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SOIL MICROBE MEDIATED ZINC UPTAKE IN SOY BEAN: A REVIEW

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ABSTRACT

The availability of the nutrients to plants depends on the inherent and derived mechanisms to access these nutrients. More attention has been given to macronutrients which are more accessible, easily replenished and utilized by plants for growth. Macronutrients are crucial and improve yield but compromise quality of the crop, leading to a phenomenon termed as 'the empty harvest'. The soil nutrient cycle processes are mediated by both biotic and abiotic factors with nutrients available in gaseous and in soil solution. Roots play a major role in the uptake of nutrients from the soils. The rhizosphere and rhizoplane of roots is rich with soil biota, amongst them microorganisms, which play a major role in nutrient availability, accessibility and translocation. Nutrient uptake can be enhanced by microorganisms through direct and indirect processes. There is sufficient evidence for nitrogen, phosphorus and micronutrient uptake and availability mediated by microorganisms. The uptake of micronutrients such as zinc depends on that of phosphorus. A large proportion of the world population has shortcomings from a nutrition perspective of being low in zinc and other essential nutrients. There is widespread zinc deficiency in diets causing zinc deficiency diseases. This is combated through pharmaceutical supplements, industrial fortification and most recently biofortification through agriculture. Biofortification has taken highest priority in guaranteeing quality of crops. However, soils exploitation for micronutrients can be enhanced by biological interventions to guarantee adequate uptake by plants and improve crop quality. Microbiological interventions that increase root growth, the availability and transfer of Zn from soil to plants are, therefore, crucial. This article reviews promising microbiological interventions for zinc uptake and gives an overview of microbiological interventions for nitrogen and for phosphorus that are directly linked with zinc uptake. Soya bean is taken as a model plant in this review to elucidate the mechanism of Zn mobilization.

Key words: Microorganisms, soy beans, zinc uptake

INTRODUCTION

Profitable cropping systems must be designed to realise a nutrient balance through continuous nutrient replenishment. Nutrients are replenished from parent rocks, processes of decomposition and mineralization of organic materials and atmospheric fixation by soil organisms. The process of soil formation is by weathering of underlying rocks through physical, chemical and predominantly by microorganisms and other soil biota through biological weathering processes [1]. Under natural conditions, the release rate of nutrients from minerals to soils and plants is not fast enough to provide nutrients for continuous annual crop production.

Increasing land pressure has lead to either shortened or even absent fallow, hence culminating in severe cases of nutrient mining in most parts of Africa [2]. In most cases, the rate of replenishment is slow and cannot surpass nutrient mining by crops and loss of nutrients by soil mismanagement. Soil replenishment of nutrients is, therefore, a necessity for sustainable production systems. The Application of N, P, and K is the most commonly used soil replenishment practice in sub-Saharan Africa (SSA). This is, however, incomplete and introduces nutrient imbalance which eventually compromises food quality. Half of the soils in SSA are deficient in one of three micronutrients Zn, Fe or B [3]. Deficient soils can be fertilized with the required major, secondary and micronutrients to address specific plant nutritional deficiencies and human nutritional demands [4, 5, 6, 7].

Not all fertilizer applied is available to crops, as nutrients may be lost through leaching, washing away, immobilization and volarization by soil organisms. Mechanisms to combat loss of nutrients and enhance nutrient use efficiency are available, amongst which are microbiological processes.

Nutrient cycling processes are mediated by soil organisms, hence forming a major component of the soil system and, therefore, greatly contributing to soil health [8]. Amongst the keystone soil microorganisms that contribute to soil health and subsequent plant growth are bacteria (symbiotic and free living) such as *Rhizobium* and *Bradyrhzobium*, and *Azotobacter*, *Azospirillum*, *Bacillus* and *Pseudomonas*; fungi in symbiosis with plants (Arbuscular Mycorrhizae), fungi in the rhizosphere (*Trichoderma*) and other plant growth promoting organisms [8].

