Response of Maize to Mycorrhizal Colonization at Various Zinc and Phosphorus Levels

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Abstract: This study looks into the effects of arbuscular mycorrhizal (AM) inoculation with Glomus intraradices on maize (Zea mays L.) growth at different phosphorus (P) and zinc (Zn) levels. A greenhouse experiment was performed with two phosphorus levels (15 and 30 mg kg^{-1}) and three zinc levels (0, 1.25, and 2.5 mg kg^{-1}). Results demonstrated that AM-inoculated plants (M^{+}) exhibited considerably enhanced root morphology, including increased root length and surface area, and higher cation exchange capacity (CEC) compared to nonmycorrhizal plants (M^{-}). Furthermore, plants inoculated with AM had increased nutrient concentrations in their roots, shoots, and grains, as well as improved phosphorus and zinc uptake. The availability and use of these nutrients were higher in mycorrhizal-inoculated soils, confirming the fungi's function in nutrient mobilization. These findings highlight the potential of AM symbiosis to boost maize growth, particularly in zinc-deficient soils, and suggest that AM fungi can be an effective tool for improving nutrient uptake and crop performance in nutrient-limited conditions, thereby contributing to sustainable agricultural practices.

Keywords: Mycorrhizal colonization, maize, phosphorus, zinc, nutrient uptake, root morphology

INTRODUCTION

Maize (*Zea mays* L.) is a cereal crop with global importance for food security, livestock feed, and industrial applications. However, its production is frequently limited by nutritional deficits, particularly in phosphorus (P) and zinc (Zn), both of which are required for plant growth and development. Phosphorus is essential for energy transfer and root development, however it is frequently unavailable in many soils due to fixation, particularly alkaline soils (Vance et al., 2003). Zinc deficiency is common in arid and semi-arid locations and has a negative impact on plant growth, photosynthesis, and grain nutritional quality, resulting in lower yields and decreased human nutrition (Alloway, 2009).

To address these nutritional constraints, improving nutrient uptake and plant tolerance to shortages is critical to increasing maize yield. Arbuscular mycorrhizal (AM) fungi, such as *Glomus intraradices*, have a positive association with plant roots, improving nutrient acquisition, notably phosphate and zinc, by expanding the root system. These fungi also boost abiotic stress resistance and nutrient utilization efficiency (Fageria et al., 2017). *Glomus intraradices* has demonstrated significant potential for improving nutrient absorption, root shape, and crop yields, particularly in soils with poor phosphorus and zinc availability (Smith & Read, 2010).

The purpose of this study is to assess the effects of AM fungal colonization on maize at various phosphorus and zinc concentrations, with an emphasis on root shape, cation exchange capacity (CEC), and nutrient uptake efficiency. Understanding these linkages will allow the study to evaluate the impact of AM fungi in increasing maize development, particularly in nutrient-limited soils, as well as providing insights for sustainable agricultural methods to improve crop yield in nutrient-deficient places.

MATERIALS AND METHODS

Experimental Setup

A greenhouse experiment was carried out utilizing red sandy loam soil (Alfisol) obtained from agricultural fields. The soil was air-dried, sieved (2 mm), and analyzed for nutritional profile using established techniques (Bray & Kurtz, 1945). The experiment used a factorial design with treatments for phosphorus (15 and 30 mg kg^{-1}), zinc (0, 1.25, and 2.5 mg kg^{-1}), and two mycorrhizal treatments (inoculated [M^{+}] and uninoculated [M^{-}]. Each treatment combination was reproduced three times.

Plant Material and AM Inoculation

Maize seeds were surface sterilized with 0.1% $HgCl_2$ solution for 2 minutes, then rinsed thoroughly with distilled water. Seeds were planted in 5 kg pots containing pre-treated soil. The AM inoculum was made up of 10 g of *Glomus intraradices* propagules (spores and colonized root pieces) put to each pot. Nonmycorrhizal control pots received the same amount of autoclaved inoculum. Plants were kept under controlled temperature (25 ± 2°C) and natural sunshine conditions, with frequent watering to keep soil moisture at 70% field capacity.

Root and shoot samples were taken 55 and 75 days after seeding. The root length was measured using a gridline intersect method (Tennant, 1975), and biomass was assessed after 48 hours of oven drying at 70°C. Root CEC was measured using a barium chloride saturation method (Gillman & Sumpter, 1986).

