

# Effects of growth control on yield and fruit quality of the apple cultivar ‘Rubin’

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The effect of tree growth-control technologies on apple tree vegetative development, productivity and fruit quality was investigated with apple cultivar ‘Rubin’ on dwarf rootstock P 60 at the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry in 2015–2018. Eight treatments were established combining tree trunk incision by chainsaw before flowering, application of prohexadione-calcium in different dose and time, summer pruning in August and root pruning before flowering. Root pruning from both sides of the tree significantly reduced tree trunk diameter, shoot length and pruning weights but at the same time reduced fruit weight. It increased tree productivity and enhanced fruit colouring. Two applications of prohexadione-calcium significantly reduced mean shoot length and increased average fruit weight. Summer pruning had a positive impact on fruit colouring. Trunk incisions enhanced leaf P, K and Fe content. Pro-Ca increased leaf Ca content. Trees root pruned from both sides had one of the lowest contents of all tested minerals. All tree growth-control technologies had a positive impact on tree productivity, fruit quality and bearing stability comparing with control treatment.

**Key words:** leaf minerals, growth parameters, fruit quality, *Malus x domestica*, prohexadione Ca, root pruning, summer pruning, trunk incision

## Introduction

Regulation of tree vegetative growth in intensive orchards is one of the most important tasks for fruit growers. To optimize the growth and yield of apple trees, different dwarfing rootstocks are usually chosen depending on the vigour of a particular apple cultivar. However, under Lithuanian climatic conditions, trees of medium- or strong-growing apple cultivars are too vigorous even on the dwarf rootstocks (Kviklys et al. 2013). Additionally, other technological means are required to optimize apple tree growth.

Growth regulator prohexadione-calcium (Pro-Ca) and root pruning are widespread tree growth-reduction technologies (Ferree et al. 1992, Rufato et al. 2017). Trunk incision effectively restricts tree growth and it was used mainly for the strong-growing trees (Hoying and Robinson 1992).

Pro-Ca is successfully used to control the vegetative growth of different fruit tree species (Cares et al. 2014, Crassweller and Smith 2017, Mac an tSaoir 2017). Pro-Ca is applied at a rate of 2.5 kg ha<sup>-1</sup> immediately after flowering when new shoots had 5 leaves or is applied twice at a rate of 1.25 kg ha<sup>-1</sup> immediately after flowering when new shoots had 5 leaves and after 2 weeks of the first application. According to Fachinello and Robinson (2017), Pro-Ca is more effective in controlling vegetative growth than root pruning, but for pear trees, both technologies reduced growth and increased fruit yield (Maas 2008). Meanwhile, Pro-Ca’s effect on apple tree productivity and fruit quality is contradictory (Meland and Kasier 2016), as well as its effect in pears (Asin and Vilardell 2008).

Root pruning is a common practice to reduce fruit tree growth. Root pruning usually is done two weeks before or after full bloom, at cutting depth 30–40 cm and at 30–120 cm from the tree depending on tree vigour, tree age and soil fertility. According to Maas (2007), root pruning can be performed only in irrigated orchards where optimal soil conditions are created for fruit trees. In other cases, root pruning can decrease fruit weight (Hoying and Robinson 1992).

Trunk incision or girdling along with reduction of vegetative growth (Autio and Greene 1994) increases apple tree productivity (Pretorius et al. 2004). Double girdling increased crop yield in ‘Packham’s Triumph’ pears as well (Rufato et al. 2015) and contributed to the better quality fruits, without the use of chemical growth regulators (Sousa et al. 2008).