There is sufficient evidence for soil nitrogen and phosphorus cycling processes mediated by microorganisms and limited information on micronutrients. This review will focus particularly on zinc (a micronutrient that is important for both plant and human health) and on the microbiological processes that enhance availability in major crops such as soy beans. Zinc is vital in human and animal growth and development, for sexual reproduction, fetal development and variety of functions of immune system deficiencies [6, 9]. It is important for skin cell development and healing of wounds. It reduces the period of acute diarrhea and lowers the prevalence of pneumonia in children [10]. Zinc is so essential that deficiency results in dwarfism. Dietary plant sources of zinc are seeds. Highlights will, however, be given on nitrogen and phosphorus cycling process as they are indirectly or directly linked with zinc uptake.

Nitrogen cycle processes mediated by bacteria and fungi

Nitrogen is the first most absorbed nutrient in soya beans. The nitrogen cycling processes are mediated by soil organisms [3, 8]. Nitrogen cycles are strongly mediated by microorganisms and comprises four major pathways: (i) Biological nitrification, the conversion of ammonium (NH_4+) to nitrite (NO_2^-) and NO_2- to nitrate (NO_3^-) mediated by *Nitrosoccus* and *Nitrobacter* bacteria; (ii) symbiotic nitrogen (N_2) fixation: mediated by *Rhizobium* and *Bradyrhizobium* associated with legumes and *Frankia*, *Nostoc* and *Azolla associated wuth* non legume; (iii) the free-living nitrogen fixers, the rhizosphere nitrogen fixing *Azotobacter*, *Azospirillum* and *Bacillus*, free-living nitrogen fixing *Cyanobacteria* and *Clostridium*; and (iv) denitrification, the conversion of nitrate to gaseous nitrogen mediated by facultative heterotrophic bacteria.

The role of fungi in nitrogen cycling process is displayed by the Arbuscular Mycorrhizae fungi (AMF), which also contribute significantly to N nutrition (N uptake and use efficiency) in soil where NO_3- N dominates, by increasing plant nitrate uptake, the percentage of plant N derived from fertilizer, and plant N use efficiency [11 - 17]. The main source of nitrogen in soy beans is through symbiosis, a process highly linked with phosphorus.

Phosphorus cycle processes mediated by microorganisms

Phosphorus is one of the most abundant minerals in the soil and also the least available nutrient in the plant rhizosphere. It is an essential macronutrient for plant growth and its deficiency is one of the major limitations in crop production in numerous soils in Africa [2]. Legumes have a high phosphorus requirement associated with nodulation and nitrogen fixation with phosphorus playing a major role in symbiotic nitrogen fixation in nodulating legumes such as soy beans [9, 18, 19, 20]. An increase in whole plant growth and plant nitrogen concentration in response to increased soil P supply have been noted for several leguminous species including soy bean [21, 22, 23]. Analysis of phosphate fractions of total P_{tot}, inorganic P_i, organic P_{org}, lipid P_{lp}, high-energetic~P, sugar

P_{suc} and nucleotide P_{nucl} showed lower concentrations of all investigated metabolites in P deficient nodules [24].

The plants' strategies for P uptake include rapid root growth, root elongation, root hair proliferation and modification of rhizosphere conditions. Microbiological modification of rhizosphere and rhizoplane are associated with fungi and bacteria, which enhance P availability and uptake [25]. Modification of rhizosphere is by (i) root extension by associations with root symbiotic fungi, the arbucular mycorrhizae fungi (AMF) forming additional threadlike root extensions, the mycelia, that absorb more P than non-mycorrhizal plants; (ii) modification by secretion of chelating agents by mycorrhizal roots in calcareous soils and in acid soils to release some bioavailable

P; (iii) modification by phosphates enzymes at mycorhizosphere to contribute to mobilization of organic P; (iv) mycorrhizae are particularly more efficient in high-P-fixing soils and the modification is by acidification, through increased proton efflux and pCO2 enhancement; and (v) modification by P-solubilizing rhizobacteria. A total of 220 plant growth promoting rhizobateria were isolated from the rhizosphere of plants in northern part of Thailand [26]. The Rhizobacteria, *Azospirillium*, *Azotobacte*r and *Pseudomonas* enhance growth of the legume chick pea (*Cicer arietinum* L.) with interaction with Rhizobium more effective on growth [27].

