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Effect of phosphite fertilization on growth, yield and fruit composition of strawberries

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ABSTRACT

Traditionally, phosphates (Pi, salts of phosphoric acid, H_3PO_4) have been used for plant fertilization, and phosphites (Phi, salts of phosphorous acid, H_3PO_3) have been used as fungicides. Nowadays several Phi fertilizers are available in the EU market despite the fact that in research trials Phi has often had a negative influence on plant growth. The objective of this study was to elucidate the effect of a Phi fertilizer on plant growth, yield and fruit composition of strawberries (*Fragaria* × *ananassa* Duch.). Experiments were carried out with 'Polka' frigo plants in South Estonia in 2005 and 2006. The number of leaves per plant, total and marketable yields, fruit size, fruit ascorbic acid content (AAC), soluble solids content (SSC), titratable acidity (TA), anthocyanins (ACY) and total antioxidant activity (TAA) were recorded.

The results indicate that Phi fertilization does not affect plant growth. Phi fertilization had no advantages in terms of yield increase, compared to traditional Pi fertilization. Fruit acidity increased and TSS decreased due to foliar fertilization with Phi in 2006. Soaking plants in Phi fertilizer solution prior planting was effective in activating plant defence mechanisms, since fruit ascorbic acid and anthocyanin content increased.

1. Introduction

Strawberry production requires large amounts of unrecyclable and non-renewable plastic, for controlling weeds. Plant growth also requires a considerable amount of water to establish plantings, and depends on frequent applications of pesticides to produce acceptable fruit quality. Therefore, strawberry production has a large environmental impact and often a negative reputation (Pritts, 2002).

In recent years, concern about prevention of environmental pollution and food safety has increased. Foliar application of fertilizers is considered more ecologically sound than soil applications (Lanauskas et al., 2006). Therefore, the number of foliar fertilizers available in the market has recently increased. Among others, foliar fertilizers containing the phosphite anion (Phi, HPO_3^{2-}), also referred to as phosphorous acid or phosphonate, are recommended as foliar fertilizers. Interestingly, Phi is also an active ingredient in several fungicides like Aliette, ProPhyt and Agrifos. Products, such as Nutrol, are advertised as fertilizer and fungicide. Traditionally, phosphates (salts of phosphoric acid, H_3PO_4) have been used for plant fertilization and phosphites (salts of phosphorous acid, H_3PO_3) as fungicides. The Phi anion is an isostere of the phosphorus (Pi) anion, in which hydrogen replaces one of the oxygen atoms bound to the P atom (Carswell et al., 1996). Fungi belonging to oomycetes, particularly *Phytophthora citricola* and *Phytophthora cinnamomi*, are sensitive to Phi (Guest and Grant, 1991; Wilkinson et al., 2001). In addition, activation of plant defence responses by Phi has also been proposed (Guest and Grant, 1991). Several attempts to use Phi in plant nutrition are also known, but results are inconclusive. It has been found that Phi is rapidly absorbed and translocated within the plant (Guest and Grant, 1991) and its mobility in both xylem and phloem is similar to that of Pi (Ouimette and Coffey, 1989). However, the similarity between Pi and Phi appears to end at the level of translocation. Because Phi is not converted into Pi in plants, it fails to enter the biochemical pathways (Varadarajan et al., 2002). Several studies with annual plants (*Allium cepa* and *Brassica nigra*) have provided evidence for the negative effects of Phi on plant growth (Sukarno et al., 1993; Carswell et al., 1996). It has been proposed that crops replanted in phosphite-fertilized soil performed similarly to crops grown in phosphate-fertilized soil (Lovatt and Mikkelsen, 2006). Interestingly, the negative effect of Phi on plant growth could be overcome by applications of Pi (Varadarajan et al., 2002).

Several Phi fertilizers are available in the EU market, including the brand names *Kalium Plus* (Lebosol), *Folistar* (Jost), *Frutogard*

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(Spiess Urania), and *Phosfik* (Kemira GrowHow), which are formulated as alkali salts of phosphorous acid (Schroetter et al., 2006). The possibility of registration of phosphite as a P fertilizer could be due to the predefinition that the composition of a P fertilizer should be expressed in terms of P_2O_5 (Kluge and Embert, 2005). *Phosfik* is the most widely used Phi fertilizer in the EU, and has been recommended for fertilization of several horticultural crops, for example cucumbers, tomatoes, salad crops, strawberries and different ornamentals (Phosfik. Anwendungsempfehlungen. http://www.biolchim.de/produkte/phosfik.html).

The objective of the current research was to study the effect of Phi fertilizer applied in different ways and rates on growth, yield and fruit composition of strawberries. More specifically, the experiment was conducted to answer the following questions:

(1) Reserve fertilizers containing Pi are usually applied to the soil before strawberry plantations are established. Does this avoid the possible negative influence of Phi on plant growth?
(2) Phi is known to activate plant defence mechanisms; does it influence the formation of bioactive compounds such as ascorbic acid, anthocyanins and total antioxidant activity of strawberry fruits?

