ADVANCES IN ENVIRONMENTAL BIOLOGY

ISSN:1995-0756
EISSN:1998-1066

2021 March; 15(3): Pages 1-8
https://doi.org/10.22587/aeb.2021.15.3.1

REVIEW ARTICLE AENSI PUBLICATIONS

Phosphate solubilizing bacteria and its role in plant growth enhancement: A review

P. Sivasakthivelan[1], P. Saranraj[2], Abdel Rahman M. Al-Tawaha[3*], K Arivukkarasu[1] Imran[4], Amanullah[4], Abdel Razzaq Al Tawaha[5], D Thangadurai[6], J Sangeetha[7], A Rauf[8], S Khalid[4], S N Sirajuddin[9], Wael Alsultan [10], Malek Alwedyan[11]

[1]Department of Agricultural Microbiology, Faculty of Agriculture Annamalai University, Chidambaram 608 002, Tamil Nadu, India
[2]Department of Microbiology, Sacred Heart College (Autonomous), Tirupattur, Tamil Nadu, India
[3]Department of Biological Sciences, Al Hussein Bin Talal University, Maan, Jordan
[4]Department of Agronomy, the University of Agriculture, Peshawar, Pakistan
[5]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[6]Department of Botany, Karnatak University, Dharwad, 580003, Karnataka, India
[7]Department of Environmental Science, Central University of Kerala, Kasaragod, 671316, Kerala, India
[8]Department of Chemistry, University of Swabi, Anbar, Khyber Pakhtunkhwa, Pakistan ICAR-Central
[9]Faculty of Animal Science, Hasanuddin University, Jl.Perintis Kemerdekaan Km.10 Makassar, South Sulawesi, Indonesia 90245
[10]Department of Plant Protection, Faculty of Agriculture, Universiti Putra Malaysia (UPM), Serdang 43400, Selangor, Malaysia
[11]Department of Entomology, Texas A&M University, College of Agriculture & life Sciences, USA

Correspondence Authors: Abdel Rahman M. Al-Tawaha, Department of Biological Sciences, Al Hussein Bin Talal University, Maan, Jordan.
E-mail: abdel-al-tawaha@ahu.edu.jo

Received date: 30 December 2020, Accepted date: 28 March 2021

Cite as: P. Sivasakthivelan., P. Saranraj., A. R. M. Al-Tawaha., K. Arivukkarasu., Imran., Amanullah., A. R. Al Tawaha., D. Thangadurai., J. Sangeetha., A. Rauf., S. Khalid., S. N. Sirajuddin., W. Alsultan., M. Alwedyan., 2021. Phosphate solubilizing bacteria and its role in plant growth enhancement: A review. Advances in Environmental Biology, 15(3): 1-8. DOI:10.22587/aeb.2021.15.3.1.

Abstract
Phosphorus is an essential constituent of many organic components of biological importance. The deficiency of phosphorus impairs growth and reproductive process; phosphorus cannot be replaced by any another element in all respects and is uniquely associated with essential metabolites. Phosphorus is required for proper growth development and maturity of field crops. This present review is focused on the role of phosphate solubilizing bacteria in the enhancement of plant growth.

Keywords: Phosphate, solubilizing bacteria, plant growth

INTRODUCTION

Phosphorus (P) is one of the most critical macronutrients; the soil in India is low in available phosphorus. Numbers of chemical, physical and biological factors are related to phosphorus availability in soil. The major problem in availability is its transformation from the soluble form into insoluble or unavailable form. Sorption (fixation), precipitation and immobilization are significant transformations that curtail or restrict phosphorous availability in soil either temporarily or permanently. Several phosphate solubilizing bacteria (PSB), particularly those belonging to the genera *Bacillus*, *Pseudomonas* and phosphate solubilizing fungi (PSF) belonging to the genera *Aspergillus* and *Penicillium* possess the ability to convert insoluble phosphates into soluble forms by secreting organic acids, thereby lowering the pH and bringing about the solubilization of bound phosphates [1].

2. MINERAL PHOSPHATE SOLUBILIZATION

The ability of different bacterial species to solubilize insoluble inorganic phosphate compounds, such as tricalcium phosphate, dicalcium phosphate, hydroxyapatite, and rock phosphate, was reported by scientists; different genera of bacteria can solubilize phosphate and are *Bacillus, Pseudomonas, Rhizobium, Agrobacterium, Burkholderia, Achromobacter, Aereobacter, Flavobacterium* and *Erwinia.* There are considerable populations of phosphate-solubilizing bacteria in soil and plant rhizospheres [2, 3]. These include aerobic and anaerobic strains, with aerobic strains in submerged soils [4]. A considerably higher concentration of phosphate solubilizing bacteria is commonly found in the rhizosphere compared to non-rhizosphere soil [5].

Manual observation and semi-quantitative estimation of the phosphate solubilizing ability of microorganisms have been possible by screening the plates, which show clearing halo zones around the microbial colonies in medium containing insoluble mineral phosphates (such as tricalcium phosphate or hydroxyapatite) as the single phosphate source. In some cases, there have been contradictory results between plate halo detection and phosphate solubilization in liquid cultures [6]. However, the method is generally reliable for isolating and preliminary characterization of phosphate solubilizing microorganisms [7, 8]. Gupta *et al*. [9] developed an improved procedure using bromophenol blue medium. In the medium, yellow-colored halos zones are formed around the colonies, responding to the drop in pH produced by the release of specific organic acids responsible for phosphate solubilization.

