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ORIGINAL ARTICLE

Effects of phosphite, a reduced form of phosphate, on the growth and phosphorus nutrition of spinach (*Spinacia oleracea* L.)

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Abstract

Phosphite (Phi) may potentially supply phosphorus (P) nutrition to plants and is widely marketed as a super P fertilizer for many crops. This study investigated the effects of Phi on growth and P nutrition in spinach (*Spinacia oleracea* L.). High-rate foliar application experiments designed to evaluate the phytotoxicity and P nutritional potential of different Phi formulations by foliar application at two rates (0.15 and 0.3% P_2O_5) showed that all Phi formulations did not improve plant growth under different available P-soils, but rather significantly decreased shoot dry weight (DW) at the higher rate. In two other soil and hydroponic experiments, Phi was foliar applied at a low rate (0.05% P_2O_5) and root P treatments were combinations of Phi and phosphate (Pi) at different Pi : Phi ratios for a high P level (the soil experiment) or a low P level (the hydroponic experiment). In both experiments, shoot DW decreased markedly as the Pi : Phi ratios decreased from 100:0 to 0:100 and Phi foliar application did not improve plant growth. In the soil experiment, plants grew poorest at 0:100, but grew well when both Phi and Pi were applied at a high rate of 115 mg P pot^{-1}, indicating that at this level Phi had a negative effect on only severely P-deficient plants. Root growth of no Pi-fertilized plants was strongly inhibited by Phi from either root or foliar application. In both experiments, P concentration drastically decreased with decreasing Pi : Phi ratios from 100:0 to 0:100, but increased substantially with foliar application of Phi compared with Pi, suggesting that Phi was absorbed poorly by the roots, but was well absorbed by the leaves compared to Pi. We conclude that Phi cannot be used as a P fertilizer for spinach via either root or foliar applications at low or high levels, and also that Phi has no beneficial effect on the growth of spinach. As Phi is now widely marketed as a P fertilizer for many crops, care should be taken in selecting Phi as a P fertilizer for a given crop.

Key words: growth, nutrition, phosphite, phosphate, spinach.

INTRODUCTION

Phosphorus (P) is an essential nutrient required by all living organisms. Phosphorus is highly reactive and is not found in its elemental form in nature. When P is fully oxidized the molecule is called phosphate (PO_4^{3-}; Pi), and when it is not fully oxidized (one oxygen less than Pi) the resulting molecule is called phosphite (PO_3^{3-}; Phi), also referred to as phosphonate or phosphorous acid. For years, Pi compounds were considered to be the only form that could supply P nutrition to plants. However, Pi fertilizers have some undesirable properties, for example, they are not readily taken up by the foliage of many plants and must be delivered to the soil for uptake by plant roots. The P use efficiency of Pi applied to the soil is very low because more than 80% of the applied Pi becomes immobile and unusable by the plant because of adsorption, precipitation or conversion to the organic form (Holford 1997). In recent years, it has been shown that plants can obtain P from Phi, which has long been thought of not as a fertilizer but rather as possessing some fungicidal properties. Phosphite is more soluble than Pi, making leaf and root uptake more efficient (Lovatt and Mikkelsen 2006). A series of US patents, such as US

