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Effects of Molybdenum on Phosphorus Concentration in Rice (*Oryza sativa* L.)

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Abstract**—**A hydroponic trial was carried out to investigate the effect of molybdenum (Mo) on uptake of phosphorus (P) in different rice cultivars. The experiment was conducted using a randomized complete-block design, with a split-plot arrangement of treatments and three replications. Four rates of Mo (0, 0.01, 0.1 and 1 mg L^{-1}) and five cultivars (MR219, HASHEMI, MR232, FAJRE and MR253) provided the main and sub-plots, respectively. Interaction of molybdenum×variety was significant on shoot phosphorus uptake ($p \leq 0.01$). Highest and lowest shoot phosphorus uptake were seen in Mo_3V_3 (0.6% $plant^{-1}$) and Mo_0V_3 (0.14% $plant^{-1}$) treatments, respectively. Molybdenum did not have a significant effect on root phosphorus content. According to results, application of molybdenum has a synergistic effect on uptake of phosphorus by rice plants.

Keywords**—**Molybdenum, Phosphorus, Uptake, rice.

I. Introduction

RICE is a staple food which is the second most cultivated cereal after wheat. More than half of world's population feed on rice [1]. Several studies have been done on synergistic and antagonistic interactions of nutrients in soil and plants. P and Mo are two essential nutrients for normal plant growth. Within micronutrients, molybdenum (Mo), as an anion, becomes more available when pH enhances and its deficiency is widely observed in acidic soils. After nitrogen, phosphorus is of importance in crop yield and nutrition [2]. Insolubility of P in the soil at both acidic and alkaline pH accounts for its low amount for sufficient plant nutrition [3]. Many investigations have conducted to determine the interactions of Mo and P on their uptake by different plants [4]-[6].

It has shown that plant uptake of Mo could be directly proportional with enhancement of P and can be declined by presence of available Sulfur (S) [7]. In contrast, some workers reported that application of Mo declined concentration of P in clover plants [8].

It was also stated that enhancement of Mo uptake was seen when P deficiency increased in tomato plants and concluded that Mo anions were absorbed by transporters of phosphate [9]. Reference [10] reported that application of P also increased soil available molybdenum and this could be led to enhancement of Mo uptake by plants. The various conflicting results impelled us to conduct this experiment focusing on molybdenum impacts on rice phosphorus status.

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II. Materials and Methods

A solution culture method was used for this experiment. Five rice (*Oryza sativa*) cultivars (V_1: MR219, V_2: HASHEMI, V_3: MR232, V_4: FAJRE and V_5: MR253) were used and soaked in tap water for 24 hours, then were placed between two damp filter paper within Petri dishes. The dishes placed in oven at 25°C for 3 days. Germinated seeds were selected and transplanted to plastic trays (36×26×8 cm) containing nutrient solution at the rate of 25 seedlings per tray.

The Yoshida nutrient solution was utilized as the growth medium [11]. The pH of nutrient solution was monitored to maintain it between 5.5 and 5.8 using 0.1 M HCl or KOH solution. Molybdenum (Mo) was added to the nutrient solution as ammonium molybdate [$(NH_4)_6Mo_7O_{24}\cdot 4H_2O$] at four rates: [$M_o$: 0, M_1: 0.01, M_2: 0.1, and M_3: 1.0 mg L^{-1}]. The nutrient solution was changed regularly at 3 days intervals. The experiment was a Split Plot Design (SPD) in Randomized Complete Block Design (RCBD) using three replications. Applied Mo and varieties were considered as main and subplots, respectively.

The plants were harvested at 35 DAT. The plant samples separated as roots and shoots for analysis of P contents, then, rinsed with deionized water and oven dried at 70°C for 48h. Dried samples weighed, placed in digestion tubes and concentrated HNO_3 was added. In order to enhance the speed of the reaction, concentrated H_2SO_4 was added. Glass tubes placed on hot plate, heated at 125°C for 4 hours and allowed to cool. To maintain wet digestion and clean digested tissues, 30% H_2O_2 was added.

Phosphorus in shoots and roots was measured by autoanalyzer device (8000 series, Lachat QuickChem FIA+, USA).

