Int.J.Curr.Microbiol.App.Sci (2019) *8*(4): 2525-2530

International Journal of Current Microbiology and Applied Sciences
***ISSN: 2319-7706* Volume 8 Number 04 (2019)**
Journal homepage: http://www.ijcmas.com

Review Article https://doi.org/10.20546/ijcmas.2019.804.294

A Review on Interactive Effects of Phosphorous, Zinc and Mycorrhiza in Soil and Plant

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Keywords

P-Zn interaction, Mycorrhizal association, Antagonism interaction, Arbuscular mycorrhizal fungi, Mycorrhizal colonization

Article Info

Accepted:
17 March 2019
Available Online:
10 April 2019

ABSTRACT

Phosphorus and zinc are two essential nutrients which are required for normal plant growth. These nutrients are mutually antagonistic in certain circumstances which can cause yield reductions in many crops due to either P or Zn deficiencies. Deficiencies typically happen when a nutrient is available in small amounts. In this phenomenon, the nutrient is present in marginal to normal levels but the antagonizing nutrient is available in such a large amount that it induces the deficiency of the other. The Zn induced P deficiency is a very rare phenomenon because growers commonly apply large amounts of P fertilizer as compared to Zn fertilizer. The P induced Zn deficiency is related to the application of phosphatic fertilizers at high dose to the soils that are low or marginal in available Zn. Vesicular arbuscular mycorrhizal fungi (VAM) when applied to soils can result in marked increases in plant growth and P uptake. AM fungi benefit plant's well establishment by enhancing plant nutrient acquisition, improving soil quality and increasing resistance to environmental stress. They also help to improve the absorption of several plant nutrients like N, P, K, Mg, Cu, Ca and Fe by the roots of plants.

Introduction

Interaction can be defined as the influence of an element upon another in relation to growth and crop yield. There may be positive or negative interaction of nutrients occurs either in soil or plant. The positive interaction of nutrients gives higher crop yield and such interactions should be exploited in increasing the crop production. Conversely, all negative interactions will lead to decline in crop yield and should be avoided in formulating agronomic packages for a crop. There are mainly two types of interactions effect viz. antagonistic and synergistic effects. Antagonistic effect means an increase in concentration of any nutrient element will decrease the activity of another nutrient (negative effect). While synergistic effects means an increase of concentration of any one nutrient element will influence the activity of another nutrient element (Positive effect). Nutrient antagonism occurs when an excess of a particular element blocks the absorption of another element the plant needs and can happen with elements of a similar size and charge (positive or negative). The most important Zn interactions are that involving phosphorus most frequently referred to as antagonism. High levels of P supply, causes an increment of Zn concentration in the roots and a reduction of Zn concentration in the shoot. This suggests that Zn×P interaction occurs within the root, due to the rupture of sidelong Zn transport to the vascular tissue or linear transport from root to upper plant parts. Formation of sparingly soluble Zn phosphates in the apoplast of the root cortex might be a reason for uneven Zn distribution between roots and upper plant parts. However there is also possibility that P/Zn complex formation in roots preventing movement of P to the tops of plants under high Zn supply. Mycorrhiza can be exploited to alleviate Zn deficiency by improving the nutritional status of host plant. Despite the fact it has also found that AM fungal colonization promotes P or Zn nutrition of host plants independently. Mycorrhizae are important for plants and ecosystem. They affect the plant production and soil health. AM fungi colonize the roots of many economically important crops and could serve as bio fertilizer and bio protectors in environmentally sustainable agriculture. Therefore this review focuses on the Phosphorus – zinc interaction in plants and interactive behavior of nutrients, mycorrhizal colonization and plant growth.

Phosphorus-zinc interaction in plants

Effect of high level of phosphorus on zinc

The study of the interaction among elements under their excessive supply in the soil is primarily of academic importance. Occasionally, it may be of practical relevance when reclaiming contaminated areas. Application of phosphorus has been reported, in some cases, to cause a decrease in the total uptake of zinc in plants (Loneragan, 1951), while in others, it has shown either to have no effect or increased uptake (Stukenholtz *et al.*, 1966). Results on uptake of zinc and phosphorus in plants as influenced by the application of phosphorus and zinc respectively, therefore, still remain controversial. Wallace et al (1978) in a solution culture experiment reported that at high pH increasing solution phosphorus decreased the concentration of zinc, copper and manganese in soybean leaf, stem and root, whereas at low pH it resulted in an increase in their concentration.