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patent numbers 5514200 (Lovatt 1996), 5830255 (Lovatt 1998), 5707418 (Hsu 1998), describe formulations containing Phi as suitable fertilizers for plants. Many current Phi products, such as *Nutri-phite* (Biagro Western Sales; Visalia, CA, USA), *Actaphos* (RSA Microtech, LLC; Saint Paul, MN, USA.), *AG-phite* (Plant Food System; Zellwood, FL, USA), are widely marketed as "superior P fertilizers" for either soil or foliar application for a wide range of crops. This has raised considerable controversy because there are many conflicting results regarding the usage of Phi as a P fertilizer. Numerous studies have indicated that Phi has negative effects on plant growth and is not really used in plants as a P fertilizer (Abel *et al.* 2002; Carswell *et al.* 1996, 1997; Forster *et al.* 1998, Schroetter *et al.* 2006), but rather it suppresses the typical molecular and developmental responses of plants to P deficiency (Abel *et al.* 2002; Carswell *et al.* 1996, 1997; Ticconi *et al.* 2001; Varadarajan *et al.* 2002). In contrast, there is also evidence that Phi application can replace Pi in some plants, such as citrus and avocado crops, suffering from P deficiency (Lovatt 1990a,b). Beneficial effects of Phi on the growth of cucumber and on the yield and quality of Satsuma orange in Japan (Watanabe 2005) and Valencia orange in Florida (Albrigo 1999) have also been reported. Rickard (2000) compiled the results of different research investigating crop responses to commercially sold Phi fertilizers. All of the results in his paper consistently showed that the growth and quality of many different crops was improved by Phi application. Although the effects of Phi on plant growth are still in debate, crop producers in many countries are applying Phi formulations that are labeled as P fertilizers (McDonald *et al.* 2001; Rickard 2000). Interest in using Phi as part of a total production package is also increasing (Lovatt and Mikkelsen 2006). Some researchers (Lovatt and Mikkelsen 2006; Rickard 2000) have claimed that the beneficial effects of Phi are not related to the molecule's fungicidal properties, but rather to other growth-stimulating properties, and that Phi, if used at appropriate rates, can provide stimulation to the plant that may not occur with Pi. It is of interest, therefore, to examine the effects of Phi on plant growth over a wide range of crops using different methods and rates of application.

This research was conducted to investigate the effects of Phi on the growth of spinach (*Spinacia oleracea* L.), an important leafy vegetable crop. The detailed objectives of the present study were: (1) to examine the phytotoxicity and nutritional potential of different Phi formulations, (2) to investigate the effect of Phi as P fertilizer on plant growth via different methods and different rates of applications, (3) to check whether Phi application had any stimulating effect on plant growth that may not occur with Pi.

To achieve these objectives, we first conducted three high-rate foliar application experiments to examine the phytotoxicity and P nutritional potential at high rates of Phi formulations by foliar application. We then conducted two additional experiments (soil and hydroponic experiments) to investigate in detail the effect of Phi on plant growth via both root and foliar applications at different rates. For root P treatments in the two additional experiments, Phi was applied in combination with Pi at different ratios for a high P level using soil culture (the soil experiment) and a low P level using water culture (the hydroponic experiment) to avoid the effects of soil on P sorption, particularly when applied at low levels, and to minimize the oxidation of Phi to Pi, which can occur by microflora in the soil.

MATERIALS AND METHODS

All experiments were conducted in a glasshouse at Kyushu University, Japan (33°37′N, 130°25′E, elevation 3 m a.s.l). Seeds of spinach (*Spinacia oleracea* L. cv. F1-Packer) were obtained from Nakahara Seed Company (Fukuoka, Japan).

High-rate foliar application experiments

Three experiments using the same procedure, but using three different soils, were carried out simultaneously on 1 March 2006. The soils used had different P concentrations that represented low P soil (Kashii soil, an Acrisol), medium P soil (Futsukaichi soil, a Fluvisol) and high P soil (Volcanic soil, an Andisol). The properties of these soils are shown in Table 1. The soil in each pot (1.5 kg air-dried soil per pot) was adjusted to pH 7.0 by mixing well with 3.0, 1.2 and 7.9 g of $CaMg(CO_3)_2$ powder for the Kasshi, Futsukaichi and Volcanic soils, respectively. The amount of $CaMg(CO_3)_2$ for each soil was calculated based on a pH buffering capacity analysis of the soil (buffering curve method; Date 1986). Pots were then placed on individual saucers and kept moist by adding water to the saucer. Two days later, six 2-day-old spinach seedlings were planted into each pot and thinned to three plants at 7 days after planting (DAP). The treatments consisted of four Phi formulations (Table 2) that were foliar applied at two concentrations (0.15 and 0.3% P_2O_5) on three occasions: 26, 34 and 42 DAP. The solutions were sprayed as a fine mist onto the leaf surface without causing droplets to coalesce and run off. Deionized water was sprayed in the same manner for the control treatment. Other nutrients were supplied sufficiently for plant growth throughout these experiments. The accumulated amounts of the nutrients applied per pot were: 1.3 g K (as K_2SO_4); 1.4 g N

Table 1 Selected chemical properties of the soils used in the high-rate foliar application experiments

Soil	pH (H_2O)	Total N†	Total K†	Total P†	Available P‡ (mg kg^{-1})
			(g kg^{-1})		
Kashii	5.0	0.56	4.75	0.38	4.77
Volcanic	6.3	4.50	3.70	2.78	134.39
Futsukaichi	6.1	0.57	1.89	0.39	96.94

†H_2SO_4-H_2O_2 digestion (Ohyama *et al.* 1991) followed by the indophenol, flame photometry and ascorbic acid methods for total N, total K and total P, respectively. ‡Bray and Kurtz (1945).

