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RESPONSE OF SOME APPLE CULTIVARS TO PROHEXADION-CA COMBINED WITH DIFFERENT FERTILIZATION METHODS IN A SUPERINTENSIVE APPLE ORCHARD

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Abstract

Supplying the trees with the optimal amount of nutrients is very important in order to obtain high quantity and high quality yields every year. Prohexadione-Ca is a dual-acting substance that is both a growth regulator and an activator of the natural defense mechanisms of apple trees against pests and diseases. The influence of this compound combined with radicular or foliar fertilizers was evaluated in three apple cultivars: 'Idared', 'Generos' and 'Florina' grafted on medium vigour M26 rootstock. The applied technology in the experimental plot included chemical treatments against the main pests and diseases which commonly affect apple orchards in Northern Transylvania. Different fertilization methods combined with this growth regulator led to a reduction of length of the terminal shoots with direct influence on labour costs and efficiency of orchard management. The results obtained during 2019-2022 revealed the benefits of supplying apple trees with foliar and soil fertilizers for the cultivars to maintain a high productive potential.

Key words*: apple, fertilizer, growth regulator, terminal shoots*

INTRODUCTION

Apple production represents an important economic activity in Northern Transylvania, Bistrița region. The fertilization of apple orchards with an optimal supply of nutrients in combination with growth regulators, are necessary and very important activities that are required to do in modern fruit trees technology.
Managing the vegetative growth in apple orchards associated with manual pruning is an intensive labour practice, essential to optimize fruit quality and productivity of the trees (Greene, 2007; Cline et al., 2016).
Many methods of growth control have been practiced in the past (Greene, 2003; Miller, 1988), one of the most popular methods is the use of dwarfing rootstocks (Greene, 2007). Uncontrolled vegetative growth affects fruit quality, productivity, pests and diseases control and extremely high pruning costs (Atay & Koyuncu, 2017).
The climate changes in the last years in Bistrița region is causing the modification of flight span and the attack degree of the most damaging apple pests, which can affect the resistance of the trees (Roşu-Mareş et al., 2020).
Prohexadione-calcium (Pro-Ca) is a plant bioregulator (PBR) that was developed by BASF, Germany and Kumiai Chemical Industry, Japan (Meland & Kaiser, 2016). It has been used as an inhibitor of excessive vegetative growth in apples (Privé et al., 2002; 2006), pears (Rademacher, 2016), strawberries (Reekie et al, 2002), and turf (Waddington et al., 1992). It was effective at reducing the incidence of scab (*Venturia inaequalis*) (Spinelli et al., 2010), blossom fire blight and shoot fire blight (*Erwinia amylovora*) (Rademacher et al., 1999; Yoder et al., 1999; Wallis & Cox., 2019) but also can reduce the occurrence of bitter pit (BP) (Amarante et al., 2020). Prohexadione-Ca induces changes in the metabolism of the plants by inhibiting the phenylpropanoids, that have often been found to be involved in defense mechanisms of higher plants (Rademacher et al., 1999) and prevention of the oxidation (Amarante et al., 2019).
Several studies have demonstrated that the prohexadione-calcium (Pro-Ca) has provided for regulating apple tree extension growth ranging from 20 to 60% (Greene, 1996; Byers & Yoder, 1999; Unrath, 1999; Yoder et al., 1999; Basak, 2004; Byers et al., 2004a; 2004b;

Porebski et al., 2006; Privé et al., 2004; 2006; Ramirez et al., 2006; Cline et al., 2008). The applications of Pro-Ca are recommended to be made before and/or after the petal fall phenophase (Rademacher & Kober, 2003). The aim of this research was to evaluate the influence of the growth regulator Regalis Plus combined with different fertilizers on the development and fructification of the apple trees in Northern Transylvania.

MATERIALS AND METHODS

The experiment was carried out in an apple orchard at Fruit Research and Development Station Bistrita (FRDS). FRDS Bistrita is located at 47°10' North latitude and 24°30' east longitude, at 358 m altitude with an average annual temperature around 10°C and multiannual average of 758.80 mm of rainfall, according to the data recorded by the meteorological station at FRDS Bistria, in the last 30 years. The climate is temperate-continental, with relatively hot summers, and less dry cold winters.

The orchard was established in 2001 (22 years old), with 'Idared', 'Generos' and 'Florina' apple trees, on M26 rootstock. The trees are conducted as spindle-bush canopy, 1.5 m between trees and 4 m between rows, with a density of 1667 trees/ha. The experimental design was arranged in 4 replicates for each treatment using 10 trees per replication.

