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Azotobacter: A Complete Review

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ABSTRACT
Azotobacter is one of the bio-fertilizer which contains living organisms which when applied on soil surface or seeds help in colonizing the rhizosphere or the interior parts of the plant parts and also help in promoting growth through the increase of the availability of primary nutrients to plants. Azotobacter is a free living gram negative bacterium which is oval or spherical in shape. It is an important bio-fertilizer which helps in increasing soil fertility through nitrogen fixation which later helps in increasing crop production through the process of biosynthesis of biologically active substances for plants uptake. It also plays an important role in nutrient cycling and increases nutrient availability so it is more ecofriendly when compared to chemical fertilizer. From research it is found that use of Azotobacter also increases the yield of some crops. With the growing importance of conserving natural resources, the use of biofertilizer alone or in combination with some fertilizer or pesticide is found to give good results in some research papers. Therefore, to decrease the rate of exhausting the soil with chemicals it is better to use bio-fertilizers. So, it is important to learn more about its importance and uses about the particular bio-fertilizer before practically using it.
Keywords: Azotobacter, biofertilizer, nitrogen fixation, soil fertility

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INTRODUCTION

Bio fertilizers also known as bio-inoculants; which are prepared organically contain microorganisms that are beneficial to agriculture products in supply of nutrients particularly N and P [1]. Bio fertilizers when used as seed treatment [2] or applied in soil [3]they rapidly multiply to develop more population in the rhizosphere [4]. Bio fertilizers are gaining more importance in agriculture nowadays as they are non-hazardous, non-toxic and eco-friendly [5].

Bio fertilizers including *Azotobacter* [6], Blue green algae[7], *Azospirillum*[8], mycorrhizae[9] and p-solubilizing microbes [10] as the advanced tools are being used and impart various benefits to the agriculture sector [11].

Azotobacter spp. are free-living, gram negative, oval or spherical in shape, aerobic soil dwelling bacteria [12.13]. *Azotobacter* was first discovered by a Dutch microbiologist and botanist Beijerinck in 1901 [14]. The genus *Azotobacter* has 7 different species which includes *Azotobacter croococcum, A. armeniacus, A. beijerinckii, A. paspali A. salinestris A. nigricans*and *A. vinelandii* [15,16]. Their size ranges from 1-2 μm wide and 2-10 μm long [17].

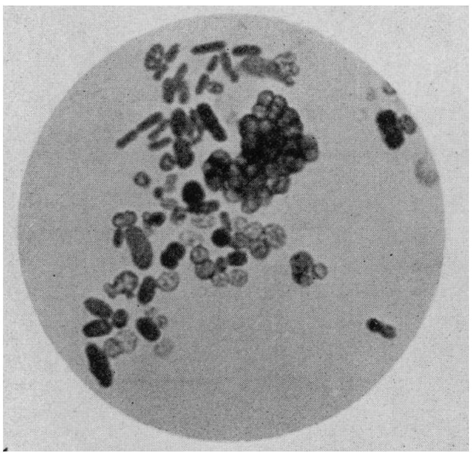

Figure 1: *Azotobacter* species cells (Beijerinck, 1901)

The atmospheric nitrogen gas is utilized by these bacteria for synthesis of their cell protein [18]. This cell protein will be mineralized after the *Azotobacter* cell is dead which will contribute the available nitrogen of the crop plants [19]. It is found that the *Azotobacter* spp. are sensitive to high temperature above 35oC, acidic pH and high salts [20]. This bacterium has beneficial effects on growth and yield of crop by stimulating rhizospheric microbes [21, 22], bio-synthesizing the active substance and producing phytopathogenic inhibitors [23, 24].

Azotobacter AS A BIO INOCULANT AND BIO FERTILIZER

The use of *Azotobacter* as bio fertilizer was introduced by Gerlach and Voel (1902) for supplying N to soil which is biologically fixed N2 as one of the activities for this microbe [25].This bacterium is playing a multifaceted role in stimulation of growth to plants which is not only the fixing of atmospheric N2 but also helps in possessing other activities of growth promotion such as phosphate solubilisation, PGRs production like auxins, cytokinins, gibberellins, amino acids and vitamins [26, 27, 28, 29, 30]. A report from Apte and Shende[28] shows that this bacterium possesses a high range of N2 fixation in the amount of 2-15mg N fixed per gram of glucose consumed and also has a high acetylene reduction assay (ARA). *Azotobacter chroococcum* helps in reducing the infection of nematodes by 48% which is followed by *Azospirillum* (4%) and Pseudomonas (11%) [31].

