

October, 28th 2011

Monopotassium phosphite

PART A. Review on the possible use of monopotassium phosphite as fertilizer

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The authors have been asked for a review regarding the possible use of monopotassium phosphite as fertilizer based on both current scientific knowledge as well as on the documentation provided by the company Tradecorp. This review is based on a literature survey of papers in peer-reviewed journals. Tradecorp has documented results from 4 studies in Spain and France underlying their claims that monopotassium phosphite has beneficial nutritional effects. Not being proficient in the Spanish and French language, we have nonetheless critically analysed both the data presented in these studies as well as the interpretation of the results in the application by the company. The following therefore presents our assessment of the current literature and of the claims by the company.

Introduction: phosphorous - use and function in plants

Phosphorus (P) is one of the major essential macronutrients. After nitrogen, inorganic P (Pi) is the second most frequently limiting macronutrient for plant growth. It occurs in a fully oxidized form as phosphate anion (PO_4^{3-} ; Pi; valence of +5) and as phosphite (PO_3^{3-} ; Phi; valence of +3).

In fertilizers, Pi is normally found in the form of phosphoric acid (H_3PO_4) and its salts, such as, triple super phosphate, ammonium phosphate and potassium phosphate. All of these forms readily disassociate to release hydrogen phosphate (HPO_4^{2-}) and dihydrogen phosphate (H_2PO_4^-). Pi uptake rates are highest between pH 5.0 and 6.0 (where H_2PO_4^- dominates). The chemical acid-dissociation constant (pKs) for the dissociation of H_3PO_4 into H_2PO_4^- and then into HPO_4^{2-} are 2.15 and 7.21, respectively. This means, that Pi is available to the plant as phosphoric acid, with H_2PO_4^- predominating over H_3PO_4 and HPO_4^{2-} . At very low external pH values the uptake of Pi as H_3PO_4 is a theoretical possibility (Abel et al., 2002).

Pi is stored in various cell compartments and/or rapidly incorporated into organic compounds such as nucleic acids, phospholipids and is very important for energy transfer in enzymatic reactions via ATP. P-esters play important roles as intermediaries in both anabolic and catabolic biochemical reactions. In storage tissues Pi is sequestered in the protein storage vacuole in grains and seeds as phytate.

Role of phosphite

Phi compounds have been recognized for a long time as fungicides for controlling plant diseases caused by Oomycetes (Jackson TJ et al., 2000; Jee et al., 2002; Smillie et al., 1989; Thao and Yamakawa, 2009) (see further in Part B of this review). In the early 1950s studies on the role of phosphite as P-fertilizer indicated that plant growth could be improved by Phi-application (MacIntire et al., 1950). The interest in phosphite as a P-source was renewed when it was discovered that foliar application of potassium phosphite to P-deficient citrus restored normal plant growth (Lovatt, 1990a; Lovatt, 1990b) and that Phi might be a cost-efficient alternative to phosphate (Lovatt, 1990c). There are indications that foliar application of Phi increased yield and improved the quality of several crops (Rickard, 2000). However, there is very recent evidence for the opposite

(Zambrosi et al., 2011), where it was found that leaf photosynthesis, nutrient-use efficiency and plant growth of citrus decreased with Phi supply.

Many new P-fertilizers based on Phi are now being marketed (Table 1) and registered under the fertilizer laws. Some are even described more as “biostimulants” than as fertilizers (Thao and Yamakawa, 2009). Phosphite-containing chemicals are offered as fertilizers suitable for use in organic farming (Morton et al., 2005). However, more recent reports clearly indicate that P-deficient plants are very sensitive to phosphite application (Fairbanks et al., 2002; Lee et al., 2005; McDonald et al., 2001; Schroetter et al., 2006; Singh et al., 2003; Varadarajan et al., 2002). As reported by (Ratjen and Gerendas, 2009), ‘*the issue gained additional impact from the revised German Fertilizer Ordinance, released on December 2008, which specifies phosphate as the only P-source in fertilizers, tolerating phosphite only as a naturally occurring contamination* (Anonymous, 2008)’. Thus the use of Phi-containing products as sources of plant nutrition has been subjected to ongoing controversy. Recently, based on published peer-reviewed literature, the controversial role of Phi as fertilizer has been critically reviewed (Ratjen and Gerendas, 2009; Thao and Yamakawa, 2009).

