Letter to Editor

Effect of Calcium Nitrate Spraying on Mineral Contents and Storability of 'Elise' Apples

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Abstract

The study was carried out in 2005-06 in the experimental orchard at Garlica Murowana in the Kraków area. The effect of early (0.4%) and late spraying (0.8%) with $Ca(NO_3)_2$ on storability and the calcium content as well as elemental mutual relations in 'Elise' fruit of a 5-year-old apple tree were studied. Trees were sprayed 3 times at 10-day intervals in the first time of fruit development (beginning of June) and 30 days before fruit harvest. Fruit mineral composition was estimated after harvest. Foliar sprayings with calcium before harvesting (30 days before) significantly increased the Ca concentration in apples in both years of the experiment. This dependence was only slight and observed in the case of early spraying (at the beginning of June). The late foliar treatment with calcium nitrate significantly reduced the N/Ca and K/Ca ratios in fruits. Fruits harvested with $Ca(NO_3)_2$ had higher flesh firmness and titratable acidity than the control ones. The use of 0.8% $Ca(NO_3)_2$ before fruit harvest reduced the percentage of physiological disorders and fungal diseases.

Keywords: 'Elise' apple, calcium sprays, K/Ca and N/Ca ratios, fruit firmness, physiological disorders, fungal diseases

Introduction

Calcium is one of the most important nutrients in apple fruit quality. Many physiological disorders of fruits are associated with low Ca levels. Increasing the fruit calcium content leads to an increase in fruit firmness and delays fruit ripening or prevents calcium-related disorders [1, 2]. The intensity of calcium accumulation in fruits is higher during the first part of fruit development and it decreases during the second part, when fruits grow faster [3, 4]. High growth rates of low-transpiring organs increase the risk of the calcium tissue content falling below the critical level. Even a relatively small increase in the fruit calcium level can be effective in preventing or at least drastically decreasing the economic losses caused by various storage disorders [5]. The presence of available calcium in the nutritive environment does not guarantee the permanent influx of Ca^{+2} ions to different plant organs. The immobility of Ca has perhaps the most practical importance. Limited translocation of Ca to the fruit, as well as lack of Ca migration from leaves, makes it difficult to elevate its concentration in fruit. Foliar calcium spraying can be an effective way of increasing its concentration in fruits [4, 6, 7]. The effect of this treatment depends however, on factors connected with the technique of spraying, salt concentrations, time and number of treatments, type of fertilizers used and growing season [8-11]. Tomala [12] recommends the first spray of winter apple cultivars with calcium salts at the beginning of June, not later than in the second half of June. According to a great number of studies, foliar application of calcium on apple trees was effective in the second half of the vegetation period, when the delivery of Ca ions to fruit uptake by roots rapidly

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decreased [4, 6, 13]. Calcium transported by xylem is moved effectively to young fruits, as organs of high metabolism rate and transpiration at the early stage of development. In the later period of growth and ripening of fruit the transport of calcium can be limited to floem, so spraying fruits with calcium solution at this time can increase the Ca concentration in fruit tissues [3, 6].

The aim of the present study was to evaluate the effect of early and late spraying with calcium nitrate on the storability, the mineral content and relations between minerals of 'Elise' apples.

Experimental Procedures

The study was carried out in 2005-06 in the experimental orchard at Garlica Murowana near Kraków. Trees of Elise cultivar, grafted on M-9 were planted in 2000 at 4 ·1.6 m spacing. The soil was kept in the herbicide strips in tree rows with grass between rows.

Every year of the experiment in spring nitrogen soil fertilization was performed at a dose of 50 kg ha^{-1} using ENTEC 26 (26% N including 18.6% N-NH_4 with the addition of nitrification inhibitor). Nitrogen fertilizer was spread around each tree, in the area of herbicide strip.

The experiment was carried out in complete randomized blocks in four replications (6 trees in one replication) and covered:

1. Control (no foliar spraying and no soil nitrogen fertilization).
2. Control (no foliar spraying, only with soil nitrogen fertilization).
3. Tree early spraying was done with 0.4% calcium nitrate.
4. Tree late spraying was done with 0.8% calcium nitrate.

Spraying was applied with the addition of the surfactant Aptolan 80EC (76% of paraffin oil) in the amount of 1,000 l ha^{-1}. The early sprayings at 10-day intervals started in the beginning of June and late spraying in August, about 30 days before the harvest.