Azotobacter IN SOIL FERTILITY

As chemical fertilizers are quite expensive and give high cost of production which also have adverse effects on microbial population as well as soil health [23], in such a situation, bio fertilizer becomes the best alternative for maintaining soil fertility [32, 33]. Bio fertilizers being environmentally friendly and economic [34], they are found to be very useful for better crop production and yield [35].

Azotobacter spp. in soils has so many benefits on growth of plants, helps in improving germination of seeds [36, 37] and also has positive response on Crop Growth Rate (CGR) [38], also the abundant presence of these bacteria has positive relation to many of the soil physico-chemicals (e.g. organic matter, pH, soil moisture and temperature of the soil) and microbiological properties [39]. According to the soil profile depth, the abundance also varies [40].

Nitrogen fixation

Nitrogen fixation turns out to be the most important microbial activity [39] and biological processes [41] happening on the earth surface right after photosynthesis. The role of biological nitrogen fixation is very important in maintaining fertility of the soil [42]. *Azotobacter* can be used for the study of nitrogen fixation as well as plant inoculation because of its rapid growth and having high levels of nitrogen fixation [43, 44]. *Azotobacter* has the capability for conversing nitrogen into ammonia which later on taken up by the plants [45]. As *Azotobacter* spp. being non-symbiotic [46] and heterotrophic bacteria, they have the capability of fixing 20 kg N per hectare per year which can be used for crop production [47]. Bacterization helps in improving growth of plants [48] and increases soil nitrogen by utilizing carbon through nitrogen fixation for its metabolism [49, 50].

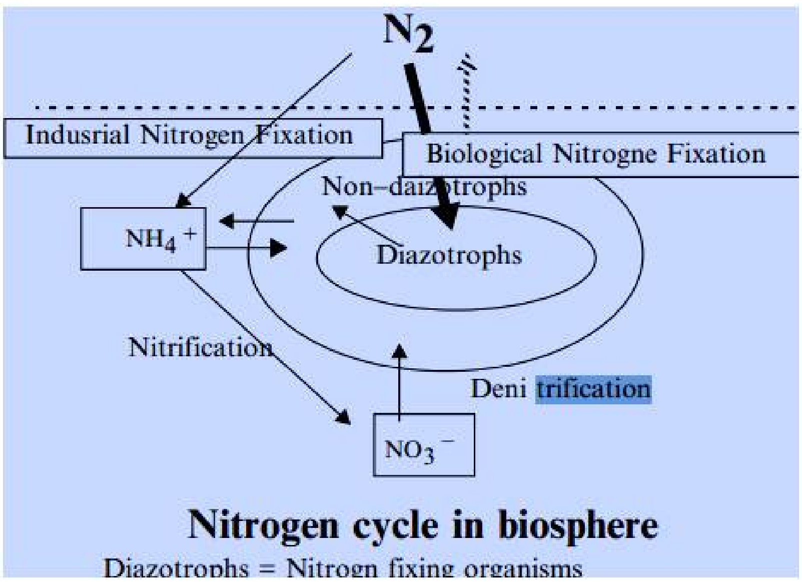

Figure 2: Nitrogen Fixation by *Azotobacter* spp. [4].

Azotobacter IN CROP PRODUCTION

Azotobacter spp. have so many beneficial effects on growth of crops through the process of biosynthesis of biologically active substances [51] producing phytopathogenic inhibitors and stimulation of rhizospheric microbes [52]. *Azotobacter* also makes the availability of some nutrients like carbon, phosphorus, nitrogen and sulphur through the process of accelerating the mineralized organic residues in soil [4] while avoiding the uptake of different heavy metals [53]. *Azotobacter* has become an important alternative for chemical fertilizers as it can provide nitrogen in ammonium form, amino acids and nitrate without leaving the situation over dosage [54]. *Azotobacter* as a nitrogen bio fertilizer helps in improving the growth and yield of different crops in field conditions [55] **Table 1**.

Azotobacter IN GROWTH AND YIELD OF CROPS

Azotobacter helps in stimulating the development of branching, flowering rooting foliage formation and fruiting which is initiated by plant growth regulator and fixed nitrogen [56]. This bacterium also helps plants in increasing tolerance to lack of water supply under adverse climatic conditions [57]. A report says that the yield of potato has been greatly increased after using *Azotobacter* spp. by 33.3% [57]. There is also a report that shows a significant increase in yield of mustard (var. Yella) and Rapeseed (7.86q ha-1) after inoculation with *Azotobacter* [58]. From a report of Das and Saha (2007) [59], the combined inoculation of *Azotobacter* with *Azospirillum* as well as *diazotrophs*helps in increasing the straw and grain yield of rice by 4.5 to 8.5 kg ha-1. Plants inoculated with *Azotobacter* have better crop yield as compared to those with non-inoculated plants and have a positive response on grain yield of maize [60].The grain yield increased while using *Azotobacter* in three different maize hybrids is shown in **Table 2.**