There is sufficient supporting evidence on the role of microorganisms in nitrogen and phosphorus uptake but still limited information on the role of microorganisms in uptake of micronutrients. The uptake of micronutrients is strongly influenced by macronutrients. There is an interaction between P and micronutrients levels, with the AMF extraradical length higher at low P than at high P only when no micronutrients were added [28, 29].

The role of microorganisms in Zinc uptake

The mobility of Cu, Zn, Mn and Fe in soil is low and as a result, uptake of these metal nutrients by roots is diffusion limited [30, 31, 32]. When no micronutrients were added to the soil, available Cu, Zn, and Fe levels were low and “a depleted zone” of these nutrients would have formed around the roots [20]. The uptake of nutrients was limited in non-mycorrhizal plants. Mycorrhizal plants take up more metal nutrients via the extraradical hyphae, which provide a large surface area than roots alone and reduce the distance for diffusion, thereby enhancing the absorption of immobile metal nutrients [33, 34]. The micronutrients have similarities with phosphorus which has low mobility and uptake is largely enhanced by the mycorrhizal root association.

Zinc availability is dependent on the kind and intensity of weathering of the parent material and the interaction with other nutrients such as P, Cu, Fe, Mn. Soils with high concentration of P are deficient in available zinc, application of high amounts of P can induce Zn deficiency in plants and the availability of Zn is highest below pH 7 [35, 36]. As pH increases, the availability of Zn decreases. It is taken up by plant roots in the form of cation Zn^{2+}. Soil usually contains very low levels of available Cu, and Zn. Copper and zinc ions like phosphorus have very low mobility in soil. Thus, similar to what is seen with P, zones of Cu and Zn depletions readily develop around plant roots, and the AM-enhanced uptake of Cu and Zn by plants seems to rely on the ability of the AM roots to exploit a larger volume of soil than the roots alone [37]. P fertilization which reduces mycelium development reduces Zn and Cu uptake. Interactions between P, Cu, and Zn, have been observed using soy beans (*Glycine max* (L) Merr.), and maize [28, 38]. In all cases, AM colonization and concentrations of Cu and Zn decreased with P fertilization in AM plants. AM fungi extraradical mycelia and root colonization were reduced by approximately 20% with micronutrient application in a nutrient poor soil-sand mix.

Arbsucular mycorrhizal infected roots mine native soil-Zn and inoculation increased both Zn concentration and uptake and the subsequent growth of rice [18]. Arbuscular mycorrhiza inoculation has also been shown to improve growth and Zn nutrition of wheat and maize in Zn-deficient soils, due to better access of roots to native Zn and Zn added as fertilizer [39].

It is widely reported that AM-fungi increase plant Cu and Zn uptake [4, 28, 38]. More Cu and Zn were measured in mycorrhizal soybean plants than in P-supplemented non-mycorrhizal soybean plants of the same size, in soil with low levels of Cu and Zn. *Glomus mosseae* contributed from 16-25% of total Zn uptake by maize growth in calcareous soil and from 52-65% of total Cu uptake by clover plants grown in the same soil [38]. This indicates that high levels of both P and Zn inhibit mycorrhizal development, resulting in the reduced uptake ability of extraradical hyphae.

CONCLUSION

The 'empty harvest' in most crops may be explained by low populations of beneficial organisms that are below the threshold level to realize effective nutrient uptake by the microorganisms. While improving plant nutrient uptake, the use of microbiological interventions could lead to efficient exploration of micronutrients such as zinc. It can also lead to a reduction in fertilizer use and the reduction of nutrient seepage into the environment, with positive benefits. The maintenance of high yield despite reduction of fertilizer application is achieved through improvement of crops nutrient uptake capacity, or increased nutrient use efficiency. There is, therefore, compatibility of microorganisms with mineral fertilizer. This is contrary to the misconception of use of microbes without fertilizer input. Fertilizer application coupled with soil microbiological interventions, if managed well would have greater impacts to enrich crops with micronutrients such as zinc hence guarantee nutritionally balanced.

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