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Microbial Inoculants- A Boon to Zinc Deficient Constraints in Plants: A Review

Sunitha kumari. K., S.N.Padma devi., S.Vasandha and S.Anitha

Department of Botany, PSGR Krishnammal college for women, Peelamedu, Coimbatore-641 004.

Abstract- Zinc is an essential micronutrient which plays a macro role in the growth and productivity of the plants. Zinc (Zn) deficiency hinders metabolic and physiological activity in plants due to its inevitable role as an enzyme cofactor. Many Indian soil exhibit Zn deficiency with the content much below the critical level of 1.5ppm. The conditions that make unavailability of zinc to plants are high pH, low organic matter content, high usage of P fertilizer, less textured soil and utilization of synthetic fertilizer to correct Zn deficiency which results in unavailability of zinc after seven days of application. An alternative eco-friendly approach to overcome Zn deficiency constraint in plants is by the application of microbial inoculants as a biofertilizer. Rhizospheric microorganisms play a vital role in the conversion of unavailable form of metal to available form through solubilization mechanism.

Index Terms- Deficiency, microbial inoculants, solubilization, zinc.

I. INTRODUCTION

Micronutrients are important for the optimum growth and productivity of the plants. Though these elements are required in critical amounts, they are very important to plant development and for profitable crop production because they work 'behind the scene' as activators of many plant functions. Of the several micronutrients that increase plant growth and productivity Zn plays a vital role. Zn is an important component of enzymes that drive and increase the rate of many important metabolic reactions involved in crop growth and development. It exerts a great influence on basic plant life processes such as N_2 metabolism and uptake of N_2 and protein quality; photosynthesis and chlorophyll synthesis, resistance to abiotic and biotic stresses and protection against oxidative damage (Potarzycki and Grzebisz, 2009). When the supply of Zn to the plant is inadequate, crop yields and the quality of production will be adversely affected. Thus for proper function of crop plants a certain minimum level of Zn supply is essential.

Zn deficiency has become a serious problem affecting nearly half of the world's population (Cakmak, 2009). This is actually due to low Zn content of the crops grown in Zn deficient soils. Many Indian soils exhibit the deficiency of Zn with the content much below the critical level of 1.5ppm (Tiwari and Dwivedi, 1994). It is expected to increase from 42% in 1970 to 63% by 2025 due to continuous depletion of soil fertility (Singh, 2009). To overcome this constraint farmers supplied Zn in the form of fertilizers like $ZnSO_3$ which in turn transformed into different insoluble forms depending upon the soil types, soil chemical reactions and becomes totally unavailable in the environment within 7 days of application (Rattan and Shukla, 1991). Therefore, efficient and economical methods to correct Zn deficiency have to be devised. Recently bacterial based approach was devised to solve these micronutrient deficiency problems (Anthoni Raj, 2002). They play a predominant role in the solubilization, transport and deposition of metals and minerals in the environment. Thus microorganisms play a major role in the transformation of unavailable form of metal to available form depending upon the reactions involved and the products formed (Lovely, 1991). The secretion of organic acids appears to be the functional metal resistance mechanism that chelates the metal ions extracellularly(Li *et al*., 2007).

Thus the following review explains the importance of micro-organisms as an alternative tool to alleviate synthetic fertilizer and to overcome Zn deficiency in plants – a major nutritional constraint today.

II. ZINC IN SOILS

The total amount of Zn present in the soil is dependent on the type, intensity of weathering, climate and numerous other predominating factors during the process of soil formation (Saeed and Fox, 1977). All types of soils may be influenced by Zn including loam, sands, clays, loess, alluvium and soils formed from basalt, sandstone, granite, volcanic ash and many other rocks (Hafeez *et al*., 2013). Deficiencies of Zn occur in many parts of the world on a wide range of soil types, semi- arid areas with calcareous soils, tropical regions with highly weathered soils and sandy textured soils in several different climatic zones tend to be the most seriously affected (Akay, 2011). High pH and high content of $CaCO_3$, organic matter, phosphate and copper can fix Zn in the soil and give rise to the reduction of available (Zn) (Kapoor *et al*., 2002). The submerged soils are well recognized for the lack of Zn availability to the plants; particularly due to the reaction of Zn with free sulphide (Mikkelsen and Shiou, 1977). Zn deficiency area may be related to weather conditions, Zn deficiency increases in cold and wet conditions. It may be due to the limited root growth in cool soils, or reduction activity of micro- organisms (Alam *et al*., 2010). According to the FAO, about 30% of the cultivable soils of the world contain low levels of plant available Zn (Sillanpaa, 1990). Indian soils are generally low in Zn and as much as half of the country soils are categorized to be Zn deficient. Total and available Zn content in Indian soils ranged between 7- 2960mg kg^{-1} and 0.1- 24.6mg kg^{-1} respectively with an average deficiency of 12 to 87% .