The treatments were applied annually during 2019-2022 growing season. The treatments variants included: V1- fertilization with manure + foliar fertilizer (Cropmax) + growth regulator (Regalis Plus); V2- fertilization with chemical fertilizers NPK+ foliar fertilizer (Cropmax) + growth regulator (Regalis Plus), V3- fertilization with chemical fertilizers NPK, V4- control trees. Regalis Plus was used as a source of Pro-Ca water-dispersible granules. It was applied at a rate of 1.5 kg/ha immediately after flowering and the second applications at a rate of 1.5 kg/ha was made after petal fall when new shoots were less than 10 cm long. Foliar fertilizer Cropmax was applied in a dosage of 2 mL/L water (2 L/ha) four times during the growth season, in four different phenophases: pink buds stage (BBCH 57), fruit size up to 10 mm (BBCH71), fruit size up to 40 mm (BBCH 74) and fruits about half final size (BBCH 75). The soil properties were improved through the application of manure in a dose of 20 kg/tree (33 t/ha) and chemical fertilizers NPK 16:16:16 in a dose of 0.250 kg/tree (416 kg/ha). The assessment of the nutrition supply status of the trees was carried out through soil and foliar diagnosis to determine the quantity in the main chemical elements necessary for a good development of the trees and quality production. The methods used to determine the macro and microelements in the leaves were performed by: Kjeldahl method (dosing by titration) for N total, P (phosphorus) by colorimetric dosing with ammonium metavanadate, K and Ca (potassium, calcium) by flame photometric dosage, Mn, Zn, Cu, Fe, Mg - dosage by atomic absorption spectrometry. Soil analysis were performed by potentiometric, colorimetric, flame photometric and titrimetric, Kjeldahl and Walkley-Black methods. For an efficient pest monitoring, pheromonal traps were installed in each experimental variant. The chemical plant protection treatments included eleven sprays per year. The moment of spray was decided depending on climate conditions and observations of the pests and diseases evolution in the experimental plots. All variants were treated evenly. Products based on mineral oil and copper were used for winter sprays. We used fungicides based on fluxapiroxade, ditianon, difenoconazole, myclobutanil, piraclostrobin, boscalid, folpet, mancozeb, captan, sulfur and tebuconazole against apple scab (*Venturia inaequalis*) and powdery mildew (*Podosphaera leucotricha*), the two main diseases that cause damage in our region. The pests that cause significant damage in Bistrita region are *Cydia pomonella, Anthonomus pomorum, Quadraspidiotus perniciosus, Eriosoma lanigerum, Aphis* spp.*, Panonicus ulmi* and *Tetranichus urticae.* We used insecticides from different chemical groups as follows: acetamiprid, dimetoat, tiacloprid, deltametrin, clorpiriphos methyl, lambda-cyhalotrine, spirotetramate, spinosad; as well as acaricides to control mites: hexitiazox and spirodiclophen.

The evaluations included number and mean length of shoots, fruit yield per tree, mean fruit weight, trunk cross-sectional area and fruit quality. The annual shoots were evaluated each year with a regular measuring tape, on each tree selected, and compared with the untreated control. Ten vigorous shoots from ten trees were measured at the end of growth period (September) and a visual estimation of the tree vigour was made at the end of vegetation period, when all the leaves had fallen.

Statistical comparisons of the mean values were performed using ANOVA analysis of variance, followed by pairwise correlations with Duncan`s multiple range test with P< 0.0001. aimed by XLSTAT (Addinsoft, France) statistical software package using MS Excel platform.

RESULTS AND DISCUSSIONS

In terms of climatic conditions of Bistrița area, the temperatures recorded in the studied years fluctuated. Annual average temperatures were between 10.5°C (2019) to 11.2°C (2022), with absolute maximum temperatures between 34.6°C (2019) ranging 35.6°C (2022) and absolute minimum temperatures registered in January of each year, recorded values from -11.8°C (2019) to 17.5°C (2022). Regarding the rainfall, the total was 538.9 mm in 2019, 678.9 mm in 2020, 784.5 mm in 2021 and 759.3 mm in 2022 (Table 1). The normal value of annual rainfall in Bistrita region is about 758.8 mm, but the years 1999 and 2000 were very dry compared with 2021-2022. The distribution of rainfall was unevenly that caused an imbalance of growth and fructification processes for apple trees. The difference between 2019 and 2022 was 174.3 mm of annual rainfall.