In vitro studies of the dynamics of phosphate solubilization by bacterial strains have been carried out based on the measurement of phosphate release into a culture broth from cultures developed using an insoluble compound as the only phosphate source. The rate of phosphate solubilization is often estimated by subtracting the final phosphate concentration (minus that of an inoculated control) from the initial theoretical phosphate supplied by the phosphate substrate. However, this estimation has the disadvantage of not considering the phosphate utilized by the cells during growth [10].

A decrease in phosphate concentration in the medium could be observed when the uptake rate is higher than that of solubilization, when the uptake rate decreases (for instance, due to decreasing growth or entry into the stationary phase) level in the medium increases again. More probably, a combination of two or more phenomena could be involved in this behaviour. Thus, the phosphate concentration in the culture broth as an indication of capacity to solubilize phosphate should be noted with caution, and a kinetic study of this parameter would be a more reliable picture of cellular behaviour toward phosphate [11].

A critical potassium concentration is necessary for optimum solubilization rates, while magnesium and sodium seem essential in some fungi but not *Pseudomonas* strains. The role of nitrogen and phosphorous uptake remains controversial [12]. Instability of the phosphate-solubilizing character of some strains after several cycles of inoculation has been reported [13]. However, the trait seems to remain stable in most isolates [14].

3. ORGANIC PHOSPHATE SOLUBILIZATION

Soil contains a wide range of organic substrates, which is also a source of phosphate for plant growth. Phosphate available for plant nutrition through hydrolyzed to inorganic phosphorous. Mineralization of organic phosphorous compounds is carried out by means of an enzyme called phosphatase. The presence of a significant amount of phosphatase activity in soil has been reported [15]. Essential levels of microbial phosphatase activity have been detected in different types of soils. The major source of phosphatase activity in soil is considered to be of microbial origin. In particular, phosphatase activity is substantially increased in the rhizosphere [16].

The presence of organic phosphate-mineralizing bacteria in soil has been documented by Greaves and Webley [17] for the rhizosphere of pasture grasses by Raghu and MacRae [18] for rice plants, as well as by Abd-Alla [19], and others. Most soils range from acidic to neutral pH values. Thus, acid phosphatases should play a major role in this process. Significant acid phosphatase activity was observed in the rhizosphere of slash pine in two forested Spodosoils [20]. Burns [21] studied the activity of various phosphatases in the rhizosphere of maize, barley, and wheat, showing that phosphatase activity was considerable in the inner rhizosphere at acidic and neutral soil pH. Soil bacteria expressing a significant level of acid phosphatases include strains from the genus *Rhizobium*, *Enterobacter*, *Serratia*, *Citrobacter, Proteus, Klebsiella,* as well as *Pseudomonas* and *Bacillus*.

4. Phosphate solubilizing bacteria as plant growth promoters

Even though many phosphate solubilizing bacteria are present in the soil, it is not high enough to compete with other rhizosphere bacteria. Thus, the quantity of phosphate released by them is not sufficient for a substantial increase in plant growth and development. Hence, inoculation of plants by a phosphate solubilizing microorganism is essential for yield enhancement. Therefore, many works have been carried out on plant growth promotion by bacteria that can solubilize inorganic and organic phosphate from the soil after their inoculation in soil or plant seeds [22].

The production by strains such as phytohormones, antibiotics, siderophores has created confusion about the specific role of phosphate solubilization in plant growth and yield simulation. However, several soil microorganisms, including bacteria, improve phosphate supply to plants as they can solubilize inorganic or organic phosphate. Considering that phosphate availability is a limiting step in plant nutrition, this evidence suggests a fundamental contribution of phosphate-solubilizing bacteria to plant nutrition and, therefore, improves plant growth performance [23].

Commercial bio inoculants for phosphate solubilization using mixed bacterial cultures have been formulated. Examples of these are: 'Phylazonit-M', a product containing *Bacillus megaterium*; *Azotobacter chroococcum,* which allows an increase in N and P supply to the plants; and the product known as 'KYUSEI EM' (EM Technologies, Inc.), a mixed inoculum including lactic acid bacteria, the lactic acid being the agent for mineral phosphate solubilization. Considerable evidence supports the specific role of phosphate solubilization in the enhancement of plant growth by phosphate-solubilizing bacteria. For example, an inoculant using *Bacillus megaterium* var. *phosphoricum* was applied successfully in the former Soviet Union and India, but it did not show the same efficiency in soils [24]. The efficiency of the Bioinoculant varies with many factors and the phosphate content of the soil is the crucial factor in determining the product's field effectiveness.

5. MECHANISM OF PHOSPHATE SOLUBILIZATION

5.1. Solubilization of mineral phosphates

It is generally accepted that the major mechanism of mineral phosphate solubilization is the action of organic acids synthesized by soil microorganisms [25]. Organic acid production results in the acidification of the surroundings of the microbial cells. Consequently, phosphate may be released from a mineral phosphate by proton substitution for calcium.

