

Phosphite, phosphate, and their interactions in soil and turfgrass

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Abstract

Phosphate (H_3PO_4) is the recognized P fertilizer source, while phosphite (phosphorous acid) (H_3PO_3) is often considered and labeled as a fungicide. However, the exact role of phosphite is unclear - is it functioning as a fertilizer, fungicide, or both? In turfgrass maintenance, phosphite is sometimes included in fertilizers, with no specific fungicidal claims attached. Previous work has shown that applications of phosphite can be detrimental to plant growth, especially if soil is low in phosphate. In the soil, phosphite will convert to phosphate, but the time required for that conversion is not well quantified. Thus, project objectives were: 1) evaluate how application of phosphite, phosphate and their combination affected turfgrass growth, and, 2) quantify the conversion of applied phosphite to phosphate, in soil. Two greenhouse studies and one soil incubation study were used to evaluate phosphite and phosphate, and their combined and separate effects on ryegrass and bentgrass, and soil conversion. Phosphite materials (labeled fungicides and phosphite-containing fertilizers) were applied based on P rate or at labeled rates. In the soil incubation study, phosphite was converted to phosphate within one month. In the greenhouse trials ryegrass was unaffected or positively benefited by application of phosphite, even at low levels of soil phosphate. In the bentgrass trials, root growth was reduced when phosphite was applied, but only when soil-test phosphate was $< 2 \text{ mg}\cdot\text{kg}^{-1}$. When ryegrass and bentgrass were fertilized with any level of phosphate ($> 15 \text{ kg}\cdot\text{P}\cdot\text{ha}^{-1}$) deleterious effects of phosphite on plant growth were not observed.

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Introduction

Phosphorus (P) is an essential element for turfgrass growth and reproduction. Existing in the soil in both inorganic and organic forms, P for plant growth is taken up by plants as the orthophosphate ions $H_2PO_4^-$ or HPO_4^{2-} [1]. The availability of that inorganic P for plant uptake is controlled in acid soils by aluminum and iron compounds, with varying solubility, and in alkaline soils by calcium compounds[2]. The quantity of inorganic P in the soil solution is also affected by both short- and long-term reactions with organic and microbial biomass P, with P cycling between all those fractions controlled by mineralization[2]. In the majority of soil fertility work the focus is upon inorganic soil P, that small pool of solution P (often called 'labile P') used by the plant, and growth responses therein.

Phosphite (H_3PO_3), unlike phosphate, is a non-nutrient form of an essential element, P. Phosphite is a generic name used to describe alkali metal salts of phosphorous acid (H_3PO_3), which also may be called phosphonate[3]. Phosphite has long been recognized for its fungicidal abilities[4-7], and has been evaluated for its ability to control *Pythium* (spp.)[8], cyanobacteria[9], dollar spot (*Clariireedia jacksonii*) [10] and pink snow mold (*Microdochium nivale*) [7,11-12] in turfgrasses. Thus, phosphite has long been included in various commercial fungicides and in liquid fertilizers not registered as fungicides, with a common source being potassium phosphite. The inclusion of phosphite in fertilizers is a regulatory issue in flux, and registration/labeling/inclusion regarding phosphite in fertilizers will vary by state and country.

Plants take up phosphite ions, with significant accumulation at 6 weeks after application, with some translocation to roots of creeping bentgrass (*Agrostis stolonifera*) velvet bentgrass (*Agrostis canina*) and *Poa annua*[13]. Plants do not metabolize phosphite into other forms, and it will persist in plant tissue[4,5]. So, when used as a fungicide repeated application of phosphite products is needed, as phosphite would be removed with grass tissue after mowing[11,13].

While most research was conducted on non-turfgrass crops, the effect of phosphite as a P source on plants tends to be highly dependent on the phosphate status of the plants[14,15]. Typically, if soil solution phosphate is high, then application of phosphite is not harmful to the plant. If soil solution phosphate is low, then application of phosphite could be toxic to the plant[15]. For example, relatively low phosphite concentrations in solution culture (1-2 mM) did not affect phosphate-fertilized oilseed rape (*Brassica napus* L.) suspension cells, but phosphate-starved oilseed rape was far more susceptible to the deleterious effects of phosphite[16]. In that work the presence of phosphite caused a 20 to 25% reduction in whole-seedling fresh weights, but only in the phosphate-starved seedlings.