Table 1: *Azotobacter* effects on crop yield

Sl. No.	Crop	Yield increased over yield obtained from chemical fertilizers (%)
1	Rice	5
2	Sorghum	15-20
3	Wheat	8-10
4	Maize	15-20
5	Potato	13
6	Tomato	2-24
7	Carrot	16
8	Cauliflower	40
9	Cotton	7.27
10	Sugarcane	9-24

Source: Bhattacherjee and Dey [54]

Table 2: Effect of *Azotobacter* spp. in maize yield

Variant	Maize hybrids			
	ZP555 su	620 k	NS 609b	NS 6030
Control	12.27	4.27	8.88	10.59
100 ml *A. chroococcum*	13.32	4.97	8.39	10.90
75 ml *A. chroococcum*	13.24	4.89	8.87	10.75
50 ml *A. chroococcum*	13.31	4.30	8.92	10.96

Source: [87]

Azotobacter IN NUTRIENT CYCLING

Azotobacter allows certain nutrients available like carbon,sulphur, phosphorus and nitrogen through the mineralization process of organic residues in soil while avoiding the uptake of different heavy metals [53]. Nowadays *Azotobacter* has become one of the most important alternatives for chemical fertilizers as it can provide nitrogen into ammonia, amino acids and nitrate without overdosing the plants [54]. The bacterium helps in sustaining the growth of plants and yield even when the soil content is low in phosphate and also helps in taking up the macro and micro nutrients for better utilizing the plant root exudates [61].

Azotobacter IN SEED INOCULATION AND NUTRIENT UPTAKE

When seeds are inoculated with *Azotobacter,* the bacterium helps in the uptake of macronutrients like N and P along with some micronutrients like Fe and Zn [62, 63]. These bacteria strains are also used for improving the nutrition of rice, wheat and maize [64,65].The yield of crops is profoundly increased as the *Azotobacter* helps in supplying nitrogen in standing crops [66]. Azotobacter inoculated seeds are found to be increased in protein and carbohydrate content of two varieties of corn (Inra260 and Inra210) in an experiment done in a greenhouse [67]. The combined application of manure with *Azotobacter* gives increase in biomass of maize crop [68].

EFFECTS OF *Azotobacter* COMBINED WITH CHEMICAL FERTILIZERS

Azotobacter when applied in combination with 50% chemical fertilizers i.e., N and P, has some effects on growth of plants, number of branches, height, dry weight and freshness of safflower as compared to chemical fertilizers only [69]. Same goes for the organic fertilizers as well when applied with *Azotobacter* biphosphate along with half dose of chemical fertilizers helps in increasing the economic yield of safflower [71]. With increased N levels, the efficiency of *Azotobacter* is found to be decreasing [70]. The best combination turns out to be with NH4Cl @ 0.1 g/L while the combination with copper and *Azotobacter* are found to be toxic even when applied in low concentration [72, 76].

EFFECTS OF *Azotobacter* COMBINED WITH PESTICIDES

The herbicide 2, 4-D along with its products p-chlorophenol and p-chlorophenoxy-acetic acid are utilized by *Azotobacter croococcum* in the form of carbon, which later on stimulate nitrogenase enzyme [73]. Result found from a report that the insecticide carbofuran helps in stimulating the activity of nitrogenase enzyme [74]. A report says that the herbicide simazine has no effect on growth of *Azotobacter croococcum*, neither growth nor sterilized or dialyzed soil medium [75]. With the presence of simazine, the Azotobacter can be grown with cells having higher ATP content.

STRESS TOLERANCE CHARACTERISTICS OF *Azotobacter*

Most of the important pollutants through irrigation in agricultural soils are the heavy metals [77]. The consecutive accumulation of these heavy metals lead to retardation of plant growth later on affects the yield [78]. Exopolysaccharides of *Azotobacter* have a great role in immobilizing heavy metals [79]. High absorptive nature of EPS removes heavy metals from the soil [80, 81]. The EPS of *Azotobacter* can directly uptake and bind the heavy metals like Cr and Cd in contaminated soils [82, 83]. Macronutrients and micronutrients can also be supplied through the decomposition of EPS from *Azotobacter* [84]. The EPS based *Azotobacter* helps in increasing the aqueous dispersion of some poorly soluble compounds by changing the affinity and magnitude between hydrocarbons and microbial soils [85, 86]. The microbial activity can differentiate the biological process between compacted soil and non-compacted soils.

