Introduction and Application of Organic Fertilizers as Protectors of Our Environment

Introduction and Application of Organic Fertilizers as Protectors of Our Environment

Edited by

Munir Ozturk,
Nudrat Aisha Akram,
Bengu Turkyilmaz Unal
and Muhammad Ashraf

Cambridge Scholars Publishing

Introduction and Application of Organic Fertilizers as Protectors of Our Environment

Edited by Munir Ozturk, Nudrat Aisha Akram, Bengu Turkyilmaz Unal and Muhammad Ashraf

This book first published 2022

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN (10): 1-5275-8098-9
ISBN (13): 978-1-5275-8098-5

CONTENTS

FOREWORD

PROF. NAFEES A. KHAN

DEPARTMENT OF BOTANY
PH. D. (ALIG.), D. SC. ALIGARH MUSLIM UNIVERSITY
PROFESSOR OF PLANT PHYSIOLOGY ALIGARH, INDIA

The world population is likely to reach around 9 billion by the year 2050. Reports from different agencies including United Nations suggested that the food crisis will be the mainstream concern for all humankind. In order to maintain the demand and supply of the food for burgeoning population along with economic growth, the production of food must be increased up to 50-70% by the year 2050. The agricultural system in the current scenario is facing several challenges such as climate change, biotic stresses, poor management in the field practices, irrigation mismanagement, extensive use of chemicals-based fertilizers, and the limited promotion of the organic agriculture around the world. The use of fertilizers was responsible for increased grain production during 1960's revolution. The fertilizers contribute about 40-60% of the food production worldwide. Developing best fertilizer management practices should include the use of fertilizers in an effective, efficient and safe manner to ensure sufficient crop production especially in developing countries. Additionally, the agricultural practices are continuously facing changes in nature and fertilizer practices, varying with crop production system, time and location, in turn significantly affect the final produce under different crop production system. Accordingly, more convincing research providing double benefits of improving fertilizer efficiency and also minimizing losses from organic/natural resources is needed to determine benefits, costs and adequate agricultural practices in order finally to avoid the necessity of using synthetic inorganic fertilizers.

This book entitled 'Introduction and Application of Organic Fertilizers as Protectors of Our Environment' is anticipated to offer an overview of developing scientific issues related with the use of organic fertilizers that have potentiality to protect lithosphere. It comprises of 22 chapters highlighting some key research activities towards developing a sustainable agriculture and environment. The first chapter explains the potential use of plant growth promoting rhizobacteria (PGPR) and suggests how it can be considered as an alternative to inorganic fertilizers to advance crop/plant yield and quality. The second chapter provides information on organic agriculture and its role in providing its supports towards sustainable ecosystem and human health; whereas the third chapter discusses the plant-microbe associations and their interface between unavailability and availability of soil nutrients. The fourth chapter highlights the importance of managing the indigenous mycorrhizae when soil borne diseases increase and the soil nutrients deplete under field conditions. Chapter five summarizes the latest information on mutations leading to a better tomorrow in the production of improved crop varieties, because crop improvement through induced mutation adds credence. The sixth chapter describes the potential benefits, tolerance and implementation of arbuscular mycorrhiza fungi and biochar interactive use in the remediation of polluted soils and also plant nutrition in sustainable agriculture. The sixth chapter aims to highlight useful information on algal bio-fertilizer for developing an ecofriendly and non-polluting approach in improving the crop productivity. The seventh chapter discusses how vermicomposting could enhance the degradation of organic wastes and enable reduction of environmental pollution. It also highlights how vermi-compost method can provide good economic benefit compared to other methods to support sustainability in agriculture. The chapter eight enlightens different aspects of melatonin. The authors highlight the potential mechanisms underlying melatonin-mediated reduction in abiotic stress-impacts on crops, reactive oxygen species-detoxification and melatonin-mediated improved crop production. In Chapter nine authors have presented a detailed overview on the topic of plant metabolomics highlighting the crucial role of metabolomics under plant growth/development and response of plants to different constraints. The chapter ten attempts to enlighten the information on the damages caused by conventional farming as well as correct and conscious use of fertilizers allowed in organic farming. The eleventh chapter covers principles of fertilizer use in organic agriculture. The chapter twelve highlights the organic farming system and organic fertilizers in improving the quality and quantity of vegetables. In chapter thirteen the topic on phenomics has been discussed with a perfect goal to link the gap between plant function, genomics and agronomic characters. The fourteenth chapter takes new direction and discusses the complex interrelation between plant nutrients and abiotic stresses like water scarcity, heat stress and elevated CO_2 concentration. Fifteenth chapter deals with the advanced technology based work and summarizes the details of green nanotechnology together with its applications like nano-fertilizers, nano-pesticides and nanoherbicides. Sixteenth chapter is devoted to the importance of ecological zoning in South Kazakhstan and describes the developmental trends of landscape structure of main territory and the agriculture land, based on local ecological studies and suggests crucial findings. Structural and functional genomics of rice is the topic of chapter seventeen. It discusses the use of rice as a model plant for genomic study of other crops. Green nanotechnology is the subject matter of chapter eighteen. It deals with the goals of green nanotechnology. Potential of organic fertilizers for fruits and vegetable production is an important subject matter in horticulture and discussed in chapter nineteen. The authors suggest that organic fertilizers are potentially better alternatives over traditional fertilizers which pose the risks of ground water contamination via nitrate leaching. In this chapter, insights into various types of organic fertilizer have been presented and interactive effects of these fertilizers on soil characteristics and vegetable production have been discussed. Chapter twenty presents the results expected to be used by the local executive bodies for industrial and agricultural development of the area studied. The chapter twenty-one deals with the topic of organelleomics in particular mitochondria and chloroplast of plants**.** The chapter brings forth an emerging research area and presents age old goals of crop improvement and yield. The last chapter (chapter twenty-two) is based on the use of green manures that can help to recover degraded soils.

