



# 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.

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## 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*<sup>®</sup>, 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<sup>-1</sup> 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

**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

altogether. Additional foliar fertilization with Phi fertilizer is marked as F (variants Control F, Phi SF, Phi SIF and Pi IF).

### 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<sub>KCl</sub> 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<sup>-1</sup> 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](http://www.mt.com)) was used with modification. Instead of using sulphuric acid, 60 mL of a mixture of metaphosphoric and acetic acid (3% HPO<sub>3</sub> + 8% CH<sub>3</sub>COOH) was added instantly to avoid vitamin C breakdown in air (Paim and Reis, 2000). TA was

determined by titration to pH 8.2 with 0.1 NaOH. Titrator Mettler Toledo DL50 with autosampler Rondolino was used for titration of AAC and TA. SSC (%) was measured using the digital refractometer ATAGO Co., Ltd., Japan.

For determination of ACY, 10 whole fruits in 3 replications from each variant were crushed and 10 g of crushed fruit soaked in an extracting solution containing HCl (0.1 M):C<sub>2</sub>H<sub>5</sub>OH (96%) = 15:85 (v/v). Solutions were shaken and held at +5 °C for 24 h. After settling, a 2 × 2 mL clear supernatant was pipetted into 50 mL volumetric flasks. The content of total anthocyanins was estimated by a pH differential method (Cheng and Breen, 1991). Absorbance was measured with a Jenway 6300 spectrophotometer at 510 and at 700 nm in buffers at pH 1.0 (HCl 0.1N) and pH 4.5 (citrate buffer). Absorbance (A) = [(A<sub>510</sub> - A<sub>700</sub>)<sub>pH 1.0</sub> - (A<sub>510</sub> - A<sub>700</sub>)<sub>pH 4.5</sub>]. As pelargonidin-3-glucoside is a predominant anthocyanin in strawberry fruits (Yoshida et al., 2002), the molar extinction coefficient of the mentioned anthocyanin of 36 000 was used as previously described by Vicente et al. (2002). Results were expressed as milligrams of pelargonidin-3-glucoside equivalent per 100 g of fresh weight.

TAA was determined using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) discoloration assay described by Brand-Williams et al. (1995) with some modifications. Fruit fresh weight (FW) samples were used for the TAA determination as described by Kondo et al. (2005). Equal sectors were cut from 10 strawberry fruits per variant, homogenized and 10 g of homogenate was diluted with 50 mL 96% ethanol. The scavenging of free radicals by the extract was evaluated spectrophotometrically at 517 nm against the absorbance of the DPPH radical. Disposable cuvettes (Starna Scientific; 1 cm × 1 cm × 4.5 cm; path length 10 mm) were used for absorbance measurements. Fruit extracts with volume 20, 40, 60, 80 and 100 µL were pipetted into the cuvettes. Methanol was added to each cuvette until a volume of 100 µL was reached. Finally 2.9 mL of 0.1 mmol/L DPPH solution in methanol was added to each cuvette, cuvettes were closed, shaken and spectrophotometrical determination was initiated instantly. The control solution consisted of 2.5 DPPH solution and 0.5 mL methanol. The decrease in absorbance was measured over 300 min at 2-min intervals.

The percentage of remaining DPPH after 30 min was calculated based on absorbance. The antioxidant activity in the current work

is expressed as EC<sub>50</sub> (the amount of antioxidant necessary to decrease the initial DPPH concentration by 50%). Values are reported as a means of three determinations.

Significant differences between fertilization treatments were tested by one-way and two-way analysis of variance at significance level of  $P \leq 0.05$ .

### 3. Results

#### 3.1. Growth and yield

In first year (2005) the total yield of 'Polka' strawberries ranged from 97 to 115 g plant<sup>-1</sup>. None of the fertilization treatments affected yield significantly.

In spring 2006 strawberry plants had an average of 62 leaves per plant and this was not affected by the previous year's fertilization. Also, the SPAD-readings of the leaves at the time of flowering did not differ significantly. At the time of fruit production, Pi IF treatment had higher SPAD-values compared to all other treatments (Table 2).

In 2006 the total yield ranged from 336 to 427 g plant<sup>-1</sup> and marketable yield from 273 to 345 g plant<sup>-1</sup> (Table 2). The average effect of additional fertilization in 2006 was significant and increased both total and marketable yield.

Fruit weight in 2006 ranged from 9.3 to 9.8 g in 2006 and was not influenced by fertilization treatments (data not shown).