Soil Analysis

Soil samples were taken from the layers of 0-20 cm and 20-40 cm, each separately from herbicide stripes and grass strips, at the time of taking leaf assays. Nutrient content in soil was estimated according to the Egner-Riehm (P and K) and Schachtschabel (Mg) methods. pH in 1 M KCl (pH_{KCl}) in soil:solution ratio 1:2 were measured [14].

Leaf Analysis

To estimate the nutritive status of the trees the leaf samples were analyzed every year at the end of July or the beginning of August. Samples of 10 mid-shoot leaves from current season terminal shoots on the periphery of each tree were collected. Plant material dried at 70ºC was digested in the mixture of HNO_3, $HClO_4$ and H_2SO_4 (6 : 2 : 0.8). The contents of K, Mg and Ca were measured using an atomic absorption spectrometer using the flame method (Unicam 969 AA spectrometr), the content of P was determined by spectrophotometric method (Unicam 5675 UV spectrometr) with ammonium molybdate. Total nitrogen in leaves was determined by Kjeldahl's methods (Tecator Kjeltec System) [14].

Table 1. The Contents of P, K, and Mg in the orchard soil.

Factor		pH_{KCl}	P	K	Mg
			mg 100 g^{-1}		
Herbicide strip	H	4.12	6.02	21.18	6.65
Grass strip	G	4.09	5.49	21.27	6.35
Soil layer (cm)	0-20	4.15	6.43	24.81	6.13
	20-40	4.05	5.09	17.64	6.88

Fruit Analysis

Fruit samples were taken from the outer part of the tree, at the height of 1 m. Average fruit weight and dry matter as well as the N, K, Mg and Ca contents were determined after mineralization in the acid mixture as previously described.

Apples were harvested at optimum maturity by Streif's index for long-term storage and stored in normal atmosphere at 0-1ºC and 88-90% relative humidity for 150 days. 20 apples for each plot were assessed for: fruit firmness, titratable acidity and soluble solids content, at harvest. The above mentioned measurements were also carried out after storage period. Physiological disorders and fungal decay was also evaluated. Fruit firmness (kG) was measured by an Effegi pressure tester with an 11.1 mm diameter head. Soluble solids concentration (%) was measured with a refractometer using juice, and titratable acidity of fruit was determined by titrating the juice with 0.1 M NaOH to pH 8.1. The data were calculated as malic acid. Streif's index was calculated according to the following formula: firmness (kG)/[soluble solids content (%) x starch index (1-10)].

The fisher test was applied to evaluate the significance of differences between the means, at the significance level of 5%. Statistical analysis was done with the Statistica 7.0 program.

Results and Discussion

The experimental orchard was established on heavy soil (>35% of loam fraction) of silt loam with a low pHKCl 4.05-4.15. The phosphorus and magnesium content was high (> 4 mg P 100 g^{-1} and about 6 mg Mg 100 g^{-1}, respectively) both in herbicide and grass strip samples of 0-20 cm and 20-40 cm layers, while the potassium content was average (17.64-24.81 mg K 100 g^{-1}) (Table 1).

Leaf Analysis

In both years of the experiment magnesium and calcium contents detected in the leaves ranged in the optimum values for the apple tree (Table 2). In the case of phosphorus and potassium, lower contents of these minerals were determined in 2006. The phosphorus level in the indicator parts of the apple tree was lower in both years, but only reached a optimum in 2005 in the control trees (without nitrogen). In 2005 a high potassium concentration (>1.5% K in d.m.) in the apple tree leaves was observed. The weather conditions also affected the nitrogen level in leaves. In 2006 its content was optimum, while in 2005 it was in the high range (more than 2.4% N in dry matter).

Table 2. Nutrient content in apple leaves.

Year	Treatment	N	P	K	Mg	Ca
		% s.m.				
2005	Control	2.58	0.19	1.83	0.25	1.29
	Control + N	2.43	0.15	1.74	0.24	1.29
	0.4% $Ca(NO_3)_2$	2.56	0.15	1.51	0.23	1.45
	0.8% $Ca(NO_3)_2$	2.52	0.14	1.69	0.24	1.43
2006	Control	2.41	0.074	1.07	0.29	1.40
	Control + N	2.29	0.092	1.21	0.26	1.36
	0.4% $Ca(NO_3)_2$	2.37	0.067	1.18	0.22	1.27
	0.8% $Ca(NO_3)_2$	2.40	0.090	1.33	0.24	1.25
$LSD_{0.05}$	Year	0.213	0.013	0.203	ns	ns
	Treatment	0.301	ns	ns	0.024	ns
	Year x Treatment x Object	ns	0.027	ns	ns	0.147

Table 3. Effect of calcium spraying on fruit weight, dry mass and Ca accumulation for 'Elise' apples at harvest.