In a study with hydroponically cultivated celery (*Apium graveolens* L.), phosphite was supplied in both low (0.05 $\text{mmol}\cdot\text{L}^{-1}$) and high (0.5 $\text{mmol}\cdot\text{L}^{-1}$) phosphate solutions. When a high rate of phosphite was applied (2 $\text{mmol}\cdot\text{L}^{-1}$) the growth of low phosphate-fertilized celery was significantly decreased[17]. In other work, the same total amount of P was applied to spinach (*Spinacia oleracea* L.), using different ratios of

phosphate:phosphite. No matter what the level of total P, plant growth was significantly reduced as the proportion of phosphite in the ratio increased^[18]. Other work by the same researchers found that if phosphate was limiting for lettuce (*Lactuca sativa* L.) production, less phosphite was needed to cause damage. Conversely, higher rates of phosphite (to 2 mmol·L⁻¹), did not affect lettuce yield if sufficient phosphate (0.3 mmol·L⁻¹) was present^[19]. In still additional work foliar application of phosphite decreased shoot and grain dry weight of bean (*Phaseolus vulgaris* L.) when soil phosphate was deficient, and there was no effect when the beans were grown in high phosphate soil^[20]. Regardless of the level of soil P, the addition of phosphite reduced the shoot and grain dry weight of bean, when compared to treatments to which no phosphite had been added^[20].

The reason why plants are damaged in low phosphate-high phosphite situations was explored in work which examined phosphate starvation-induced gene expression^[3]. Researchers found that the cause of suppression of phosphate starvation was the intervention of phosphite in signal transduction, with the pathway considering phosphite as phosphate. As a result, plants could not perceive phosphate deficiency, even in an extremely low concentration of phosphate^[3]. Phosphate starvation inducible genes, such as LePT2 (high affinity Pi transporters), LePS2 (APase) and TPS11 (novel genes) were not expressed in phosphate-absent tomato (*Solanum lycopersicum* L.) when phosphite was present in the growth media^[6,16]. In a study with *Brassica* spp., the enzyme (APase) and transporters (high-affinity plasmalemma phosphate translocator) of the phosphate starvation response were reduced by application of phosphite, with a 75% reduction in APase^[16].

Although phosphite is not transformed to any other compound in the plant, in the soil it is converted to phosphate, with an approximate half-life of phosphite oxidation to phosphate of 12–16 weeks^[21]. In that study soil microorganisms (such as *Pseudomonas fluorescens*) metabolized phosphite to phosphate^[21]. Due to this slow conversion, some plants grew better in the second year or in subsequent crops, after applying phosphite fertilizer^[5,22], as soil phosphite would have been converted to phosphate, subsequently available for plant uptake^[17]. In other work, soil phosphate content increased slightly after 7 d (to 74 mg·kg⁻¹) as compared to that measured in control plots (52 mg·kg⁻¹) after applying 7.5 g·P·m⁻² as KH₂PO₃ (potassium phosphite) solution. After 30 d, extractable PO₄²⁻ had increased to 199 mg·kg⁻¹, with highest phosphate concentration (330 mg·kg⁻¹) detected two months after applying phosphite to the soil^[23].

Other than the work cited above^[23] research that explores the conversion of soil phosphite to phosphate is essentially relegated to two early studies, with very limited data^[15,21]. The work by Adams & Conrad was conducted on four soil types (San Joaquin clay loam, Aiken clay loam, Corning gravelly loam, Daulton sandy loam), but only data from the San Joaquin soil was reported. For the other soils it was only noted that 'comparable results were obtained'^[21]. Since this early work showed that soil phosphite is converted to phosphate, more work which examines the rapidity with which this conversion occurs could be of value, especially in other soil types. This would allow agronomists to better consider the impact of long-term phosphite applications on soil phosphate, and possible effects on plant growth.

Phosphite is often applied in turfgrass systems, both as a fungicide and as a part of fertilizers marketed as 'stress control' products, with no stated fungicidal claim. The phosphite in such products is usually not included in the guaranteed analysis, and typically no P fertilizer value is accorded the phosphite (this will vary, by state and country). Given the lack of information on phosphite transformation in various soil types, and the possible effects on turfgrass growth, the objectives of this study were to: 1) evaluate phosphite applications in combination with rates of soil phosphate for effects on creeping bentgrass and perennial ryegrass performance, and, 2) conduct a laboratory incubation study to quantify the conversion of phosphite to phosphate.

Materials and methods

Greenhouse study 1 – perennial ryegrass (*Lolium perenne* L.)

Two runs of this study were conducted at the Plant Science Research Center (PSRC), under ambient light conditions (Auburn, AL, USA). The first experiment was conducted from 18 April 2014 to 10 June 2014 (7 weeks) and the second from 12 August 2015 until 22 September 2015 (6 weeks). For the first run (Run 1), an experimental unit was a single pot (14.5 cm diameter) containing 100% sand into which perennial ryegrass was seeded. Six weeks prior to the start of each experiment 1.8 g (0.11 kg·m⁻²) of 'Eagle Select' perennial ryegrass seed blend (cultivars were 'Playoff II', 'Allsport 3', and 'Greenville') were placed on top of 1365 g sand in each pot, and another 70 g of sand covered the seed.