Table 2 Phosphite formulations used in the high-rate foliar application experiments

Phosphite formulation	Derived chemicals	pH	
		0.15% P_2O_5	0.3% P_2O_5
$K_{1/2}NH_4H_{3/2}PO_3$	NH_4OH and K_2HPO_3	6.5	6.4
$K_{3/2}H_{3/2}PO_3$	H_3PO_3 and K_2HPO_3	6.4	6.5
$(NH_4)_2HPO_3$	NH_4OH and H_3PO_3	7.7	7.8
$Na_{3/2}H_{3/2}PO_3$	NaOH, H_3PO_3 and Na_2HPO_3	6.4	6.4

(as $(NH_4)_2SO_4$) and 14 mg Fritted trace element fertilizer (FTE; Tokan Material Technology, Osaka, Japan; micronutrients). The pots were arranged in a completely randomized design with three replicates. Plants were harvested at 52 DAP.

Soil experiment

The soil experiment was carried out from 10 October 2006 using the low-P soil (Kashii soil). The same procedure as described above was used except for the treatments. The experiment had a total of 24 treatments, a combination of eight root P treatments and three foliar P treatments, and was conducted as a completely randomized 8×3 factorial design. The root P treatments were combinations of Pi and Phi at different Pi : Phi ratios (100:0, 75:25, 50:50, 25:75, 0:100, 0:0, 25:0 and 100:100), with 100 equivalent to 115 mg P per pot. This P level was selected based on the growth response of spinach to different Pi treatments in a preliminary experiment to ensure an adequate supply of P for maximum plant growth (high P level). The Pi and Phi used were, respectively, potassium dihydrogenphosphate (KH_2PO_4) and potassium dihydrogenphosphite (KH_2PO_3). The three foliar P treatments were: deionized water (control), a Pi solution and a Phi solution. The Pi and Phi solutions for foliar application were prepared from KOH and either H_3PO_4 (Pi solution) or H_3PO_3 (Phi solution) and had the same $K_2O : P_2O_5$ ratio of 28:26 as most Phi fertilizers marketed for foliar application and the same final concentration of 0.05% P_2O_5. The pH of the two solutions was similar (6.2 for Pi and 5.9 for Phi). The foliar solutions were applied to the leaves in the same manner as in the preliminary experiments on three occasions: 24, 32 and 40 DAP. Plants were harvested at 48 DAP.

Hydroponic experiment

The hydroponic experiment had a total of 15 treatments that combined five root P treatments and three foliar P treatments as a 5×3 factorial in three completely randomized blocks. The root P treatments consisted of a no P treatment (0:0) and four Pi : Phi ratios of 100:0, 50:50, 25:75 and 0:100 at a low total P concentration of 0.07 mmol L^{-1} (the P concentration required to obtain approximately 70% of the maximum yield in a preliminary experiment using the same hydroponic pot system). On 15 October 2006, uniform seedlings grown in vermiculite for 18 days were selected and transferred into 7-L hydroponic pots (nine plants per pot) containing 30% strength Hoagland solution, with P modified according to the root P treatment. The nutrient solution was renewed every 5 days and the pH was adjusted to 6.5 every 2 days by adding 1 M H_2SO_4 or 1 M NaOH as needed. The foliar P treatments were the same as those in the soil pot experiment and were applied on three occasions: 4, 12 and 20 days after transplanting (DAT). The nine plants per pot were harvested on three separate occasions (three plants per time) at 10, 20 and 30 DAT.

Plant analysis

The root lengths of the plants at harvest in the hydroponic experiment were measured from the junction of the shoot and the root to the tip of the longest root.