Year	Treatment		% d.m.	Fruit weight (g)	Fruit diameter (cm)	Ca quantity in a fruit (mg)
2005	Control		12.0	189.4	7.63	5.28
	Control + N		12.2	197.2	7.72	5.94
	0.4% $Ca(NO_3)_2$		11.2	163.9	7.32	5.32
	0.8% $Ca(NO_3)_2$		11.0	164.4	7.42	7.33
2006	Control		15.0	166.5	6.85	3.99
	Control + N		14.9	150.2	6.63	4.28
	0.4% $Ca(NO_3)_2$		15.5	180.2	7.02	5.69
	0.8% $Ca(NO_3)_2$		15.1	176.5	7.05	6.52
Average	Year	2005	11.6	178.7	7.52	5.97
		2006	15.1	168.4	6.89	5.12
	Treatment	1	13.5	178.0	7.24	4.63
		2	13.5	173.7	7.18	5.11
		3	13.4	172.1	7.17	5.51
		4	13.0	170.5	7.23	6.93
$LSD_{0.05}$	Year		0.55	9.762	0.130	0.663
	Treatment		ns	ns	ns	0.938
	Year x Treatment		ns	19.523	0.260	ns

Table 4. Effect of calcium sprayings on N, K, Mg i Ca (mg kg^{-1} d.m.) concentration and on the N/Ca, K/N, K/Ca and K/Mg ratios in 'Elise' fruit at harvest in 2005-06.

Year	Treatment		N	K	Mg	Ca	N/Ca	K/N	K/Ca	K/Mg
2005	Control		398	961	43.5	28.0	14.4	2.44	34.5	22.1
	Control + N		493	1028	48.1	30.1	16.6	2.09	34.5	21.4
	0.4% $Ca(NO_3)_2$		507	1121	47.1	32.5	15.7	2.21	34.7	23.8
	0.8% $Ca(NO_3)_2$		508	1117	43.7	44.6	11.4	2.20	25.1	25.7
2006	Control		430	1326	50.8	24.0	18.0	3.08	55.3	26.1
	Control + N		376	1294	52.3	28.8	13.1	3.45	45.5	25.0
	0.4% $Ca(NO_3)_2$		481	1509	54.3	31.6	15.3	3.16	47.7	27.8
	0.8% $Ca(NO_3)_2$		498	1383	58.1	41.6	12.8	2.85	35.3	23.9
Average	Year	2005	476	1057	45.6	33.8	14.5	2.2	32.2	23.2
		2006	446	1378	53.9	31.5	14.8	3.1	46.0	25.7
	Treatment	1	414	1144	47.1	26.0	16.2	2.8	44.9	24.1
		2	434	1161	50.2	29.5	14.9	2.8	40.0	23.2
		3	494	1315	50.7	32.0	15.5	2.7	41.2	25.8
		4	503	1250	50.9	43.0	12.1	2.5	30.2	24.8
$LSD_{0.05}$	Year		28.5	81.8	3.58	ns	ns	0.27	4.25	1.63
	Treatment		40.3	115.7	ns	4.54	2.45	ns	6.02	ns
	Year x Treatment		57	ns	ns	ns	3.46	ns	ns	3.26

Fruit Analysis

Fruits harvested in 2005 had a higher average weight (178.7 g) as compared to those from the second experimental year (about 168.4 g). Their dry matter was lower than of the fruits analyzed in 2006, while the calcium concentration in one kilogram of fresh matter and its content in one fruit was higher (Table 3, Fig. 1). Treatments with calcium nitrate did not affect the dry matter, average weight and diameter of fruits. In general, fruits picked from the trees treated with $Ca(NO_3)_2$ had more calcium than those from the non-treated ones, but significantly higher calcium concentration was determined only in the case of late spraying with 0.8% $Ca(NO_3)_2$.

In Table 4 the results of the mineral composition of apple fruits taken at harvest are presented. The growing season significantly affected nitrogen, potassium and magnesium contents of 'Elise' apples. In the fruits analyzed in 2005 the lower K, and Mg and higher N levels were determined, while the average calcium content was similar in both experimental years.