Table 1. Climate indicators 2019-2020

Climate indicators	2019	2020	2021	2022
Average annual temp. (°C)	10.5	10.1	9.5	11.2
Absolute maximum temp.(°C)	34.6	33.7	33.6	35.6
Rainfall (mm)	538.9	678.9	784.5	759.3

In May 2019 occurred a hail fall of low intensity, which affected part of the apple plots in the FRDS Bistrita area, leading to partial destruction of the foliage of the trees with repercussions on the formation and development of the fruits (Figure 1). The late spring frosts occurred in 4th of April 2020 and 2022 (-5.8°C, respectively -2.2°C) and in 8th of April 2021 (-3.2°C) which did not affect the flower buds, because the values were below their resistance threshold. After analyzing the climatic data, we observed a warming of the weather and the decrease of the rainfall volume in the first two years and climatic accidents (hail and late frosts), which lead to a decrease of the resistance of fruit trees to the attack of diseases and pests, as well as the modification of the manifestation of pathogen infections on fruits and leaves even at varieties with genetic resistance.

Figure 1. The effects of hail fall on foliage and apples

The results regarding the nutrition status of trees indicated an adequate amount of macro and microelements in the soil and leaves (Tables 2 and 3).

Table 2. Soil chemical content

	Deepness cm	Ph	Humus %	Nt %	P mg/kg	K mg/kg
V1	0-20	5.80	4.12	0.241	61.50	356.00
	20-40	5.51	2.83	0.194	18.25	171.25
V2	0-20	5.63	4.05	0.257	65.50	258.75
	20-40	5.48	2.69	0.159	19.75	116.00
V3	0-20	5.70	3.93	0.240	54.50	246.00
	20-40	5.41	3.10	0.175	16.50	139.5
Untreat	0-20	6.02	2.21	0.144	51.00	240.00
	20-40	5.48	3.46	0.191	22.00	173.00

Table 3. Foliar diagnosis

	Macroelements (%)				
	N	P	K	Ca	Mg
V1	2.07	0.12	1.76	0.75	0.23
	2.14	0.22	2.02	1.06	0.29
V2	1.92	0.13	1.66-	1.06	0.27
	2.07	0.20	2.14	1.13	0.31
V3	1.93	0.13	1.68	0.96	0.25
	2.17	0.21	2.01	1.33	0.34
Untrea	1.90	0.12	1.56	0.88	0.23
ted	2.14	0.20	1.67	1.06	0.30

The applied phytosanitary treatments contributed to the prevention and combat of the disease and pests flight were monitored with pheromone traps (Figure 2). Considering that all cultivars and all variants were treated with the same treatment scheme, certain cultivars presented a sensitivity to the disease attack.

Figure 2. Pheromonal traps for pests

The number and size of the annual shoots was visibly lower in the treated variant compared to the untreated variant (Figure 3) with the purpose to obtain quality fruit production. Results regarding the number of shoots in the treated variant were between 15-25 shoots/tree when compared with the untreated variant which were between 40-55 shoots/tree.

Figure 3. Untreated variant vs. treated variant

Average length of shoots in the untreated variant had values between 80-87 cm long, and in the treated variant had values between 55-65 cm long (Figure 4).

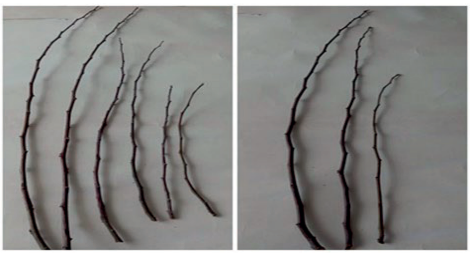

Figure 4. Comparison of shoots length (left-untreated variant, right-treated variant)

After analyzing the data, results showed that the length of annual shoots in all 4 years of study were significantly different in the untreated variant compared with treated variant (V1 and V2) but no significant differences were observed in V3 variant (NPK fertilizer applied but without growth regulator) (Table 4). The time allocated for pruning in the treated variant was significantly reduced due to the reduction of the number and size of the annual shoots.

Table 4. Length of annual shoots (cm)

Variant	2019	2020	2021	2022
Untreated-Florina	83.793 a	83.069 a	86.483 a	87.138 a
Untreated-Idared	80.379 a	79.586 ab	86.448 a	85.310 ab
Untreated-Generos	80.345 a	77.966 ab	85.414 a	84.207 ab
V3 Generos	78.367 ab	72.967 bcd	73.200 bc	74.633 cd
V3 Florina	72.867 abc	68.333 cde	76.633 b	77.567 bc
V3 Idared	67.600 bcd	76.267 abc	73.100 bc	78.933 bc
V2 Florina	61.100 cd	65.633 def	67.367 bc	67.200 de
V2 Idared	58.833 d	67.800 cde	68.767 bc	65.567 e
V2 Generos	57.833 d	67.033 de	67.467 bc	68.900 de
V1 Florina	61.967 cd	68.333 cde	70.467 bc	71.367 cde
V1 Idared	57.267 d	57.833 f	66.067 c	64.833 e
V1 Generos	55.533 d	59.867 ef	68.500 bc	64.633 e