Studies have indicated that success of growth-control methods depended on tested variety and rootstock, orchard constructions and climate conditions, and not all results could be directly applied to other places. At the same time, these studies were mainly focused on tree growth parameters and tree productivity. However, there is limited research data of the effect of tree growth regulation on tree nutrition and chemical composition of apple fruit. It is known that summer pruning reduces the competition between shoot growth and fruit for available calcium which increases calcium levels in fruits (Ashraf and Ashraf 2014). Similar, application of Pro-Ca causes reduction in vegetative growth and thus reduces competition between shoot growth and plant leaves as well as fruits for available calcium and potassium that increases minerals level in them (Lal et al. 2020). Meanwhile Serban and Kalcsits (2018) report that treatment with P-Ca did not affect fruit mineral concentration or bitter pit incidence. Despite some differences in the results of the studies, the positive effect of Pro-Ca on the mineral nutrition of fruit trees is more often reported (Guak 2013, Javaid and Misgar 2017). Root pruned apple trees also tend to have higher levels of foliar minerals than unpruned ones (Schupp and Ferree 1990).

The aim of our study was to investigate the impact of growth-control technologies on apple cv. 'Rubin' tree vegetative development, productivity, nutrition and external and internal fruit quality.

## Materials and methods

A field trial was conducted in 2015–2018 in an experimental orchard of the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry (55°60' N, 23°48' E). We tested strong-growing and moderate-yielding cultivar 'Rubin' (Czech Republic) on dwarf rootstock P 60 (Poland). The orchard was planted in 1999 at 4 × 1.5 m distances. Trees were pruned as slender spindles and maintained at 2.5 m height. Orchard was not irrigated. A sustainable plant protection system was used (Valiuškaitė et al. 2017). The soil in the orchard was Epicalcari-Endohypogleyic Cambisol: heavy clay loam containing 2.16% humus, 84.5 mg kg<sup>-1</sup> P, 152.7 mg kg<sup>-1</sup> K, 4595.0 mg kg<sup>-1</sup> Ca, 972.0 mg kg<sup>-1</sup> Mg, 1.16 mg kg<sup>-1</sup> B, 8.44 mg kg<sup>-1</sup> Cu, 90.0 mg kg<sup>-1</sup> Mn, 1.85 mg kg<sup>-1</sup> Zn and 952.0 mg kg<sup>-1</sup> Fe, with pH 7.3 (in 1 mol l<sup>-1</sup> KCl extract).

Eight treatments of apple tree vegetative growth control were established: 1) control, where apple trees were maintained according to intensive technologies; 2) apple tree trunk incision 2 weeks before flowering by chainsaw at the level of 20 cm above the ground from one side and 60 cm from the other side; 3) apple tree root pruning 2 weeks before flowering 20 cm from the stem and cut to a depth of up to 40 cm from one side; 4) apple tree root pruning two weeks before flowering 20 cm from the stem and cut to a depth of up to 40 cm from both sides; 5) application of growth regulator prohexadione-calcium (Pro-Ca at a rate of 2.5 kg ha<sup>-1</sup> immediately after flowering when new shoots had 5 leaves; 6) application of Pro-Ca at a rate of 1,25 kg ha<sup>-1</sup> immediately after flowering when new shoots had 5 leaves and after 2 weeks of the first application; 7) application of Pro-Ca at a rate of 1.25 kg ha<sup>-1</sup> on the tree top immediately after flowering when new shoots had 5 leaves and after 2 weeks of the first application; and 8) summer pruning performed in the middle of August removing the most vigorous and vertical shoots.

The trials were arranged in a randomized block design, with 4 replicates and 5 trees per plot.

Tree growth was evaluated by measuring the trunk diameter, 20 cm above graft union, converted to the trunk cross sectional area (TCSA) in cm<sup>2</sup>, by measuring total (m) and average (cm) current shoot (above 5 cm) length, and by measuring pruning weights (kg).

Fruits were harvested in the 3<sup>rd</sup> decade of September. Fruit yield (kg) and mean fruit weight (g) from each tree were recorded, and for data analysis, the averages per tree of a replicated plot were calculated. Yield efficiency was calculated as a ratio of yield per tree to TCSA and expressed in kg cm<sup>-2</sup>.

Fruit colour (surface red colour) was estimated by visual evaluation and expressed as percentage of skin covered with red blush. Fifty fruits per replicate were analysed.