As it's uncommon to have soil with zero P content in practice, for the second run (Run 2) the growth medium was changed from 100% sand used in Run 1 to a Marvyn loamy sand containing 19 mg·kg⁻¹ P (fine-loamy, kaolinitic, thermic Typic Kanhapludult), with the experiment installed as described previously. Sand and soil were collected from the Auburn University Turfgrass Research Unit (Auburn, AL, USA). Before the start of the experiment, bulk soil samples were analyzed for nutrient content (Table 1).

Treatments were three commercial phosphite/phosphate sources: 1) Turfite (Headland Amenity Ltd., Caldecote, Cambridge, UK), 2) TKO (Growth Products, White Plains, NY, USA), and, 3) triple super phosphate (TSP) (Table 2). These three P sources were all applied at four P rates: 13, 26, 40, and 52 kg·P·ha⁻¹. All materials were converted from phosphite- and phosphate-P content to a P basis for equal observation. Thus, P rates were based on P from phosphite/phosphate, phosphite, or phosphate, varying with source (Table 2). The study design

Table 1. Initial soil-test results[†] for all soil used in greenhouse and laboratory experiments.

		mg·kg ⁻¹				pH
		P	K	Ca	Mg	
greenhouse-ryegrass	Run 1	0	2.5	28	2	7.4
	Run 2	19	42	70.5	18.5	5.7
greenhouse-bentgrass	Run 1	2	9	73.5	23.5	4.9
	Run 2	2	10.5	110.5	31.5	4.7
laboratory incubation	Marvyn loamy sand	2	36.5	464	35.5	6.5

[†]Mehlich 1 soil test extraction.

Table 2. Nutrient/active ingredient content of phosphite/phosphate, phosphite and phosphate products for greenhouse perennial ryegrass, bentgrass, and laboratory soil incubation studies.

Commercial trade name	Manufacturer	Formulated from	Percent P	Percent from PO ₃	Percent from PO ₄	%N-P-K	Studies Used
Turfite	Headland Amenity Ltd. Cambourne, Cambridgeshire, UK	Phosphoric acid Ammonium phosphate Ammonium citrate	8.9	75.9	24.1	8-9-0 [†]	ryegrass
TKO	Growth Products. White Plains, NY 10603, USA	Phosphorous acid Potassium hydroxide	29.6	100	0	0-0-22 [‡]	ryegrass soil
Title Phyte	Harrell's. Lakeland, FL 33802, USA	Mono- and Di- Potassium phosphite	15.0 [§]	100	0	0-0-25 [‡]	ryegrass bentgrass soil
Alude	Cleary Chemical, Dayton, NJ [¶] 08810, USA	Mono- and Di- Potassium Salts of Phosphorous Acid	11.0 [±]	100	0	n/a	bentgrass
Triple super phosphate	Piedmont Fertilizer Company. Opelika, AL 36801, USA	Triple superphosphate	20.7	0	100	0-20-0	ryegrass soil

[†] Guaranteed analysis does not include P contribution from phosphite. [¶] Manufacturer and formulation specifications for this product at the time of this work (newer product currently with NuFarm). [§] Calculated on 571 g-H₃PO₃·L⁻¹, 1,455 g·L⁻¹. [±] Calculated on 401 g-H₃PO₃·L⁻¹, specific gravity of 1.35.

was a completely randomized design with five replications used for each treatment.

Phosphorus treatments were incorporated with soil once at the beginning of the study before seeding, and all other nutrients were supplied weekly *via* a P-depleted Hoagland's nutrient solution, applied at 20 ml per pot to supply 4.2 mg-N·pot⁻¹ (0.2 g-N·m⁻²) per week. Treatments were not balanced to uniformity for added N or K, since Hoaglands solution was used. Turfgrass was watered as needed to prevent turfgrass stress. All pots were placed randomly on the greenhouse bench every day, after watering or observation.

In both runs, clippings were harvested twice (monthly). Dry weight of clippings was recorded and clippings were saved for tissue P analyses, following standard procedures^[24], followed by analysis *via* inductively coupled argon plasma spectrometry^[24]. Phosphorus uptake in above-ground plant tissue was determined (for each separate harvest) by multiplying tissue dry weight by phosphorus concentration.

Greenhouse study 2 – creeping bentgrass (*Agrostis stolonifera*)

This study was conducted twice, using creeping bentgrass that was established as vegetative samples (7 cm diameter) in 14 cm (height) by 14.5 cm (diameter) pots. Bentgrass ('Penn G-2') was collected from a 5-year-old putting green (maintained at a cutting height of 0.3 cm, with cutting 6 of 7 d) at the Auburn University Turfgrass Research Unit (Auburn, AL, USA) on 17 July, 2015 and 22 Sept, 2015 (for each of two separate runs). Plugs were washed clean of soil, and were placed into pots filled with a USGA-type greens mix^[25]. Pots were filled with 500 g of a USGA-type mix (80% sand/20% reed sedge v/v). Soil test analyses are in Table 1. The experiment was conducted in the greenhouse (Plant Science Research Center, Auburn, AL, USA), using ambient light.