Regarding the influence of Pro-Ca or fertilizers on tree trunk growth over the years, we can conclude that there are slight differences between V1 variants when compared with the untreated variants and chemical fertilizer variants but these results must be correlated also with the synergistic effect of the vigour of rootstock/scion combination, knowing the fact that ‘Florina’ cultivar has a stronger vigour than ‘Generos’ cultivar. The numerical differences between V1 variants and the untreated variants are multifactorial, mainly due to rootstock and scion influence and just a slight effect being produced by Pro-Ca. Analyzed generally, TCSA relatively increased year to year in all variants (Table 5) showing the viability of the scion/rootstock combinations still after 22 years from the establishment of the orchard.

The results regarding the biometric measurements showed that the size and diameter of fruits was specific to the varieties, with the largest fruit in ‘Generos’ cultivar, followed by ‘Florina’ and ‘Idared’.

Table 5. TCSA (trunk cross sectional area cm^2)

Variant	2019	2020	2021	2022
Untreated Florina	142.655 a	155.085 a	158.582 a	161.080 a
Untreated Idared	93.774 e	100.522 d	108.697 d	120.527 c
Untreated Generos	109.753 bcde	117.598 bcd	125.370 bcd	131.353abc
V3 Generos	113.687 bcde	123.364 bcd	130.340 bcd	143.706abc
V3 Florina	129.091 ab	133.279 ab	137.006 abc	148.025 ab
V3 Idared	115.955 bcde	128.253 abc	138.533 ab	148.025 ab
V2 Florina	121.242 abcd	128.091 abc	134.414 abcd	139.348abc
V2 Idared	94.986 de	105.819 cd	117.085 bcd	127.364 bc
V2 Generos	106.443 bcde	116.000 bcd	123.888 bcd	133.132abc
V1 Florina	123.413 abc	130.224 ab	137.006 abc	141.702abc
V1 Idared	93.878 e	105.819 cd	109.269 cd	120.527 c
V1 Generos	101.570 cde	109.470 bcd	118.001 bcd	125.099 bc

The weight of the fruits varied between 147.7-262.7 g for 'Generos', for the 'Florina' the weight of the fruits ranged between 131.8-223.8 g and 125.3-203.6 g for the 'Idared' cultivar. The Pro-Ca did not have a significant effect on fruit development, weight or quality. The fruits were at optimal level of quality for 'Generos' and 'Florina' cultivars, exception made by 'Idared' cultivar, where the fruits showed a higher sensitivity to the attack of diseases on the fruits. The statistical data indicated that the V1 'Florina' variant was statistically different than the other V2 and V3 variants, showing the great influence of the applied manure together with the foliar fertilization completed with the productiveness and vigour of the 'Florina' cultivar, being a multifactorial influence of variant V1. On the other hand the other V1, V2, V3 variants were statistically not different among them being in the same statistical class when compared with the untreated 'Idared' cultivar (Table 6).

Table 6. Fruit production

Variant	Fruit Production (kg/Tree)	Yield (tons/ha)
V1 Florina	31.025 a	51.700 a
V2 Florina	26.250 ab	43.738 ab
V2 Generos	25.720 ab	43.485 ab
V1 Generos	25.325 ab	42.193 ab
V1 Idared	22.850 ab	38.055 ab
V3 Generos	22.750 ab	37.750 ab
V3 Florina	22.748 ab	37.350 ab
V2 Idared	21.425 ab	37.000 ab
Untreated Generos	16.500 ab	27.805 ab
V3 Idared	16.200 ab	26.233 ab
Untreated Florina	15.690 ab	25.975 ab
Untreated Idared	14.675 b	20.350 b

The untreated 'Idared' variant in our research produced the lowest yield per tree and per hectare. The registered values were between 14.67-16.5 kg/tree for control variant (without soil or foliar supply) and 21.42-31.025 kg/tree for treated variants.

CONCLUSIONS

In all three cultivars 'Generos','Idared' and 'Florina' yield and average fruit weight at harvest stage was not significantly different among treatments, while the influence of growth regulator Regalis Plus on the reduction of annual growth was significantly different, compared with the control. The time allocated for pruning in the treated variant was significantly reduced due to the reduction of the number and size of the annual shoots, with direct influence on labour costs and efficiency of orchard management.

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