The calcium content in 'Elise' apples analyzed at harvest time ranged between 24.0 and 44.6 mg kg^{-1} of fresh matter. In both years of the experiment the early spraying of calcium nitrate did not significantly affect the calcium content in apples determined at harvest time. Schlegel and Schönherr [15] concluded that spraying calcium salt solutions can be effective all over the season. Penetration into the young fruit was very rapid, but older fruits tolerated higher concentrations than the young ones. The amount retained by the young fruit may be too to small to significantly increase the total calcium content of fruit. Baab [16] reports that several sprayings of apples with calcium salts can increase the content of these minerals by 5-8 mg Ca mg kg^{-1} of fresh weight. According to this author, even a slight increase of Ca concentration can reduce the risk of a bitter pit.

The best results were obtained in the second part of the growing season (late sprayings). Foliar application of calcium in the form of 0.8% calcium nitrate solution significantly increased the Ca content in fruits (Table 4). Benavides et al. [3] reported that the most effective results for increasing the calcium content of apples were noticed when Ca was applied in the second growing season. The calcium nitrate spray significantly increased the nitrogen content in fruit harvested in 2006. The potassium concentration in sprayed fruits was higher in both years of experiment, while the average magnesium content was similar (Table 4).

The K/Ca ratio varied from 25.1 to 34.7 in 2005 and from 35.3 to 55.3 for 2006. The late foliar treatment with calcium nitrate significantly reduced the N/Ca and the K/Ca ratio in fruits (Table 4, Fig. 2). In the fruits from both the control trees and those treated with $Ca(NO_3)_2$, the N/Ca ratio was, as reported by Baab [16], within the usual range, e.g. 10-20.

Table 5. Fruit firmness (kG) of 'Elise' apples as affected by calcium sprayings.

Treatment	At harvest		
	2005	2006	Mean for treatment
Control	7.8 a	9.7 a	8.8 a
Control + N	7.9 a	9.9 b	8.9 ab
0.4% $Ca(NO_3)_2$	8.1 b	9.8 ab	9.0 b
0.8% $Ca(NO_3)_2$	8.1 b	9.8 ab	9.0 b
Mean for year	8.0 a	9.8 b	
After storage			
Control	5.4 a	5.1 a	5.3 a
Control + N	5.7 b	5.1 a	5.4 b
0.4% $Ca(NO_3)_2$	5.8 c	5.8 b	5.8 c
0.8% $Ca(NO_3)_2$	6.0 d	6.0 c	6.0 d
Mean for year	5.7 b	5.5 b	

Numbers followed by the same letter within the same column and analysis time are not different at P=0.05.

Table 6. Titratable acidity (% of malic acid equivalents) of 'Elise' apples as affected by calcium sprayings.

Treatment	At harvest		
	2005	2006	Mean for treatment
Control	0.58 a	0.70 a	0.64 a
Control + N	0.69 c	0.74 b	0.71 b
0.4% $Ca(NO_3)_2$	0.64 b	0.81 c	0.72 b
0.8% $Ca(NO_3)_2$	0.64 b	0.92 d	0.78 c
Mean for year	0.65 a	0.78 b	
After storage			
Control	0.52 a	0.35 a	0.44 a
Control + N	0.56 c	0.43 b	0.47 b
0.4% $Ca(NO_3)_2$	0.54 b	0.42 b	0.47 b
0.8% $Ca(NO_3)_2$	0.55 c	0.51 c	0.53 c
Mean for year	0.54 b	0.48 a	

Numbers followed by the same letter within the same column and the analysis time are not different at P=0.05.

The higher N/Ca ratio increased the possibility of storage disorders [20]. In the present study the K/Ca ratio was high (e.g > 30) in both experimental years. According to Tomala [12] the storage ability of apples depends more often on the K/Ca ratio than on individual contents of these minerals. The proper ratio between these elements should be within the 25-30 range.

Streif's index values were not affected by the calcium nitrate spraying and soil nitrogen fertilization. The level of this index averaged 0.08-0.10 in 2005 and 0.10-0.12 in 2006, respectively. Apples treated with $Ca(NO_3)_2$ revealed higher fruit firmness both at early and late period (Table 5). Gąstol et al. [19] report that calcium fertilizers have a beneficial effect on fruit firmness. Only in the second year of the study were flesh firmness values not differentiated. Timing of spraying had no influence on flesh firmness at harvest, but after storage higher firmness for 0.8 % $Ca(NO_3)_2$ in comparison to 0.4% was noted. Titratable acidity of fruits sprayed with calcium nitrate and soil nitrogen fertilization was higher than the non-treated ones (Table 6). The late spraying promoted higher titratable acidity. The soluble solid concentrations in fruit were not affected by treatments (unpublished data).