This study consisted of two Runs, with the first conducted from 29 July to 22 Sept, 2015 (8 weeks), and the second from 1 Oct to 23 Nov, 2015 (7 weeks), with the experiment started anew in each Run. Clippings of bentgrass were collected once at the end of each Run (the bentgrass was not clipped for the duration of the experiment), with dry weight of clippings recorded, and saved for tissue P analyses (ICP)^[24]. Roots were saved for dry weight determination. Phosphorus uptake was also determined by multiplying tissue dry weight by phosphorus concentration.

Treatments were 5 P rates, all as triple superphosphate (0, 15, 30, 60, 120 kg·P·ha⁻¹), with and without phosphite sources that were applied at labeled fungicidal or product rates (Table 2). Phosphite products were Alude (a phosphite fungicide) and Title Phyte (fertilizer containing phosphite). Following labeled directions, Alude was sprayed every other week (three applications) and Title Phyte was applied weekly (six applications), at labeled rates. These rates were 3.2 ml Alude per m² and 1.3 ml Title Phyte per m² (approximately 5.0 kg·P·ha⁻¹ in each Alude treatment, and 3.5 kg·P·ha⁻¹ in each Title Phyte treatment). All other nutrients were supplied weekly *via* a P-depleted Hoaglands solution, applied at 20 ml per pot (4.2 mg N) per week. Pots were watered every day to prevent turfgrass stress, and rerandomized on the greenhouse bench weekly (completed randomized design with five replications).

Soil incubation study

This study was initiated on 2 July 2014, and continued until 15 January 2015. The study was conducted using sealable plastic tubs (17 × 15 × 13 cm) to which soil and treatments had been added. One soil type was used: a Marvyn loamy sand (Fine-loamy, kaolinitic, thermic Typic Kanhapludult). Initial nutrient content of this soil is shown in Table 1. Three phosphite or phosphate sources (Triple super phosphate, TKO, and Title Phyte) were all applied at four P rates: 56, 84, 112, and 140 kg·P·ha⁻¹ (Table 2). All phosphite and phosphate in the products were converted to a P-basis for uniformity and rate calculations.

Each tub was filled with 500 g of soil, and watered uniformly to 80% of field capacity. All materials were applied and mixed thoroughly with the soil. Each tub was sealed and placed into a growth chamber set to a constant 21 °C temperature. Each week tubs were removed, opened to stimulate air movement, and resealed. Tub was replaced randomly in the growth chamber.

After 20 d of incubation, soil samples were taken every month, with soil in each tub mixed thoroughly before sampling. Each month the following was carried out: 1) a 2 g subsample was removed and dried to measure soil moisture content, 2) a 5 g subsample was extracted with CaCl₂ (50 ml 0.01 M), and, 3) a 5 g subsample was extracted with Mehlich I soil extract^[26]. Samples were analyzed for P *via* two methods. First was the determination of P *via* inductively coupled argon plasma spectrometry (ICP)^[27]. Second was the separate

Turfgrass response to phosphite application

Table 4. Effect of P rate and P source (TSP (phosphate), TKO (phosphite), Turfite (phosphate/phosphite)) on the dry weight of perennial ryegrass topgrowth. Run 2 of a greenhouse experiment.

P Rate (kg·ha ⁻¹)	Dry weight of topgrowth (g)		
	P source		
	Turfite	TKO	TSP
0	0.28	0.28	0.28
13	0.37 ab ^{††}	0.41 a	0.32 b
26	0.39 a	0.43 a	0.40 a
40	0.48 a	0.36 b	0.41 ab
52	0.43 a	0.39 a	0.36 a
Regression	Q [†]	NS	Q

[†] From linear regression (each column), Q = significant quadratic response within each P source; NS – no linear or quadratic response. ^{††} From mean separation, means followed by the same letter are not significantly different from each other (alpha = 0.05), between P sources (each row), within each P rate.

Table 5. Effect of P rate and P source (TSP (phosphate), TKO (phosphite), Turfite (phosphate/phosphite)) on P uptake by perennial ryegrass as affected by P source, two harvests in Run 2 of the experiment.

P source	P rate (kg·ha ⁻¹)	Tissue P uptake (mg ⁻¹ ·pot ⁻¹)		
		Turfite	TKO	TSP
Harvest 1, Run 2	0	0.03	0.03	0.03
	13	0.12	0.14	0.09
	26	0.18	0.17	0.17
	40	0.15	0.10	0.19
	52	0.15	0.12	0.26
Regression	Q [†]	NS	L	
Harvest 2, Run 2	0	0.02	0.02	0.02
	13	0.11 a	0.08 a	0.08 a
	26	0.17 a	0.15 a	0.13 a
	40	0.30 a	0.17 b	0.15 b
	52	0.32 a	0.23 b	0.17 c
Regression	L	L	L	

[†] From regression, L = significant linear, or Q = quadratic response within each P source and Harvest/Run, NS = not significant.

uptake of P as P rate increased (Table 5), a response not observed when TKO was applied. This response was likely a fact that both Turfite and TSP contained some amount of fertilizer phosphate, while TKO only contained phosphite, which is not an immediate fertilizer nutrient. At the second harvest, which occurred at 8 weeks of growth, P uptake increased as a function of P rate in every P source, likely a result of the conversion of applied phosphite to phosphate within that time period^[15,21,23].