According to Boawn and Rasmussen (1971), excess Zn restricts root growth which results in decreased P uptake. They also found that the cause behind this antagonism may be the precipitation of zinc phosphates in the roots. Youngdahl *et al.,* (1977) also stated that Zn-P interaction takes place within the plant. High levels of P supply, causes an increment of Zn concentration in the roots and a reduction of Zn concentration in the shoot. This suggests that Zn×P interaction occurs within the root, due to the rupture of sidelong Zn transport to the vascular tissue or linear transport from root to upper plant parts. Halder and Mandal (1981) reported that application of phosphorus caused a decrease in the concentration of zinc, copper, iron and manganese both in shoots and roots. They concluded that decrease in the concentration of the elements in the shoots was not due to dilution effect or to the reduced rate of translocation of the elements from the roots to tops. Zn becomes part of the fabric of the root and thus, becomes unavailable for transport to the leaves also under conditions of high Zn application; P may circumvent Zn in roots by the formation of Zn-phytate (Singh *et al.*, 1988; Hopkins *et al.*, 1998; Rupa *et al.*, 2003).

Soltangheisi *et al.,* (2014) also reported that Zn deficiency can enhance P uptake and translocation to such extent that P may accumulate to toxic levels in leaves in their experiment carried out on effect of different levels of Zn, P on the yield, Zn and P uptake and chlorophyll content of corn plants.

Effect of high level of zinc on phosphorus

Cakmak and Marshner (1987) reported that high amounts of Zn may be kept in the roots by the formation of zinc-phytate. They also observed that application of zinc also similarly lowered the concentration of phosphorus, copper and iron, but increased that of manganese in shoots and roots, they also concluded that the decrease in the concentration of the elements in the shoots was not due to dilution effect or to the reduced rate of translocation of the elements from the roots to tops.

A study by Li *et al.*, (2003) reported that it is not always that Zn-P relationship can be referred to as antagonism but sometimes increasing Zn rates stimulate phosphorus concentration of plants. Research results also suggested that the ratio of both elements must be maintained at an appropriate level. The zinc fertilization of barley accompanied by a low phosphorus application caused the yields to increase slightly, whereas a higher phosphorus rate reduced the Zn: P ratio and increased the yields in a distinct manner. They observed that the interactive effects of phosphorus and zinc in most of crops showed an increase in P concentrations when the doses of zinc were increased in combination with the doses of P.

Barben *et al.,* (2007) reported that phosphorus concentrations in the top leaves and middle leaves and stems (middle) are depressed with increasing Zn activity in solution. They also found that Root P concentration increased with increasing Zn activity in solution possibly due to binding of these two elements within the root tissue and preventing P transport to tops. In the studies carried out by various researchers on potato it is revealed that high Zn influenced Mn distribution in the plant. It is reported that there is a direct impact of increasing solution Zn concentration on P uptake. They found that with increase in zinc content in solution, zinc content in the plant increased, however P concentration in both top leaves and middle leaves and stems decreased with a concomitant increase of P in roots. From their studies, they suggest that a P/Zn complex formation in roots preventing movement of P to the tops of plants under high Zn supply. With their results they also concluded that although high P levels in potato did not directly reduce Zn content or cause Zn deficiency, they may reduce the activity of Zn by interacting with other micronutrients such as Mn.

Interactive behaviour of nutrients, mycorrhizal colonization and plant growth

Effect of mycorrhiza on nutrient uptake

Mycorrhizal inoculation alone does not significantly influence the concentration of plant phosphorus and total nitrogen (N). However, AM fungi and P fertilizer together result in significant increase in the concentration of both phosphorus and nitrogen. AMF increased plant growth. This beneficial effect has frequently attributed to higher phosphorus uptake and enhanced P nutrition of mycorrhizal plants (Baylis, 1972; Koide, 1988; Smith and Read, 1997). In another studies, Jansa *et al.,* (2003) showed that mycorrhizae constitute efficient root extension organs involved in uptake and translocation of phosphate and other nutrients with low diffusion rates. Marschner (1993) found that under deficient conditions of nutrients, mycorrhizal symbiosis is omnipresent and known to improve the nutritional status of host plants as a result of transport of slowly diffusing nutrient ions such as PO^{4-}, Zn^{2+}, and Cu^{2+} by the external mycelium of AM fungus.