The contributions made by the authors and also the efforts of editors are timely in the changing scenario of agriculture and crop productivity. The publication of this book has very significant importance for scientists, teachers, students, agricultural agronomists and farmers to understand the advantages of organic fertilizers. I sincerely hope that the information presented in this book will be of great value to those directly engaged in the handling and use of organic fertilizers and will be proven a good use of organic fertilizers to accomplish a sustainable agriculture without environmental orientations.

Dated: October 15, 2021
Prof. Nafees A. Khan

PREFACE

This book aims to deal with organic fertilizers, as there is an increasing demand for organic production and protection of environment. From such perspectives, this book is very timely as many countries are now trying to commercially produce organic fertilizers and are practicing organic agriculture not only to improve their soil resources but also produce environmentally sustainable and safe food for healthy human life. The organic fertilizers are commonly produced through different ways using organic substances. Animal manure and agricultural waste are recycled as the main raw materials, this way they are not only creating economic benefits for the producers, but also making a great contribution to soil and natural environments. The rapid development of livestock and poultry farming produces a lot of wastes. The organic fertilizers are commonly produced through different ways using organic substances. Animal manure and agricultural waste are recycled as the main raw materials, this way they are not only creating economic benefits for the producers, but also making a great contribution to soil and natural environments. Biological organic fertilizer is widely used in farmland, fruit trees, flowers, landscaping, high grade lawn and soil improvement. This book contains state-of-the-art information in organic farming for researchers, educators, graduate students and industry. It consists of 22 Chapters.

Chapter 1 provides the reader with information about “Plant Growth Promoting Rhizobacteria” (PGPR) which are the natural soil microorganisms and are generally colonized in plant roots and are called rhizobacteria in the so-called rhizosphere. They can be considered as alternative way for inorganic fertilizer with a specific goal to advance plant development, quality and yield. The aim of *Chapter 2* is to examine the aspects and problems of conventional agricultural production that prevent sustainability and to suggest solutions based on organic farming practices as to overcome this problem. Organic production model supports ecosystem and human health. The *third Chapter* deals with the plant microbial association. In the plant production environment there are completely different kinds of microbial interactions with different microbes. Microbial interactions are ubiquitous, diverse, critically important in the function of any biological community, and are crucial in global biogeochemistry. The organic production model supports ecosystem and human health.

Importance of organic agriculture from the microbiological point of view is discussed in *Chapter 4*. It is known that the soil and water qualities are significantly affected by the use of chemicals in agriculture. For several reasons, microbiologically, using plant rhizosphere mechanisms such as management of indigenous mycorrhizae or/and selected mycorrhizal application may increase the soil fertility and increase the biomass production ultimately contributing to the agricultural sustainability.

The *Chapter 5* summarizes the latest information on mutations leading to a better tomorrow in the production of improved crop varieties, because crop improvement through induced mutation adds credence. The review suggests that induced mutation is an indomitable approach and has contributed enormously towards economic step up of developing as well as developed countries. Similarly, the authors in *Chapter 6* deal also with the importance of exploitation of mycorrhizae and their function as biological and organic amendments, which are the cost effective and environment friendly approaches for plant growth and phytoremediation in polluted soils. This chapter also points out the potential benefits, tolerance and implementation of mycorrhizae use in the remediation of polluted soils and plant nutrition in sustainable agriculture.

Green fertilization is the subject matter of *Chapter 7* which is considered for agriculture in a long time. Different plants are used for green fertilization; leguminous plants are generally preferred and are accepted as the best green fertilization plants, due to their content of nutrients. The green fertilization technique involves burying green plant materials in the ground to increase the quality of the soil for plant production. Vermicompost is the subject matter of *Chapter 8*. They enhance degradation of organic wastes and enable the reduction of environmental pollution, consequently increase the sustainability of the soil fertility and protect environmental and human health.

In *Chapter 9* authors have presented a detailed overview on the topic of plant metabolomics and their role in crop improvement. This topic reflects an integration of gene expression, protein interaction and other different regulatory processes being closer to the phenotype than mRNA transcripts or proteins alone. It summarizes the latest data on circadian rhythms, crop improvement, metabolite profiling, crop breeding, environmental stresses, spatial and temporal characterization of metabolome with examples from the studies on *Arabidopsis thaliana*. It discusses the crucial role of metabolomics under plant growth, development and response of plants to different biotic and abiotic environmental constraints.

Production of indoleamine in plants has emerged as an interest in plant sciences and this matter is discussed in *Chapter 10*. The indoleamine melatonin as a free radical scavenger, electron donor, and antioxidant used largely in vitro and in vivo studies. Melatonin has been confirmed to aid plants to grow in the harsh environment. This chemical is recognized to have great potential to promote crop production especially under environmentally stress conditions.

The Authors of *Chapter 11* discusses organic fertilizers such as compost, humic acids, fulvic acids, leonardit, farmyard manure, green manures, seaweeds, mycorrhizas. Some fertilizers include enzymes, amino acids, seaweed extracts and microorganisms. They suggest that excessive use of fertilizers should not be permitted in organic production, as in the use of commercial fertilization. It is suggested and explained here the damage caused by conventional farming as well as correct and conscious use of fertilizers that are allowed in organic farming. The principles of fertilizer use in organic agriculture is explained in *Chapter 12*. It is known that organic agriculture systems usually don't use chemicals as fertilizers. The chapter indicates that organics that are used are naturally derived materials of biological or mineral origin and have low nutrient concentrations or solubility.