Greenhouse bentgrass study

Dry weight of plant tissue

In both Runs the dry weight of bentgrass tissue was unaffected by P rate, and the interaction of P rate and P source was not significant (Table 3). Application of phosphite materials at labeled rates/timing never decreased tissue yield, and in some cases yield was increased. For example, in Run 1 the application of Alude increased dry weight of clippings (when compared to the control) at P rates of 15, 60 and 120 kg·P·ha⁻¹. In Run 2 this same effect was observed at 0, 15, 30, and 60 kg·P·ha⁻¹. While the active ingredient of TitlePhyte is similar to Alude, application of TitlePhyte was less likely to increase yield, and such effects were only significant at 120 kg·P·ha⁻¹ (Run 1) and 0 kg·P·ha⁻¹ (Run 2). Averaged over all rates of P fertilization

and both Runs, the average dry weight of bentgrass tissue was 1.2, 1.3, and 1.6 g per pot for bentgrass which received no treatment, TitlePhyte, or Alude, respectively (P = 0.07).

Tissue P and P uptake

For both tissue P and P uptake, the interaction of P rate and phosphite addition was significant (P = 0.05). Results for tissue P and P uptake were the same, and so only P uptake will be discussed.

As P rate increased both tissue P and P uptake increased, but only in the treatments not receiving supplemental phosphite (Fig 1). Once phosphite was applied, P uptake was always significantly greater than that measured in bentgrass not receiving any phosphite. Tissue data was collected after 8 (Run 1) or 7 (Run 2) weeks of growth, and some portion of applied phosphite may have been converted to phosphate by that point, thus being utilized by the bentgrass.

In these experiments labeled application rates/timings were followed, so that Alude was applied biweekly, three times, at 3.2 mL·product·m⁻² for a total of 15 kg·P·ha⁻¹ applied (P was all phosphite). TitlePhyte was applied weekly, six times at 1.3 mL·product·m⁻², for a total of 21 kg·P·ha⁻¹ (P was phosphite). Phosphorus uptake was not directly linked to these P rates, as bentgrass to which Alude was applied often had greater P uptake (Fig 1). For P uptake, this was partly due to the fact that bentgrass to which Alude was applied had more tissue growth. As with the ryegrass experiments, the application of phosphite products, even in the presence of very low soil phosphate, did not negatively affect bentgrass shoot growth.

Dry weight of roots

In both Runs the interaction of P rate and phosphite application was significant (Fig 2). When no phosphate was added root growth was reduced when a phosphite product was applied. This was significant in both runs for the application of Alude, and in Run 1 for the application of TitlePhyte (Fig 2). In general, as P rate increased above 15 kg·P·ha⁻¹ this effect was largely gone, and root growth was generally unaffected by phosphite application, in the presence of phosphate.

This effect – that plant growth parameters are negatively affected by greater amounts of phosphite when phosphate is limited, has been shown previously^[17,18,29,30], and specifically for roots (*Brassica rape* var. *peruviridis*)^[14]. Our result with bentgrass is similar to this cited work, as root growth was reduced when phosphite was applied, in the presence of low levels of phosphate. Initial soil-test P was 2 mg·kg⁻¹ for this work, well below the level at which P fertilization would be recommended (Table 1). Thus, simply providing some amount of recommended P fertilizer would eliminate this negative effect. This effect was not observed in the ryegrass experiments.

Incubation study

Two soil extractions were used for the incubation study: CaCl₂, for a relative measure of weakly sorbed and solution P, and Mehlich-1, the common soil-test extractant used in the southeastern United States^[24]. Use of CaCl₂ extracted low amounts of measurable P, which were not high enough for subsequent phosphite and phosphate analyses via ion chromatography. Thus, Mehlich-1 extracts were used for subsequent IC analyses.

Soil treated with either phosphite material (TKO or TitlePhyte) had exactly the same response over time, and so only results from the TSP and TKO treatments are shown (Fig 3).