Flowering intensity was estimated by visual evaluation on a five-point scale, where 1 = no flowers and 5 = very abundant flowering.

A sample of 50 fruits per replicate was graded according to grading classes every 5 mm, and fruit size distribution (%) was established.

Soluble solids were quantified with a digital refractometer PR-32 (Atago Co., Ltd., Japan). Fruit firmness was determined by the TA.XTPlus texture analyser (Stable Micro Systems, United Kingdom) using the P/2 probe. The starch index was determined using a 0.1N iodine and potassium iodine solution (scale 1–10). Ten fruits per replicate were analysed. Analysis were performed at harvest time.

Alternate bearing index (ABI) was calculated according Monselise and Goldschmidt (1982):

$$\text{ABI} = (\text{year 1 yield}) - (\text{year 2 yield}) / (\text{year 1 yield} + \text{year 2 yield}),$$

where ABI = 0 is no alternate bearing and ABI = 1.0 is complete alternate bearing.

### Leaf chemical analysis

Random samples of 50 leaves taken from the middle part of shoots were used. Content of leaf nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) (% in dry weight [DW]), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) and boron (B) ( $\text{mg kg}^{-1}$  in DW) was established. The content of leaf N was measured by the Kjeldahl method using Tecator Digestion System DK 20 (VELP Scientifica, Usmate, Italy) and Semi-automatic Distillation Unit UDK139 (VELP Scientifica, Usmate, Italy). P was determined by spectrometer ICP Optima 2100 (Perkin Elmer), K by flame photometry with Jenway PFP7 (Bibby Scientific Limited, Staffordshire, UK) and Ca and Mg by atomic absorption spectrophotometry (AAAnalyst 200, Perkin Elmer precisely, Waltham, USA). Leaf mineral content for Cu, Zn, Fe, Mn and B after digestion was extracted with aqua regia and determined with an inductively coupled plasma spectrometer ICP Optima 2100 (Perkin Elmer, USA).

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Lithuanian climate conditions are favourable for fruit growing having mild temperatures and sufficient amount of precipitation during the vegetation period. It was established that in 2015 air temperature during vegetation was close to multiannual averages except in August when the temperature was 3 °C higher than the multiannual average. 2015 precipitation deficits were observed in June and in August. 2016 was characterized by a slightly warmer and drier May but with double amount of precipitation in July and August. 2017 air temperature was close to multiannual averages. Precipitation deficit was observed in May, but surplus of precipitation was in April, August and September. In 2018 air temperature during whole vegetation period the air temperature was 2–3 °C higher than the multiannual average. Precipitation deficit was observed in June, August and September, but with higher amount of precipitation in July.

### Statistical analyses

Because there were no interactions between years, the data are presented as the average of 4 years of experiment. Means and standard deviations were calculated with STATISTICA 10 (StatSoft, Inc., USA) and Excel (Microsoft, USA) software. One-way analysis of variance (ANOVA) and the posthoc Tukey's HSD test were employed for statistical analysis. Differences were considered to be significant at  $p < 0.05$ .

## Results and discussion

### Vegetative development

In our study all applied growth-control treatments significantly reduced total shoot length and average shoot length compared with the control treatment (Table 1). Similar results were reported by other researchers from different growth-control studies (Costa et al. 2001, Crassweller and Smith 2017, Rufato et al. 2017). In our trial, application of Pro-Ca on the top of the tree most effectively stunted total shoot length. Pro-Ca reduces terminal growth by inhibiting the synthesis of gibberellins that are responsible for regulation of terminal growth in apple trees, which is the most pronounced in treetops. During the summer pruning, usually the longest shoots are removed, which results in significant reduction of total growth. All applied treatments significantly reduced pruning weights when the pruning was done in the dormant season. Reduction of pruning leads to simpler and faster implementation of orchard management works and better economical results. Root pruning from both sides was the most effective technology. Similar results were achieved with summer pruning, but pruning weights during the summer are not added to dormant pruning weights. Comparing Pro-Ca treatments, double application in lower doses provided significant benefits compared with a single application.