Table 1 From fungicides to fertilizers: the marketing of some products with phosphorous and phosphite as the active ingredient

Product	Company	Country	Active ingredient	Marketed as
Aliette	Bayer Cropscience	Germany	Aluminum phosphite	Fungicide
Nutri-phite	Biagro Westem Sales	USA	Phosphite and organic acids	Fertilizer
Ele-Max	Helena Chemical	USA	Phosphorous acid	Foliar fertilizer
ProPhyt	Luxembourg-pamol	USA	Monopotassium phosphite	Systemic fungicide
Nutrol	Lidochem	USA	Potassium phosphite	Fertilizer and fungicide
Phostrol	NuFarm America	USA	Phosphorous acid	Biochemical pesticide
Agrifos	Liquid Fert Pty (Agrichem)	USA	Monopotassium phosphite	Fungicide
Foli-r-fos 400	UiM Agrochemicals	Australia	Monopotassium phosphite	Fungicide
Fosphite	Jh Biotech	USA	Monopotassium phosphite	Fungicide
Lexx-a-phos	Foliar Nutrients Inc	USA	Monopotassium phosphite	Fungicide
Trafos line	Tradecorp	Spain	Potassium phosphite	Fertilizer and defense stimulator
Phytos’K	Valagro	Italy	Potassium phosphite	Biostimulant (registered as EC fertilizer)
Phosfik line	Biolchem	Italy	Phosphorous acid	EC fertilizer
Fosfisan, Vigorsan	Agrofill	Italy	Potassium phosphite	Defense stimulator (registered as fertilizer)
Geros-K	L-Gobbi	Italy	Potassium phosphite	EC fertilizer
Kalium Plus	Lebosol	Germany	Potassium phosphite	EC fertilizer
Frutoguard	Spieess Urania	Germany	Potassium phosphite	EC fertilizer
Foliaphos	Plantin	France	Potassium phosphite	EC fertilizer

Source: Leymonie 2007. EC, European Commission (for identifying chemicals).

It has been shown that plants are able to take up Phi and this process has even been monitored real time by *in vivo* ³¹P NMR (Danova-Alt et al., 2008). The presence of phosphite in shoots after foliar application (Ratjen and Gerendas, 2009) or after providing phosphite to the root (Thao et al., 2008) clearly indicates that phosphate is translocated in both the phloem and the xylem. However, although most plants readily absorb and translocate Phi, it does not appear to be readily oxidized or metabolized in plants and thus does not contribute to P-nutrition (Carswell et al., 1997; Carswell et al., 1996). Therefore, any reports claiming the possibility of Phi assimilation in plants need evaluation with utmost care.

On the other hand, the oxidation of phosphite by soil microorganisms is well documented (Morton et al., 2005; Smith et al., 2011). As the conversion rate of phosphite to phosphate depends on the chemical conditions in the soil, this may account for positive nutritional effects of phosphite. In addition, the greater mobility of phosphite in soils could deliver P to deeper roots (Morton et al., 2005). However, possible turnover rates of Phi to Pi are rather slow (Morton et al., 2005).

Phi was found to have negative effects on the growth and metabolism of P-deficient plants by suppressing the typical molecular and developmental responses (Fairbanks et al., 2002) of plants to P-deficiency (Carswell et al., 1997; Carswell et al., 1996; Varadarajan et al., 2002). Phi intensifies the deleterious effects of P-deficiency by tricking Pi-deprived plant cells into sensing that they are Pi-sufficient, when in fact their cellular Pi-content is extremely low (McDonald et al., 2001).

Studies on crop responses to commercial Phi-derived P-fertilizers were summarized by Rickard (2000). Most of the studies in his review were carried out under field conditions and all results showed that soil or foliar application of Phi-fertilizer improved the yield and quality of many crops. However, there is no evidence that Phi can be used directly by plants as a source of nutritional P. In addition, data showing that the effectiveness of Phi-derived P-fertilizer is equal to or better than that of conventional Pi-fertilizers are very rare.

In contrast, many other studies have indicated that Phi-compounds cannot be used as P-fertilizer by plants. Tomato and pepper plants (Varadarajan et al., 2002) and maize (Avila et al., 2011; Schroetter et al., 2006) treated with Phi exhibited a significant reduction in growth compared with Pi-fertilized plants. Recently, a series of studies by Thao et al. (Thao and Yamakawa, 2009; Thao and Yamakawa, 2010; Thao et al., 2008; Thao et al., 2009) on various crops using different methods and rates of Phi-application was conducted to intensively investigate the effects of Phi as well as a combination of Phi and Pi on the growth and P-nutrition of plants. No beneficial effect of Phi on plant growth was detected. These results suggested that Phi was not a substitute for Pi at any rate, and that there was no stimulating effect from any Phi-Pi combination on plant growth. Foliar application of Phi significantly increased the total-P and Phi-contents in the plant tissues, but did not improve plant growth.