All data were statistically analyzed using Excel 2010 and ANOVA procedure in SAS 9.2 (SAS institute, Cary, NC, USA). Also, interactions and main effects of factors were analyzed following the principle of F statistics.

III. Results and Discussion

The results showed that increase in percentage of shoot P was achieved when Mo rates enhanced. The highest percentage of P (0.43% $plant^{-1}$) was seen in the maximum rate of applied Mo and the lowest (0.18% $plant^{-1}$) was observed in treatments without applied Mo (Fig. 1). Reference [12] represented that application of Mo enhanced P concentration in rice plants and uptake of Mo increased by application of P in solution culture.

These reports show that synergistic effects exist between Mo and P application so that formation of anionic complexes between P and Mo (which are more likely to be absorbed by plant roots) could be accounted for such effects. Also, High availability of P and Mo ions can be due to ligand exchange mechanism and then hydroxyl ion increase [13].

TABLE I
MEAN COMPARISON OF INTERACTION EFFECTS OF MOLYBDENUM × VARIETY ON PHOSPHORUS CONCENTRATION

M	V	P (%)
0	1	0.16637g
	2	0.26424defg
	3	0.14605g
	4	0.15142g
	5	0.21068fg
1	1	0.26805defg
	2	0.20760fg
	3	0.24412efg
	4	0.29085def
	5	0.24512efg
2	1	0.37670cd
	2	0.37672cd
	3	0.54321ab
	4	0.43367bc
	5	0.37725cd
3	1	0.35790cde
	2	0.34565cde
	3	0.60681a
	4	0.43785bc
	5	0.42301c

The given means within each column of each section followed by the same letter are not significantly different (*P*=0.05).

In contrast, other researcher reported that application of Mo decreased total amount of P in mustard due to hindering of P enzyme activity such as phosphatase [14]. According to the results, enhancement of applied Mo increased shoot P contents at each level of Mo in all varieties. This is in agreement with those of other workers who found that higher amount of Mo in solution culture of canola increased P effectiveness [15]. The interaction of Mo and V on percentage of shoot P was significant ($p \leq 0.01$) (Table II) so that highest and lowest P were seen in Mo_3V_3 (0.6% plant^{-1}) and Mo_0V_3 (0.14% plant^{-1}) treatments, respectively (Table I).

TABLE II
ANALYSIS OF VARIANCE (MEAN SQUARES) OF MOLYBDENUM LEVELS ON SHOOT AND ROOT PHOSPHORUS CONCENTRATION

	Phosphorus (%)	
	Shoot	Root
Replication	0.01338328	0.06497441
Molybdenum levels (Mo)	0.22765525**	0.04712849ns
Error a	0.01348933	0.02277460
Variety (V)	0.01650350**	0.00837481ns
Mo×V	0.01406416**	0.00635216ns
Error b	0.00246067	0.00878042

†ns indicates non-significance.‡** indicates significant at the 0.01 probability levels

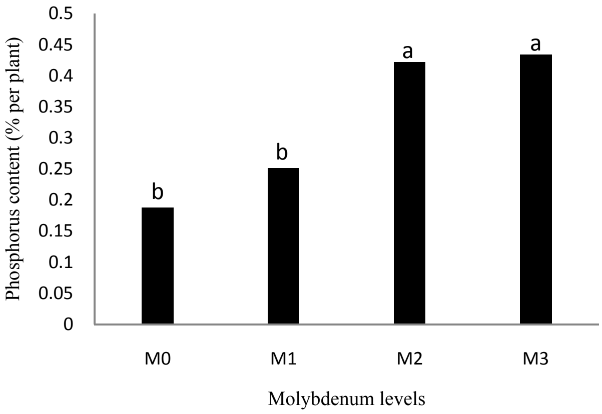

Fig. 1 Effects of molybdenum on shoot phosphorus content

This implies that responses of varieties to absorb P during application of various levels of Mo are different. While levels of Mo increased, the trends of P content enhanced in rice cultivars so that trends of enhancement were observed in the order of V_3□$V_5 > V_4 > V_1 > V_2$ (Fig. 1). According to results, the main effects of Mo and V and their interactions on root P concentration were not significant (Table II).

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