Table 3 Growth response of spinach to foliar application of different phosphite formulations at two rates in the high-rate foliar application experiments

Treatment	Shoot dry weight (g plant^{-1})		
	Kashii	Futsukaichi	Volcanic
Phi rate (% P_2O_5)			
0 (control)	0.15 a	2.06 a	2.80 a
0.15	0.09 b	2.09 a	2.75 a
0.30	0.07 c	1.98 b	2.38 b
Phi formulation			
$K_{1/2}NH_4H_{3/2}PO_3$	0.08	1.94	2.54
$K_{3/2}H_{3/2}PO_3$	0.09	2.10	2.59
$(NH_4)_2HPO_3$	0.08	2.03	2.63
$Na_{3/2}H_{3/2}PO_3$	0.07	2.03	2.51

Means followed by different letters within a column are significantly different using least significant difference ($P < 0.05$). Means without letters indicate that the *F*-test was not significant ($P < 0.05$). Phi, phosphite.

After harvesting, the plant samples were washed first in running tap water and then in deionized water. The dry weight (DW) was obtained after drying samples for 3 days at 70°C. The dried plant samples were analyzed for total P using the H_2SO_4-H_2O_2 Kjeldahl digestion method (Ohyama *et al*. 1991) followed by calorimetrically measuring P (Murphy and Riley 1962).

Statistical analysis

The data were statistically analyzed using IRRISTAT for Windows version 4.0 (Biometric Unit, International Rice Research Institute, Manila, Philippines). Separation of the means was carried out using least significant differences (LSD) at $P = 0.05$ whenever significant ANOVA ($P < 0.05$) results occurred.

RESULTS

High-rate foliar application experiments

Table 3 shows that plant growth under low (Kashii soil), moderate (Futsukaichi soil) and high (Volcanic soil) P available conditions was not improved by foliar application of the different Phi formulations at either 0.15 or 0.3% P_2O_5. In Futsukaichi and Volcanic soils, plant growth significantly decreased at the higher rate, whereas in the Kashii soil, plant growth significantly decreased at both rates compared with the control. No difference in plant growth among the Phi formulations was observed. Surprisingly, all Phi formulations caused slightly toxic symptoms in the foliage, even at the low rate. Small necrotic spots on leaves were observed at the low rate and increased numbers and larger necrotic spots were observed at the higher rate (data not shown).

Table 4 Effects of phosphate : phosphite ratios and foliar phosphorus treatments on shoot dry weight and shoot phosphorus concentration in spinach in the soil pot experiment

Treatments	Shoot DW (g plant^{-1})	Shoot P concentration (mg g^{-1} DW)
Soil P treatment (Pi : Phi ratio)		
100:0	2.60 A	4.51 B
75:25	2.48 AB	3.96 C
50:50	2.30 B	3.12 D
25:75	1.77 C	2.63 E
0:100	0.13 E	3.06 D
0:0	0.34 D	1.90 F
25:0	1.66 C	2.44 E
100:100	2.58 A	4.90 A
Foliar P treatment		
Water	1.72	3.11 b
Phosphate	1.77	3.33 a
Phosphite	1.69	3.46 a

Within a column means followed by the same small letters or capital letters, respectively, are not significantly different using least significant difference ($P < 0.05$). Means without letters indicate that the *F*-test was not significant ($P < 0.05$). DW, dry weight; P, phosphorus; Phi, phosphite; Pi, phosphate.

Soil experiment

Table 4 shows that there was no significant difference in shoot DW between the 100:0 and 75:25 treatments, but further decreases in the Pi : Phi ratio from 75:25 to 0:100 significantly decreased shoot DW. The shoot DW of plants in the 0:100 treatment decreased to only 5% of that of plants in the 100:0 treatment and was even smaller than that in the 0:0 treatment. No difference in shoot DW between the 25:75 and 25:0 or between the 100:100 and 100:0 treatments was found. Foliar application of Phi did not significantly influence shoot DW averaged over all Pi : Phi ratios, nor did it significantly influence shoot DW at each Pi : Phi ratio (detailed data not shown).