Mohammadi *et al.,* (2011) observed that the most prominent effect of AMF is to improve P nutrition of the host plant in soils with low P levels due to the large surface area of their hyphae and their high affinity P uptake mechanisms. To substantiate this concept of plant growth promotion by AMF, several studies have shown that AM fungi contribute up to 90% of plant P demand. For instance, the P depletion zone around a non-mycorrhizal roots extends to only 1-2 mm, nearly the length of a root hair whereas extra radical hyphae of AMF extends 8 cm or more beyond the root making the P in this greater volume of soil available to the host.

Effect of mycorrhizae on plant growth and Yield

Arbuscular mycorrhizal (AM) fungi play a significant role in sustainable farming system because AM fungi are efficient when nutrient availability is low and nutrients are bound to organic matter and soil particles. They directly or indirectly affect plant growth. Indirectly they promote plant growth by improving the soil quality and by suppressing the pathogens responsible for reduced crop production. However, some *Glomus* isolates have been shown to stimulate plant growth independent of plant P nutrition or when P is non-limiting (Davies *et al.*, 1993; Fidelibus *et al.*, 2001) and also Fitter (1985) found that the potential of AM fungal functioning in plant growth and yield is not maximized when naturally occurring, particularly under intensive soil management.

Research by El-Ghandour et al (1996) has established the fact that dual inoculation of AM fungi increased the plant growth, nodulation and yield in legumes. Podila and Douds (2001) revealed that AM fungi are important due to their great capability to increase plant growth and yield under certain conditions. They found that the major reason for this increase is the ability of plants in association with AM to take some nutrients such as phosphorus efficiently. Gianinazzi and Vosatka (2002) revealed that Arbuscular mycorrhizae association is the most common mycorrhiza type involved in agricultural systems, it is generally accepted that appropriate management of this symbiosis and its effect on plant growth and production should permit reduction of agrochemical inputs, and thus provide for sustainable and low-input plant productivity.

Effect of mycorrhiza colonization at varying nutrient levels

A field trial was conducted by Chandrashekara *et al.,* (1995), to study the response of sunflower to different phosphorus levels (16, 24 or 32 kg P ha^{-1}) and inoculation with vesicular-arbuscular mycorrhizal fungus, *Glomus fasciculatum*. They found that at the vegetative stage of sunflower, per cent mycorrhizal root colonization, spore count, dry biomass and P uptake did not differ significantly between inoculated and uninoculated control plants. However, at later stages (flowering and maturity) per cent root colonization, spore count; total dry biomass and total P uptake were significantly higher in inoculated plants than in uninoculated control plants.

The total dry biomass, P content and seed yield increased with increasing P level in uninoculated plants, whereas no significant difference was observed between 16 and 32 kg P ha^{-1} in inoculated plants. The positive effect of mycorrhizal inoculation decreased with increasing P level above 16 kg P ha^{-1}, due to decreased per cent root colonization and spore count at higher P levels.

Pot experiment carried out by Habibzadeh (2015) reported that different level of phosphorus along with mycorrhizal colonization increased root dry weight, root volume, leaf phosphorus content and mycorrhizal colonization percentage and inoculated plants had more fresh weight, root dry weight and root volume (731.67 mg, 59.17 mg and 0.59 cm^3) as compared to uninoculated plants. Apart from this the root dry weight and root volume increased with increase in phosphorus levels.

Acknowledgement

The authors are thankful to the Department of Soil Science and Water Management, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan (Himachal Pradesh) for providing necessary research facilities.

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How to cite this article:

Gitika Bhardwaj, Uday Sharma and Perminder Singh Brar. 2019. A Review on Interactive Effects of Phosphorous, Zinc and Mycorrhiza in Soil and Plant. *Int.J.Curr.Microbiol.App.Sci.* 8(04): 2525-2530. doi: https://doi.org/10.20546/ijcmas.2019.804.294