Several authors have reported the organic acid production by phosphate solubilizing bacteria, and Among them, gluconic acid seems to be the most frequent agent of mineral phosphate solubilization. It is noticed that the significant organic acid is produced by phosphate solubilizing bacteria such as *Pseudomonas* sp., *Erwinia herbicola*, *Pseudomonas cepacia* and *Burkholderia cepacia*. Other, strains with phosphate solubilizing ability was *Rhizobium leguminosarum*, *Rhizobium meliloti* and *Bacillus firmus.* Strains of *Bacillus liqueniformis* and *Bacillus amyloliquefaciens* were also found to produce various acids as mixtures of lactic, isovaleric, isobutyric, and acetic acids. Other organic acids, such as glycolic, oxalic, malonic, and succinic acid, have also been identified among phosphate solubilizers [26].

Experimental evidence also supports the vital role of organic acids in the solubilization of phosphate. Liu *et al*. [26] showed that the organic acids isolated from a culture of *Rhizobium leguminosarum* solubilized an amount of P nearly equivalent to the amount that was solubilized by the whole culture. Besides, treatment of the culture filtrates from several *Rhizobium* strains with pepsin or removal of proteins by acetone precipitation did not affect phosphate release capacity, showing that this was not an enzymatic process. However, neutralization with NaOH destroyed the solubilization activity. Based on these findings, following the cloning of mineral phosphate solubilization genes, Goldstein and Liu [27] has proposed that the mineral phosphate solubilization phenotype in some Gram-negative bacteria forms the metabolic basis for the direct periplasmic oxidation of glucose to gluconic acid, and often 2-ketogluconic acid.

Other than organic acids for mineral phosphate solubilization, alternative possibilities have been proposed based on the lack of a linear correlation between pH and the amount of solubilized phosphate [28]. Studies have shown that the release of H1 to the outer surface in exchange for cation uptake or with the help of H1 translocation ATPase could constitute alternative ways for solubilization of mineral phosphates. In addition, other mechanisms have been considered, such as the production of chelating substances by microorganisms and the production of inorganic acids, such as sulphidric, nitric and carbonic acid [29]. However, the effectiveness of these processes has been questioned and their contribution to P release in soil appears to be negligible [30].

5.2. Mineralization of organic phosphorous

Several environmental parameters strongly influence the mineralization of organic phosphorus by phosphate solubilizing microbes; even slight alkalinity favours the mineralization of organic phosphorus. The degradability of organic phosphorous compounds depends mainly on their molecules' physicochemical and biochemical properties, e.g., nucleic acids, phospholipids and sugar phosphates are easily broken down, but phytic acid, polyphosphates and phosphonates are decomposed more slowly [26]. These compounds are mineralized by the action of several phosphatases (also called phosphohydrolases). These dephosphorylating reactions involve the hydrolysis of phosphodiester or phosphoanhydride bonds. The phosphohydrolases are clustered in acid or alkaline. The acid phosphohydrolases shows optimal catalytic activity at acidic to neutral pH values, unlike alkaline phosphatases. Moreover, they can be further classified as specific or nonspecific acid phosphatases concerning their substrate specificity [31].

Macronutrients play a vital part in growing and developing plants [32-48]. On the other hand, many studies concluded that low productivity is primarily related to management practices in dryland agriculture [50-56]. In addition, research has demonstrated substantial linkages between temperature, fertilizer applications, plant populations and planting dates [56-72].

Numerous studies indicate that the availability of nutrients is vital for plant growth, particularly in the case of weeds that influence and inhibit crop growth for nutrients in the soil. In addition, active organic matter provides habitat and nutrition for beneficial soil organisms, which help create soil structure and porosity, provide plant nutrients, and improve the ability of the soil to retain water [73-112].

6. CONCLUSION

Phosphorus is an essential constituent of many organic components of biological importance. The deficiency of phosphorus impairs growth and the reproductive process; phosphorus cannot be replaced by any other element in all respects and is uniquely associated with essential metabolites. Phosphorus is required for proper growth development and maturity of field crops. Generally, *Bacillus, Pseudomonas* and phosphate solubilizing fungi were found to be the most efficient in solubilizing various insoluble forms of phosphates. The rock phosphate and casein solubilization by all the microbial isolates were more pronounced than the other sources of phosphates in inorganic and organic.