The *chapter 13* discusses the topic on phenomics with a perfect goal to link the gap between plant function, genomics and agronomic characters. The aim of authors here has been to enlighten the facts related to the field based phenomics, a simultaneous proximal feeling for spectral reflectance, canopy warmth, and vegetation architecture. *Chapter 14* aimed to explain the application of *pranic* agriculture protocol on tomatoes, pole beans, cucumber and European cucumber plants. Prana is the energy needed by the plants for its growth. Authors study shows that pranic agriculture could play a significant role in improving the quality and quantity of vegetable production.

Positive affect of organic fertilizers to improve the physical and chemical productivity characteristics and microbial properties of the soil is the subject matter of *Chapter 15*. Organic fertilizers all add important plant nutrients as well as significant amount of carbon to the soil. It is well known that unconscious and excessive use of fertilizers in organic farming also can lead to a damage of the environment. Here authors provide information about the damage caused by conventional farming as well as correct and conscious use of fertilizers in organic farming.

Chapter 16 is a review paper aimed to discuss the complex interrelation between plant nutrients (nitrogen, phosphorus, potassium and magnesium), water scarcity, heat stress and elevated CO_2 concentration. Many climate change models suggest that the effects of the occurrence and duration of heat and drought stress on major crops will increase in many regions, negatively affecting the food security. In addition to soil scientists plant breeders, botanists and molecular geneticists are trying to identify genes involved in drought tolerance under water scarce conditions.

Structural and functional genomics of rice is the topic of *chapter 17*. It discusses the use of rice; with a genome size of 430 Mb having 12 chromosomes and >50,000 genes; as a model plant for genomic study of other crops. Different techniques including cytogenetic, molecular genetics and physical mapping have been discussed for constructing rice genome map thus providing information regarding general features of the rice genome. Green nanotechnology is the subject matter of *Chapter 18*. It deals with the goals of green nanotechnology and includes its applications in nano fertilizers, pesticides and herbicides in the soil and plant diseases management.

Potential of organic fertilizers for fruits and vegetable production is an important subject matter in horticulture and discussed in *Chapter 19*. The authors suggest that organic fertilizers are potentially better alternatives over traditional fertilizers which pose the risks of ground water contamination via nitrate leaching. In this chapter, insights into various types of organic fertilizer have been presented and interactive effects of these fertilizers on soil characteristics and vegetable production have been discussed.

Chapter 20 was devoted to the importance of ecological zoning in South Kazakhstan in agricultural production and describe the developmental trends of landscape structure of main territory and the agriculture land. The *chapter 21* deals with the topic of organellomics in particular mitochondria and chloroplast of plants**.** The chapter brings forth an emerging research area.

Several theories propounded to elucidate the evolution of both mitochondria and chloroplast, endosymbiont theory of evolution, lateral gene transfer theory and nucleosymbiosis or fusion theory have been summarized together with the mechanism of RNA splicing and different proteins involved in the process. The chapter therefore presents age old goals of crop improvement and yield. The results expected to be used by the local executive bodies for industrial and agricultural development of the area studied. Green manure use in organic agriculture is the subject matter of the last *Chapter* (*22*) of the book. The use of green manures can help to recover degraded soils and improve crop yields with low cost with easy application techniques.

Prof. Dr. Ahmet Ruhi Mermut
University of Saskatchewan, Canada
Harran University, Şanlıurfa, Turkey

CHAPTER 1

PLANT GROWTH-PROMOTING RHIZOBACTERIA AS AN ORGANIC FERTILISER SOURCE

METIN TURAN,[1*] EKREM OZLU,[2]
ERTAN YILDIRIM,[3] NURGUL KITIR,[4]
ADEM GUNES,[1] HIKMET KATIRCIOĞLU,[5]
SANEM ARGIN,[6] ILGIN KARACAN,[1]
CANSU COBAN,[1] DILEK UCAR,[6]
DENIZ OLGUN,[1] HAZAL ELITAS,[1]
NUKHET HALILOĞLU,[1] DILA OMACER,[1]
SHEYDA SHAKOORY[1]

[1] Department of Genetics and Bioengineering, Faculty of Engineering, Yeditepe University, Istanbul, Turkey.
[2] Department of Soil Science, Wisconsin-Madison University, Madison, Wisconsin, USA
[3] Department of Horticulture, Faculty of Agriculture, Ataturk University, Erzurum, Turkey
[4] Department of Plant Production and Technologies Faculty of Agriculture and Natural Sciences Konya Food and Agriculture University, Konya, Turkey
[5] Secondary School Science and Mathematics Education, Gazi University, Ankara, Turkey
[6] Department of Agricultural Trade and Management Yeditepe University, Istanbul, Turkey. m_turan@hotmail.com

Abstract

In order to meet the increased demand for food resulting from population growth, environmental damage is increased owing to the intensive use of chemicals in agriculture. The high usage of chemicals and inorganic fertilizers result in the degradation of arable land and an increase in the negative effects of plant pathogens present in the soil. In addition, plants face other stress conditions such as salinity, drought, temperature changes, frost, and heavy metals, which negatively affect their growth, especially the growth of roots. Plant growth-promoting Rhizobacteria (PGPR) can be considered an alternative to the use of inorganic fertilisers with the specific goals of advancing plant development, quality and yield. PGPR are natural soil microorganisms, which are generally colonised in plant roots and grow in a variety of ways in the rhizosphere and in the phytospheres. PGPR generally play various roles in increasing the nutrient ratio of the plant, encourage plant growth, and control organic pollutants and diseases by colonising the plant roots and leaves. They can act as biofertilisers or biocontrol agents due to their inherent capabilities, and as phytostimulators when the PGPR are applied to the plant roots. Furthermore, PGPR have agronomic significance on account of plant growing cycles on the planet in differing spells of cold conditions. PGPR can be examined in two subsections of the mechanism of actions, direct and indirect. PGPR might enhance the accessibility of the plant to nutrients and water by providing for the integrity of the plant root under stress conditions and, indirectly, affecting the repair of damaged areas. In addition, PGPR found in the soil are capable of increasing the availability of phosphorus to the plant by producing organic acids and enzymes. Moreover, PGPR have potential in protecting the plant against cold stress by producing antifreeze proteins, and in being able to produce metabolites like plant development controllers, which can specifically advance growth and plant nutrient take-up. In summary, PGPR can find applications in bioengineering, phytostimulation, and rhizoremediation.