Table 1. Effect of growth control technologies on growth parameters of apple cv. ‘Rubin’, average of 2015–2018

Treatment	Total shoot length, m tree <sup>-1</sup>	Average shoot length, cm	Pruning weight, kg tree <sup>-1</sup>	Trunk cross sectional area, cm <sup>2</sup>
Control	65.1 a	39.6 a	3.4 a	110.6 a
Trunk incision	51.7 b	31.9 b	3.0 b	106.3 a
Root pruning from one side	47.2 bcd	30.2 bc	2.4 c	99.1 ab
Root pruning from both sides	46.1 bcd	24.0 d	1.6 d	91.7 b
Pro-Ca 2.5 kg ha <sup>-1</sup>	44.6 bcd	32.9 b	3.0 b	106.3 a
Pro-Ca 1.25 kg ha <sup>-1</sup> × 2	44.6 bcd	29.9 bc	2.6 c	111.2 a
Pro-Ca on top 1.25 kg ha <sup>-1</sup> × 2	38.1 d	27.4 cd	3.1 b	106.3 a
Summer pruning	40.5 cd	33.4 b	1.7 d	101.6 ab

The different letters on the same column indicate significant differences between growth control technologies ( $p < 0.05$ )

Regarding the impact of growth-control technologies on the changes in the tree trunk area, significant reduction was achieved only with root pruning from both sides of the tree.

### Tree productivity and external fruit quality

Fruit yield differed between years. The variation between treatments was 27.9–38.6 t ha<sup>-1</sup> in 2015, 23.2–30.7 t ha<sup>-1</sup> in 2016, 9.6–14.2 t ha<sup>-1</sup> in 2017 and 32.2–48.5 t ha<sup>-1</sup> in 2018. Despite of differences between seasons the tendencies between treatments remained the same and the data is presented as the average of the whole trial period. Cv. Rubin has a distinct terminal bearing growth habit and forms flowers only on the terminal buds of long shoots. Tree management strategies to achieve high yields of such an architectural type of apple cultivars should be directed at the promotion of branching with a higher number of shorter shoots. Root pruning from both sides of the tree was the only treatment that significantly improved tree branching (Table 2). That also correlated with the highest yield, though there were no significant differences among treatments. Flowering intensity was very similar between treatments with some positive impact of summer pruning and lower doses of Pro-Ca. Numerous studies proved these findings that various growth-control technologies have more significant impacts on tree vegetative growth but not on the yield (Costa et al. 2001, Maas 2008, Meland and Kasier 2016, Atay and Koynucu 2017).

Table 2. Effect of growth control technologies on the productivity and alternate bearing index of apple cv. ‘Rubin’, average of 2015–2018

Treatment	Shoot number tree <sup>-1</sup>	Flowering intensity, points 1–5	Yield, t ha <sup>-1</sup>	Efficiency, kg TCSA <sup>-1</sup>	Alternate bearing index
Control	164 b	3.8 b	26.8 ab	0.14 cd	0.37 a
Trunk incision	162 b	3.8 b	28.6 a	0.16 bc	0.31 b
Root pruning from one side	156 bc	3.9 ab	27.7 ab	0.17 ab	0.32 b
Root pruning from both sides	192 a	3.8 b	29.4 a	0.19 a	0.30 b
Pro-Ca 2.5 kg ha <sup>-1</sup>	136 cd	3.8 b	23.3 b	0.13 d	0.30 b
Pro-Ca 1.25 kg ha <sup>-1</sup> × 2	149 bc	4.0 a	27.6 ab	0.15 bcd	0.31 b
Pro-Ca on top 1.25 kg ha <sup>-1</sup> × 2	139 cd	4.0 a	27.9 ab	0.16 bc	0.30 b
Summer pruning	121 d	4.0 a	26.6 ab	0.16 bc	0.31 b

The different letters on the same column indicate significant differences between growth control technologies ( $p < 0.05$ )

The efficiency index that describes the ratio between vegetative tree growth and apple yield indicated that root pruned trees were the most productive. Root pruning from both sides significantly increased the efficiency index compared with the rest of the treatments (Table 2). All tree growth control technologies had a positive impact on apple tree bearing stability. Alternate bearing index was significantly higher in control treatment.