REFERENCES

[1] Pal S S 1998 Interaction of an acid tolerant strain of phosphate solubilizing bacteria with a few acid-tolerant crops Plant Soil 198 167–77
[2] Alexander M 2007 Introduction to Soil Microbiology (New York: Wiley and Sons)
[3] Sperberg J I 2008 The incidence of apatite-solubilizing organisms in the rhizosphere and soil Aus. J.
[4] Agri. Res. 9 781–8
[5] Raghu K and MacRae I C 2006 Occurrence of phosphate dissolving microorganisms in the rhizosphere of rice plants and in submerged soils J. Appl. Bact. 29 582–6
[6] Katznelson H, Peterson E A and Rovatt J W 2012 Phosphate dissolving microorganisms on seed and in the root zone of plants Can. J. Bot. 40 1181–6
[7] Das A C 2013 Utilization of insoluble phosphates by soil fungi J. Ind. Soc. Soil Sci. 11 203–17
[8] Illmer P and Schinner F 2012 Solubilization of inorganic phosphates by microorganisms isolated from forest soil Soil Biol. Biochem. 24 389–95
[9] Ostwal K P and Bhide V P 2012 Solubilization of tricalcicum phosphate by soil Pseudomonas Ind. J. Exp. Bio. 10 153–4
[10] Gupta R, Singal R, Sankar A, Chander R M and Kumar R S 1994 A modified plate assay for screening phosphate solubilizing microorganisms J. Gen. Appl. Micro. 40 255–60
[11] Bardiya M C and Gaur A C 2014 Isolation and screening of microorganisms dissolving low grade rock phosphate Folia Micro. 19 386–9
[12] Gupta R, Singal R, Sankar A, Chander R M and Kumar R S 1994 A modified plate assay for screening phosphate solubilizing microorganisms J. Gen. Appl. Micro. 40 255–60
[13] Cabala Rosand P and Wild A 2012 Direct use of low grade phosphate rock from Brazil as fertilizer II Effects of mycorrhiza inoculation and nitrogen source Plant Soil 65 363–73
[14] Kucey R M N 2013 Phosphate solubilizing bacteria and fungi in various cultivated and virgin Alberta soils Can. J. Soil Sci. 63 671–8
[15] Arora D and Gaur C 2009 Microbial solubilization of different inorganic phosphates Ind. J. Exp. Bio. 17 1258–61
[16] Babenko Y S, Tyrygina G, Grigoryev E F, Dolgikh L M and Borisova T I 2014 Biological activity and physiological and biochemical properties of bacteria dissolving phosphates Microbiolo. 53 533–9
[17] Bardiya M C and Gaur A C 2014 Isolation and screening of microorganisms dissolving low grade rock phosphate Folia Micro. 19 386–9
[18] Greaves M P and Webley D M 2006 A study of the breakdown of organic phosphates by microorganisms from the root region of certain pasture grasses J. Appl. Bact. 28 454–65
[19] Raghu K and MacRae I C 2006 Occurrence of phosphate dissolving microorganisms in the rhizosphere of rice plants and in submerged soils J. Appl. Bact. 29 582–6
[20] Abd-Alla M H 2014 Use of organic phosphorus by Rhizobium leguminosarum biovar. Viceae phosphatases Biol. Ferti. Soils. 18 216–8
[21] Fox T R and Comerford N B 2012 Rhizosphere phosphatase activity and phosphatase hydrolyzable organic phosphorus in two forested spodosols Soil Bio. Biochem. 24 579–83
[22] Burns R G 2013 Extracellular enzyme-substrate interactions in soil Microbes in their Natural Environment ed J H R Slater, J W T Whittenbury, Wimpenny (Cambridge: Cambridge University Press) pp 249–98
[23] Datta M, Banish S and Dupta R K 2012 Studies on the efficacy of a phytohormone producing phosphate solubilizing Bacillus firmus in augmenting paddy yield in acid soils of Nagaland Plant Soil 69 365–73
[24] Lifshitz R, Kloepper J W, Kozlowski M, Simonson C, Carlson J, Tipping E M and Zalesca I 2007 Growth promotion of canola (rapeseed) seedlings by a strain of Pseudomonas putida under gnotobiotic conditions Can. J. Micro. 33 390–5
[25] Smith J H, Allison F E and Soulides D A 2012 Phosphobacteria as a soil inoculant Tech US Dept Agriculture Bulletin 1 63–70
[26] Salih H M, Yahya A Y, Abdul Rahem A M and Munam B H 2009 Availability of phosphorus in a calcareus soil treated with rock phosphate or superphosphate as affected by phosphate dissolving fungi Plant Soil 120 181–5
[27] Liu T S, Lee L Y, Tai C Y, Hung C H, Chang Y S, Wolfram J H, Rogers R and Goldstein A H 2012 Cloning of an Erwinia herbicola gene necessary for gluconic acid production and enhanced mineral phosphate solubilization in Escherichia coli HB101: Nucleotide sequence and probable involvement in biosynthesis of the coenzyme pyrroloquinoline quinone J. Bact. 174 5814–9
[28] Goldstein A H and Liu S T 2007 Molecular cloning and regulation of a mineral phosphate solubilizing gene from Erwinia herbicola Biotech. 5 72–4