Key words: PGPR, soil enzymes, mitigation of cold stress, nutrient uptake

Introduction

Plant growth-promoting rhizobacteria (PGPR) are potential alternatives to inorganic fertilisers in terms of promoting crop growth, yield, and quality. The bacterial characteristics they possess, such as biological nitrogen fixation, the solubilisation of inorganic phosphate, the mineralisation of organic phosphate, nutrient uptake, 1-aminocydopropane-1-carboxylic acid (ACC) deaminase activity, and the production of siderophores and phytohormones, can be assessed as plant growth-promotion traits. PGPR, which increase plant tolerance against biotic and abiotic stresses, are also capable of promoting plant growth by colonising the plant root. An increase in plant growth due to the addition of PGPR occurs through increases in germination rates, root growth, yield, leaf area, chlorophyll content, nitrogen content, protein content, shoot and root weight, tolerance to drought, salinity, heavy metal stress and delayed leaf senescence. The addition of PGPR can increase agronomic efficiency by reducing costs and environmental pollution. If the selected organisms and inoculation are efficient, the use of harmful materials can be reduced or eliminated. This chapter deals with various aspects: (i) fixation of nitrogen, solubilisation/mineralisation of mineral and organic phosphates and other nutrients; (ii) production of plant hormones, ACC deaminase and siderophore; (iii) promotion of soil health, plant physiology, vigour, yield and quality; and (iv) alleviation and mitigation of abiotic stress on wheat by PGPR. Further elucidation of the different mechanisms may help to make microorganisms a valuable asset in developing future agriculture.

PGPR and Nutrient Uptake

PGPR are natural soil microorganisms that grow in free soil in the rhizosphere or in phytospheres, to promote plant growth and yield. They generally colonise plant roots (root surface or root redicardial tissue) and are called rhizobacteria that support plant growth.

PGPR can be examined in two sub-categories in terms of the mechanism of action. Direct-acting PGPR are effective at each step, from sowing to production, whereas indirect PGPRs affect plant development by bio-control. Depending on the category, PGPR generally play various roles—to increase the nutrient ratio of the plant, encourage plant growth, and control organic pollutants and diseases. Thus, PGPR can find applications in bioengineering, phytostimulation, and rhizoremediation.

Mechanism of direct action: Fig. 1.

- Asymptomatic nitrogen fixation.
- Increase inorganic phosphate solubility.
- Mineralisation of organic phosphorus compounds
- Beneficial bacterium maintains alkaline environment sustainability by improving mineral intake of plants
- Siderophore (iron and organic acid) production
- Facilitating the uptake of a plant-derived compound (phytohormones, etc.) by bacteria
- Production of plant hormones, such asoxine, gibberellin, cytokinin
- Inhibition of ethylene synthesis by ACC deaminase activity
- Reducing the environmental stress to which the plant is exposed by moderating the environment
- Vitamin synthesis
- Increase in root permeability

The induction of plant growth with PGPR depends on all these effects: germination rate, chlorophyll content responsible for photosynthesis, Mg-N content, and delay formation of the absent layer present in the leaf to help in plant growth.

On the other hand, PGPR affect plant growth directly or indirectly (PGPR soil bioremediation) as follows:

- Encouraging plant growth
- Increasing plant tolerance
- Reducing diseases by antibiotic production
- Protecting the plant by removing the xenobiotics.

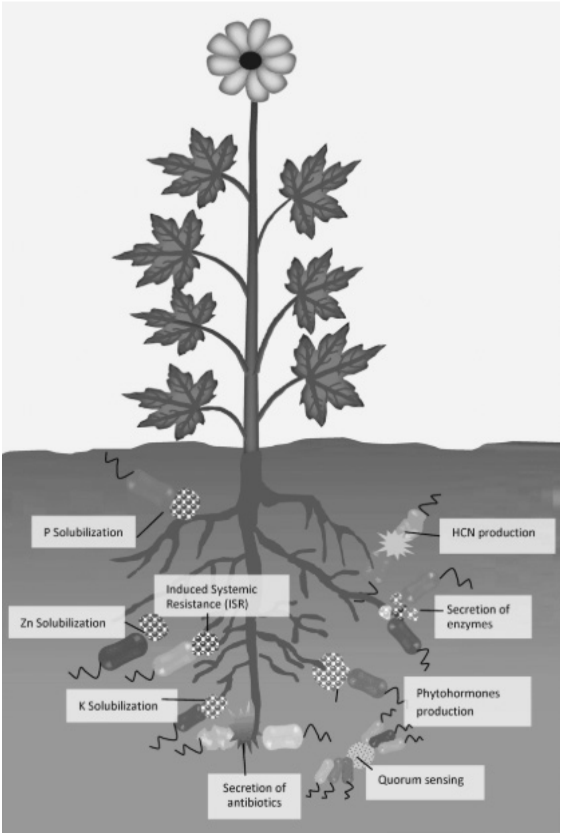

Fig. 1. Key influences of PGPR (Mishra, Prakash, and Arora 2016)

PGPR Bacteria and Made-Up Studies

Acinetobacter, *Alcaligenes*, *Arthrobacter*, *Azospirillium*, *Azotobacter*, *Agrobacterium*, *Bacillus*, *Beijerinckia*, *Burkholdria*, *Clostridium*, *Enterobacter*, *Erwinia*, *Flavobacterium*, *Klebsiella*, *Micrococcus*, *Pseudomonas*, *Rhizobium Rhodobacter*, *Rhodospirrilum*, *Serratia* and *Xanthomonas* belong to the PGPR family (Bloemberg and Lugtenberg 2001, Rodrıiguez and Fraga 1999, Sturz and Nowak 2000, Sudhakar et al. 2000, Vessey 2003, Esitken 2011, Niranjan Raj, Shetty, and Reddy 2006).