### Fruit colour and size distribution

The efficiency index negatively correlated with average fruit weight (Table 3). Significantly, the smallest fruit weight was from the trees to which root pruning from both sides was applied. Though, root pruning resulted in lower share of fruits over 85 mm only. Similar results were reported by Hoying and Robinson (1992). Application of Pro-Ca twice was the only treatment that significantly increased fruit weight compared with control trees. A positive Pro-Ca effect on fruit size was mentioned by Atay and Koynucu (2017).

Table 3. Effect of growth control technologies on the fruit surface colour, weight and fruit size distribution of apple cv. ‘Rubin’, average of 2015–2018

Treatment	Fruit colour, %	Fruit weight, g	Fruit size distribution, %		
			<70	70–85	>85
Control	68.3 bc	206 b	4.0 a	69.9 a	26.1 ab
Trunk incision	69.3 bc	207 ab	1.6 b	70.2 a	28.2 ab
Root pruning from one side	77.3 a	200 bc	3.8 a	72.0 a	24.2 b
Root pruning from both sides	75.8 a	196 c	1.6 b	73.5 a	24.9 b
Pro-Ca 2.5 kg ha <sup>-1</sup>	66.8 c	210 ab	0.5 b	70.4 a	29.1 ab
Pro-Ca 1.25 kg ha <sup>-1</sup> x 2	69.5 bc	216 a	1.9 b	69.0 a	29.5 a
Pro-Ca on top 1.25 kg ha <sup>-1</sup> x 2	70.4 b	207 ab	2.4 ab	66.3 a	31.2 a
Summer pruning	74.3 a	208 ab	3.8 a	66.2 a	30.0 a

The different letters on the same column indicate significant differences between growth control technologies ( $p < 0.05$ )

Restriction of tree growth increases light penetration into tree canopies, which is a prerequisite for better fruit colouring (Rufato et. al. 2017). In our study, we obtained comparable results: root pruning from one or both sides of the tree and summer pruning resulted in lower canopy density due to shoot growth inhibition and significantly increased fruit colouring.

In our study, Pro-Ca did not have a positive effect on fruit colouring. Contradictive results of Pro-Ca’s influence on fruit colour have been reported by other researches. Pro-Ca promoted fruit colour development in ‘Cripps Pink’ (Wan Zaliha and Singh 2013) and ‘Fuji’ apples but not in ‘Royal Gala’ apples (Mata et al. 2006).

### Fruit chemical composition

Growth-control technologies did not have a significant effect on fruit firmness, starch index and dry matter content, but fruit soluble solid content depended on applied treatments (Table 4). Summer pruning, Pro-Ca applied on the top or twice, and root pruning from both sides of the tree significantly increased soluble solid content.

Table 4. Effect of growth control technologies on chemical composition of apple fruits, average of 2015–2018.