[29] Asea P E A, Kucey R M N and Stewart J W B 2008 Inorganic phosphate solubilization by two Penicillium sp. in solution, culture and soil Soil Bio. Biochem. 20 459–64
[30] Hopkins C G and Whiting A L 2006 Soil bacteria and phosphates Agri. Exp. Bul. 190 395–406
[31] Hussein T F, Darweish G A and Rattiba M M 2006 Effect of planting dates on growth yield and quality of some soybean cultivars J. Agri. Sci. 31 587–94
[32] Rudolfs W 2012 Influence of sulfur oxidation upon growth of soy beans and its effect on bacterial flora of soil Soil Sci. 14 247–62
[33] Turk M A and Tawaha A M 2001 Common vetch (Vicia sativa L.) productivity as influenced by rate and method of phosphate fertilization in a mediterranean environment Agric. Mediterr. 131 108– 11
[34] Tawaha A M and Turk M A 2001 Effects of dates and rates of sowing on yield and yield components of Narbon vetch under semi-arid condition Acta Agron. Hungarica. 49 103–5.
[35] Sulpanjani A, Yang M S, Tawaha A R M And Lee K D 2005 Effect of Magnesium application on yield, mineral contents and active components of Chrysanthemum coronarium L. under Hydroponics Conditions Biosci. Res. 2 73–9
[36] Lee K D, Sulpanjani, Tawaha A M and Min Yang S 2005 Effect of Phosphorus application on yield, mineral contents and active components of Chrysanthemum coronarium L Biosci. Res. 2 118–24
[37] Lee K D, Turk M A and Tawaha A M 2005 Nitrogen fixation in rice based farming system. Biosci.Res. 2 130–8
[38] Nikus O, Nigussie M, and Al Tawaha A M 2005 Agronomic performance of maize varieties under irrigation In Awash Valley, Ethiopia Biosci. Res. 2 26–30
[39] Abera T, Feyisa D, Yusuf H, Nikus O, Al-Tawaha A M 2005 Grain yield of maize as affected by biogas slurry and N-P fertilizer rate at Bako, Western Oromiya, Ethiopia Biosci. Res. 2 31–8
[40] Supanjani, Tawaha A M, Min Yang M S, and Lee K D 2005 Role of calcium in yield and medicinal quality of Chrysanthemum coronarium L J. Agron. 4 188–92
[41] Supanjani, Tawaha A M, Yang M S, Lee Y D 2005 Calcium effects on yield, mineral uptake an terpene components of hydroponic chrysanthemum coronarium L Res. J. Agric. Biol. Sci. 1 146–51
[42] Nikus O, Abebe G, Takele A, Harrun H, Chanyalew S, Al Tawaha A M, and Mesfin T 2005 Yield response of tef (Eragrostis tef (Zucc.) Trotter) to NP fertilization in the semi arid zones of the central rift valley in Ethiopia Eur. J. Sci. Res. 4 49–60
[43] Lee K D, Tawaha A R M and Supanjani 2005 Antioxidant status stomatal resistance and mineral composition of hot pepper under salinity and boron stress Biosci. Res. 2 148–54
[44] Tawaha A M, Turk M A, Lee K D, Supanjani, Nikus O, Al-Rifaee M, Sen R 2005 Awnless barley response to Crop Management under Jordanian Environ. Biosci. Res. 2 125–9
[45] Abebe G, Assefa T, Harrun H, Mesfine T, and Al-Tawaha A M 2005 Participatory selection of drought tolerant maize varieties using mother and baby methodology: A case study in the semi arid zones of the central rift valley of ethiopia World J. Agric. Sci. 1 22–7
[46] Assefa T, Abebe G, Fininsa C, Tesso B and Al-Tawaha A M 2005 Participatory Bean Breeding with Women and Small Holder Farmers in Eastern Ethiopia World J. Agric. Sci. 1 28–35
[47] Yang M S, Tawaha A M, and Lee Y D 2005 Effects of ammonium concentration on the yield, mineral content and active terpene components of Chrysanthemum coronarium L. in a hydroponic system Res. J. Agric. Biol. Sci. 1 170–5
[48] Tawaha A R M, Turk M A, and Lee K D 2005 Adaptation of chickpea to cultural practices in a Mediterranean type environment. Res. J. Agric. Biol. Sci. 1 152–7.
[49] Mesfine T, Abebe G, and Al-Tawaha A M 2005 Effect of reduced tillage and crop residue ground cover on yield and water use efficiency of sorghum (Sorghum bicolor (L.) Moench) under semi- arid conditions of Ethiopia World J. Agric. Sci. 1 152–60
[50] Abebe G, Sahile G, and Al-Tawaha A M 2005 Evaluation of potential trap crops on Orobanche soil seed bank and tomato yield in the central rift valley of Ethiopia World J. Agric. Sci. 1 148–51
[51] Abebe G, Sahile G, and Al-Tawaha, A.M. 2005. Effect of soil solarization on Orobanche soil seed bank and tomato yield in the central rift valley of Ethiopia World J. Agric. Sci. 1 143–7.
[52] Abebe G, Hattar B and Al-Tawaha A M 2005 Nutrient availability as affected by manure application in cowpea (Vigna unguiculata (L.) Walp on calacarious soils J. Agric. Soc. Sci. 1 1–6
[53] Zheng W J, Tawaha A M and Lee K D 2005 In situ hybridization analysis of mcMT1 gene expression and physiological mechanisms of Cu-Tolerant in (Festuca rubra cv Merlin) Biosci. Res.1 21–6
[54] Al-Tawaha A M, Turk M A, Lee K D, Zheng W Z, Ababneh M, Abebe G and Musallam I W 2005 Impact of fertilizer and herbicide application on performance of ten barley genotypes grown in Northeastern part of Jordan Int. J. Agric. Biol. 7 162–6
[55] Zaitoun S T, Al Ghzawi A, Shannag H K and Al-Tawaha A M 2006 Comparative study on the pollination of strawberry by bumble bees and honeybees under plastic house conditions in Jordan valley J. Food, Agric. Environ. 2 237–40
[56] Assaf T A, Hameed K M, Turk M A and Tawaha A M 2006 Effect of soil amendment with olive mill by-products under soil solarization on growth and productivity of faba bean and their symbiosis with mycorrhizal fungi World J. Agric. Sci. 2 21–8
[57] Turk M A, Al-Jamali A F and Tawaha A M 2002 Effect of seeding rate and ethrel spray on the morphology and the yield traits of irrigated faba bean (Vicia faba (L) major) Crop Res 23 305–7
[58] Al-Tawaha A M, Seguin P, Smith D L and Beaulieu C 2006. Foliar application of elicitors alters isoflavone concentrations and other seed characteristics of field-grown soybean. Can. J. Plant Sci. 86 677–84