The stimulation of different products with PGPR is demonstrated by laboratory and field experiments. It was determined that *Pseudomonas* *putida* and *Pseudomonas fluorescens* bacterial strains enhanced the root and shoot length in canola, lettuce, potato, radish, bean, rice, sugar beet, wheat, tomato, apple, citrus and subtropical plants. Wheat yield was reported to be increased by 30% with inoculation of *Azotobacter*, and by 43% with *Bacillus* inoculation; and *Bacillus megaterium* and *Azotobacterchroococcum* increased yields by 10–20% in some crops. *Azospirillum* has been found to increase efficiency in corn, sorghum and wheat, and *Bacillus* has been found to do the same in peanuts, potatoes, sorghum and wheat (Rodrıiguez and Fraga 1999). Moreover, it has been determined that different PGPR strain treatments increased the dry weight of root and shoot for bean (Vedder-Weiss et al. 1999), lettuce, cucumber and tomato; dry weight of root and leaf for onion (Van Peer and Schippers 1988); fruit number and yield of cucumber and tomato (Gagne et al. 1993, McCullagh et al. 1996); fresh and dry weight of basil (Golpayegani and Tilebeni 2011); and plant growth and plant yield of cabbage (Yildirim et al. 2016).

The Role of PGPRs in Food Intake

Together with environmental damage and an increasing population, enabling people to consume good quality food has become much harder. It is expected that today's population of around 7.6 billion will reach 10 billion in the next 50 years (Glick 2014). The intensive use of chemicals and excessive tillage in agriculture increase the necessity of enhancing plant yield per unit area due to increases in the global population. This causes degradation in agricultural lands and increases the negative effectiveness of plant pathogens present in the soil. In addition, unbalanced and unplanned agriculture has destroyed the soil integrity of fertile soils and caused high levels of degradation of soil chemistry. In addition, global warming, which affects day-to-day wellbeing, causes an increase in biological stress in agricultural areas (Carmen and Roberto 2011).

One example is soil salinity, one of the most important issues in agricultural land; and frost damage owing to seasonal imbalances, turns 1–2% of fertile land every year into inefficient areas. Soil salinization depredates 7% of the soil and 20% of the total arable area (Rasool et al. 2013).

Most of the salt is found in areas where the plant is growing and limits its development, thus reducing plant yield. Furthermore, plant growth and metabolism have seriously changed in terms of physiological, morphological, and biochemical properties because of salinity (Gupta and Huang 2014). On the other hand, drought is one of the significant issues influencing fertility in agricultural lands. Critical issues in plant growth for above 50%

of arable land may be due to more severe and frequent drought-induced climate change by 2050 (Vinocur and Altman 2005). Drought stress may be a reason for the destructive consequences for plant development and metabolic processes in essential field plants by influencing water connections, photosynthetic digestion and nutrient uptake.

Under all these circumstances, PGPR play an essential role in expanding protection from both biotic and abiotic stresses, as sustainable agriculture is at stake (Etesami and Beattie 2017, Meena et al. 2017).

The availability of soluble salts and high contents of soil Na^{+} and Cl^{-} ions reduce nutrient uptake by plants. For example, high osmotic pressures, like N, P, K, soluble salts, and high ion contents, cause water to translocate in plants (Feigin 1985, Sharpley et al. 1992). In addition, some elements in the soil negatively affect the nutrient intake of the plant. For example, the high levels of Cd^{+2} in the soil, decreases the intake of Ca^{+2}, Mg^{+2}, Fe^{+2} and Zn^{+2}, by the plant.

1. The Direct Effect of PGPR in Nutrient Uptake Efficiency

1.1. Nitrogen Fixation

Molecular nitrogen (N_2) is one of the most significant components of both the atmosphere and the earth. One of the factors that makes this component so important is its involvement in vital structures such as nucleic acids and proteins. In order to participate in biological systems, N_2 must combine with hydrogen to form a complex that can be reduced. Nitrogen can be converted to nitrate by nitrite bacteria, and can be used by plants. This binding occurs both by symbiotic and non-symbiotic nitrogen binding bacteria via the action of nitrogenase enzyme. The nif gene, which has a part in the synthesis and purpose of the nitrogenase complex, namely the nitrogenase enzyme, is reported to be in a cluster of 7 operons, 20–24 kb.

For plants, this reduction process occurs with legumes and rhizobia in their roots. The reduction of nitrogen with *Rhizobium* accounts for about 20% of all global nitrogen reductions and occupies a large space. It is reduced to 75–300 kg N per hectare, per year.