As shown in Table 4, P concentration in shoots was markedly decreased with decreasing Pi : Phi ratios from 100:0 to 25:75. The high shoot P concentration in the 0:100 treatment is likely to have resulted from an extremely low biomass growth, leading to an accumulation of nutrients in plants grown in this treatment. Interestingly, shoot P concentration in the 25:75 treatment was only 8% higher than that in the 25:0 treatment. Although both treatments had the same amount of Pi applied (28.8 mg P per pot), the former had an additional 86.2 mg P per pot Phi, making the total amount of P applied in this treatment four times higher than that in the latter. Similarly, shoot P concentration in the 100:100 treatment was only 9% higher than that in the 100:0 treatment. Foliar Phi treatment

Table 5 Effects of phosphate : phosphite ratios and foliar phosphorus treatments on growth and phosphorus concentration in the shoots and roots of spinach at final harvest in the hydroponic experiment

Treatment	Shoot DW (g plant^{-1})	Root DW (g plant^{-1})	Root length (cm)	Root/Shoot ratio	P concentration Shoot (mg g^{-1} DW)	P concentration Root (mg g^{-1} DW)
Root P treatment (Pi : Phi ratio)						
100:0	2.23 a	0.54 a	38.1 a	0.239 b	3.40 a	5.85 a
50:50	1.68 b	0.43 b	34.3 a	0.253 b	2.45 b	4.24 b
25:75	1.27 c	0.32 c	27.9 b	0.246 b	1.69 c	3.18 c
0:100	0.75 d	0.16 e	21.9 c	0.206 c	0.99 d	1.91 d
0:0 (0P)	0.70 d	0.25 d	28.5 b	0.377 a	0.84 e	1.38 e
Foliar P treatment						
Water (Control)	1.33	0.37 A	31.87 A	0.278 A	1.76 C	3.17 B
Phosphate	1.35	0.35 A	30.67 AB	0.264 A	1.84 B	3.29 B
Phosphite	1.31	0.30 B	27.93 B	0.227 B	2.03 A	3.48 A

Means followed by the same small letters and capital letters within a column, respectively, are not significantly different using least significant difference ($P < 0.05$). Means without letters indicate that the F-test was not significant ($P < 0.05$). DW, dry weight; P, phosphorus; Phi, phosphite; Pi, phosphate.

increased shoot P concentration more than the foliar Pi treatment; the increases in shoot P concentration (average over all Pi : Phi ratios) over the control were 11.25% (by foliar Phi) and 7% (by foliar Pi).

Hydroponic experiment

A small inhibition effect of Phi on plant growth was found after 10 days of treatment, but became more pronounced with time (data not shown). Table 5 shows the results of plant growth and P concentrations at final harvest. There was a more obvious decrease in both shoot and root growth with decreasing Pi : Phi ratios from 100:0 to 0:100. Shoot DW of plants in the 0:100 treatment was only 34% of that in the 100:0 treatment. Root DW in the 0:100 treatment was smallest and was only 30 and 64% of that in the 100:0 and 0:0 treatments, respectively. Root length also decreased to 57 and 77% of that in the 100:0 and 0:0 treatments, respectively. Using the naked eye, it was observed that roots in the low Pi : Phi ratio treatment of 0:100 turned dark in color, and the root hairs and root tips died off gradually, resulting in smaller and shorter root systems (Fig. 1A).

Foliar application of Phi did not improve shoot growth (Table 5), but tended to decrease root growth, especially in the 0:0 treatment (Fig. 1B). The root to shoot (R/S) ratio of plants grown in the 0:0 treatment with foliar application of Phi strongly decreased, similar to that of plants grown in the 0:100 treatment (Fig. 2).

The shoot P and root P concentrations shown in Table 5 were dramatically decreased as the Pi : Phi ratio decreased from 100:0 to 0:100. The shoot P concentration of plants grown in the 0:100 treatment was only 18% higher than that in the 0:0 treatment and approximately 29% of that in the 100:0 treatment; whereas for the root, it was, respectively, 38 and 33%. The P concentrations in both shoots and roots were significantly higher with foliar application of Phi than with foliar application of Pi or the control.