CONCLUSION

Azotobacter spp. are gram negative and capable of fixing 20 kg N per hectare per year. This bacterium is regarded as PGPR which helps in synthesizing growth substances and takes a great role in enhancing growth, development, and inhibiting phytopathogenic growth as they secrete inhibitors. From more research, *Azotobacter* spp. helps in increasing soil fertility, germination rate and has a positive response on Crop growth rate which results in more yield and healthy growth. *Azotobacter* spp. can also be used combining with chemical fertilizers as well as pesticides which help in increasing the economic yield. More stress can be tolerated by this bacterium as they can also produce EPS. More research is required so as to get more good qualities of the *Azotobacter* spp.

REFERENCES

1. Chatterjee, R. and Bandyopadhyay, S., (2017). Effect of boron, molybdenum and Bio fertilizers on growth and yield of cowpea (*Vigna unguiculata* L. Walp.) in acid soil of eastern Himalayan region. *Journal of the Saudi Society of Agricultural Sciences*, *16*(4), pp.332-336.
2. Singh, M., Dotaniya, M.L., Mishra, A., Dotaniya, C.K., Regar, K.L. and Lata, M., (2016). Role of Bio fertilizers in conservation agriculture. In *Conservation Agriculture* (pp. 113-134). Springer, Singapore.
3. Wani, Sartaj A., Subhash Chand, Muneeb A. Wani, M. Ramzan, and Khalid Rehman Hakeem. "Azotobacter chroococcum–a potential bio fertilizer in agriculture: an overview." *Soil science: agricultural and environmental prospective* (2016): 333-348.
4. Sharma, K., Dak, G., Agrawal, A., Bhatnagar, M. and Sharma, R., (2007). Effect of phosphate solubilizing bacteria on the germination of Cicerarietinum seeds and seedling growth. *Journal of Herbal Medicine and Toxicology*, *1*(1), pp.61-63.
5. Sudhakar, P., Chattopadhyay, G.N., Gangwar, S.K. and Ghosh, J.K., (2000). Effect of foliar application of Azotobacter, Azospirillum and Beijerinckia on leaf yield and quality of mulberry (Morusalba). *The Journal of Agricultural Science*, *134*(2), pp.227-234.