PGPR can upgrade plant N uptake because the cooperative and non-harmonious N_2 fixation improves different situations, for example, the mineralisation of organic forms of soil nitrogen and the expansion of plant root framework by the generation of phytohormone IAA and ACC deaminase. These bacteria, which are essential for soil micro-ecological dynamics and able to bind nitrogen, are collected into two groups: symbiotic and nonsymbiotic. They are known as symbiotic bacteria that bind *Mesorhizobium*, *Sinorhizobium*, *Azorhizobium* and *Bradyrhizobium* nitrogen to 16S rRNA sequence homology, or nod genes (which promote the formation of nodules in plant roots). The non-nociceptive bacteria binding to nitrogen can be classified as *Azoarcus*, *Gluconacetobacter*, *Diazotrophicus*, *Azotobacter*, *Herbaspirillium*, *Archomobacter*, *Acetobacter*, *Arthrobacter*, *Azospirillum*, *Azomonas*, *Bacillus*, *Beijerinckkia*, *Clostridium*, *Corynebacterium*, *Derxia*, *Enterobacter*, *Klebsiella*, *Pseudomonas*, *Rhodopseudomonas* and *Xanthobacter*.

The expansion in nutrient uptake due toPGPR has been noted in numerous crops, namely, rocket (Dursun, Ekinci, and Dönmez 2008), chickpea (Elkoca, Kantar, and Sahin 2007); barley (Cakmakci, Dönmez, and Erdoğan 2007), and cabbage (Turan et al. 2014, Yildirim et al. 2016). This expansion in plant nutrient uptake might be ascribed to the mechanisms of non-symbiotic N_2-fixation.

1.2. Solubility of Complex Phosphate (P)

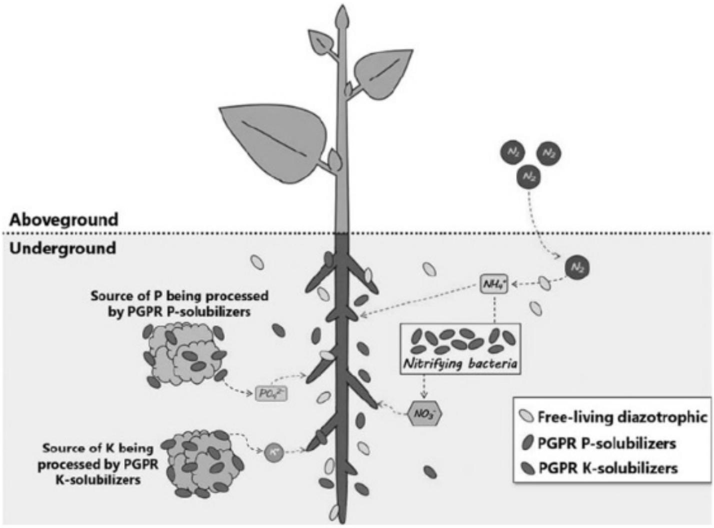

Fig. 2.a. Mechanism of phosphate (P) and potassium (K) uptake in plants (Figueiredo et al. 2016)

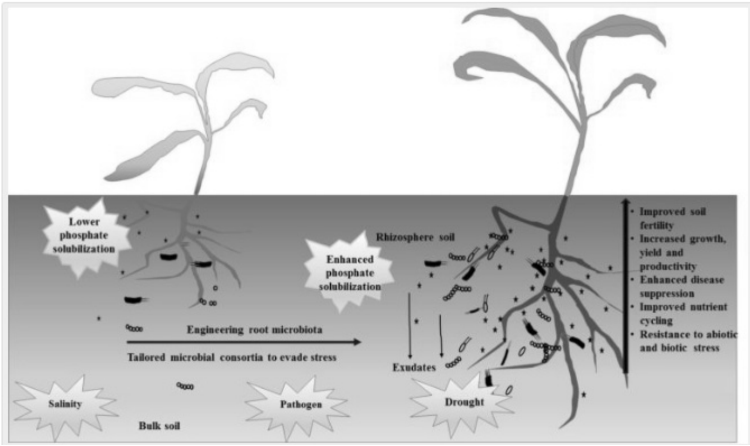

Fig. 2.b. Phosphate solubilisation (Figueiredo et al. 2016)

After nitrogen, the fundamental mineral component that restrains the development of plants is P, which is taken with soluble forms ($H_2PO_4^-$) or (HPO_4^{-2}). $H_2PO_4^-$ and HPO_4^{-2} anions are highly restricted due to their co-precipitation with Ca^+, Mg^{+2}, Fe^{+3}, Mn^{+2}, Zn^{+2} and Al^{+3} cations, and P, in the form that can be taken, is rather rare. It is found especially as organic precipitates on the mineral surfaces of the earth (Richardson and Simpson 2011).

PGPRs have a leadership role in this P cycle from soil to vegetation at different stages. These are: PGPRs in soil and insoluble phosphates (Fig.2. a., b.) (Fig. 3.)

i) Acidification
ii) Chelates
iii) Direct reaction
iv) Secretion of siderophores
v) Secretion of mineral solvent components
vi) IAA production
vii) ACC deaminase activity
viii) Production of extracellular polysaccharides
ix) Increase in P intake of plants by inducing mechanisms of conversion to Fe and Al.

Organic acids and phosphoric acids play a critical part in the mineralisation of soil organic phosphorus and, therefore, in making it ready for plant use. The PGPR bacteria found in the soil are capable of dissolving phosphorus by producing organic acid. These are: *Bacillus polymyxa*, *B. megatarium*, *B. circulans*, *B. subtilis*, *B. firmus*, *Pseudomonas striata*, *P. rathonia*, *Rhizobium leguminosarum* and *R. meliloti*. Even some *Bacillus* species are able to produce a mixture of lactic, isovaleric, isobutyric and acetic acid groups. The best phosphate solvent root bacteria include *Pseudomonas*, *Bacillus* and *Rhizobium* (Antoun 2003).