DISCUSSION

Phytotoxicity of different phosphite formulations

Although Phi is absorbed well by the foliage of many plants (Lovatt 1990a,b, 1998; Rickard 2000; Watanabe 2005), it is also highly toxic to the leaves of plants. It was expected that the phytotoxicity of Phi would be suppressed by using a proper combination of Phi with other chemicals and, thus, the concentration of the Phi solution for foliar application would be able to be increased to significantly supplement P to plants without causing injury to the foliage. The results from the high-rate foliar application experiments, however, showed high toxicity to the leaves of all the tested Phi formulations, even at the lower rate of 0.15% P_2O_5. This suggests that even if Phi can be used as a P fertilizer, there would be a challenge to supply a significant amount of P to plants without causing leaf damage by foliar application.

Nutrition of phosphite

The results of both the soil and hydroponic experiments strongly indicated that Phi could not be used as

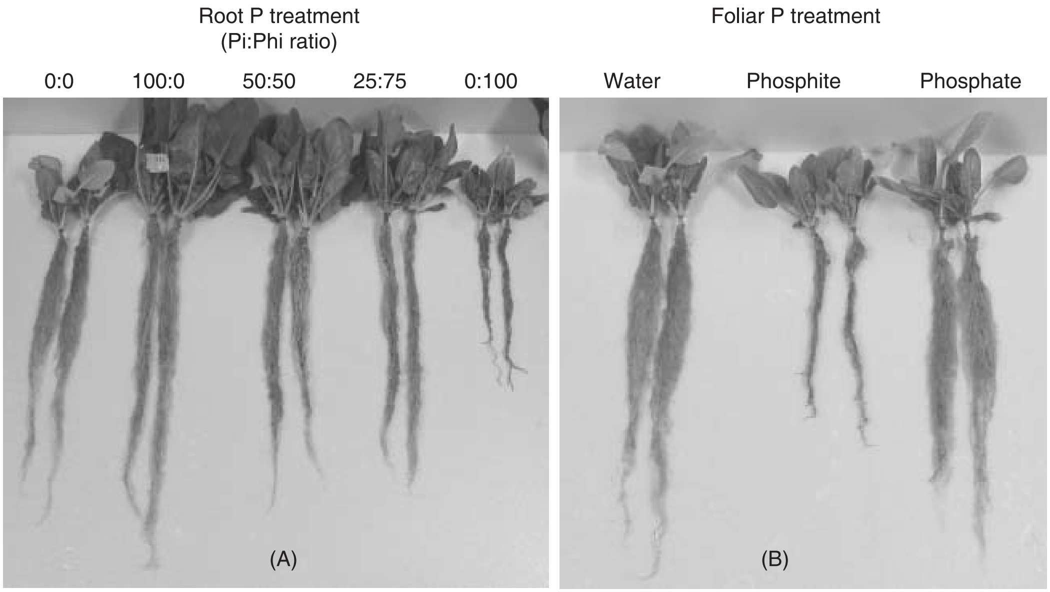

Figure 1 Effects of Phi on root growth in hydroponic experiment. (A) Root growth in different Pi:Phi ratios with foliar application of deionized water; and (B) Root growth in no 0:0 treatment with different foliar P treatments.

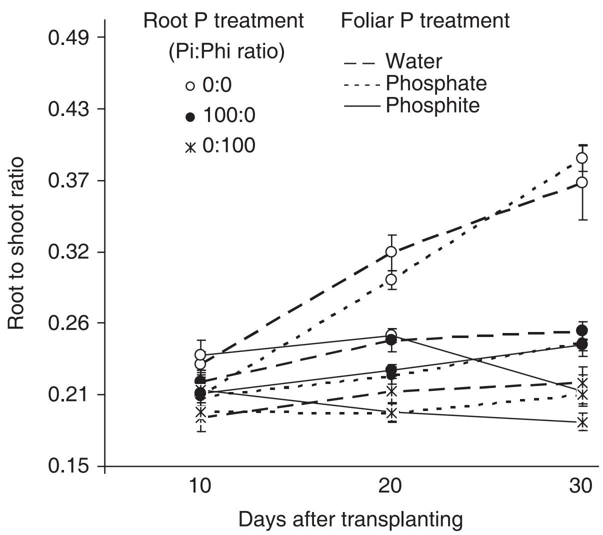

Figure 2 Effects of Pi:Phi ratios and foliar P treatments on root to shoot ratio of spinach in the hydroponic experiment. Bars represent SEM (n = 3).