6. Tripathi, R.D., Dwivedi, S., Shukla, M.K., Mishra, S., Srivastava, S., Singh, R., Rai, U.N. and Gupta, D.K., (2008). Role of blue green algae bio fertilizer in ameliorating the nitrogen demand and fly-ash stress to the growth and yield of rice (Oryza sativa L.) plants. *Chemosphere*, *70*(10), pp.1919-1929.
7. Mehnaz, S., (2015). Azospirillum: a bio fertilizer for every crop. In *Plant microbes symbiosis: Applied facets* (pp. 297-314). Springer, New Delhi.
8. Sadhana, B., (2014). Arbuscular Mycorrhizal Fungi (AMF) as a bio fertilizer-a review. *Int J CurrMicrobiol App Sci*, *3*(4), pp.384-400.
9. Kalayu, G., (2019). Phosphate solubilizing microorganisms: promising approach as Bio fertilizers. *International Journal of Agronomy*, *2019*.
10. Selvakumar, G., Lenin, M., Thamizhiniyan, P. and Ravimycin, T., (2009). Response of Bio fertilizers on the growth and yield of blackgram (Vignamungo L.). *Recent Research in Science and Technology*, *1*(4), pp.169-175
11. Gandotra, V., Gupta, R.D. and Bhardwaj, K.K.R., (1998). Abundance of Azotobacter in great soil groups of North-West Himalayas. *Journal of the Indian Society of Soil Science*, *46*(3), pp.379-383.
12. Kloepper, J.W., (1978). Plant growth-promoting rhizobacteria on radishes. In *Proc. of the 4th Internet. Conf. on Plant Pathogenic Bacter, Station de Pathologie Vegetaleet Phytobacteriologie, INRA, Angers, France, 1978* (Vol. 2, pp. 879-882).
13. Kaviyarasan, G.P., Shricharan, S.P. and Kathiravan, R.P., (2020). Studies on isolation, biochemical characterization and nitrogen fixing ability of Azotobacter sp. isolated from agricultural soils. International Journal of Scientific Engineering and Applied Science (IJSEAS) – 6, 11.118-125
14. Martyniuk, S. and Martyniuk, M., (2003). Occurrence of Azotobacter spp. in some Polish soils. *Polish Journal of Environmental Studies*, *12*(3), pp.371-374.
15. Garrity, G.M., Bell, J.A. and Lilburn, T., (2015). Proteobacteriaphyl. nov. *Bergey's Manual of Systematics of Archaea and Bacteria*, pp.1-1.
16. Alhia, Basel Mohammed Hassan (2010). The Effect of Azotobacter Chrococcum as Nitrogen Biofertilizer on the Growth and Yield of Cucumis Sativus. *the islamic university. http://hdl.handle.net/20.500.12358/21551*
17. Yates, M.G. and Jones, C.W., (1974). Respiration and nitrogen fixation in Azotobacter. In *Advances in Microbial Physiology* (Vol. 11, pp. 97-135). Academic Press.
18. Bishop, P.E., Premakumar, R., Dean, D.R., Jacobson, M.R., Chisnell, J.R., Rizzo, T.M. and Kopczynski, J., (1986). Nitrogen fixation by Azotobacter vinelandii strains having deletions in structural genes for nitrogenase. *Science*, *232*(4746), pp.92-94.
19. Tchan, Y.T., Wyszomirska-Dreher, Z., New, P.B. and Zhou, J.C., (1983). Taxonomy of the Azotobacteraceae determined by using immunoelectrophoresis. *International Journal of Systematic and Evolutionary Microbiology*, *33*(2), pp.147-156.
20. Baral, B.R. and Adhikari, P., (2013). Effect of Azotobacter on growth and yield of maize. *SAARC Journal of Agriculture*, *11*(2), pp.141-147.
21. Parmar, N. and Dufresne, J., (2011). Beneficial interactions of plant growth promoting rhizosphere microorganisms. In *Bioaugmentation, biostimulation and biocontrol* (pp. 27-42). Springer, Berlin, Heidelberg.
22. Chen, J.H., (2006), October. The combined use of chemical and organic fertilizers and/or bio fertilizer for crop growth and soil fertility. In *International workshop on sustained management of the soil-rhizosphere system for efficient crop production and fertilizer use* (Vol. 16, No. 20, pp. 1-11). Land Development Department Bangkok Thailand.
23. Lenart, A., (2012). Occurrence, Characteristics, and Genetic Diversity of Azotobacter chroococcum in Various Soils of Southern Poland. *Polish Journal of Environmental Studies*, *21*(2).
24. Franche, C., Lindström, K. and Elmerich, C., (2009). Nitrogen-fixing bacteria associated with leguminous and non-leguminous plants. *Plant and soil*, *321*(1), pp.35-59.
25. Tien, T.M., Gaskins, M.H. and Hubbell, D., 1979. Plant growth substances produced by *Azospirillum brasilense* and their effect on the growth of pearl millet (*Pennisetum americanum* L.). *Applied and environmental microbiology*, *37*(5), pp.1016-1024.
26. Barea, J.M. and Brown, M.E., (1974). Effects on plant growth produced by Azotobacter paspali related to synthesis of plant growth regulating substances. *Journal of Applied Bacteriology*, *37*(4), pp.583-593.
27. Apte, R. and Shende, S.T., (1981). Studies on Azotobacter chroococcum: I. Morphological, biochemical and physiological characteristics of Azotobacter chroococcum. *Central sheet for bacteriology, parasite science, infectious diseases and hygiene. Second Science Department: Microbiology of Agriculture, Technology and Environmental Protection, 136 (7), pp.548-554.*Abbass, Z. and Okon, Y., (1993). Plant growth promotion by *Azotobacter paspali* in the rhizosphere. *Soil Biology and Biochemistry*, *25*(8), pp.1075-1083.
28. Damir, O., Mladen, P., Božidar, S. and Srñan, N., (2011). Cultivation of the bacterium Azotobacter chroococcum for preparation of Bio fertilizers. *African Journal of Biotechnology*, *10*(16), pp.3104-3111.
29. Chahal, P.P.K. and Chahal, V.P.S., (1988). Biological control of root-knot nematode of brinjal (Solanummelongena L.) with Azotobacter chroococcum. In *US-Pakistan International Workshop on Plant Nematology, Karachi (Pakistan), 6-8 Apr 1986*. NNRC.
30. Mishra, D., Rajvir, S., Mishra, U. and Kumar, S.S., (2013). Role of bio-fertilizer in organic agriculture: a review. *Research Journal of Recent Sciences ISSN*, *2277*, p.2502.
31. Bhardwaj, D., Ansari, M.W., Sahoo, R.K. and Tuteja, N., (2014). Bio fertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial cell factories*, *13*(1), pp.1-10.

