Root Growth and Phosphorus Uptake Affected by Fertilizer Management in Soybean and Wheat

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ABSTRACT

Plant root growth patterns can be affected by nutrient and water availability. The objective of this study was to assess the effect of phosphorus (P) fertilizer management on soybean (*Glycine max.* L) and winter wheat (*Triticum aestivum* L.) root system growth and macro and micronutrients uptake. Two greenhouse studies were carried out at Kansas State University, Manhattan, Kansas under controlled environment. The experimental design was a completely randomized design with four replications. Winter wheat treatments (experiment 1) consisted of three P fertilizer sources: (1) mono-ammonium phosphate (MAP), (2) MicroEssentials (MESZ), and (3) MAP + ammonium sulfate (AS) + $ZnSO_4$ (MAP+AS+Zn). Phosphorus fertilizer sources were applied at 3 rates: 30, 60, and 90 lb. P_2O_5 ac^{-1}. Soybean treatments (experiment 2) consisted of three P placements: (1) broadcast at soil surface, (2) in band-applied 2x2 in, and (3) deep band at 7.8 in. Triple superphosphate was applied using two rates: 54 and 107 lb. P_2O_5 ac^{-1}. In each study there was an additional treatment with 0 lb. P_2O_5 ac^{-1} (control). The plant response parameters assessed were plant shoot dry weight, P, S and Zn uptake, as well as root length through scanned images, estimated using the software WinRHIZO Pro. The increase in P rates promoted an increase in root length growth in the wheat study and a decrease at highest rate when P was applied in the row in soybeans. The MESZ and MAP+AS+Zn showed greater P and Zn uptake at 90 lb. P_2O_5 ac^{-1} rate than MAP. Is possible that the changes in root growth observed in our study due to P fertilizer management may affect plant growth and yield under conditions of water stress in the field.

INTRODUCTION

Immobile nutrients such as phosphorus (P) when applied as mineral fertilizers, can promote a localized increase in the soil test P levels in the soil profile; which can affect plant development and consequently P uptake (Hansel et al., 2017a). Plant root systems typically show high adaptability during the growing season, adjusting to environmental conditions as well as water and nutrient availability (Williamson et al., 2001). Exposure of the root system to high phosphorus concentrations can cause a localized increase in the initiation and subsequent extension of the primary and secondary roots when compared to the low concentration zone (Drew, 1975; Salisbury and Ross, 1992). The magnitude of these changes can alter plant capacity for nutrient and water uptake, as well as plant tolerance to environmental stresses (Hansel et al., 2017b). Therefore, P fertilization management can play an essential role in improving P acquisition and support yield potential (Shen et al., 2011, Adee et al., 2016).

As important as P rate and placement to increase fertilization efficiency, different P fertilizer sources may affect plant absorption efficiency depending on the conditions and chemical reactions in the soil, as well as the fertilizer composition (Hansel et al. 2014). The increase in secondary and micronutrient needs for crop production also raises questions about the role of these nutrients for plant root growth and nutrient uptake. The objectives of this study were to evaluate the effect of P sources and rates on wheat and soybean root and shoot growth as well as changes in the macro and micronutrients uptake by the plant.