To assess phosphorus and zinc concentrations in plant tissues, samples were digested in a diacid combination (HNO□:HClO□, 4:1) and concentrations were determined by ICP-OES (PerkinElmer Optima 8000). Calibration standards were developed using approved reference materials (USEPA, 1994).

Post-harvest soil samples were tested for available P using the Bray I method (Bray & Kurtz, 1945) and available Zn using DTPA extraction (Lindsay & Norvell, 1978).

ANOVA was performed on the data using R program (v.4.1.2). Tukey's HSD test was used to compare mean values at $\alpha = 0.05$ level.

RESULTS

Root Morphology and CEC

Mycorrhizal inoculation (M□) led to considerable improvements in root shape, including increased length and biomass, compared to nonmycorrhizal plants. M□ plants had higher root CEC at both phosphorus levels, indicating better nutrient absorption and exchange. AM fungi play a synergistic function in nutrient uptake, as seen by the significant improvements at higher Zn levels (2.5 mg kg□^{1}). Zhang et al. (2021) found similar findings, observing improved root growth in AM-inoculated plants under nutritional stress.

Table 1

Treatment	Root Length (cm)	Root CEC (cmol$_-$ kg^{-1})
M^- , P15, Zn0	12.3 ± 0.8	5.2 ± 0.3
M^+ , P15, Zn0	18.7 ± 1.1	7.8 ± 0.4
M^- , P30, Zn2.5	13.4 ± 0.7	5.9 ± 0.2
M^+ , P30, Zn2.5	20.2 ± 1.0	8.4 ± 0.5

Nutrient Uptake

Mycorrhizal plants had considerably greater P and Zn concentrations in their roots, shoots, and grains, regardless of treatment amount. The increased nutrient uptake was attributed to the wide root network aided by AM fungi, as well as the increased solubility of P and Zn in the rhizosphere. These findings support the findings of Rillig et al. (2019), who emphasized the importance of AM fungus in micronutrient mobilization.

Table 2

Treatment	P (mg g^{-1}) in Shoots	Zn (mg g^{-1}) in Shoots
M^- , P15, Zn0	2.1 ± 0.2	0.9 ± 0.1
M^+ , P15, Zn0	3.8 ± 0.3	1.6 ± 0.2
M^- , P30, Zn2.5	2.4 ± 0.3	1.1 ± 0.2
M^+ , P30, Zn2.5	4.2 ± 0.3	1.8 ± 0.1

Soil Nutrient Status

Post-harvest research revealed that AM-inoculated soils had considerably greater accessible P and Zn levels than non-inoculated soils. This improvement emphasizes the importance of AM fungus in nitrogen cycling and soil fertility. The findings are consistent with Alloway (2009), who stressed the importance of microbial interactions in nutrient-deficient soils.

Table 3

Treatment	Available P (mg kg^{-1})	Available Zn (mg kg^{-1})
M^-	12.4 ± 0.6	0.8 ± 0.1
M^+	19.6 ± 0.8	2.1 ± 0.2

DISCUSSION

The observed improvements in maize root shape, nitrogen uptake, and soil nutrient status following AM colonization highlight the importance of mycorrhizal fungi in agricultural systems. AM colonization dramatically improved root length and CEC, both of which are crucial for maize plants' nutrient absorption capacity. This is consistent with the findings of Smith and Read (2010) and Zhang et al. (2021), who showed that AM fungi improve the acquisition of immobile nutrients like as P and Zn, especially in nutrient-deficient soils.

The synergistic relationship between Zn and P revealed in this work demonstrates the complex methods by which AM fungi enhance nutrient availability in the rhizosphere. These interactions not only boost nutrient uptake, but also plant health and yield. Rillig et al. (2019) emphasized the relevance of AM fungi in stabilizing soil aggregates, allowing for improved root-soil contact and nutrient exchange. This demonstrates the ability of AM fungi to alleviate nutrient shortages, particularly in marginal soils.

The higher post-harvest soil nutrient levels in AM-inoculated treatments indicate that AM fungi play an important role in nutrient cycling and soil fertility restoration. This finding is consistent with Alloway (2009), who stressed the importance of biological processes in soil health. AM fungi's ability to improve nutrient utilization efficiency makes them an essential component of sustainable agriculture techniques, particularly in places with micronutrient deficits.

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