32. Kour, D., Rana, K.L., Yadav, A.N., Yadav, N., Kumar, M., Kumar, V., Vyas, P., Dhaliwal, H.S. and Saxena, A.K., (2020). Microbial Bio fertilizers: Bioresources and eco-friendly technologies for agricultural and environmental sustainability. *Biocatalysis and Agricultural Biotechnology*, *23*, p.101487.
33. Nagananda, G.S., Das, A., Bhattacharya, S. and Kalpana, T., (2010). In vitro Studies on the Effects of Bio fertilizers(Azotobacter and Rhizobium) on Seed Germination and Development of Trigonellafoenum-graecum L. using a Novel Glass Marble containing Liquid Medium. *International Journal of Botany*, *6*(4), pp.394-403.
34. Yousefi, S., Kartoolinejad, D., Bahmani, M. and Naghdi, R., (2017). Effect of *Azospirillum lipoferum* and Azotobacter chroococcum on germination and early growth of hopbush shrub (Dodonaeaviscosa L.) under salinity stress. *Journal of Sustainable Forestry*, *36*(2), pp.107-120.
35. Sobariu, D.L., Fertu, D.I.T., Diaconu, M., Pavel, L.V., Hlihor, R.M., Drăgoi, E.N., Curteanu, S., Lenz, M., Corvini, P.F.X. and Gavrilescu, M., (2017). Rhizobacteria and plant symbiosis in heavy metal uptake and its implications for soil bioremediation. *New biotechnology*, *39*, pp.125-134.
36. Wani, S.A., Chand, S. and Ali, T., (2013). Potential use of Azotobacter chroococcum in crop production: an overview. *CurrAgric Res J*, *1*(1), pp.35-38.
37. Kizilkaya, R., (2009). Nitrogen fixation capacity of Azotobacter spp. strains isolated from soils in different ecosystems and relationship between them and the microbiological properties of soils. *J. Environ. Biol*, *30*(1), pp.73-82.
38. Vojinoviv, Z., (1961). Microbiological properties of main types soil in Serbia for nitrogen cycling. *Journal for Scientific Agricultural Research*, *43*, pp.3-25.
39. Hamilton, T.L., Ludwig, M., Dixon, R., Boyd, E.S., Dos Santos, P.C., Setubal, J.C., Bryant, D.A., Dean, D.R. and Peters, J.W., (2011). Transcriptional profiling of nitrogen fixation in Azotobacter vinelandii. *Journal of bacteriology*, *193*(17), pp.4477-4486.
40. Vance, C.P. and Graham, P.H., (1995). Nitrogen fixation in agriculture: application and perspectives. In *Nitrogen fixation: Fundamentals and applications* (pp. 77-86). Springer, Dordrecht.
41. Hakeem, K.R., Akhtar, M.S. and Abdullah, S.N.A. eds., 2016. *Plant, soil and microbes: volume 1: implications in crop science*. Springer.
42. Robson, R.L. and Postgate, J.R., (1980). Oxygen and hydrogen in biological nitrogen fixation. *Annual Reviews in Microbiology*, *34*(1), pp.183-207.
43. Prajapati, K., Yami, K.D. and Singh, A., (2008). Plant growth promotional effect of Azotobacter chroococcum, *Piriformospora indica* and vermicompost on rice plant. *Nepal Journal of Science and Technology*, *9*, pp.85-90.
44. Shokri, D. and Emtiazi, G., (2010). Indole-3-acetic acid (IAA) production in symbiotic and non-symbiotic nitrogen-fixing bacteria and its optimization by Taguchi design. *Current microbiology*, *61*(3), pp.217-225.
45. Hajnal, T., Jarak, M. and Milosevic, N., (2004). Bacterization of maize: yield response of maize to inoculation. In *Book of abstracts of the 10th international symposium on microbial ecology: isme-10, cancun, mexico* (Vol. 207).
46. Gosal, S.K., Kalia, A., Uppal, S.K., Kumar, R., Walia, S.S., Singh, K. and Singh, H., (2012). Assessing the benefits of Azotobacter bacterization in sugarcane: a field appraisal. *Sugar Tech*, *14*(1), pp.61-67.
47. Bali, A., Blanco, G., Hill, S. and Kennedy, C., (1992). Excretion of ammonium by a nifL mutant of Azotobacter vinelandii fixing nitrogen. *Applied and Environmental Microbiology*, *58*(5), pp.1711-1718
48. Monib, M., Abd-El-Malek, Y., Hosny, I. and Fayez, M., (1979). Seed inoculation with Azotobacter chroococcum in sand cultures and its effect on nitrogen balance. *Zentralblattfür Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene. Zweite Naturwissenschaftliche Abteilung: Mikrobiologie der Landwirtschaft, der Technologie und des Umweltschutzes*, *134*(3), pp.243-248.
49. Kukreja, K., Suneja, S., Goyal, S. and Narula, N., (2004). Phytohormone production by Azotobacter–a review. *Agricultural Reviews*, *25*(1), pp.70-75.
50. Jnawali, A.D., Ojha, R.B. and Marahatta, S., (2015). Role of Azotobacter in soil fertility and sustainability–A Review. *Adv. Plants Agric. Res*, *2*(6), pp.1-5.
51. Lévai, L., Veres, S., Bákonyi, N. and Gajdos, É., (2008). Can Wood Ash and Bio-fertilizer Play a Role in Organic Agriculture?. *Agronomskiglasnik: GlasiloHrvatskogagronomskogdruštva*, *70*(3), pp.263-272.
52. Joshi, K.K., Kumar, V., Dubey, R.C., Maheshwari, D.K., Bajpai, V.K. and Kang, S.C., (2006). Effect of Chemical Fertilizer-adaptive Variants, Pseudomonas aeruginosa GRC 2 and Azotobacter chroococcum AC 1, on Macrophominaphaseolina Causing Charcoal Rot of Brassica juncea. *Korean Journal of Environmental Agriculture*, *25*(3), pp.228-235.
53. Bhattacharjee, R. and Dey, U., (2014). Bio fertilizer, a way towards organic agriculture: A review. *African Journal of Microbiology Research*, *8*(24), pp.2332-2343.
54. Barea, J.M. and Brown, M.E., (1974). Effects on plant growth produced by Azotobacter paspali related to synthesis of plant growth regulating substances. *Journal of Applied Bacteriology*, *37*(4), pp.583-593.
55. Zena, G.G. and Peru, C., (1986). Effect of different rates of Azotobacter and frequency of application of Agrispon on yield and quality in the growing of onion (Allium cepa L.) in Cajamarca. *National University of Cajamarca Faculty of Agriculture Sciences and Forestry*.
56. Singh, M.S. and Dutta, S., (2006). Mustard and rapeseed response to Azotobacter-A review. *Agricultural Reviews*, *27*(3), pp.232-234.
57. Das, A.C. and Saha, D., (2007). Effect of diazotrophs on the mineralization of organic nitrogen in the rhizosphere soils of rice (*Oryza sativa*). *J Crop Weed*, *3*, pp.47-51.