Treatment	Soluble solids, % FW	Firmness, kg cm <sup>-2</sup>	Dry matter, %	Starch index, points
Control	14.4 ± 0.2 c	10.6 ± 3.1 a	16.4 ± 1.1 a	7.2 ± 0.3 a
Trunk incision	14.9 ± 0.1 bc	10.6 ± 3.1 a	16.4 ± 0.9 a	7.0 ± 0.4 a
Root pruning from one side	14.5 ± 0.5 c	10.2 ± 3.2 a	16.2 ± 0.9 a	7.4 ± 0.2 a
Root pruning from both sides	15 ± 0.3 ab	9.9 ± 2.8 a	16.3 ± 0.7 a	7.3 ± 0.3 a
Pro-Ca 2.5 kg ha <sup>-1</sup>	14.8 ± 0.7 bc	11.3 ± 3.5 a	16.0 ± 0.8 a	7.4 ± 0.5 a
Pro-Ca 1.25 kg ha <sup>-1</sup> x 2	15.4 ± 0.2 ab	10.6 ± 3.3 a	16.5 ± 1.2 a	7.5 ± 0.4 a
Pro-Ca on top 1.25 kg ha <sup>-1</sup> x 2	15.7 ± 0.1 a	9.9 ± 2.5 a	16.4 ± 1.0 a	7.4 ± 0.3 a
Summer pruning	15.7 ± 0.2 a	9.5 ± 2.2 a	16.9 ± 1.4 a	7.3 ± 0.4 a

The different letters on the same column indicate significant differences between growth control technologies ( $p < 0.05$ )

Mineral fruit tree nutrition

The highest fruit tree leaf N content (2.26%) was found when roots were pruned from one side of the row (Table 5). Significantly lower leaf N content (2.05%) was found after two applications of Pro-Ca on the top of fruit tree canopies at a rate of 1.25 kg ha<sup>-1</sup>. The rest of the treatments did not affect fruit tree N nutrition. The highest leaf P and K content was established after trunk incisions – 0.22% and 1.41%, respectively. The lowest leaf P content (0.18–0.19%) was found after root pruning and two applications of Pro-Ca at a rate of 1.25 kg ha<sup>-1</sup>. Similar to the P nutrition, the lowest leaf K content was found after treatments with root pruning from both sides and two applications of Pro-Ca at the rate of 1.25 kg ha<sup>-1</sup> – 1.12% and 1.20%, respectively. The highest fruit tree leaf Ca content (1.67%) was established after Pro-Ca application at a rate of 2.5 kg ha<sup>-1</sup> and the least (1.29%) when roots were pruned from one side of the row. Applied means did not affect leaf Mg content. Information about Pro-Ca’s effect on apple mineral nutrition is scarce. Javaid and Misgar (2017) established that Pro-Ca increased content of N, P, K and Ca in apple leaves. Our research did not show that this preparation has a significant effect on the fruit tree mineral nutrition. A slightly more pronounced increase in leaf Ca content was found after two of the three treatments with Pro-Ca application. This can be explained by the effect of Pro-Ca on shoot growth. Vegetative parts of apple trees accumulate most of the calcium (Wojcik 2004). By inhibiting the growth of the shoots, Pro-Ca reduces the need for Ca and increases its concentration in plant tissues.

Table 5. Effect of growth control technologies on leaf macronutrient content (%), average of 2017–2018

Treatment	N	P	K	Ca	Mg
Control	2.21 ab	0.21 ab	1.27 bc	1.45 bc	0.23 a
Trunk incision	2.15 ab	0.22 a	1.41 a	1.34 bc	0.22 a
Root pruning from one side	2.26 a	0.19 b	1.33 ab	1.29 c	0.21 a
Root pruning from both sides	2.20 ab	0.18 b	1.12 c	1.35 bc	0.23 a
Pro-Ca 2.5 kg ha <sup>-1</sup>	2.13 ab	0.20 ab	1.36 ab	1.67 a	0.24 a
Pro-Ca 1.25 kg ha <sup>-1</sup> × 2	2.20 ab	0.19 b	1.20 c	1.43 bc	0.23 a
Pro-Ca on top 1.25 kg ha <sup>-1</sup> × 2	2.05 b	0.20 ab	1.25 bc	1.50 ab	0.23 a
Summer pruning	2.19 ab	0.21 ab	1.35 ab	1.34 bc	0.21 a
Optimum	2.10–2.40*	0.15–0.26*	1.00–1.50*	1.50–2.00**	0.22–0.32*

The different letters on the same column indicate significant differences growth control technologies ( $p < 0.05$ ); \* according to Wójcik (2014); \*\* according to Rom (1994)