III. Importance of Zinc in Plants

Zn is vital to the crop nutrient as it plays a structural constituent or regulatory co- factor of a wide range of different enzymes and proteins in many important biochemical pathways and these are mainly concerned with carbohydrate metabolism, both in photosynthesis and in the conversion of sugars to starch, protein metabolism, auxin metabolism, pollen formation and the resistance to infection by certain pathogens (Alloway, 2008). It is also a part of the enzymes such as superoxide dismutase and catalase which prevents oxidative stress in plant cells. Early development of fruits or tubers is also influenced by Zn. In the process of cell differentiation after flowering high levels of IAA or Zn in the plant will increase cell differentiation. The greater the cell differentiation the larger and denser will be the fruit **(**www.alcanada.com/index_htm_files/Zinc**).** The regulation and maintenance of the gene expression required for the tolerance of environment stresses in plants are Zn dependent (Cakmak, 2000). Thus Zn plays an indispensable role in various enzymatic reactions, metabolic processes and oxidation- reduction reactions of plants.

IV. Zinc Deficiency in Plants

For optimum function of crop plants a certain minimum level of Zn supply is essential. If the soil which is a principal resource from where plants draw their Zn needs is unable to supply the minimum amount of Zn thens a Zn deficiency situation arises. Inadequate supply of Zn to the plant result in the cessation of physiological functions which lead to the development of visible symptoms of stress such as interveinal chlorosis (yellowing of the leaves between the veins), bronzing of chlorotic leaves, small and abnormally shaped leaves, stunting and rosetting (leaves form a whorl or shortened stems) (http://www.zinc.org/info/zinc). Many researchers observed that zinc is closely related to N_2 metabolism pathway of plants, thus causing a reduction in protein synthesis for Zn deficient plants. Zn deficiency significantly affects the root system including root development (Fageria, 2004). Epstein and Bloom, 2005 indicated that the flowering and fruiting process were greatly reduced under severe Zn deficiency. Quality of harvested products, plant susceptibility to injury by high or light temperature intensity and to infection by fungal diseases can also increased by Zn deficiency (Cakmak. 2000). Zn seems to affect the capacity for water uptake and transport in plants and also reduce the adverse effects of short periods of heat and salt stress (Tavallali *et al*., 2010). Zn deficient plants exhibit low levels of auxins such as IAA. Many research shows us that Zn is required for the synthesis of tryptophan, which in turn is the precursor for the synthesis of IAA. In the absence of IAA plant growth is stunted particularly internodes growth and leaf size (www.alcanada.com/index_htm_files/Zinc). A more direct influence of Zn deficiency is that of grain or seed yield which are reduced to a greater extent by Zn deficiency (www.alcanada.com/index_htm_files/Zinc). Plants vary considerably in their requirements for Zn. Crops with high Zn requirements include corn, onion and spinach. Those with medium requirements are barley, beans, beet, canola, cucumber, lettuce, lupines, potato, radish, sorghum, soybean, tobacco and tomato (Schulte, 2004).

V. Unavailability of Zn to Plants

In soils, Zn is found in both available and unavailable forms. There is plenty of Zn in soil to support crop growth, but the crop exhibit deficiency due to the presence of unavailable fractions. There are many adverse factors in the soil that affect the Zn availability to plants. These include low total Zn content, neutral or alkaline pH, high salt concentration, and high calcium carbonate content in calcareous soil (Antoniadis and Alloway, 2002). In the case of soils characterized by high contents of hydroxyl (OH^-) ions, it is difficult to get a crop response even after applying Zn. The lower availability of Zn under alkaline conditions is attributed to the precipitation of Zn as $Zn(OH)_2$ or $ZnCO_3$ (Shukla and Mittal, 1979). The higher carbonate contents in alkaline soils also absorb Zn and hold it in an unexchangeable form (Udo *et al*., 1970). These factors contribute to the low availability of Zn at higher pH values. Heavier textured soils with larger CEC have higher capacities for Zn adsorption than light textured soils (Stahl and James, 1991). Zn usability decreases by decreasing temperature and light intensity due to limited root development. Zn usability by plants decreases with high levels of P in the soil. Zn uptake by plants is inhibited by some metal cations such as Cu^{2+} and Fe^{2+}. Organic matter which behaves much like a chelate in holding Zn in the soil also forms an important factor for Zn availability. Low organic matter contents in soils give rise to Zn deficiency as it is observed that available Zn increases with increase in organic matter in soil. Thus the role of Zn in a plant is complex in which the interaction reduces its availability.