MATERIALS AND METHODS

Experimental Design

Two studies were carried out under controlled greenhouse environment at Kansas State University, Manhattan, Kansas. The studies were carried out during the 2016 and 2017 growing seasons. The experimental design was a completely randomized design with four replications. Wheat treatments consisted of three P fertilizer sources: (1) mono-ammonium phosphate (MAP), (2) MicroEssentials (MESZ), and (3) MAP + ammonium sulfate (AS) + $ZnSO_4$ (MAP+AS+Zn). Thus, phosphorus fertilizer sources were applied at three rates: 30, 60, and 90 lb. P_2O_5 ac^{-1}. Soybean treatments consisted of three P placements: (1) broadcast at the soil surface, (2) in band-applied 2x2 in, and (3) deep band at 7.8 in. Triple superphosphate was applied using two rates: 54 and 107 lb. P_2O_5 ac^{-1}. In each study, there was an additional treatment with 0 lb. P_2O_5 ac^{-1} (control). Polyvinyl chloride (PVC) columns were used to grow wheat and soybeans. For wheat, columns were 23.6 in tall and 5.9 in diameter. For soybeans, columns were 39.4 in cm tall and 7.8 in diameter. Columns were filled with a soil blend, where 25% was topsoil soil and 75% sand (<2 mm). The soil blend extractable P was determined by the Mehlich-3 method (Frank et al., 1998), and K by ammonium acetate ICP Spectrometer (Warncke and Brown, 1998). Soil pH was measured using a 1:1 soil:water ratio (Watson and Brown, 1998), SO_4-S was determined by calcium phosphate extraction, and Cu, Mn and Zn were analyzed by DTPA-extraction using ICP (inductively coupled plasma) spectrometer (Whitney, 1998). Soil texture was analyzed using the hydrometer method (Bouyoucos, 1962). Soil chemical and physical characteristics for both studies are presented in Table 1. The wheat fertilizer rate was calculated considering a surface area of 0.306 ft^2. This area corresponds to the row length (5.90 in) and the row spacing of 7.5 in. The soybeans fertilizer rate was calculated considering a surface area of 1.07 ft^2 . This area corresponds to the row length (5.9 in cm) and the supposed distance between plants at the field condition.

Plant Sampling and Analyses

Fertilizer was applied using a stake to open the row and place the fertilizer. Wheat was sowed approximately 0.8 in away from the fertilizer with 10 seeds per pot (column) and thinned to eight seedlings after germination. The wheat variety used was Everest (Kansas State University Research Foundation) considered the variety most popular in Kansas. Soybean was sowed with three seeds per column and thinned to one seedling after germination. The genotype of soybean used was NK S45-V8 (Syngenta) maturity group 4.5.

Wheat plants were sampled at the heading growth stage (Feekes 10.1) (Large, 1954), and partitioned into shoot and root parts. Root samples were divided in two portions (0-4 in and >4 in soil layer), pre-cleaned in the greenhouse to remove most of the soil and then using tap water to separate the remaining soil. The evaluation of the treatment effects on wheat root length was performed considering the roots at 0-4 in portion. Soybean plants were sampled at R2 growth stage (Saratha, 2010) and partitioned into shoot and root parts. Root samples were pre-cleaned in the greenhouse to remove most of the soil and after using tap water to separate the remaining soil.

The evaluation of total RLD was performed by digitalizing the roots with a scanner (Epson Expression 11000XL, Epson America, Inc., Long Beach, CA), in a 400 dpi resolution. The generated images were analyzed using the WinRhizo Pro software (Régent Instruments, Québec, Canada). After, shoots parts were dried at 65°C for six days and weighted to get the total dry weight. The shoots were ground separately and analyzed for total nutrient content. Total P was analyzed by the sulfuric peroxide digest as described by (Lindner and Harley, 1942). Total P was determined using inductively coupled plasma (ICP) spectrometer (720-ES ICP; Varian Australia Pty Ltd, Mulgrave, Victoria, Australia). Analysis of sulfate (SO_4) and Zinc (Zn) were done using perchloric digest with inductively coupled plasma (ICP) following the method of (Gieseking et al., 1935). Phosphorus uptake was calculated using P tissue concentration and total plant dry weight.

Statistical analysis

The effects of P fertilizer managements on wheat and soybean root length, shoot and root growth as well as nutrients uptake were determined by running Anova in R statistical environment (R Core Team, 2014). When single effects or interactions were significant, multiple comparisons of means among treatments including the control treatment were conducted by performing post-hoc Tukey's test using Agricolae package (De Mendiburu, 2009). Significant differences were established at $P<0.05$.

RESULTS AND DISCUSSION

Root and shoot growth

Phosphorus fertilization management promoted significant changes in root growth and nutrient uptake of wheat and soybeans (Table 1). There was an increase of root length of 94 and 119% for MAP and MESZ, respectively, when the rate was increased from 30 to 90 lb. ac^{-1} in the wheat study (Fig. 1). The effect of high P concentrations promoting stimulus to root growth had been reported in previous studies (Drew, 1975; Anghinoni and Barber, 1980; Hansel et al., 2017b). The MAP+AS+Zn did not show difference in root growth among P rates in the wheat study. However, when the sources are compared at the highest rate of 90 lb. ac^{-1} the MAP+AS+Zn showed lower root length compared to the MAP (-48%). Is possible that the ammonium sulfate N source contributed to an unfavorable environment for root growth. According to Botella et al. (1997) the salinity effect promoted by N sources such as ammonium sulfate can significantly reduce shoot and root growth. Thus, the further application of ammonium sulfate may damage mainly the fine roots (Olsthoorn et al., 1991; Majdi and Persson, 1995). Wheat shoot dry weight was not affected by P sources and rates (Fig. 1).