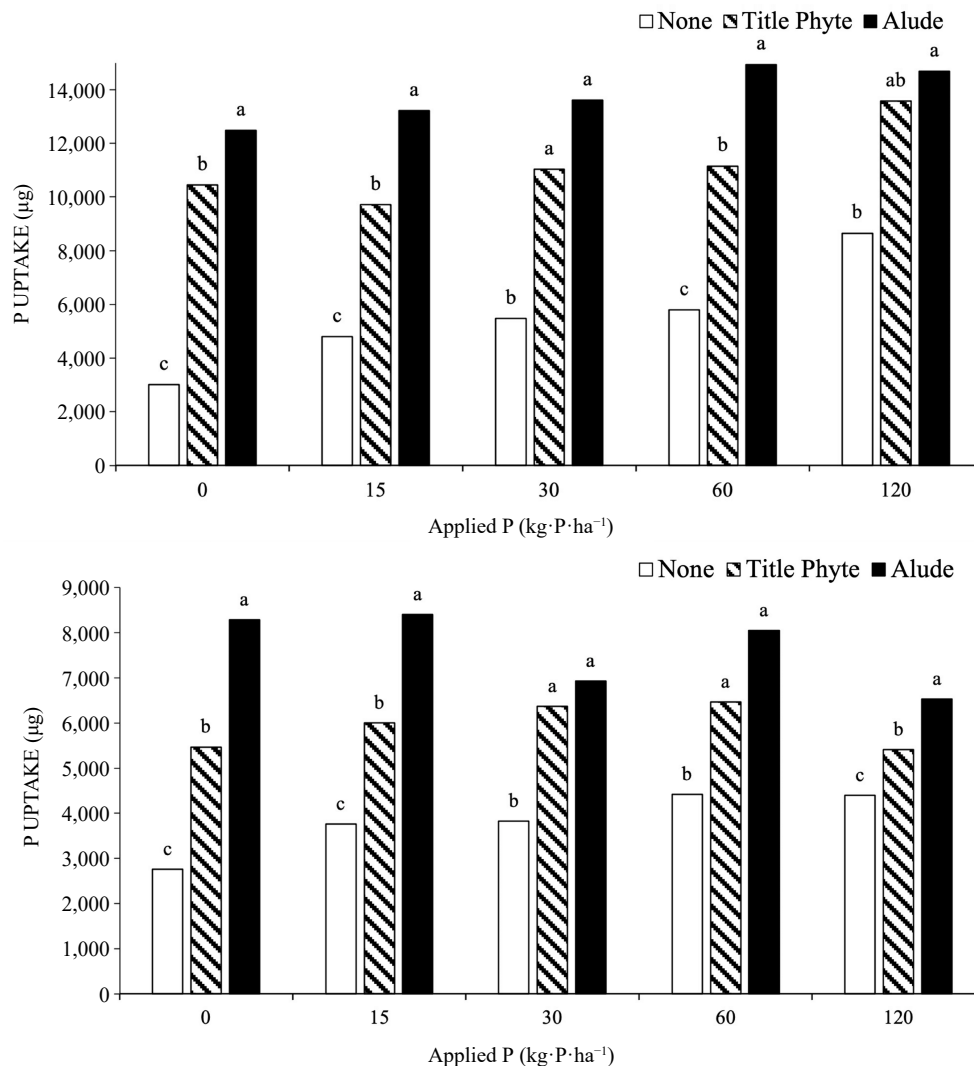


Fig. 1 Effect of P rate (provided through TSP) and phosphite products on P uptake by creeping bentgrass, Run 1 (top) and Run 2 (bottom). Treatments with the same letter above the bars are not significantly different ($\alpha = 0.05$) within an experiment and each rate of P fertilization.

When the phosphite material was added to soil it became undetectable after one month. The conversion of phosphite to phosphate was essentially complete in that first month, and this was the same in both phosphite treatments (TKO or Title-Phyte).

The inclusion of the phosphate-only treatment shows the lack of conversion when phosphite was not present (Fig 3). As expected, extractable P increased as P rate increased, and there was also a slight increase over time.

This study found a more rapid conversion of phosphite than found in the small number of previous studies. In one paper extracted phosphite was halved over a 16 week incubation period, driven by a wide range of soil microorganisms^[21]. In work with alfalfa (*Medicago sativa* L.) separate fertilizations with phosphite and phosphate (no factorial treatments were included) found that growth in phosphite-treated soil did not equal that from phosphate-treated soil until 90 d (~13 weeks) after fertilization with the phosphate or phosphite^[22]. In other work, applications of various phosphite materials were detrimental to initial plantings of red clover (*Trifolium pratense* L. var. *sativum* (Mill.)), ryegrass (*Lolium multiflorum* L.) and alfalfa, and toxicity was most evident when phosphite applications were

high. However, subsequent crops were unaffected by residual phosphite, reflecting the transformation of phosphite to phosphate in the soil^[15]. Unfortunately, the exact length of each experiment was not provided in the paper, but included photographs and crop descriptions allow estimates of 8 to 16 weeks before planting of the second crops. It was also noted that the conversion of phosphite to phosphate was more rapid in a limed soil (soil pHs not given) than unlimed^[15].

In this study, the majority of phosphite was converted to phosphate within 30 d. This is more rapid than results from previous studies, which found a half-life of 3–4 months^[21]. Based on their work, the oxidation of phosphite to phosphate in soil was largely due to the microbial activity within soil. The soil used in this study (Maryvn loamy sand) was different from the soil used in previous studies, so different soil-dwelling bacteria may have a particular microbial activity thus affecting the time of oxidation of phosphite to phosphate.