#### 3.2. Taste-related parameters

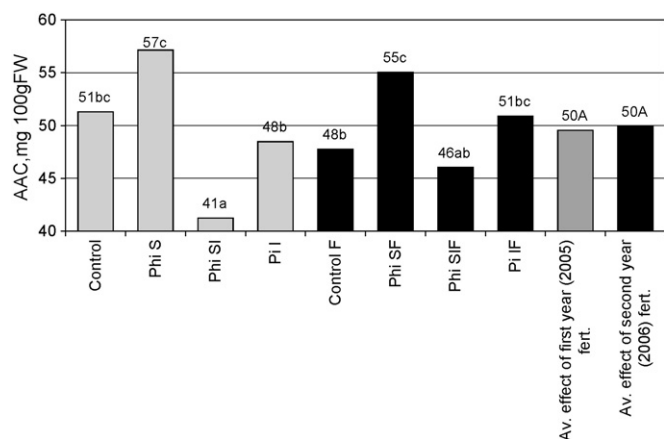
The SSC of 'Polka' fruits ranged from 10.0 to 12.7% (Table 2). All first year fertilization treatments reduced SSC in fruits, although the effect was significant only in Pi I variant. Additional fertilization with Phi in 2006 reduced SSC in the control treatment and the Phi SF treatment. On average additional Phi fertilization significantly reduced SSC in strawberry fruits.

First year Phi treatments had a significant increasing effect on TA content in fruits (Table 2). Additional Phi fertilization in 2006 significantly increased TA content in fruits in Control F and Pi IF variant. On average additional Phi fertilization significantly increased strawberry TA.

**Table 2**  
The effect of first year (2005) fertilization with liquid NPK 3:12:15 fertilizer containing phosphite (Phi) and traditionally used water soluble NPK 7:4:27 fertilizer containing phosphate (Pi), and effect of additional Phi fertilization the next year (2006) on strawberry 'Polka' plants, yield and fruit quality parameters

	Control	Phi S	Phi SI	Pi I	Mean
SPAD-value of leaves in yielding time					
Effect of first year treatment	40.6a	41.5a	40.5a	41.3a	41.0A
Effect of additional treatment with Phi (F) on the following year	40.2a	41.2a	40.9a	42.4b	41.2A
Total yield (g plant <sup>-1</sup> )					
Effect of first year treatment	336a	349ab	390ab	369abc	361A
Effect of additional treatment with Phi (F) on the following year	405abc	403abc	408bc	427c	411B
Marketable yield (g plant <sup>-1</sup> )					
Effect of first year treatment	273a	275a	305a	302a	289A
Effect of additional treatment with Phi (F) on the following year	340a	332a	332a	345a	337B
Soluble solids (%)					
Effect of first year treatment	12.7c	12.1bc	11.3b	10.6a	11.6B
Effect of additional treatment with Phi (F) on the following year	11.3ab	10.0a	11.2ab	11.3ab	10.9A
Titrateable acids (%)					
Effect of first year treatment	0.98a	1.08b	1.12b	0.98a	1.04A
Effect of additional treatment with Phi (F) on the following year	1.11b	1.08b	1.15b	1.13b	1.12B
Soluble solids/titrateable acids					
Effect of first year treatment	13.1c	11.2b	10.1ab	10.8ab	11.3B
Effect of additional treatment with Phi (F) on the following year	10.2ab	9.3a	9.8ab	10.0ab	9.8A

Mean values followed by the same letter are not significantly different at  $P \leq 0.05$ .



**Fig. 1.** The effect of first year (2005) fertilization with liquid NPK 3:12:15 fertilizer containing phosphite (Phi) and traditionally used water soluble NPK 7:4:27 fertilizer containing phosphate (Pi) and effect of additional Phi fertilization the next year (2006) on fruit ascorbic acid content (AAC) of strawberry 'Polka' fruits. Mean values followed by the same letter are not significantly different at  $P \leq 0.05$ .

The SSC/TA ratio was significantly reduced by all first year treatments (Table 2). Additional fertilization with Phi in the next year reduced SSC/TA significantly in the control F and in the Phi SF treatment. The average effect of additional Phi fertilization in 2006 was significant, decreasing the SSC/TA ratio by 13%.

### 3.3. Bioactive compounds and total antioxidant activity

The AAC of strawberry fruits ranged from 41 to 57 mg 100 g FW<sup>-1</sup> (Fig. 1). Fruits from Phi S and Phi SI treatments had the highest and fruits from Phi SI and Phi SIF treatments the lowest AAC.

The ACY content ranged from 25 to 34 mg 100 g FW<sup>-1</sup> (Fig. 2). Of the first year fertilization treatments, Phi S and Pi I significantly increased ACY content. Additional Phi fertilization in 2006 increased ACY content in the control F variant and decreased it in the Pi IF variant. The average effect of additional Phi fertilization in 2006 on ACY was not significant.