VI. Negative Effect of Chemical Fertilizer

Green revolution has greatly increased the food crop production in India but resulted in the depletion of soil micronutritents pools. Soil health relies on a balance of macronutrients and micronutrients, as well as microbial health. Farmers gave more attention towards NPK than micronutrients in the intensive cultivation method. The increased use of NPK fertilizers devoid of micronutrients has no doubt increased the food production but it brought a host of problems related to micronutrient deficiencies, of which Zn deficiency is the most predominant. Zn deficiencies are most commonly corrected by application of the Zn fertilizer to the soil since its requirement is modicum. Several different Zn compounds are used as fertilizers in which $ZnSO_4$ is the most common. It is estimated that about 85,000- 90,000 tones/ annum consumption of $ZnSO_4$ in agriculture either through straight fertilizer application or through micronutrients mixture**.** This indicates the indispensable role of Zn in plant development and for profitable crop production. Supplementation of Zn in the form of fertilizers like ($ZnSO_4$) also remains vain because only 1- 4% is utilized by the crop and 75% of applied Zn is transformed into other mineral fractions which is not available. Thus correction of Zn deficiency via fertilization is not always successful due to agronomic and economic factors which include reduced availability of Zn due to top soil drying, subsoil constraints, disease interactions, and cost of fertilizers.

VII. Alternative source to chemical fertilizer

External addition of soluble Zn to alleviate deficiency results in the transformation of about 96- 99% to various fractions of unavailable forms and about 1- 49% is left as available fraction in the soil. So the water soluble Zn ($ZnSO_4$. $7H_2O$) advocated and applied in the soil cannot be detected beyond 15 days of period (Rattan and Shukla, 1991) and become unavailable which make the Zn nutrition to the plants critical. This requires a system that releases the required quantity of Zn that are converted to unavailable state and retained in the soil to available form. Numerous microorganisms, especially those associated with roots have the ability to increase crop growth and productivity. This effect has been due to the involvement of these organisms in the solubilization of unavailable mineral nutrients (Cunningham and Kuiack, 1992). Zinc solubilizing potential of few micribial genera such as Bacillus sp, Pseudomonas sp and Aspergillus sp were explored by researchist recently (Saravanan et al., 2003). Thus microbial inoculants will be an alternative approach to overcome constraints due to synthetic fertilizer, and to revive soil's fertility resulting in the intensive farming.

VIII. Mechanism involved in solubilization of zinc

The rhizospheric microorganisms play a pivotal role in the enhancement of crop production by the solubilization of unavailable form of metal into available form. This metal solubilization was due to the production of organic acids and pH drop by organisms (Alexander, 1997). Plants take up Zn as (Zn^{2++}) divalent cation. The release of organic acids that sequester cations and acidify the micro environment near root is thought to be a major mechanism of Zn solubilization. A number of organic acids such as acetic, citric, lactic, propionic, glycolic, oxalic, gluconic acid etc have been considered due to its effect in pH lowering by microorganisms (Cunnigham and Kuiack, 1992). Organic acid secreted by micro- flora increase soil Zn availability in two ways, they are probably exuded both with protons and as counter ions and consequently, reduce rhizospheric pH. In addition, the anions can chelate Zn and increase Zn solubility (Jones and Darrah, 1994) which results in the conversion of available form (Zn^{2+}) to plants.

IX. Conclusion

Supplementation of both macro and micro nutrients is required for the healthy growth of the plants. Lack of awareness in farmers about the importance of micro nutrients lead to the major economic loss due to its deficiency in plants. Though farmers rely on synthetic fertilizers to correct Zn deficiency it still remains a major issue in agriculture. Therefore, application of microbial inoculants will be a viable alternative technology to overcome Zn deficiency and the negative impact of chemical fertilizer on plant and its environment.

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AUTHORS

First author: K.Sunitha kumari M.Sc., Ph.D scholar, Department of Botany, PSGR Krishnammal college for women, Peelamedu, Coimbatore-641 004. E-mail: sunitha239kk@gmail.com.

Second author: Dr.S.N.Padma Devi, Associate professor, Department of Botany, PSGR Krishnammal college for women, Peelamedu, Coimbatore-641 004.

Third author: Mrs. S. Vasandha, Dean-student affairs, PSGR Krishnammal college for women, Peelamedu, Coimbatore-641 004.

Fourth author: S.Anitha M.Sc., Ph.D scholar, Department of Botany, PSGR Krishnammal college for women, Peelamedu, Coimbatore-641 004.

Correspondence author: K.Sunitha kumari M.Sc., Ph.D scholar, Department of Botany, PSGR Krishnammal college for women, Peelamedu, Coimbatore-641 004. E-mail: sunitha239kk@gmail.com.