Sufficient research has shown that, in the presence of low soil phosphate, application of phosphite may negatively affect plant growth. Most often, this was shown in cell culture^[16], growth media^[6], or hydroponic experiments^[14,17,18,31]. When studies were done in soil, negative effects from applied

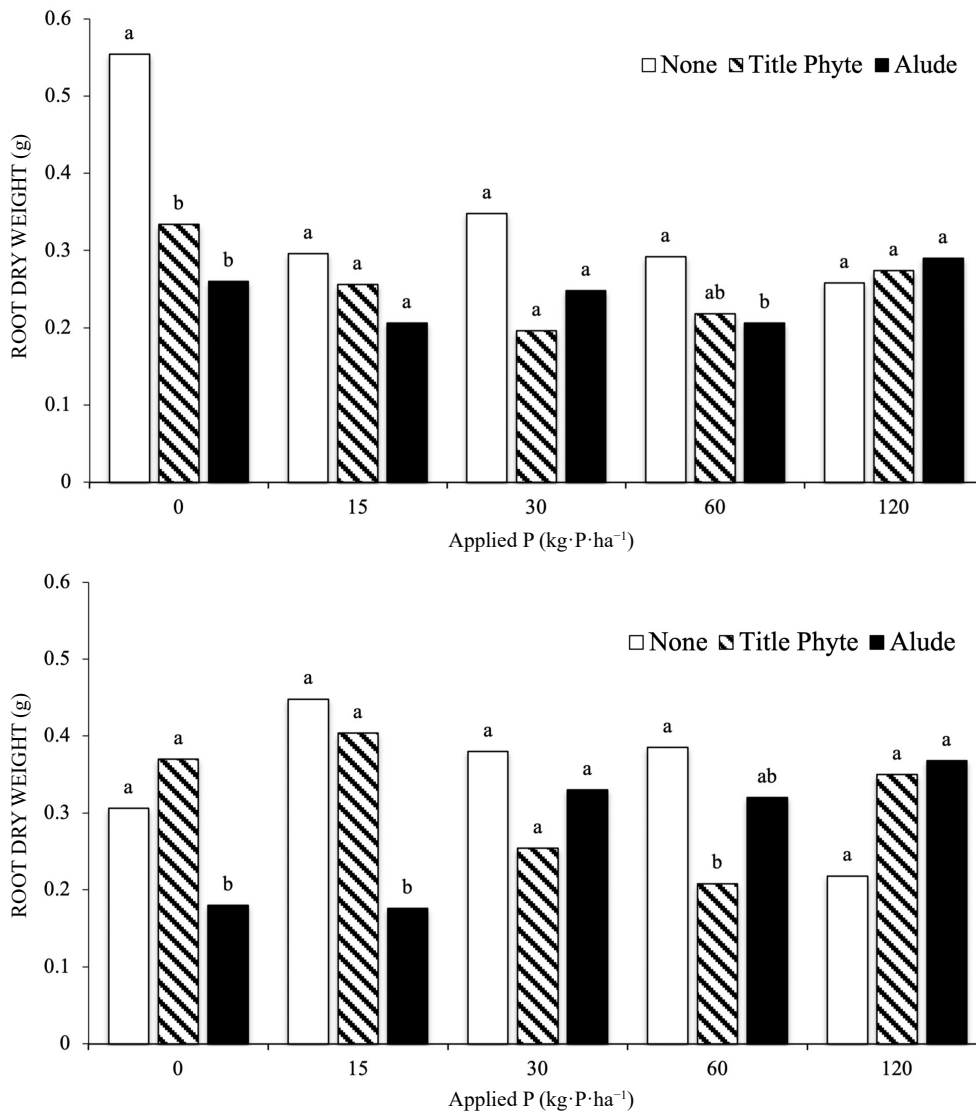


Fig. 2 Effect of P rate (provided through TSP) and phosphite products on creeping bentgrass root dry weight, Run 1 (top) and Run 2 (bottom). Treatments with the same letter above the bars are not significantly different ($\alpha = 0.05$) within an experiment and each rate of P fertilization.

phosphite were more mixed. In some cases, application of phosphite in low phosphate soil negatively affected plant growth^[14,18,20], while in other work, application of phosphite did not suppress or promote strawberry (*Fragaria x ananassa* Duch.) growth^[32]. Typically, when phosphite did not create a negative effect, it was because soil phosphate was adequate for plant growth^[9,11], or because phosphate was not included as a factorial treatment variable in the study^[32].

In this work the addition of phosphite, even when soil phosphate was minimal had no negative effect on ryegrass shoot or root growth, or bentgrass shoot growth. This may be a function of our rates. In soil-based work, negative effects of phosphite (in low phosphate conditions) were observed at phosphite rates of 75 and 150 kg·P·ha⁻¹, regardless of the soil phosphate status^[20]. In contrast, our highest rate of phosphite was 52 kg·P·ha⁻¹, for the ryegrass study.