[59] Seguin P, Bodo R and Al-Tawaha A M 2007 Soybean isoflavones: Factors affecting concentrations in seeds Advances in Medicinal Plant Research ed S N Acharya and J E Thomas (Kerala: Research Signpost) pp 65–81
[60] Al-Tawaha A R M and Al-Ghzawi A L A 2013 Effect of chitosan coating on seed germination and salt tolerance of lentil (Lens culinaris L.) Res. Crop. 14 489–91.
[61] Al-Tawaha A M and Ababneh F 2012 Effects of site and exogenous application of yeast extract on the growth and chemical composition of soybean International Conference on Agricultural, Environment and Biological Sciences pp 52–4.
[62] Kiyyam M A A, Turk M, and Tawaha A R 2007 Effect of plant density and nitrogen rate on essential oils of marjoram under mediterranean conditions. Pak. J. Sci. Ind. Res 50 383–8.
[63] Hammed K, Turk M, Assaf T, and Al-Tawaha M A L 2008 Effects of application of olive mill by- products on chickpea yield and their symbiosis with mycorhizal fungi under arid conditions. Int.J.Plant Prod 2 341–52.
[64] Al-Kiyyam M A, Turk M, Al-Mahmoud M, and Al-Tawaha A R 2008 Effect of plant density and nitrogen rate on herbage yiels of marjoram under mediterranean conditions. J. Am. J. Agric. Environ. Sci. 3 153–8
[65] Hani N B, Al-Ramamneh E A D, Haddad M., Al-Tawaha A R, and Al-Satari Y 2019 The impact of cattle manure on the content of major minerals and nitrogen uptake from 15N isotope-labeled ammonium sulphate fertilizer in maize (Zea mays L.) plants Pak. J. Bot. 51 185–9
[66] Amanullah, Khan N, Khan M I, Khalid S, Iqbal A and Al-Tawaha A M 2019 Wheat biomass and harvest index increases with integrated use of phosphorus, zinc and beneficial microbes under semiarid climates J. Microbiol. Biotechnol. food Sci. 9 242–7
[67] Al-Taey D K, Al-Shareefi M J, Mijwel A K, Al-Tawaha A R and Al- Tawaha A R 2019 The beneficial effects of bio-fertilizers combinations and humic acid on growth, yield parameters and nitrogen content of broccoli grown under drip irrigation system. Bulg. J. Agric. Sci 25 959–6
[68] Khalid S, Khan H A, Arif M., Altawaha A R, Adnan M, Fahad S, and Parmar B 2019 Organic matter management in cereals based system: Symbiosis for improving crop productivity and soil health Sustainable Agriculture Reviews Ed (Berlin: Springer) pp 67-92
[69] Singh B, Upadhyay A K, Al-Tawaha T W, Al-Tawaha A R, and Sirajuddin S N 2020 Biofertilizer as a tool for soil fertility management in changing climate IOP Conf. Ser. Earth Environ. Sci. 492 012158
[70] Al-Tawaha A R, Al-Karaki G N, Al –Tawaha A R, Sirajuddin S N, Makhadmeh I, Wahab P E M, Refat A, Youssef, Al Sultan W, Massadeh A 2018 Effect of water flow rate on quantity and quality of lettuce (Lactuca sativa L.) in nutrient film technique (NFT) under hydroponics conditions. Bulg. J. Agric. Sci. 24 791–8
[71] Hayyawi W A, Al-Juthery, Kahraman H, Habeeb, Altaee F J K, D K A AL-Taey , Al-Tawaha A R M 2018 Effect of foliar application of different sources of nano-fertilizers on growth and yield of wheat. Biosci. Reserch 15 3988–97.
[72] Al-Ghzawi A L A, Al Khateeb W, Rjoub A, Al-Tawaha A R M, Musallam I, and Al Sane K O 2019 Lead toxicity affects growth and biochemical content in various genotypes of barley (Hordeum vulgare L.) Bulg. J. Agric. Sci. 25 55–61.
[73] Al-Juthery H W, Habeeb K H, Altaee F J K, AL-Taey D K, and Al-Tawaha A R M 2018 Effect of foliar application of different sources of nano- fertilizers on growth and yield of wheat Biosci. Res. 15 3976–85.
[74] Ananthi T, Amanullah M M, and Al-Tawaha A R M S 2017 A review on maize-legume intercropping for enhancing the productivity and soil fertility for sustainable agriculture in India Adv. Environ. Biol. 11 49–64.
[75] Al-Tawaha A R and Al-Tawaha A R M 2017 Response of soybean plants to exogenous application of yeast extract: Growth and chemical composition Am. J. Sustain. Agric. 11 31–6
[76] Al-Tawaha A R M, Jahan N, Odat N, Al-Ramamneh E A D, Al-Tawaha A R, Rauf A R A, Wadyan M (2020). Growth, yield and biochemical responses in barley to DAP and chitosan application under water stress J. Ecol. Eng. 21 86–93
[77] Turk,. M.A. And Tawaha, A.M. 2001. Common vetch (Vicia sativa L.) productivity as influenced by rate and method of phosphate fertilization in a Mediterranean environment. Agricultura Mediterranea, 131: 108-111.
[78] Tawaha, A.M. And Turk, M.A. 2001. Effects of dates and rates of sowing on yield and yield components of Narbon vetch under semi-arid condition. Acta Agronomica Hungarica, 49(1): 103- 105.
[79] SULPANJANI, A., YANG M.S., TAWAHA A.R.M. AND. LEE, K.D 2005.. Effect of Magnesium
[80] application on yield, mineral contents and active c/omponents of Chrysanthemum coronarium L. under Hydroponics Conditions. Bioscience Research, 2(2):73-79.
[81] Lee, K. D., Sulpanjani, Tawaha A.M. and Min Yang, S. 2005. Effect of Phosphorus application on yield, mineral contents and active components of Chrysanthemum coronarium L. Bioscience Research, 2(3): 118-124.
[82] Lee, K.D., Turk, M.A and. Tawaha, A.M.2005. Nitrogen fixation in rice based farming system.
[83] Bioscience Research, 2(3):130-138.
[84] Nikus,O., Nigussie, M., and Al Tawaha, A. M. 2005. Agronomic performance of maize varieties under irrigation In Awash Valley, Ethiopia. Bioscience Research, 2(1):26-30.
[85] Abera, T., Feyisa, D., Yusuf, H., Nikus, O., And Al-Tawaha, A.M. 2005. Grain yield of maize as affected by biogas slurry and N-P fertilizer rate at Bako, Western Oromiya, Ethiopia. Bioscience Research, 2(1): 31-38.
[86] Supanjani, Tawaha,A.M., Min Yang, M.S., And Lee, K.D. 2005. Role of calcium in yield and medicinal quality of Chrysanthemum coronarium L. Journal of Agronomy, 4 (3): 188-192.
[87] Supanjani, Tawaha, A.M., Yang, M.S., And Lee, Y.D. 2005. Calcium Effects on Yield, Mineral Uptake and Terpene Components of Hydroponic Chrysanthemum coronarium L. Research Journal of Agriculture and Biological Science, 1(1): 146-151.