In the soybean study, there was a reduction in root length when P fertilizer was applied on the row at the highest rate (107 lb. ac^{-1}). In this treatment, soybean root growth was 18.6% lower than the control (Fig. 1). The reduction observed in this treatment can be related with the close contact between the fertilizer and plant root with increased P availability to the plant (Borkert and Barber, 1985). This behavior under a soil with initially high P level could be a response of the plants to adopt and save energy and reduce root biomass growth (Sun et al., 2017). Changes in the soybean shoot dry weight also is reported when P is applied in DB with 22.2% lower than the control (Fig. 1).

Phosphorus S and Zn content in tissue

Nutrient tissue analysis showed an increase in P uptake with the increase in P fertilizer rate in both studies (Fig. 2). However, in the wheat study at the rate of 90 lb. ac^{-1} P fertilizer source also showed differences in P uptake (Fig. 2). The MESZ showed higher P uptake with 23% higher than the MAP at the rate of 90 lb. ac^{-1}. The presence of S into the MESZ and MAP+AS+Zn may have contributed to an increase in P uptake.

Greater Zn content in shoot tissue was observed when sources contenting additional Zn were applied (Fig. 3). At the 30 lb. ac^{-1}, the MESZ showed higher Zn content, 74% greater than the MAP. When the rate was increased to 90 lb. ac^{-1} there was no difference between sources contenting Zn (MESZ and MAP+AS+Zn), but the MAP showed average lower Zn content (Fig. 3). Increased phosphorus applications decrease concentrations of Zn in the shoot (Streeter et al., 2001). However, sources contenting Zn show to be efficient to promote an increase in Zn soil availability and consequently Zn wheat shoot concentration (Yilmaz et al., 1997). There was no effect of P fertilizer management on S tissue content in wheat, neither S and Zn in the soybeans in this study (Fig. 2 and 3).

SUMMARY

The use of different P fertilizers managements resulted in different root growth and nutrients uptake by wheat and soybean plants. These changes may have a significant effect on crop yields in the field under certain conditions of plant stress. The increase in P rates from 30 to 90 lb. ac^{-1} promoted an increase in the wheat root length growth of 94 and 119% for the MAP and MESZ, respectively. However, there were differences between sources in root growth when the highest rate was used. In the soybean study, there was a reduction in root length when P fertilizer was applied in the row at highest rate (107 lb. ac^{-1}). In this treatment, soybean root growth was 18.6% lower than the control. P fertilizer managements also affected nutrient uptake by wheat and soybeans. There was an increase in P uptake with the increase in P fertilizer rates in both studies. In addition, the MEZS and MAP+AS+Zn showed greater P and Zn uptake at 90 lb. P_2O_5 ac^{-1} rate than the MAP in the wheat study. Thus, producers may need to consider this for secondary and micronutrient source selection. Also, is possible that changes in root growth due to P fertilizer source and rate can may affect plant growth and yield particularly under conditions of water stress in the field.

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Table 1. Initial soil test of the soil blend used in the two studies.

Studies	pH	P	K	SO_4-S	Cu	Mn	Zn	Sand	Silt	Clay
			- - - - - - - ppm - - - - - - -						%	
Soybean	7.1	47	243	-	-	-	-	50	30	20
Wheat	7.1	17	130	25	0.9	4	0.39	62	28	10

Table 2. Significance of F values for the effects of plant shoot dry weight (DW), root length and P, S and Zn shoot tissue content as affected by P management.