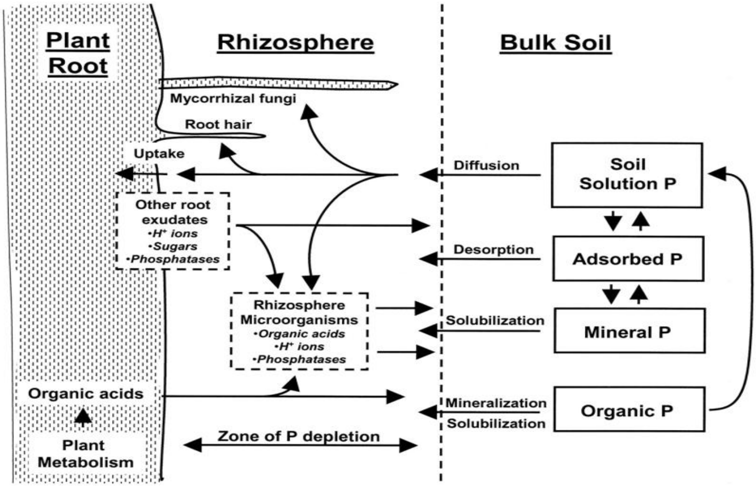

Fig. 3. Solubilisation mechanism of phosphate.

1.3. Uptake of Potassium (K)

Potassium (K) is one of the macro-elements which play an essential role in plant development. The maximum amount of K a plant needs to be able to grow adequately is 50–300 kg ha^{-1} (Zörb, Senbayram, and Peiter 2014).

The K resolution, where PGPR predominate, is almost identical to the P dissolution stages of the action mechanisms. Generally, potassium-solubilizing bacteria (KSB) dissolve K-bearing minerals, and release K by creating capsular polysaccharides, hydroxyl anions, exopolysaccharides, siderophores, organic ligands, extracellular catalysts, synthesis of organic and inorganic acids and biofilms on rhizospheric mineral surfaces (Etesami and Beattie 2017, Meena, Maurya, and Verma 2014, Uroz et al. 2009).

Besides minerals bearing potassium, some PGPR (i.e. *Bacillus*, *Burkholderia* and *Pseudomonas*), which are also known as silicate solvent bacteria, can break down silicon from the silicon minerals. Organic acids are, in particular, the most active substances for dissolving silicate minerals, for example, gluconic acid, feldspar, muscovite and biotite (Fig. 2a.).

1.4. Uptake of Micronutrients

PGPR increase the uptake of plant micronutrients (Fe, Mn, Zn, Cu, etc.). This increase is achieved in different ways. As an example, it can be done by lowering the soil pH to make it alkaline and increasing the air gaps between the soil particles.

1.4.1. Uptake of Iron (Fe)

Iron (Fe) is an important micronutrient, and is especially lacking in plants grown under dry and calcareous conditions. Siderophore-producing strains of PGPR may enhance iron-feeding in the plant. Iron (Fe) plays an important role in the energy metabolism of plants. Despite this, it is very difficult for the plant to pick up the debris from the soil. Because Fe does not exist as free ions in the soil, it is found as a ferric hydroxide polymer. In order to be able to obtain the iron found in this limited amount of soil, the bacteria living in the rhizosphere produce a water-soluble molecule, siderophore. Siderophores are organic compounds with low molecular weight and high affinity for binding some elements, such as Fe^{3+} and other metal ions, and for increasing plant availability. Siderophores are synthesised both by the PGPR bacteria found in the root region and by the plant itself (Altin and Tayyar 2005).

Fig. 4 shows intracellular transport of iron by siderophores carried out by microorganisms. This transport actually occurs in two ways: low coherent iron transport and high coherent iron transport. In low compatible iron transport, Fe^{+3} is transported into the cell through the cell membrane-associated receptor proteins.

In high compatible iron transport, siderophore forms a complex with Fe^{+3}, and the cell is trapped by zygotic receptor proteins. Iron is released from the Fe^{+3} + siderophore complex entering the cell, and this separation is by way of reduction. The iron-releasing siderophores re-enter the cell and form the Fe^{+3} + siderophore complex again.

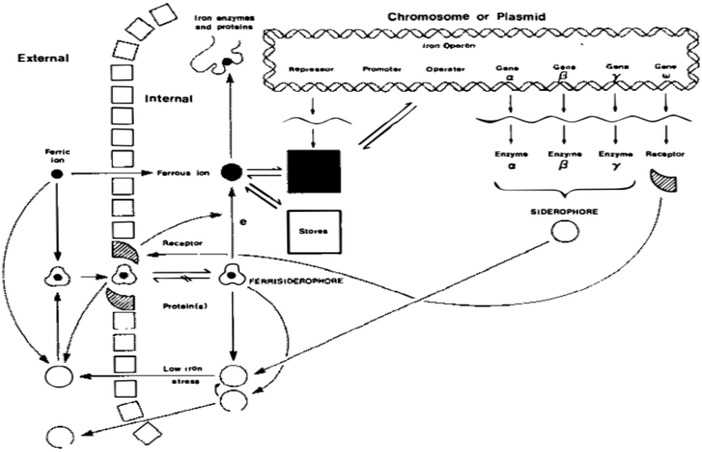

Fig.4. Low and high compatible iron transport in microorganisms.

1.4.2. Uptake of Manganase (Mn)

Some PGPR bacteria (*Bacillus*, *Pseudomonas and Geobacter*) reduce Mn^{+4} to Mn^{+2}. These bacteria increase the availability of Mn to the plant, while Mn^{+2} in the soil affects plant root growth. When the increase in the root secretion is carried out entirely by PGPR bacteria, the electron necessary for the reduction of MnO_2 to Mn^{+2} is obtained by decomposition of the carbonaceous compounds in the root secretion, and the proton required is obtained by proton elimination from the stem cells. Moreover, roots and PGPRs create chelating compounds (phenolic compounds and organic acids) that shape soluble complexes with Mn, Fe, and different components that keep their re-precipitation.