Conclusion of the review

Taken together, these results consistently show that plants are incapable of directly using Phi as a P-source and thus Phi cannot complement or substitute Pi-fertilizer. There is no reason to assume that the metabolic efficiency of P derived from phosphite is superior to P derived from phosphate. Phosphite is not to be considered a suitable P-source and should therefore not be used as P-fertilizer (Ratjen and Gerendas, 2009).

The number of products such as potassium phosphites, magnesium phosphites and calcium phosphites would not have expanded in the market if there was no benefit from the application of Phi. Why some studies have shown a negative effect of Phi on plant growth and others have found positive crop responses is not clear. In any case, there is no evidence to date that can clearly demonstrate that plants use Phi directly as a P-nutrient. Moreover, there is no known plant enzyme that could oxidize Phi to Pi (Thao and Yamakawa, 2009). On the other hand, it is well known that Phi is able to effectively control many plant diseases caused by species of the order of *Oomycetes* (see further in Part B of this review). Thus, the benefits of Phi versus Pi in the field are likely to result from its fungicidal actions (McDonald et al., 2001; Ratjen and Gerendas, 2009; Thao and Yamakawa, 2009).

The results from the peer-reviewed published literature prove unequivocally that phosphite does not contribute to the P-nutrition of plants and should not be considered as a suitable P-source.

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PART B. Review on the fungicidal effects and mode of action of monopotassium phosphite

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The present review on the plant protection effects of monopotassium phosphite is based solely on existing international peer-reviewed literature since the forwarded documentation on these effects were non-English material.

Introduction

Phosphite salts are alkali salts of phosphorous acid and should not be confused with phosphates derived from phosphoric acid. Phosphonates are often used as a synonym for phosphites but the former contain an organic group bound to the P-ion (an example is the commercial fungicide fosetyl-AL), i.e. monopotassium phosphite is a phosphite salt.

Recently, Deliopoulos et al. (2010) reviewed the literature on fungicidal effects of inorganic salts including the phosphites. The present evaluation is largely based on the outcomes of their review.

Fungicidal effects

In contrast to phosphates that are mostly used as fertilizers most studies on phosphites have focused on their effects against plant diseases (Deliopoulos et al., 2010). The effect of phosphites seems to be limited to the pseudo-fungi belonging to the group of Oomycetes (e.g. potato late blight and cabbage clubroot) and phosphites seem to be more effective applied preventatively than curatively. The “active ingredient” of phosphites is assumed to be phosphorous acid.

Phosphites have been shown to have effects both on foliar diseases when applied as a spray (e.g. Dorn et al., 2007; Mayton et al., 2008) and on soil-borne diseases when applied as a root drench or through drip irrigation (Smilie et al., 1989; Oren & Yogeve, 2002). In their review, Deliopoulos et al. (2010) refer to studies showing effects of phosphites on 15 different fungi belonging to the Oomycetes causing diseases on 14 different crops.

In most field studies phosphites were applied several times during the growing season. This is necessary to obtain good disease control because phosphites should be applied preventatively. The doses applied were typically in the range of 2 to 5 kg phosphites/ha. In some studies phosphites were applied until run-off at concentrations of 0.5 to 1.0 g/L. Potato tuber blight has been the target of several of the phosphite studies. Phosphites have been applied as foliar sprays during the growing season (e.g. Cooke & Little, 2002) or to potatoes after bulking (Johnson et al., 2004) and good effects have been observed following both uses.

A few studies have compared the fungicidal activity of phosphites to commercial organic fungicides. Cooke & Little (2002) conducted several field studies comparing the effects of the commercial fungicides to mono- and dipotassium phosphite on potato tuber blight. The phosphites were found to be superior to the commercial fungicide mancozeb. In a subsequent experiment they compared the effect of commercial fungicides applied alone and in combination with phosphites and found a significantly better effect on potato tuber blight when phosphites were included in the spraying programme. In contrast to the majority of the commercial fungicides used to control diseases caused by Oomycetes, phosphites are systemic and can be transported to underground plant

tissue. This probably explains why phosphites more effectively control potato tuber blight than commercial fungicides like mancozeb (Mayton et al., 2008).

Mode of action

Some controversy exists concerning the mode of action of phosphites. Whereas the effects of phosphates seems only to be through stimulation of the natural defence mechanisms the existing evidence suggest that phosphites have both a direct effect (reducing spore germination and growth rate) and an indirect effect through stimulation of the plants own defence mechanisms (summarized by Deliopoulos et al., 2010). The involvement of the plants natural defence systems have been confirmed by studying the effect of known inhibitors of the processes involved in plants own defence systems. These studies have clearly shown that these inhibitors reverse the fungicidal activity of phosphites (reviewed by Guest & Bompeix, 1990).

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