salomon *et al.*, 2014). Besides bacteria, an endophytic fungus, *Piriformospora indica*, can also improve drought tolerance by inducing drought stress-related gene in *Arabidopsis* (Sheramati *et al.*, 2008). Thus, microbial strains isolated from prolonged water deficit environment might be useful for enhancing drought tolerance and water homeostasis by colonizing plants.

### **5.3 Phytoremediation of Saline Soils**

Salinity in soils is one of the most brutal environmental factors that limit the growth of crop plants. The concentration of soluble salts in the soil near plant roots restricts the uptake of water and balanced absorption of essential nutrition ions by the roots. Salt stress also interferes with metabolism in plants. PGPB promote plant growth in saline soils by lowering plant ethylene (stress hormone) levels. These bacteria can help in improving the soil conditions as well as plant growth by direct and indirect mechanisms. The direct mechanism involves solubilization of mineral phosphates, asymbiotic nitrogen fixation and production of plant hormones. The indirect improvement of such soils can take place through the production of antibiotics, cell wall degrading enzymes, hydrogen cyanide and siderophores as well as by biological control of pathogenic microbes. Some rhizobacteria such as *Pseudomonas fluorescens* MSp-393, confer salt tolerance through the synthesis of osmolytes, alanine, glutamic acid, and threonine in their cytosol. Altering the cell envelope is also one of the mechanisms adopted by such bacteria to survive under saline conditions. This is accomplished through the production of exopolysaccharides, which enhance water retention and regulate the diffusion of carbon sources.

Soil salinization involves the accumulation of water-soluble salts in the soil that include ions of potassium, magnesium, calcium, chloride, sulfate, etc. Some of the possible reasons for soil salinity could be salt water intrusion and, wind-born salt deposition in the land. Excessive accumulation of these salts in the soil

destroys soil texture, deteriorates soil hydraulic properties, raises soil pH and reduces water infiltration and soil aeration, leading to soil compaction and erosion. Soil salinity has been reported to reduce yield, nodulation and the total nitrogen content in leguminous plants. Moreover, the photosynthetic capacity is reduced in some plants due to partial closure of stomata and osmotic stress.

The characteristics of PGPB such as phosphate solubilization, production of IAA and siderophores can aid in the tolerance to salinity of soils. Lowering the precursor of ethylene concentrations through the activity of 1-aminocyclopropane-1-carboxylate (ACC) deaminase is one of the strategies adopted by PGPR. The enzymatic activity of ACC deaminase improves plant growth by lowering the available ACC in the ethylene biosynthetic pathway. This pathway produces ACC which is secreted by the plant into the rhizosphere, where ACC deaminase producing PGPR can consume ACC as a source of fixed nitrogen. This ultimately leads to the development of more PGPR around the rhizosphere in saline soils. Also, IAA producing PGPR secrete the auxin into the rhizosphere, where the plant is able to take up the hormone, resulting in improved cell growth. Such an increase in IAA concentration leads to an upregulation of ACC synthase production and activity. So, these are major strategies adopted by PGPR which prove to be helpful for remediation of saline soils.

#### **5.4 Phytoremediation of Hydrocarbon Contaminated Soils**

Hydrocarbons are one of the most hazardous classes of pollutants that can persist for a long time and get accumulated in the soil due to their hydrophobicity and chemical stability. The toxicity of lower molecular hydrocarbons in the soil not only inhibits the growth and development of plants but also affect their absorption capacity of water and minerals. The use of PGPR with ACC deaminase activity as well as genetically engineered rhizobacteria can serve as a useful tool for remediating such pollutants. The mechanisms used by rhizobacteria for depleting hydrocarbons are somewhat similar to those which they use for tolerating saline environment. Moreover, plants are also found to release some organic compounds like terpenes and flavonoids that induce expression of hydrocarbon degrading genes in the bacteria residing in the rhizosphere. The root exudates of some plants contain certain compounds like acetate and alanine that effectively enhance

the success rate of phytoremediation in contaminated soils. Hence, PGPR phytoremediation provides an ecologically and economically attractive technique for remediating soils contaminated with hydrocarbons.