2. Materials and methods

2.1. Plant material and fertilization treatments

The strawberry plantation was established with cv. 'Polka' A+ frigo plants on 10-cm high, 100-cm wide raised beds, in South Estonia in May 2005. Strawberries were planted in single rows and beds covered with 0.04-mm thick black polyethylene mulch. Row spacing was 120 cm and plant spacing was 33 cm. The experimental design was a complete randomized block design with 4 replications of 25 plants each. No irrigation system was used and water was provided by rain.

Two fertilizers were used in the experiment:

(1) Liquid NPK 3:12:15 (Phi) fertilizer Phosfik®, also containing micronutrients B 0.01%, Mn 0.02% and Zn 0.01%.
(2) Water soluble NPK 7:4:27 (Pi) fertilizer, also containing micronutrients Mg 2.7%, S 4.5%, B 0.02%, Fe 0.2%, Mn 0.2% and Zn 0.1%.

Fertilization treatments were the following:

(1) *Control*: Control plants, not fertilized in either 2005 or 2006;
(2) *Phi S*: Plants were soaked prior to planting in a 0.3% liquid NPK 3:12:15 (Phi) fertilizer solution for 10 min.
(3) *Phi SI*: Plants were soaked prior to planting as described in the previous treatment, but additionally irrigated with the same fertilizer 0.1% solution at a rate of 1 L per plant 2 and 4 weeks after planting. Thus, in addition to soaking each plant received 140 mg N, 79.2 mg P and 540 mg K.
(4) *Pi I*: Plants were irrigated with water soluble NPK 7:4:27 fertilizer 0.1% solution at a rate of 1 L per plant 2 and 4 weeks after planting.

In 2006 all previously described treatments were divided into two sections, half of the plants had foliar treatment with liquid NPK 13:12:15 (Phi) fertilizer at the minimum recommended rate for strawberries (3.3 mL L^{-1} three times at 10-day intervals starting from the beginning of flowering). Thus, with the additional Phi fertilization, plants received 4.7 mg N, 18.7 mg P and 23.4 mg K altogether. Additional foliar fertilization with Phi fertilizer is marked as F (variants Control F, Phi SF, Phi SIF and Pi IF).

Table 1
Weather conditions in summer 2005 and 2006 in South Estonia: monthly mean air temperature (°C) and total monthly precipitation (mm) as compared to the same figures of many years (1966–1998) in Estonia (average, Av.)

Month	Air temperature (°C)			Precipitation (mm)		
	2005	2006	Av.	2005	2006	Av.
May	10.6	10.3	11.0	124	48	55
June	14.1	16.1	15.1	71	48	66
July	17.7	18.5	16.7	34	25	72
August	15.8	16.7	15.6	102	84	79
September	12.3	13.1	10.4	47	28	66

2.2. Weather conditions and soil analyses

In 2005 the weather in May, when strawberries were planted, was favourable for young plant development. Air temperature was at the average level, but it rained twice as much as usual in May in Estonia (Table 1). June was relatively cool and it rained sufficiently. July, August and September were warmer than the average of many years. July was drier and August more rainy than usual in Estonia (Table 1).

In 2006 the whole summer was very warm and dry, especially July, when it rained only a third of the usual amount. In August it rained a little more than the average.

Soil in the experimental area was sandy loam. Soil pH $_{KCl}$ was 5.8 and humus content was 4.4%, which were suitable for strawberry production. The content of P, K, Ca, Mg and Cu was sufficient in the soil, only B and Mn content was low. Complex fertilizer NPK 10:10:20 was applied according to the soil analyses. It was applied evenly to the whole experimental area at the reserve rate of 300 kg ha^{-1} before planting.

2.3. Measurements and analyses

The fruit were harvested and divided into two categories: marketable and spoiled (diseased and malformed). The number of marketable and spoiled fruits were calculated per plant. Since the first year (2005) production of frigo A+ plants was low, fruit chemical parameters such as soluble solids concentration (SSC), titratable acidity (TA), ascorbic acid content (AAC), content of anthocyanins (ACY) and total antioxidant activity (TAA) were determined only in the 2006 production season. Also in 2006, the number of leaves per plant was counted at full bloom. A portable Minolta soil–plant analysis development SPAD-500 chlorophyll meter was used for non-destructive determination of relative leaf chlorophyll content during full bloom and at the middle of the yielding period. Relative values displayed by this instrument are positively correlated with chlorophyll concentration (Schepers et al., 1996). SPAD-values were determined from 30 leaves from each replication. In 2006, 2 kg of strawberries from each experimental plot was picked from the third harvest for determination of chemical parameters. AAC, SSC and TA were determined from fresh fruits on the day of harvest. Content of ACY and TAA were determined from deep frozen (−20 °C) fruits after 2 months. For determination of AAC, 10 randomly chosen fruits from each plot were cut into sections, then crushed quickly and 10 g of pulp was taken for each analysis. The iodometric determination method M167 (www.mt.com) was used with modification. Instead of using sulphuric acid, 60 mL of a mixture of metaphosphoric and acetic acid (3% HPO_3 + 8% CH_3COOH) was added instantly to avoid vitamin C breakdown in air (Paim and Reis, 2000). TA was