P fertilizer via either root or foliar application and could not substitute for P at any rate at either low or high levels. The drastic decrease in root growth (root DW and root length) with decreasing Pi : Phi ratios together with a significant decrease in the R/S ratio in the 0:100-treated plants, as well as in the 0:0-treated plants that received Phi from foliar application at a very low rate (0.05% P_2O_5) suggested that in serious Pi-deficient conditions, root growth of the plants was very sensitive to Phi and the small amount of Phi from foliar application was sufficient to cause severe root growth inhibition. Enhanced root growth relative to shoot growth is known to be a classic response of plants to Pi deficiency, which results in an increased R/S ratio. A suppression of root growth in Pi-deficient plants treated with Phi has also been reported in black mustard (Carswell *et al.* 1996), Arabidopsis (Ticconi *et al.* 2001) and tomato (Varadarajan *et al.* 2002). One of the primary mechanisms for the inhibition effect of Phi on Pi starvation-induced responses of plants, including enhanced root growth, is its ability to interfere with Pi starvation-induced gene expression (Abel *et al.* 2002; Carswell *et al.* 1996, 1997; Ticconi *et al.* 2001; Varadarajan *et al.* 2002).

The results of this study are consistent with our previous research in komatsuna plants (Thao *et al.* in press). Although komatsuna plants are more sensitive to Phi than spinach plants, it is clear that Phi cannot be used as a supply of P in either plant using either application method (foliar or root application). In addition, no beneficial effects of Phi on the growth of either komatsuna or spinach were detected. Our results are also in agreement with some earlier studies that have provided evidence on the negative effects of Phi on the growth and development of plants (Carswell *et al.* 1996; Forster *et al.* 1998; Schroetter *et al.* 2006; Ticconi *et al.* 2001). Some researchers (Lovatt and Mikkelsen 2006; Rickard 2000) have claimed that the negative response of plants to Phi in many studies results from improper use of this material (use as the sole source of P or in excessive rates), and that Phi, if used at appropriate rates, can provide stimulating effects to plants that may not occur with Pi. In addition, combinations of Phi and Pi ions are believed to be more effective than either alone in plant assimilation (US patent number 6824584; Young 2004). Forster *et al.* (1998) found that Phi did not perform as well as Pi fertilizer, but they did observe growth enhancement of tomato plants treated with a mixture of Pi and Phi when compared to Pi alone. Our study, however, provides further evidence that even when applied at a very low rate or when applied in combination with Pi at different ratios at either low or high levels, no stimulating effect of this material on plant growth occurs. With the same total amount of P (Pi + Phi) applied to the roots, plant growth was significantly decreased as the proportion of Phi increased.

Phosphite has been reported to be more soluble than Pi, making leaf and root uptake more efficient (Lovatt and Mikkelsen 2006; Watanabe 2005). However, the significant decrease in the concentration of P in plants in both the soil and hydroponic experiments together with the small difference in shoot P concentration between the 25:0 and 25:75, 100:0 and 100:100 treatments or between the 0:0 and 0:100 treatments implies that Phi is very poorly absorbed by the roots of spinach. This provides evidence that not all plant species can uptake Phi well by their roots. In contrast, foliar application of Phi, even at a low concentration, increased the P concentration of plants compared to the control (water) and foliar application of Pi, indicating that Phi was well absorbed by spinach leaves compared with Pi. The significant increase in total P concentration by foliar application of Phi coupled with the lack of plant growth improvement in different P conditions corroborates evidence that Phi is not significantly oxidized or otherwise metabolized in plants (Carwell *et al.* 1996, 1997; Forster *et al.* 1998 . . .). Similar results have also been found in maize (Schroetter *et al.* 2006).

We conclude that Phi does not provide any P nutrition to spinach plants via either root or foliar application, but rather inhibits root growth in severely Pi-deficient plants, even at low foliar application levels of Phi. Beneficial effects from this material or from any combination of Pi and Phi were not detected. Phosphite was well absorbed by the foliage, but was very poorly absorbed by the roots of spinach. As Phi is now widely marketed as a P fertilizer for many crops, care should be taken in selecting Phi as a P fertilizer for a given crop.

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