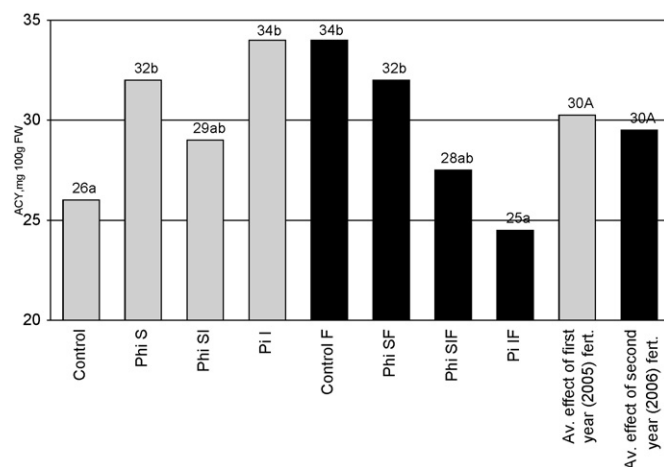
Total antioxidant activity of strawberry fruits ranged from 3.75 to 4.85 mmol DPPH 100 g FW<sup>-1</sup>. TAA of strawberries was not affected by either of the fertilization treatments in the current experiment (data not shown).

## 4. Discussion

### 4.1. Growth and yield

In spring 2006 the number of leaves and the relative chlorophyll content of leaves (SPAD-readings) were not significantly different between fertilized plots with Pi or Phi in previous year, which indicates that Phi fertilization did not affect strawberry plant growth compared to the Pi fertilization or the control treatment. Thus, we may suppose that reserve fertilizers containing Pi provide strawberries with available Pi and thus avoid the negative influence of Phi on plant growth.

During the 2006 production season, after foliar application of additional Phi, the chlorophyll meter reading in the PiF treatment was the only one with a significantly higher value (Table 2). Schepers et al. (1996) have stated that chlorophyll meter readings do not only respond to crop nitrogen status, but can also be affected by availability of other nutrients. Thus we may consider our result as an indirect indication that plant nutritional status was improved by supplying phosphorous as Pi in one year and as Phi in another.



**Fig. 2.** The effect of first year (2005) fertilization with liquid NPK 3:12:15 fertilizer containing phosphite (Phi) and traditionally used water soluble NPK 7:4:27 fertilizer containing phosphate (Pi) and effect of additional Phi fertilization the next year (2006) on fruit anthocyanin (ACY) content of strawberry 'Polka' fruits. Mean values followed by the same letter are not significantly different at  $P \leq 0.05$ .

In the first year neither Pi nor Phi fertilization affected the yield significantly. It is known that higher amounts of P and K are required for berry formation (Lieten and Misotten, 1993), however, as flower initiation in A+ frigo plants takes place before planting, it was foreseeable that fertilization would not influence the fruit number.

In the second year, the effect of previous year's Pi and Phi fertilization did not significantly affect the total yield. Additional Phi fertilization in 2006 tended to increase both total and marketable yield. The highest total yield (427 g plant<sup>-1</sup>) was obtained from a variant which had been fertilized with Pi in the previous year and received additional Phi in the second year. Since only the average effect of the second year Phi treatment was significant, this slight increase in yield could also be the effect of micronutrients in the fertilizer, or can be attributed to the activation of plant defence mechanisms. Lanauskas et al. (2006) carried out an experiment where Phosfik 3-27-18 was used in the strawberry cultivar 'Honeoye'. He observed no effect on strawberry yield, average fruit weight or fruit firmness. The mentioned research is in agreement with our results, and we may suggest that using Phi fertilization with the aim of gaining higher yields is not justified in strawberries.

### 4.2. Taste-related parameters

In the present study, SSC was decreased and TA increased by the foliar application of liquid Phi fertilizer the second year. Consequently, the SS/TA ratio decreased significantly from 11.3 to 9.8 (Table 2), meaning that fruit flavour became more acidic and less sweet. A good and well-balanced flavour of strawberry fruit is based on high sugar and comparatively high acid content, i.e. there is a balance between sweetness and acidity (Wang et al., 2002). Bentvelsen and Bouw (2002) carried out the study with a consumer panel where 12 different genetic sources of strawberries were judged on taste and found a strong correlation between appreciation of fruit taste and total sugar content. Schöpplein et al. (2002) also found that the sensory popularity of strawberry cultivars correlated positively with fruity odour, sweet and aromatic taste, but negatively with watery taste.

