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Applications of Sulfur Oxidizing Bacteria in agriculture

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Introduction

In terms of plant growth, sulphur (S) is regarded as an essential nutrient that is equally as crucial as nitrogen, phosphorus, and potassium. It has been acknowledged for almost a century as being important to agriculture. Due to sulphur's immobility or relatively moderate mobility in plant tissue, a sulphur deficit is a critical growth-limiting factor for crop plants. In India, about 46% of soils lack sulphur, which lowers crop yields by 20% to 40%. The use of non-sulphur fertilisers, increasing biomass production, decreased sulphur emissions, and agronomic methods are some of the causes contributing to the rise in sulphur shortage in agro-ecosystems around the world. Many organic and inorganic forms of sulfur may be found in the soil. While sulphur is present in the majority of soils in organic forms, about 85-90%, it is not readily available for plant uptake. Utilizing elemental sulphur fertilizer is a cost-effective alternative for quickly replenishing sulfur levels, but it must be oxidized to sulfate before plants can take it up for nutrition.

Sulphur oxidizing bacteria plays a significant role in this transformation from inorganic sulphur to organic sulphur in the biosphere. Various sulphur oxidizing bacteria carry out the process of oxidizing sulphur compounds to sulphate (SO^{3-}). It has been understood that when elemental sulphur fertiliser is added to the organic pool, additional sulphur oxidising bacteria are required to oxidise the sulphur and make it available to the plant for nourishment. Because agricultural soils contain sulphur oxidisers that are displaced when sulphur is added, these amendments are required. Since they carry out the most oxidation and transformation in soil, *thiobacilli* are thought to be the most effective genus of bacteria that oxidise sulphur. Although SOB occur naturally in soils, the most essential species are not typically present in agricultural soils; hence, inoculation is generally utilized to get a desirable result.

Applications of Sulfur Oxidizing Bacteria in agriculture

There are following application of Sulfur Oxidizing Bacteria (SOB) in agriculture as followings-

1. ***Increase Sulphur availability in soil & nutrition in crop plants:*** Applying SOB can increase natural S oxidation, which produces sulphates that plants can readily absorb at different stages of development. This can boost plant production and yield in addition to addressing the soil's sulphur shortage.
2. ***Reclamation of Problematic soil as well as heavy metal-contaminated soils:*** When it comes to the reclamation of calcareous, sodic, and alkaline soil characteristics, SOB can be quite helpful. In calcareous soils, SOB can dissolve $CaCO_3$ and lower soil pH by producing H_2SO_4 by biochemical sulphur oxidation (Yi *et al.,* 2021). The application of Thiobacillus sp. and sulfur has been shown to improve plant growth in calcareous and saline soils by increasing nutrient availability (Yi *et al.,* 2021).
3. ***Biocontrol of pests and diseases:*** Through a variety of methods, SOB has demonstrated

promise in the management of plant diseases and pests. It has been noted that these bacteria's oxidation of sulphur compounds balances the soil's salt concentration, which in turn regulates some plant diseases. For example, sulphur-amended soil can be inoculated with Thiobacillus in an acidic environment to prevent potato scab and sweet potato rot caused by *Streptomyces scabies* and *S. ipomoea*, respectively. This is because there is more phosphorus and sulphur available. Furthermore, it has been noted that plants with higher sulphur content develop resistance to a variety of plant diseases, including *Verticillium dahliae* and *Rhizoctonia* (Avato *et al.* 2000). Therefore, the application of SOB can be a promising strategy for biocontrol of plant pathogens and pests (Gao and Fan 2023). It has been also demonstrated that several sulphur-containing secondary metabolites, including glucosinolates, isothiocyanates, thiocyanates, and nitriles, have anti-insect and anti-disease properties. After tissue injury, chemicals called isothiocyanates are created enzymatically from sinigrin. These substances possess antinematicidal, antifungal, and antibacterial properties (Tarar and Peng, 2022).

4. ***Plant growth promoting activity:*** It has also been demonstrated that applying SOB improves stress tolerance against salinity, drought, pests, and diseases. This can be done directly by generating growth-promoting substances such as gibberellins, salicylic acid, ACC-deaminase, IAA, and siderophores, or indirectly by increasing the production of compounds.
5. ***Synergistic interaction with other nutrients:*** In soil, boron and molybdenum interact negatively with sulphur, while nitrogen, phosphorus, potassium, magnesium, and zinc interact positively (Tabak *et al*., 2020).
   In S-deficit soils, the inoculation of SOB with Rhizobium produced synergistic interactions that promoted the yield and oil content of groundnuts, as we discuss most limiting nutrients like nitrogen. When SOB and a nitrogen-fixing bacterium were introduced into onions, there was a notable increase in plant height, yield, and N uptake (Awad *et al.*, 2011).
   When it comes to phosphorus, the majority of the phosphorus in the soil is in a form that is inaccessible to agricultural plants. Phosphoric fertilisers are often fixed in the soil, and around 90% of the phosphorus that is applied is inaccessible to plants. Deficiencies in phosphorus can lead to poor root formation and growth, which lowers quality and production. It is possible to enhance phosphorus nutrition in an agro-ecosystem by using SOB in conjunction with a reduced form of sulphur, either alone or in conjunction with a complex phosphorus source such as rock phosphate (RP). Following inoculation with the SOB, RP, elemental sulphur, and vermicompost, the soil's concentration of water-soluble phosphate rose (Jazaeri *et al.,* 2016).
6. ***Bio-acidulation of RP:*** Since RP is the least expensive form of P fertiliser, there has been a lot of interest in using it practically as fertiliser in recent years. But since most RP deposits worldwide are low-reactive, they cannot be applied directly without first being pre-treated. There have been suggestions for using microbiological techniques to raise RP's agronomic value. It has been demonstrated that inoculating RP with phosphate solubilizing bacterial species significantly improves RP solubilization. The solubilization of RP has always been accompanied by a decrease in the pH of the incubation mixture. In calcareous alkaline soils, biochemical sulfur oxidation produces sulfuric acid (H_2SO_4), which lowers soil pH and dissolves calcium carbonate ($CaCO_3$). This, in turn, increases the available P in soil by increasing the solubility of phosphate rocks, providing phosphorus to the plant growth (Stamford *et al.,* 2007).

7.

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