Fixed factors	Shoot DW	Root Length	Shoot tissue content		
			P	S	Zn
	- - - - - - - - - - - - p>F - - - - - - - - - - - -				
		Wheat			
Source (S)	0.511	0.184	0.022	0.262	<0.001
Rate (R)	0.738	0.005	0.007	0.592	0.894
S×R	0.207	0.001	0.282	0.751	0.114
		Soybean			
Placement (P)	0.037	0.221	0.246	0.106	0.264
Rate (R)	0.129	0.038	<0.001	0.010	0.168
P×R	0.229	0.046	0.452	0.198	0.825

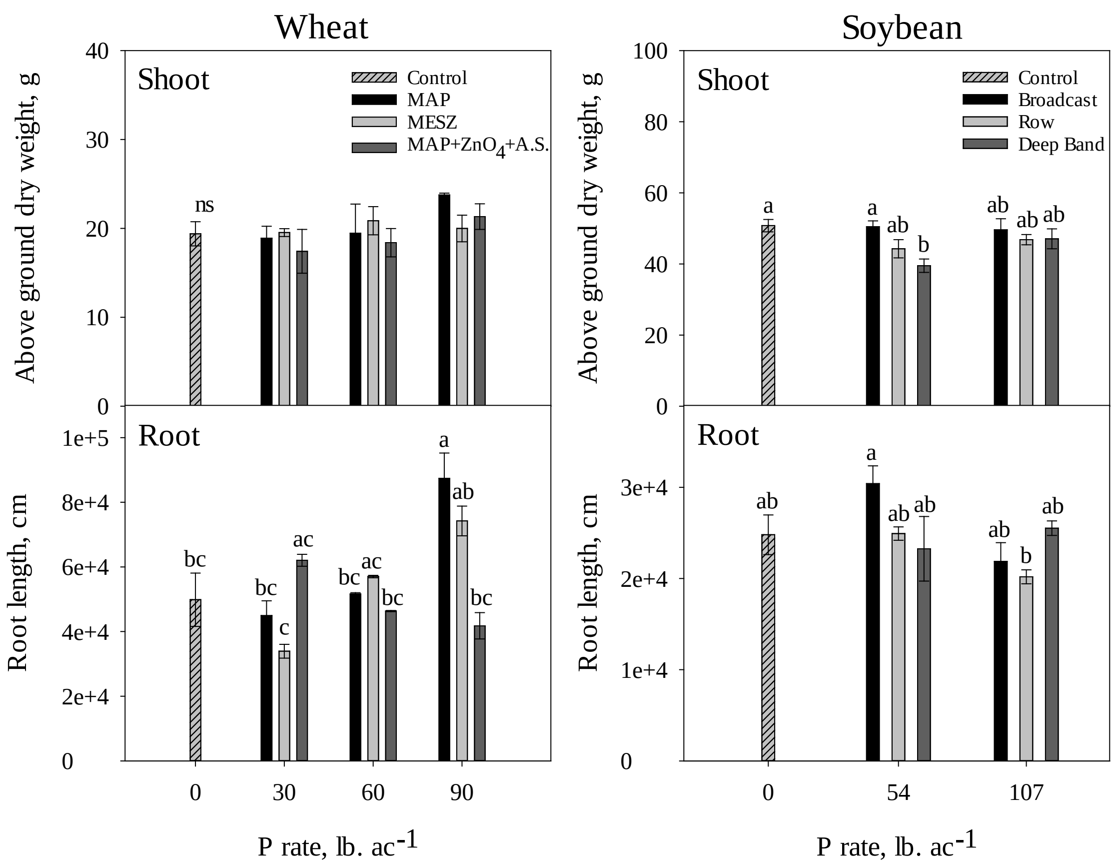

Figure 1. Wheat and soybean shoot dry weight and root length under different P fertilizer managements. Values followed by same letter indicate no significant difference at the $p \leq 0.05$ probability level.