Harker et al. (2002) investigated the relationship between objective and sensory measurements of apple taste and concluded that acid taste may be predicted on the basis of titratable acidity. Differences in TA as low as 0.08% between apples could evoke a

perceived acid taste response for the median panellist. Suggesting that similar differences could be detected in strawberries, we may suppose that the changes in flavour could also be detected by consumers. In the current experiment change of flavour due to fertilization was not a favourable result.

#### 4.3. Bioactive compounds and total antioxidant activity

Average strawberry ACY content in the current experiment was 30 mg 100 g FW<sup>-1</sup> and AAC 50 mg 100 g FW<sup>-1</sup>. Da Silva Pinto et al. (2008) have reported that the average content of ACY of seven most common strawberry cultivars grown in Brazil ranged from 12.4 to 44.2 mg 100 g FW<sup>-1</sup>, with the average being 25.2 mg 100 g FW<sup>-1</sup>, which is slightly lower than in our experiment. According to Hakala et al. (2003), vitamin C content in 'Polka' strawberries grown in Finland was 62 and 48 mg 100 g FW<sup>-1</sup> in 1997 and 1998, respectively, which is similar to our findings.

Fertilization treatments had an effect on both AAC and ACY content. Thus, our hypothesis that Phi fertilization may affect content of bioactive compounds, appears to be correct. Interestingly, soaking plants in Phi fertilizer solution prior to planting was favourable both for ACY and ascorbic acid formation (Figs. 1 and 2). When soaked plants were later also irrigated with Phi (Phi SI), both ACY and AAC decreased significantly compared to the variant, where plants were only soaked in fertilizer and had no treatment afterwards (Phi S variant). This finding indicates that in activating plant defence mechanisms, soaking strawberries prior to planting is the right technology and additional irrigation with Phi solution is not justified. The effect of soaking remains significant, even in the year after treatment. Additional foliar fertilization with Phi in the following year did not have any beneficial effect on either ACY or AAC in variants which had already received Phi in the previous year. Fertilization with Pi had an increasing effect on ACY content, but not on AAC of strawberries.

In our previous studies with cultivar 'Bounty' we found that both mulch and fertilization had a significant influence on anthocyanin content in strawberry fruits. In the mentioned study, control fruits without fertilization contained the highest amount of anthocyanins both in 2002 and 2003 (Moor et al., 2005). In the current experiment, the control variant had the lowest ACY content. Differences in results could be due to different plant material (runner plants and A+ frigo plants), fertilizers or different cultivars. Häkkinen and Törrönen (2000) found similar levels of phenolic compounds in the cultivars 'Polka' and 'Honeye' when different cultivation techniques (organic and conventional) were used.

Total antioxidant activity of strawberry fruits in the current experiment ranged from 3.75 to 4.85 mmol DPPH 100 g FW<sup>-1</sup>. Our results are in agreement with findings by Ferreyra et al. (2007), who reported antioxidant activity of ripe 'Selva' strawberries to be 3–5 mmol DPPH 100 g FW<sup>-1</sup>. In the current experiment, TAA of strawberries was not affected by either of the fertilization treatments. There could be several reasons for this. Although pelargonidin-3 glycoside is the main phenolic compound in strawberries (Proteggente et al., 2002; Yoshida et al., 2002), there are also others, for instance *p*-coumaric glucose, cinnamoyl glucose, quercetin-3-glucoside, kaempferol-3-glucoside (Proteggente et al., 2002) and (±)catechin (Törrönen and Määttä, 2002). Content of the last mentioned phenolic compounds were not determined in our study, but these compounds could be expected to contribute to total antioxidant activity. Even though these last mentioned phenolic compounds are usually found in low levels in strawberries, some of them probably influenced the TAA content such that the effect of fertilization was significant on anthocyanins, but not on TAA. Wu et al. (1998) have stated that a

synergistic effect could exist between different antioxidants, which means that the total antioxidant effect may be greater than the sum of individual antioxidant activities and the isolation of one compound will not exactly reflect the overall action.

#### 5. Conclusions

1. Phi fertilization did not either suppress or promote strawberry plant growth.
2. Strawberry flavour was influenced towards being more acidic and less sweet by additional foliar fertilization with Phi.
3. Based on our results, Phi fertilizer Phosfik is suitable for use as a plant defence stimulator, rather than fertilizer in strawberry production. Phi fertilization of strawberries has no advantages compared to the traditional Pi fertilization with the aim of gaining higher yields.
4. Phi treatment can activate the plant defence mechanism, but application time and technology are important. Soaking plants in Phi fertilizer solution prior to planting is effective, since this increased ascorbic acid and anthocyanin content. Soaking prior to planting can also be recommended to reduce potential environmental pollution.
5. Phi residues in horticultural crops should be monitored in future, especially in perennial crops where Phi fertilizers are used continuously.

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