58. Sandeep, C., Rashmi, S.N., Sharmila, V., Surekha, R., Tejaswini, R. and Suresh, C.K., 2011. Growth response of Amaranthus gangeticus to *Azotobacter chroococcum* isolated from different agroclimatic zones of Karnataka. *Journal of Phytology*, *3*(7).
59. Moriri S, Owoeye LG, Mariga IK (2015). Role of Azotobacter in Soil Fertility and Sustainability–A Review. Adv Plants Agric Res 2(6): 00069. DOI: 10.15406/apar.2015.02.00069.
60. Abdiev, A., Khaitov, B., Toderich, K. and Park, K.W., (2019). Growth, nutrient uptake and yield parameters of chickpea (*Cicer arietinum* L.) enhance by Rhizobium and Azotobacter inoculations in saline soil. *Journal of Plant Nutrition*, *42*(20), pp.2703-2714.
61. Naseri, R. and Mirzaei, A., (2010). Response of yield and yield components of Safflower (Carthamus tinctorius L.) to seed inoculation with Azotobacter and Azospirillum and different nitrogen levels under dry land condition. *Agric. Environ. Sci*, *9*, pp.445-449.
62. Naseri, R., Moghadam, A., Darabi, F., Hatami, A. and Tahmasebei, G.R., (2013). The effect of deficit irrigation and Azotobacter chroococcum and *Azospirillum brasilense* on grain yield, yield components of maize (SC 704) as a second cropping in western Iran. *Bull Env Pharmacol Life Sci*, *2*, pp.104-112.
63. Sahoo, R.K., Ansari, M.W., Dangar, T.K., Mohanty, S. and Tuteja, N., (2014). Phenotypic and molecular characterisation of efficient nitrogen-fixing Azotobacter strains from rice fields for crop improvement. *Protoplasma*, *251*(3), pp.511-523.
64. Gholami, A., Shahsavani, S. and Nezarat, S., (2009). The effect of plant growth promoting rhizobacteria (PGPR) on germination, seedling growth and yield of maize. *World Academy of Science, Engineering and Technology*, *49*, pp.19-24.
65. Kizilkaya, R., (2009). Nitrogen fixation capacity of Azotobacter spp. strains isolated from soils in different ecosystems and relationship between them and the microbiological properties of soils. *J. Environ. Biol*, *30*(1), pp.73-82.
66. Chen, J.H., (2006), October. The combined use of chemical and organic fertilizers and/or bio fertilizer for crop growth and soil fertility. In *International workshop on sustained management of the soil-rhizosphere system for efficient crop production and fertilizer use* (Vol. 16, No. 20, pp. 1-11). Land Development Department Bangkok Thailand.
67. Yasari, E. and Patwardhan, A.M., (2007). Effects of (Azotobacter and Azosprillium) inoculants and chemical fertilizers on growth and productivity of canola (Brassica napus L.). *Asian Journal of Plant Sciences*.
68. Soleimanzadeh, H. and Gooshchi, F., (2013). Effects of Azotobacter and nitrogen chemical fertilizer on yield and yield components of wheat (Triticumaestivum L.). *World Applied Sciences Journal*, *21*(8), pp.1176-1180.
69. Ojaghloo, F., Farahvash, F., Hassan-Zadeh, A. and Pour-Yusef, M., (2007). Effect of inoculation with azotobacter and barvar phosphate Bio fertilizers on yield of safflower (*Carthamus tinctorius* L.). *Journal of Agricultural Sciences, Islamic Azad University, Tabriz Branch*, *3*, pp.25-30.
70. Sarıbay, G.F., (2003). Growth and nitrogen fixation dynamic of Azotobacterchroococcum in nitrogen-free and omw containing medium (Master's thesis).
71. Balajee, S. and Mahadevan, A., (1990). Influence of chloroaromatic substances on the biological activity of Azotobacter chroococcum. *Chemosphere*, *21*(1-2), pp.51-56.