[88] Nikus, O., Abebe, G., Takele, A., Harrun, H., Chanyalew, S., Al Tawaha A.M., And Mesfin, T. 2005. Yield response of tef (Eragrostis tef (Zucc.) Trotter) to NP fertilization in the Semi arid zones of the central rift valley in Ethiopia. European Journal of Scientific Research, 4(4): 49-60
[89] Lee, K.D., Tawaha A.R.M. And Supanjani, 2005. Antioxidant status, stomatal resistance and mineral composition of hot pepper under salinity and boron stress. Bioscience Research, 2(3): 148-154.
[90] Lee, K.D., Tawaha A.R.M. And Supanjani, 2005. Antioxidant status, stomatal resistance and mineral composition of hot pepper under salinity and boron stress. Bioscience Research, 2(3): 148-154.
[91] Tawaha, A.M. Turk, M.A., Lee, K.D., Supanjani, Nikus, O., Al-Rifaee M., And Sen, R. 2005. Awnless barley response to Crop Management under Jordanian Environment. Bioscience Research, 2(3): 125-129.
[92] Abebe, G., Assefa, T., Harrun, H., Mesfine T., And Al-Tawaha, A.M. 2005. Participatory Selection of Drought Tolerant Maize Varieties using Mother and Baby Methodology: A Case Study in the Semi Arid Zones of the Central Rift Valley of Ethiopia. World Journal of Agricultural Sciences, 1(1): 22-27.
[93] Assefa, T., Abebe, G., Fininsa, C., Tesso, B And Al-Tawaha, A. M. 2005. Participatory Bean Breeding with Women and Small Holder Farmers in Eastern Ethiopia. World Journal of Agricultural Sciences, 1(1): 28-35.
[94] Yang, M.S., Tawaha, A.M., And Lee, Y.D. 2005. Effects of ammonium concentration on the yield, mineral content and active terpene components of Chrysanthemum coronarium L. in a hydroponic system. Research Journal of Agriculture and Biological Science, 1(2): 170-175.
[95] Tawaha, A.R.M., Turk, M. A., And Lee, K.D. 2005. Adaptation of chickpea to cultural practices in a Mediterranean type environment. Research Journal of Agriculture and Biological Science, 1(2): 152-157.
[96] Zaitoun, S. T. ,Al_Ghzawi, A., Shannag, H. K. And Al -Tawaha, A. M. 2006. Comparative study on the pollination of strawberry by bumble bees and honeybees under plastic house conditions in Jordan valley. Journal of Food, Agriculture and Environment. 2(4): 237-240.
[97] Hani, N. B., Al-Ramamneh, E. A. D., Haddad, M., Al-Tawaha, A. R., and Al-Satari, Y. (2019). The impact of cattle manure on the content of major minerals and nitrogen uptake from 15N isotope- labeled ammonium sulphate fertilizer in maize (Zea mays L.) plants. Pak. J. Bot, 51(1), 185-189.
[98] Amanullah, Khan N, Khan M.I , Khalid S., Iqbal A. and Al-Tawaha A.M..2019. Wheat Biomass and Harvest Index Increases With Integrated Use Of Phosphorus, Zinc And Beneficial Microbes Under Semiarid Climates Journal of microbiology, biotechnology and food sciences 9(2):242-247.
[99] Al-Taey, D. K., Al-Shareefi, M. J., Mijwel, A. K., Al-Tawaha, A. R., and Al-Tawaha, A. R. (2019). The beneficial effects of bio-fertilizers combinations and humic acid on growth, yield parameters and nitrogen content of broccoli grown under drip irrigation system. Bulgarian Journal of Agricultural Science, 25(5), 959-966.
[100] Khalid, S., Khan, H. A., Arif, M., Altawaha, A. R., Adnan, M., Fahad, S., and Parmar, B. (2019). Organic matter management in cereals based system: Symbiosis for improving crop productivity and soil health. In Sustainable Agriculture Reviews 29 (pp. 67-92). Springer, Cham.