The highest leaf Fe content (100.9 mg kg<sup>-1</sup>) was established after trunk incisions (Table 6). The highest Mn and Zn content was found after two applications of Pro-Ca at the top of fruit tree canopies at a rate of 1.25 kg ha<sup>-1</sup>. The highest B content (39.1 mg kg<sup>-1</sup>) resulted from two applications of Pro-Ca to the whole fruit tree at a rate of 1.25 kg ha<sup>-1</sup>. The highest Cu content was in the leaves from control fruit trees and those treated with root pruning from one side – 6.68 and 6.80 mg kg<sup>-1</sup>, respectively. The most significant negative impact on nutrition with trace elements was in fruit trees with roots pruned from both sides.

Table 6. Effect of growth control technologies on leaf trace element content (mg kg<sup>-1</sup>), average of 2017–2018

Treatment	Fe	Mn	Cu	Zn	B
Control	82.4 ab	81.5 ab	6.68 a	16.7 ab	37.5 a
Trunk incision	100.9 a	82.4 ab	6.25 ab	14.9 ab	31.6 ab
Root pruning from one side	77.5 ab	74.6 ab	6.80 a	14.6 ab	26.7 b
Root pruning from both sides	64.2 b	68 b	5.65 b	13.2 b	23.6 b
Pro-Ca 2.5 kg ha <sup>-1</sup>	103.4 a	77.7 ab	6.33 ab	15.2 ab	33.8 ab
Pro-Ca 1.25 kg ha <sup>-1</sup> × 2	73.2 ab	85.0 ab	5.70 ab	17.2 ab	39.1 a
Pro-Ca on top 1.25 kg ha <sup>-1</sup> × 2	71.1 ab	91.1 a	5.58 b	18.4 a	25.0 b
Summer pruning	78.5 ab	82.4 ab	5.50 b	16.7 ab	29.4 ab
Optimum	40–400**	41–100*	6–25**	15–200**	25–45*

The different letters on the same column indicate significant differences growth control technologies ( $p < 0.05$ ), \* according to Wójcik (2014); \*\* according to Rom (1994)

Investigated measures can be considered to have caused the plant stress. However, they did not have a negative effect on the mineral fruit tree nutrition. Content of the most tested nutrients, except Ca, Zn and Cu, in apple leaves was within optimum limits. Other studies have shown that measures such as summer pruning or intervention to the trunk also had no negative effect on the mineral nutrition of fruit trees (Sosna 2010). Root pruning, if done properly, also has no negative consequences on fruit tree nutrition (Dong et al. 2003, Yehia et al. 2014).

## Conclusions

The tested growth-control technologies have a significant impact on tree vegetative growth, productivity characteristics, fruit quality and tree nutrition. Root pruning from both sides of the tree 2 weeks before flowering significantly reduced tree trunk diameter, shoot length and pruning weights; and resulted in better fruit colouring and a higher amount of fruit soluble solids, but it reduced fruit weight and resulted in one of the lowest contents of all tested leaf macronutrients and trace elements. Root pruning from one or both side of the tree were the most efficient treatments for the increase of tree productivity. Trunk incision 2 weeks before flowering reduced shoot length and pruning weights and enhanced leaf P, K and Fe content. Two applications of Pro-Ca immediately after flowering and two weeks later significantly reduced mean shoot length and increased average fruit weight. Pro-Ca applied once at a rate of 2.5 kg ha<sup>-1</sup> immediately after flowering increased leaf Ca content. Summer pruning reduced shoot length and pruning weights and had a positive impact on fruit colouring. The tested growth-control technologies did not have effect on fruit dry matter content, starch index and fruit firmness, but determined lower apple tree alternate bearing index, thus, increased apple bearing stability. The main effect of growth-control technologies was noticed in stunted tree vegetative growth that leads to a significant reduction of labour and orchard management costs.

## Acknowledgments

This work was supported by a grant from the Research Council of Lithuania, project No. S-MIP-17-8.

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