Additionally, plant species clearly has a role. We observed no significant negative effects from the application of phosphite in our ryegrass work, and in fact what is likely beneficial fungicidal effects were observed. However, in the bentgrass, root

length was shortened when labeled rates of phosphite-containing materials were applied, but only when phosphate was extremely low in the soil. The P soil-test result in the soil mix for the bentgrass work would have certainly resulted in a recommendation for the application of P fertilizer, which would have eliminated any negative effects from the phosphite applications.

Conclusions

In this work, the application of phosphite materials at labeled and recommended rates did not negatively affect the topgrowth of perennial ryegrass or creeping bentgrass. While the root growth of bentgrass was reduced when phosphite was applied, this only occurred at soil-test phosphate levels that were minimal. Thus, for turfgrass managers, it is important to determine soil test phosphorus levels if phosphite-containing products are a regular part of their application program as our results have shown the negative effects of phosphite applications when soil P is low. Application of P fertilization would

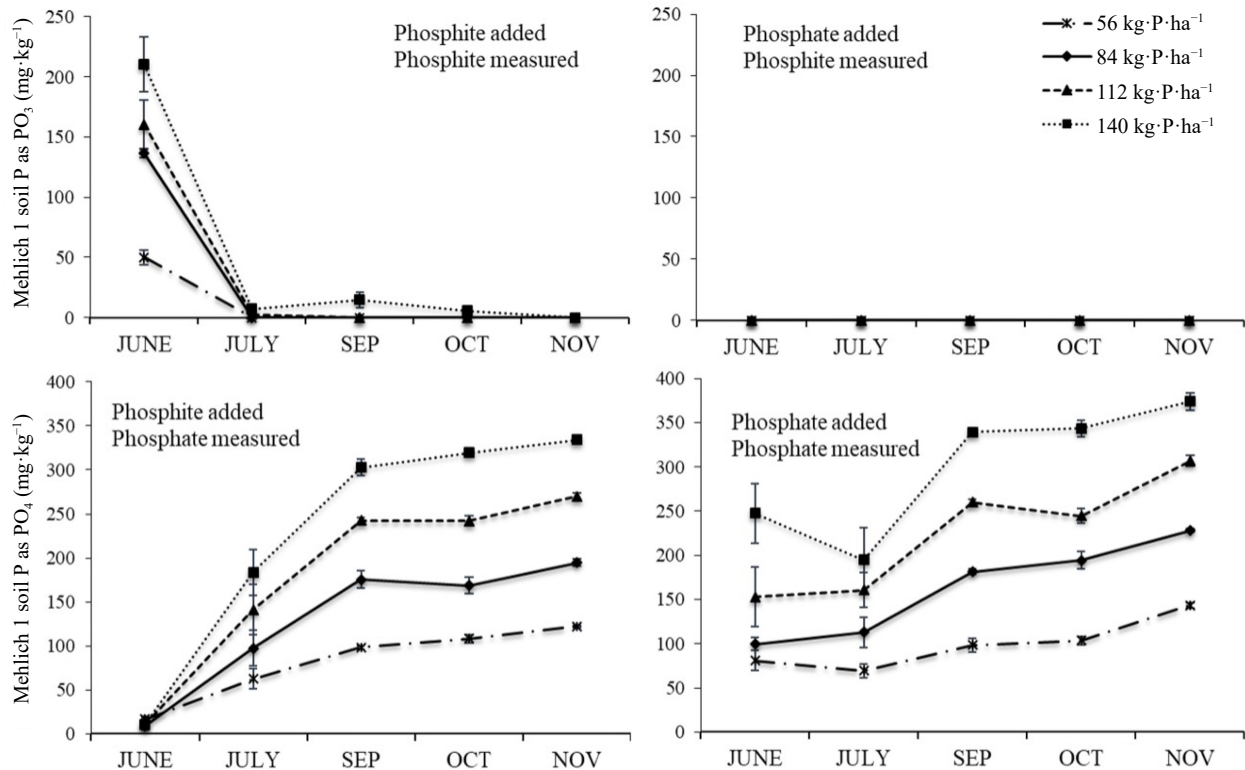


Fig. 3 Mehlich-1 extractable phosphite (top) and phosphate (bottom) as affected by the addition of phosphite supplied as TKO (left) or phosphate supplied as TSP (right) at four rates of P.

rectify this issue. Conversion of applied phosphite, in the soil, to phosphate occurs more quickly than measured in previous work. We measured almost 100% conversion of soil phosphite to phosphate within 30 d. This effect needs additional work, in a wide range of soils, and with more frequent sampling times, in a wider range of soils, to better understand the process.

Conflict of interest

The authors declare that they have no conflict of interest.

Dates

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Turfgrass response to phosphite application

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