Fruits treated with 0.8% $Ca(NO_3)_2$ were less susceptible to bitter pit and internal breakdown (Table 7). The highest percentage of physiological disorders was noted for the control fruits. On the contrary, the control fruits were seriously damaged by fungal disorders (grey mould, gloeosporium rot and storage brown rot). Susceptibility to storage disorders for fruits treated with 0.4% $Ca(NO_3)_2$ and soil nitrogen fertilization was similar. The high Ca content and the low K/Ca ratio noted for fruits sprayed with calcium

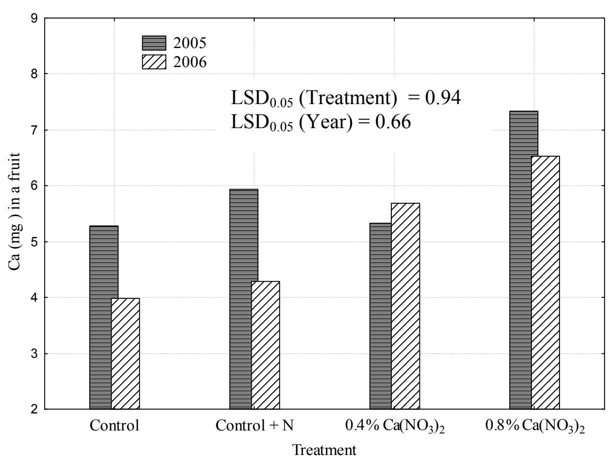

Fig. 1. Ca accumulation (mg) in 'Elise' fruit in 2005-06.

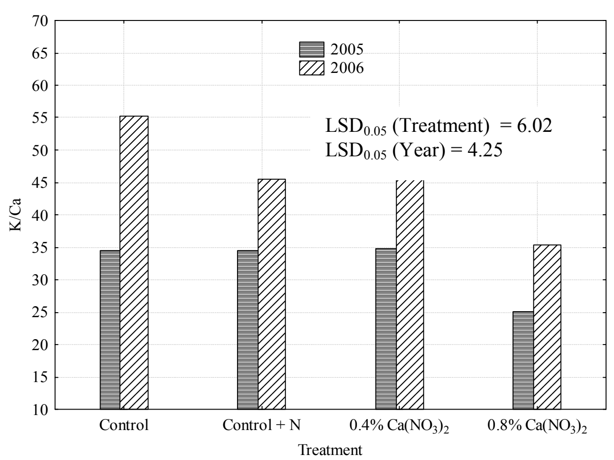

Fig. 2. K/Ca ratio in 'Elise' fruit in 2005-06.

Table 7. Physiological (1) and fungal (2) diseases (%) of 'Elise' apples as affected by calcium sprayings.

Treatment	2005		2006		Mean for treatment	
	1	2	1	2	1	2
Control	9.5 b	0.7 a	4.7 d	2.8 b	7.1 c	1.8 a
Control + N	0.0 a	0.8 a	3.3 c	4.8 d	1.7 b	2.8 b
0.4% $Ca(NO_3)_2$	0.0 a	1.3 b	2.9 b	3.7 c	1.5 b	2.5 b
0.8% $Ca(NO_3)_2$	0.1 a	3.6 c	0.3 a	1.8 a	0.2 a	2.7 b
Mean for year	2.4 a	1.6 a	2.8 a	3.3 b		

Numbers followed by the same letter within the same column and analysis time are not different at P=0.05.

nitrate were associated with a low percentage of physiological disorders of the apples. Results of the present study correspond with the results obtained by Słowińska and Tomala [17] and Ben [18].

Conclusions

1. Foliar sprayings with calcium before harvesting (30 days before) significantly increased the Ca concentration in apples in both years of the experiment. This dependence was only slight and observed in the case of the early spraying (at the beginning of June) with calcium nitrate.
2. The N/Ca and K/Ca ratios determined in the fruits at the harvest time significantly decreased as a result of the late applied treatment with 0.8 $Ca(NO_3)_2$.
3. Fruits harvested with $Ca(NO_3)_2$ had higher flesh firmness and titratable acidity than the control ones.
4. The use of 0.8% $Ca(NO_3)_2$ before fruit harvest reduced the percentage of physiological disorders and fungal disease.

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