## **6. Production of Biomass on Marginal Soil**

With increasing population, the demand for food and energy is also increasing. The shortage of energy has become a key issue all over the world. Biomass is a biological material from living organisms (mostly plants or plant derived material), which is a renewable source. Biomass can be used both directly and indirectly for production of biofuel. Some plants are termed as hyper accumulators as they can accumulate large quantities of heavy metals in their biomass (Wu *et al.*, 2006). In this context, PGPB play multiple roles as they help their host plant to cope not only with contaminant induced stress but also in improving plant growth. Plants grown in contaminated soil aided by PGPB cannot be used as food and fodder but they are suitable for use as stocks for biofuel and carbon sequestration through biomass production (Taghavi *et al.*, 2009). The competition of agricultural crops for energy and food is one of the main socioeconomic issues with the increasing use of biofuels. This dilemma could be overcome by producing biofuels feedstock on marginal soils and also using non-food crops. Foxtail millet (*Setaria italica*) is an annual C4 grass grown in arid and semi-arid regions of the world and it is considered to be a good candidate for biofuel production (Pandey *et al.*, 2017). Sweet sorghum (*Sorghum bicolor* L) is considered as one of the most drought-resistant energy crops with high biomass yield and photosynthetic efficiency and lower production costs than many other energy plants. Heavy metals such as Cd, Pb, and Cu could be removed by using sweet sorghum and therefore it is a good candidate for biofuel production on marginal land.

Bacterial endophytes which are in close association with plants colonize the internal tissues of plants and could be of great significance in enabling energy plants to grow better on marginal land for promoting the production of biofuel stocks. *Bacillus species* SLS18 exhibited resistance to numerous antibiotics as well as heavy-metals which is probably responsible for the survival of the endophytes in the interior of Mn-hyperaccumulator, *P. acinosa* (Luo *et al.*, 2012). SLS18 inoculation facilitates phytoremediation efficiency of sweet sorghum which

reveals its potential for increasing the biomass of sweet sorghum for biofuel stock production on marginal land.

Growth and productivity of plants is highly compromised due to abiotic stress, poor nutrition and heavy metal contamination. There is a need for an *in-situ* selection of high biomass and/ or metal accumulating clones. High metal-resistant bacterial cells which can accumulate heavy metals like- lead and zinc, may take the advantage of their cellular metabolism and metal detoxification mechanism to take up the metals with an increase in biomass when grown in marginal soil (Li and Ramakrishna 2011). *Pseudomonas sp.* TLC 6-6.5-4 which is a free-living metal resistant PGPB isolated from Torch lake sediment promoted maize growth and nutrient uptake and increased biomass (Li *et al.*, 2014). The interaction between PGPB and maize is mutualistic, where PGPB helps in promoting plant growth by production of IAA and other compounds and in turn maize plant gives out phenolic compounds in root rhizosphere, which serve as carbon source for PGPB. As PGPB enhance biomass of plants grown in marginal soil, there is potential for the use of the biomass in producing bio-fuels. With the help of PGPB, plants grown in very poor soil can cope with heavy metal stress by regulating a number of proteins and metabolic pathways (Li *et al.*, 2014). Another related study, evaluated the effect of arbuscular mycorrhiza and PGPB on element uptake, biomass and metabolic responses in maize roots grown in mining-affected soil. The element uptake and biomass were significantly higher in the plants treated with arbuscular mycorrhiza and PGPB as compared to normal plants. These were attributed most likely to changes in galactose metabolism, fatty acid synthesis, and phenylpropanoid biosynthesis among others. A similar study with sorghum grown in marginal soil with mycorrhiza and PGPB resulted in increased uptake of elements and enhanced the root and shoot biomass (Dhawi *et al.*, 2016). The metabolites upregulated by PGPB are part of galactose metabolism and fatty acid biosynthesis.

Plants under abiotic or biotic stress are known to induce the production of reactive oxygen species (ROS). ROS at low levels provide a balanced cellular redox for growth regulation whereas at high concentrations, ROS interferes with lipid peroxidation, DNA synthesis, and enzymatic activities. Analysis of sorghum treated with microbial inoculations showed the upregulation of proteins such as superoxide dismutase (SOD) which is involved in scavenging of ROS (Dhawi *et*

*al.*, 2017). Foxtail millet is considered as a biofuel source due to high biomass production suited for saccharification (Dhawi *et al.*, 2018). Foxtail millet inoculated with mycorrhiza and PGPB increased metabolites which led to increase in sugar yield (Dhawi *et al.*, 2018). Overall, a better understanding of metabolic pathways will help in enhancing PGPB interactions with plants in order to exploit them for promoting plant growth in marginal soil.

## **7. Conclusion**

Energy crisis is one of the biggest issues faced by both developed and developing countries. Increasing food production to meet the demands of growing population is another key issue. Exploitation of marginal land with poor soil health can lead to mitigation of one or both of the above issues. Employment of high biomass and/ or metal hyperaccumulating plants in combination with PGPB can produce biofuels and/ or enhance crop productivity depending on the type of marginal land. In short, marginal soil can be termed as brown gold whose full potential will be realized when mining is performed with the help of plants and PGPB.

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