PHOSPHORUS AND ZINC INTERACTIONS IN POTATO

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ABSTRACT

Potato production requires high soil phosphorus (P) application with potential negative environmental and nutrient uptake effects. Impacts of high available P on species in potato cropping rotations are not adequately understood, nor have the causes of reduced yield and quality from excess P been fully explored. Antagonistic interactions with cationic micronutrients such as zinc (Zn) are plausible explanations. Two hydroponic experiments were conducted with Burbank potato to elucidate P and Zn relationships and associated interactions with other nutrients. In the first experiment, P solution concentration was constant at 256 uM while Zn concentration varied: 0.05, 2, 6, 18, 54, 162 and 456 uM Zn. In the second experiment, solution concentration Zn was constant at 6 uM while P concentration varied: 32, 64, 128, 264, 512, 1024 and 2048 uM P. A direct impact of increasing solution Zn concentration on P uptake in potato was clearly observed. While Zn content increased in all plant parts as solution Zn increased, P concentration declined in both top leaves and middle leaves and stems with a concomitant increase of P in roots. This suggests a P/Zn complex formation in roots preventing movement of P to the tops of plants under high Zn. However, contrary to expectations, no direct impact of increased solution P on Zn uptake or distribution in potato was observed. Instead, increased solution P resulted in accumulation of Mn in potato roots which may be indirectly impacted by Zn in potato. Therefore, although high P levels in potato did not directly reduce Zn content or cause Zn deficiency, high P may reduce the activity of Zn by interacting with other micronutrients such as Mn.

INTRODUCTION

A combination of high phosphorus (P) requirement in potato and low plant availability of P under high pH and calcium carbonate concentrations of arid-zone soils has stimulated elevated P fertilization in potato cropping systems (Marschner, 1986; Moraghan and Mascagni, 1991; Stark and Westerman, 2002). The soaring P application is critical to potatoes grown in alkaline, calcareous soil, but the trap of “if some is good, more is better.” can lead to environmental and nutritional challenges. Consequently, many fields in eastern Idaho have received so much excess P from fertilizer and animal waste applications that soil test levels are extremely high (Potash and Phosphate Institute, 2001). Yet, high residual soil P has not slowed P fertilizer application and could lead to deterioration of water quality from surface runoff and erosion, to reductions in revenue and to micronutrient deficiencies in all species in potato cropping systems.

Excessive P fertilizer application to potatoes can reduce Zn uptake (Christensen, 1972; Christensen and Jackson, 1981; Soltanpour, 1969), yield and tuber size (Idaho Potato Commission, 1997). Additionally, excessive soil and/or fertilizer P may also negatively affect crops grown in rotation with potatoes (Moraghan and Mascagni, 1991). The effects of excess available P on potato and on crops grown after potato have not been adequately studied.

The causes of the reduction in crop yield and quality due to excess P have not been fully elucidated. One likely reason is an antagonistic interaction with other nutrients (James et. al., 1995; Brown and Tiffin, 1962). Although P interacts with many nutrients, the most commonly observed and studied antagonistic interaction is with Zn. Zinc is absorbed by plants as Zn^{2+} and P absorbed as $H_2PO_4^{-1}$ or HPO_4^{-1}. Positively and negatively charged ions have an electrical attraction to one another, facilitating the formation of a chemical bond in either the soil or the plant tissue. The relative strength of the P-Zn bond is strong and does not readily break without dramatic changes in the physical or chemical environment. If excess P binds a large amount of the Zn normally available to the plant, the result can be a P-induced Zn deficiency (James et al., 1995; Brown and Tiffin, 1962).

Ultimately, greenhouse and field experiments will be required to understand P-Zn relationships in potato cropping systems and to recommend management guidelines. However, in order to accurately determine P impact upon Zn in potato without interference from conflicting variables present in soil environments, controlled nutrient hydroponic experiments were conducted to identify P/Zn ratios in potato tissue associated with sufficiency, deficiency and toxicity.

METHODS

Two hydroponic experiments were conducted with Burbank potato to elucidate P and Zn relationships and associated interactions with other nutrients. In each of the experiments treatment solutions were made with optimum levels of all essential plant nutrients except either Zn or P. Hydroponic solution pH was buffered between 5.9 and 6.1. Each experiment consisted of seven treatments of four plants each with 4 replications of each treatment. Potato plantlets grown on agar provided by University of Idaho were transferred into pretreatment solution and grown for 17 days prior to placement in treatment solution for a period of 14 days. Plants were observed in their respective treatments for relative health and appearance, harvested and dried at the end of the 14-day treatment period, digested in nitric-perchloric acid and analyzed by inductively coupled plasma (ICP) spectroscopy. Top leaves, middle leaves and stems, and roots were analyzed for dry weight and nutrient content.

In the first experiment, P solution concentration was constant at 256 uM while Zn concentration varied: 0.05, 2, 6, 18, 54, 162 and 456 uM Zn. In the second experiment, solution concentration Zn was constant at 6 uM while P concentration varied: 32, 64, 128, 264, 512, 1024 and 2048 uM P.

RESULTS AND DISCUSSION

In both experiments plants grown in mid level treatments (6, 18 and 54 uM Zn and 128 and 264 uM P) appeared most healthy based on visual observation. Plants grown in low level treatments of Zn appeared stunted and exhibited reduced growth in both tops and roots. Although plants grown in the upper level treatments of Zn generally exhibited rapid growth and often more plant mass than plants grown in mid level Zn treatments, unhealthy symptoms of yellowing, mottling, curling, burning at leaf edges and early leaf drop in older leaves were observed. Again based on visual observation, potatoes grown in low level treatments of P were stunted with upturned leaves and a general purpling in young leaves. Growth appeared to be slightly inhibited as well in upper level P treatments compared with mid level P treatments. Yellowing, mottling and curling similar to upper level Zn treatments were also expressed in upper level P treatments.