72. Kanungo, P.K., Adhya, T.K. and Rao, V.R., (1995). Influence of repeated applications of carbofuran on nitrogenase activity and nitrogen-fixing bacteria associated with rhizosphere of tropical rice. *Chemosphere*, *31*(5), pp.3249-3257.
73. Martinez-Toledo, M.V., Salmeron, V. and Gonzalez-Lopez, J., (1991). Effect of simazine on the biological activity of Azotobacter chroococcum. *Soil Science*, *151*(6), pp.459-467.
74. Schenckzu Schweinsberg-Mickan, M. and Müller, T., (2009). Impact of effective microorganisms and other Bio fertilizers on soil microbial characteristics, organic-matter decomposition, and plant growth. *Journal of plant nutrition and soil science*, *172*(5), pp.704-712.
75. Mandal, S.M., Pati, B.R., Das, A.K. and Ghosh, A.K., (2008). Characterization of a symbiotically effective Rhizobium resistant to arsenic: isolated from the root nodules of Vignamungo (L.) Hepper grown in an arsenic-contaminated field. *The Journal of general and applied microbiology*, *54*(2), pp.93-99.
76. Say, R., Denizli, A. and Arıca, M.Y., (2001). Biosorption of cadmium (II), lead (II) and copper (II) with the filamentous fungus Phanerochaete chrysosporium. *Bioresource technology*, *76*(1), pp.67-70.
77. Gauri, S.S., Mandal, S.M. and Pati, B.R., (2012). Impact of Azotobacter exopolysaccharides on sustainable agriculture. *Applied microbiology and biotechnology*, *95*(2), pp.331-338.
78. Weppen, P. and Hornburg, A., (1995). Calorimetric studies on interactions of divalent cations and microorganisms or microbial envelopes. *Thermochimicaacta*, *269*, pp.393-404.
79. Gauri, S.S., Archanaa, S., Mondal, K.C., Pati, B.R., Mandal, S.M. and Dey, S., (2011). Removal of arsenic from aqueous solution using pottery granules coated with cyst of Azotobacter and portland cement: Characterization, kinetics and modeling. *Bioresource technology*, *102*(10), pp.6308-6312.
80. Gauri, S.S., Mandal, S.M. and Pati, B.R., (2012). Impact of Azotobacter exopolysaccharides on sustainable agriculture. *Applied microbiology and biotechnology*, *95*(2), pp.331-338.
81. Joshi, P.M. and Juwarkar, A.A., (2009). In vivo studies to elucidate the role of extracellular polymeric substances from Azotobacter in immobilization of heavy metals. *Environmental science & technology*, *43*(15), pp.5884-5889.
82. Otero, A. and Vincenzini, M., (2003). Extracellular polysaccharide synthesis by Nostoc strains as affected by N source and light intensity. *Journal of Biotechnology*, *102*(2), pp.143-152.

83. Zhang, Y. and Miller, R.M., (1994). Effect of a Pseudomonas rhamnolipid biosurfactant on cell hydrophobicity and biodegradation of octadecane. *Applied and Environmental Microbiology*, *60*(6), pp.2101-2106.
84. Barkay, T., Navon-Venezia, S., Ron, E.Z. and Rosenberg, E., (1999). Enhancement of solubilization and biodegradation of polyaromatic hydrocarbons by the bioemulsifieralasan. *Applied and environmental microbiology*, *65*(6), pp.2697-2702.
85. Šantrůčková, H., Heinemeyer, O. and Kaiser, E.A., (1993). The influence of soil compaction on microbial biomass and organic carbon turnover in micro-and macroaggregates. In *Soil Structure/Soil Biota Interrelationships* (pp. 587-598). Elsevier.
86. Jafari TH, Latkovic D, Duric S, Mrkovacki N, Najdenovska O (2012) Research. J Agric Sci 44(2)

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