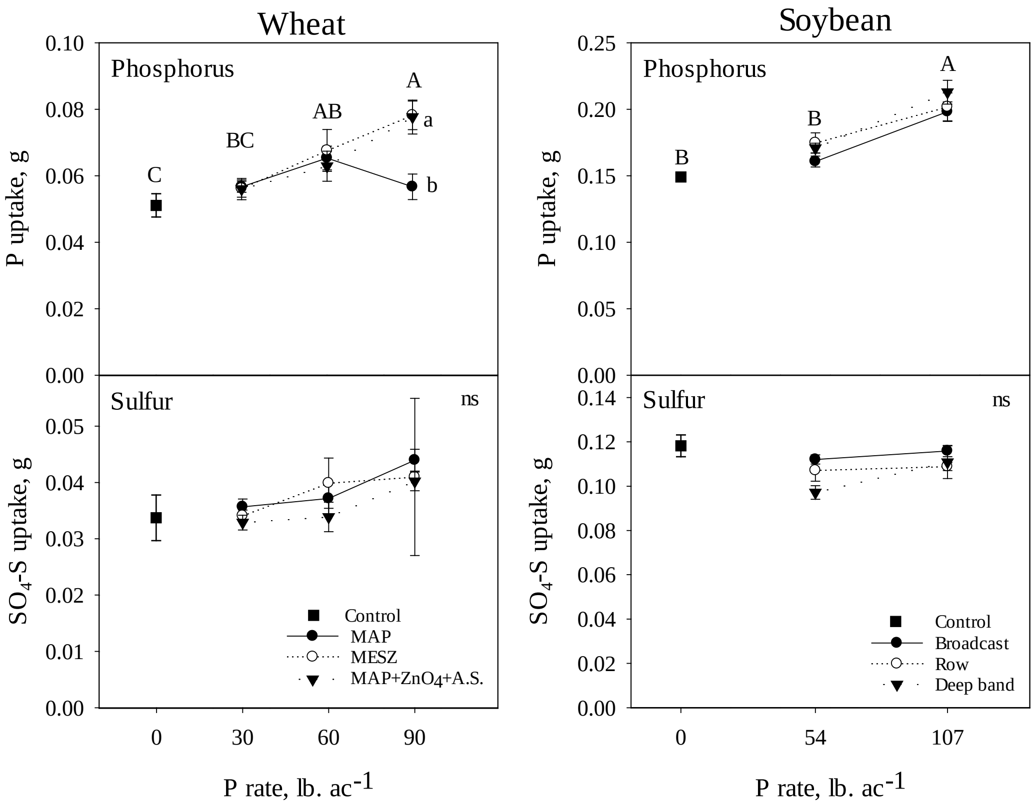

Figure 2. Phosphorus and sulfur plant uptake influenced by different P fertilizer managements. No fertilization (Control). Uppercase letters compare P rates. Lowercase letters in the wheat study compare P sources. Values followed by same letter indicate no significant difference at the $p \leq 0.05$ probability level. ns no significant.

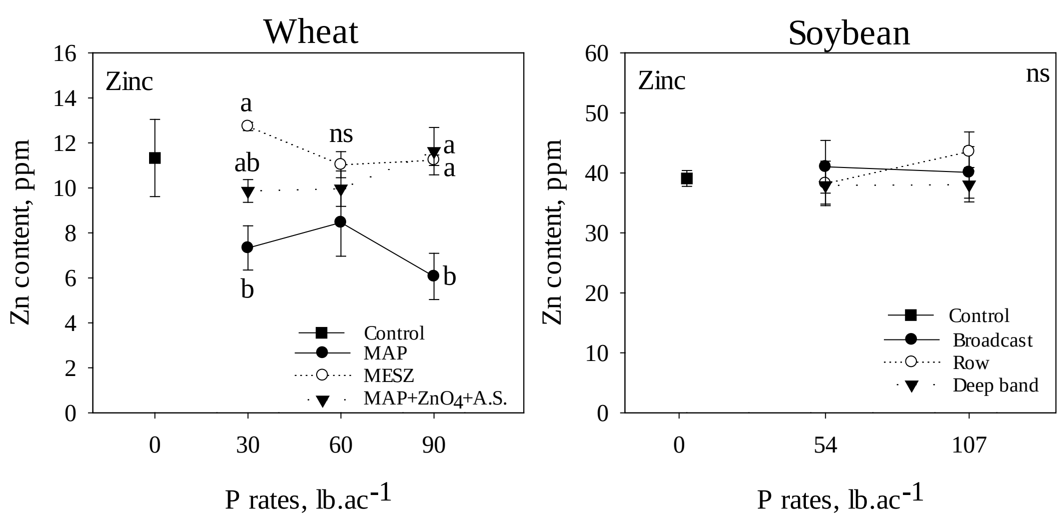

Figure 3. Zinc plant tissue concentration influenced by different P fertilizer managements. No fertilization (Control). Uppercase letters compare P rates. Lowercase letters in the wheat study compare P sources. Values followed by same letter indicate no significant difference at the $p \leq 0.05$ probability level. ns no significant.