In the variable Zn experiment, Zn deficiency resulted in decreased top and root dry matter yields at the lowest levels of solution Zn (Table 1) and both roots and tops were affected. The apparent decreased yield at the high level of solution Zn was not statistically significant.

As expected, top, middle, and root Zn concentrations increased as solution Zn levels rose (Table 2). Phosphorus concentrations in the top leaves and middle leaves and stems (middle) are depressed with increasing Zn activity in solution. 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. Unexpectedly, top and middle Mn concentrations increased with increased solution Zn concentration at the two highest levels of Zn (Table 2). Root Mn concentration is depressed with intermediate Zn levels (6, 18 and 54 uM Zn) but is essentially similar at low and high Zn rates. Thus, high Zn appears to influence Mn distribution in potato. Mn contents in potato tops were generally similar as Zn increased up to 54 uM Zn, but higher solution Zn resulted in massive transport of Mn from roots to top leaves and middle leaves and stems.

In the variable P experiment, top and total dry matter yields were negatively impacted by P deficiency and toxicity at the low and high rates of P, respectively (Table 3). Root yields were also depressed at the two highest levels of solution P but not with P deficiency. Thus, root size and mass appeared relatively smaller in high P treatments compared with both lower and mid level P treatments.

Also as expected, top, middle, and root P concentrations increased with increasing solution P; however, the concentrations plateau at the highest few treatments (Table 4). However, there was no clear impact on Zn concentrations in any plant part with dramatic changes in solution P activity. Thus, Zn concentration remained unexpectedly unchanged as solution P increased; unlike the impact of increasing solution Zn on potato P contents in the previous experiment. Manganese concentrations in top leaves where depressed at intermediate solution P levels while Mn contents in middle leaves and stems were highest at the lowest solution P level, probably due to a dilution effect. Overall, however, top and middle Mn concentration remained relatively constant. However, there was a consistent increase in Mn concentration in the roots with increasing P concentration.

CONCLUSIONS

A direct impact of increasing solution Zn concentration on P uptake in potato was clearly observed in these studies. While Zn content increased in all plant parts as solution Zn increased, P concentration in both top leaves and middle leaves and stems declined with a concomitant increase of P in roots. This suggests a P/Zn complex formation in roots preventing movement of P to the tops of plants under high Zn. However, contrary to expectations, no direct impact of increased solution P on Zn uptake or distribution in potato was observed. Instead, increased solution P resulted in accumulation of Mn in potato roots which may be indirectly impacted by Zn in potato. Therefore, 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.

Table 1. Dry weight of potato tops and roots grown for 14 days at seven levels of Zn.

Treatment uM Zn	Tops	Roots	Total
	Yield, g pot^{-1}		
0.1	7.8	1.1	8.9
2.0	9.2	1.6	10.8
6.0	11.5	1.5	12.9
18.0	11.4	1.2	12.6
54.0	13.0	1.5	14.5
162.0	14.2	1.8	15.9
486.0	11.5	1.8	13.3
$LSD_{0.05}$	3.2	0.5	3.6

Table 2. Concentration of Zn, Mn and P in Burbank potato at 7 levels of Zn in solution

Treatment				Plant	Part				
uM Zn	Top	Middle	Roots	Top	Middle	Roots	Top	Middle	Roots
		Zn, mg kg^{-1}			P, %			Mn, mg kg^{-1}	
0.1	5	12	19	1.41	1.70	0.42	29	63	600
2.0	13	18	22	1.21	1.73	0.36	40	79	526
6.0	17	22	33	1.00	1.17	0.48	30	65	377
18.0	23	30	53	0.87	0.87	0.90	28	67	357
54.0	44	46	81	0.83	0.70	0.90	37	97	302
162.0	66	175	125	0.85	0.72	0.95	93	203	509
486.0	216	410	1614	0.86	0.72	1.18	139	254	516
$LSD_{0.05}$	15	25	179	0.47	0.37	0.13	13	22	117

Table 3. Potato dry weight grown 14 days at 7 levels of P

Treatment uM P	Tops	Roots	Total
		Yield, g pot^{-1}	
32	8.30	1.81	10.11
64	10.61	1.77	12.38
128	11.85	1.73	13.59
256	11.43	1.56	12.99
512	11.46	1.61	13.06
1024	10.02	1.30	11.31
2048	10.33	1.47	11.81
$LSD_{0.05}$	1.40	0.32	1.59

Table 4. Concentration of P, Zn and Mn in Burbank potato at 7 levels of P in solution

Treatment				Plant	Part				
uM P	Top	Middle	Roots	Top	Middle	Roots	Top	Middle	Roots
		P, %			Zn, mg kg^{-1}			Mn, mg kg^{-1}	
32	0.55	0.31	0.32	35	22	36	47	86	314
64	0.92	0.49	0.38	38	17	32	42	60	388
128	1.09	1.04	0.49	33	16	30	39	57	507
256	1.53	1.72	0.78	31	17	33	38	60	659
512	1.80	2.31	0.87	32	18	30	40	65	669
1024	1.93	2.28	1.05	33	18	30	43	57	927
2048	1.83	2.32	1.10	34	22	31	44	61	945
$LSD_{0.05}$	0.16	0.31	0.10	6	4	4	5	13	191

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