[101] Singh, B., Upadhyay, A. K., Al-Tawaha, T. W., Al-Tawaha, A. R., and Sirajuddin, S. N. (2020, April). Biofertilizer as a tool for soil fertility management in changing climate. In IOP Conference Series: Earth and Environmental Science (Vol. 492, No. 1, p. 012158). IOP Publishing.
[102] Al-Tawaha, A.R., Al-Karaki, G.N., Al -Tawaha, A.R., Sirajuddin, S. N., Makhadmeh, I.,Wahab,P.E.M, Refat A. Youssef, Al Sultan,W., Massadeh, A. (2018). Effect of water flow rate on quantity and quality of lettuce (Lactuca sativa L.) in nutrient film technique (NFT) under hydroponics conditions. Bulgarian Journal of Agricultural Science,24(5), 791–798
[103] Hayyawi W. A. Al-Juthery, Kahraman H. Habeeb, Fadil Jawad Kadhim Altaee, Duraid K.A.AL-Taey, Abdel Rahman M. Al-Tawaha.2018. Effect of foliar application of different sources of nano- fertilizers on growth and yield of wheat. Bioscience Research 15(4): 3988-3997.
[104] Al-Ghzawi, A. L. A., Al Khateeb, W., Rjoub, A., Al-Tawaha, A. R. M., Musallam, I., and Al Sane,K. O. (2019). Lead toxicity affects growth and biochemical content in various genotypes of barley (Hordeum vulgare L.). Bulgarian Journal of Agricultural Science, 25(1), 55-61.
[105] Al-Juthery, H. W., Habeeb, K. H., Altaee, F. J. K., AL-Taey, D. K., and Al-Tawaha, A. R. M. (2018). Effect of foliar application of different sources of nano-fertilizers on growth and yield of wheat. Bioscience Research, 15(4), 3976-3985
[106] Ananthi, T., Amanullah, M. M., and Al-Tawaha, A. R. M. S. (2017). A review on maize-legume intercropping for enhancing the productivity and soil fertility for sustainable agriculture in India. Advances in Environmental Biology, 11(5), 49-64.
[107] Turk, M. A., Assaf, T. A., Hameed, K. M., and Al-Tawaha, A. M. (2006).Significance of mycorrhizae. World Journal of Agricultural Sciences, 2(1), 16-20.
[108] Al-Tawaha, A. R., and Al-Tawaha, A. R. M. (2017). Response of soybean plants to exogenous application of yeast extract: growth and chemical composition. American-Eurasian Journal of Sustainable Agriculture, 11(2), 31-36.
[109] Al-Tawaha, A. R. M., Jahan, N., Odat, N., Al-Ramamneh, E. A. D., Al-Tawaha, A. R., Rauf, A., ... & Turk12, M. (2020). Growth, Yield and Biochemical Responses in Barley to DAP and Chitosan Application Under Water Stress. Journal of Ecological Engineering, 21(6), 86-93.
[110] Saranraj P, Sivasakthivelan P, Al-Tawaha AR, Bright R, Al-Tawaha AR, Thangadurai D, Sangeetha J, Rauf A, Khalid S, Al Sultan W, Safari ZS. Macronutrient management for the cultivation of Soybean (Glycine max L.): A review. In IOP Conference Series: Earth and Environmental Science 2021 Jun 1 (Vol. 788, No. 1, p. 012055). IOP Publishing.

[111] Saranraj P, Sivasakthivelan P, Al-Tawaha AR, Sudha A, Al-Tawaha AR, Sirajuddin SN. Diversity and evolution of Bradyrhizobium communities relating to Soybean cultivation: A review. In IOP Conference Series: Earth and Environmental Science 2021 Jun 1 (Vol. 788, No. 1, p. 012208). IOP Publishing.
[112] Tawaha AR, Khanum S, Al Tawaha AR, Thangadurai D, Sangeetha J, Rauf A, Khalid S, Saranraj P, Safari ZS, Zahid NA, Qazizadah AZ. Use of mycorrhiza in organic farming. In IOP Conference Series: Earth and Environmental Science 2021 Jun 1 (Vol. 788, No. 1, p. 012167). IOP Publishing.
[113] Saranraj P, Jayaprakash A, Devi VD, Al-Tawaha AR, Al-Tawaha AR. Isolation and nitrogen fixing efficiency of Gluconacetobacter diazotrophicus associated with sugarcane: A review. InIOP Conference Series: Earth and Environmental Science 2021 Jun 1 (Vol. 788, No. 1, p. 012171). IOP Publishing.