1.4.3. Uptake of Selenium (Se)

Selenium is the main component of selenoproteins, and plays an important role for plants. In addition to providing the necessary nutrients for plants, some PGPR (e.g. *Paenibacillus sp.*, *Bacillus sp.*, *Klebsiella*, *Acinetobacter sp.*, *Stenotrophomonas sp.*, *Enterobacter sp.*, *and Pseudomonas sp.*) are known as selenobacteria, which improve selenium accumulation in plants.

Selenobacteria are bacteria with a high selenium tolerance. These bacteria increase the transfer of selenium to shoots. In addition, they not only cause the amount of selenium in the crop to increase, but also remove the selenium stress that is caused by the excess of selenium present in the soil and seen in plants.

2. Indirect Effect of PGPR in Nutrient Uptake Efficiency

Plants face stress conditions, such as salinity, drought, temperature, frost and heavy metals. These stress conditions negatively affect plant growth, especially the growth of roots. This effect on roots causes a decrease in nutrient uptake.

These aforementioned drawbacks, stemming from stress in plant roots, can be solved by the PGPR producing IAA (indole-3-acetic acid), and PGPR containing the enzyme ACC (1-aminocyclopropane-1-carboxylate) deaminase. These PGPR might enhance the accessibility of the plant to the nutrients and water by providing the integrity of the plant root under stress conditions and, indirectly, affecting the repair of damaged areas. (Fig. 5)

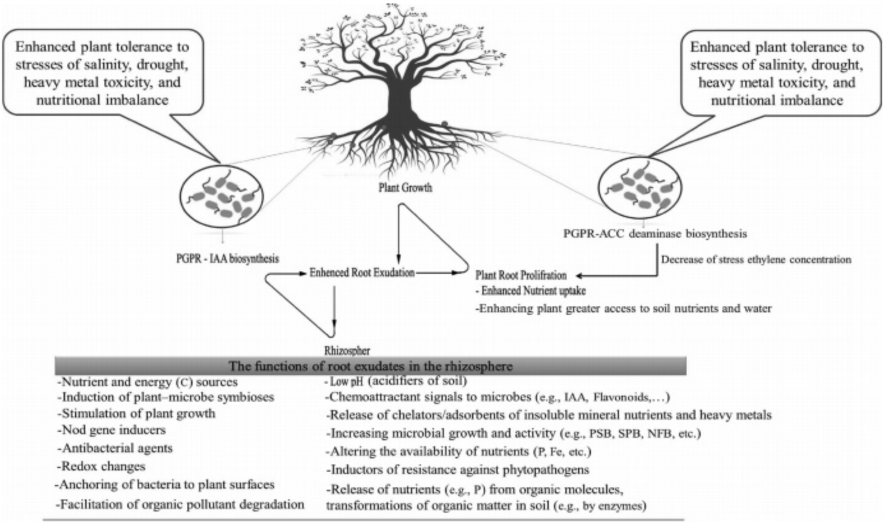

Fig. 5. The functions of root exudates in the rhizosphere

Root secretions usually contain substances essential to bacteria in the rhizosphere. These are saccharide, organic acid, L-Trp, phenols, vitamins, nucleotides and enzymes.

PGPR in the rhizosphere synthesise and secrete IAA. This IAA can build the plant cells and/or develop plant tissues (expanded root development and root length), thus together with the plant-determined incorporated IAA, a bigger root surface zone is achieved. The plant is therefore provided with more supplements and water, and discharges more leachate. IAA, likewise, gives extra supplements to help the rhizosphere bacteria develop by loosening the cell walls of the plant and increasing the root exudation. The release of more supplements increases microbial dynamics as well as IAA, and this procedure proceeds in a cycle. PGPRs producing ACC deaminase might expand root development and root length by diminishing ethylene stress, thus increasing plant development and root exudates.

Hormones, like IAA (indole-3-acetic acid), cytokinin and gibberellin are viable in plant development. IAA (the so-called auxin hormone) and cytokinin are involved in the intake of plant nutrients, and indirectly affect the nutrient intake of plants by inducing events, for instance, cell division, seed germination, root improvement, chlorophyll sequestration and leaf advancement. While the major hormone produced by PGPR is IAA (Fallik et al. 1989), the hormones such as indole lactic acid, indole-3-butyric acid, indole-3-ethanol, indol-3-methanol, some gibberellin and some cytokinin are also produced by PGPR (Bashan and Levanony 1990, Crozier et al. 1988, Tien, Gaskins, and Hubbell 1979). For instance, IAA synthesis, which was induced by indole-pyruvic acid and indole-3-acetic aldehyde, was detected in *Erwiniaherbicola*, some saprophytic *Pseudomonas* and *Agrobacterium* species, *Bardyrhizobium*, *Rhizobium*, *Azospirillum*, *Klebsiella* and *Enterobacter*. IAA, which is derived from Tryptophan, is found in *Cyanobacterium* bacteria, whereas IAA production, which is independent from Tryptophan, was detected in *Azospirila* and C*yanobacteria* (Imriz 2014).

Ethylene is a very important hormone for plants, but its over-expression in stress conditions damages the plant. This hormone affects seed germination, root growth, root nodulation, flowering and fruit formation in plants. The 1-aminocyclopropane-1-carboxylate (ACC) deaminase, one of the previously mentioned enzymes stabilises the ethylene hormone by inhibiting the excessive secretion of ethylene hormone into this sheath (Glick 1995, Glick, Penrose, and Li 1998).