Influence of foliar nutrition on apple production

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Summary: On the basis of different experiments the technology of intensive foliar nutrition was studied in apple orchards in the period from 1996 until 2000. Yearly apple nutrition programs based on soil analyses. The foliar nutrition program was prepared in accordance with the soil, fruit analyses and climatic conditions. If needed, certain improvements were made according to the analyses of leaves and precipitation in the current year. The richness of the soil and ratios between individual nutrients gradually improved. The foliar nutrition influenced the yield quantity, quality and flower bud differentiation. The yield was doubled and the mean of five years reached 70 tons per hectare. In spite of high yields there were no problems with alternative bearing. The analyses of soluble solids, firmness, fructose, glucose, sucrose, malic acid, citric acid in the fruits and mineral soil composition indicated that the produced fruits were of high quality despite greater yields.

Key words: apple, *Malus x domestica*, soil nutrition, foliar nutrition, yield, sugar, organic acid

Introduction

The soil and climate condition and orchard management practices are the key factors in the production of apples (*Bramlage*, 1993).

Nutrition of fruit trees is very important due to the decisive influence it has on the quality and quantity of the yield. Occasional high demands of fruit plants for specific nutrients due to the growing specifics or poor absorption from the soil, can be compensated with foliar fertilization.

With the soil fertilization in the apple orchards certain quality and quantity can be achieved (30000–40000 kg/ha) in the climate conditions in Slovenia; however, nowadays this does not provide an economical production. The foliar nutrition can influence the quantity and quality of the yield, especially in the circumstances when irrigation is not applied (*Štampar* et al., 1999; *Štampar* et al., 2000). For this purpose we have a lot of different foliar products on the market to use it in fruit production.

Vegetative growth is a stronger sink than fruit for available calcium (Ca) in the tree (*Hanger*, 1997). Calcium (Ca) together with some microelements takes part in the formation of chlorophyll and the process of photosynthesis (*Larcher*, 1995). In the orchards, the foliar application of calcium (Ca) is important, because its translocation from the soil through the roots is limited from the sixth week after flowering. Fruit quality and physiological disorders of apples and pears are therefore related to the mineral composition of the fruit, especially lower content of calcium (Ca) and higher contents of nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) in the fruits (*Raese* & *Staiff*, 1990). Nitrogen (N) is important for chlorophyll and ATP synthesis, amino acids synthesis, protein co-enzymes and nucleic acids formation. Phosphorus (P) is engaged in the energy transport mechanism, which affects the synthesis of sugars through the ATP activity (*Faust*, 1989). Potassium (K) takes part in the protein synthesis and regulates the osmotic water condition in the plant cells and influences the stomata regulation and net assimilation of CO_2. Because of its effect on cell expansion, potassium has vital importance in increasing fruit growth as well as in carbohydrate storage. Foliar application of boron (B) in autumn or just before blooming has great importance in spring periods with lower air temperatures, as it increases cell expansion in flowers on which frost has a break influence and therefore inhibits the flower drop (*Crassweler* et al, 1981). Boron deficiency in apple fruits causes their flatness and formation of corky tissue, whereas the increased content of B in fruits after the application in summer time decreases cracking of the epidermis of the fruits with cv. 'Elstar' (*Zude* et al, 1997). Zinc (Zn) is involved in the synthesis of protein and plant hormone auxin (IAA) (*Faust*, 1989).

The content of free sugars, organic acids, minerals, vitamins, etc., fruit colour, taste and firmness of fruit depend also on the activity of photosynthesis and the use of its products (*Yamaki*, 1995). Sink regulation of photosynthesis is highly dependent on different physiological processes. Among other factors mineral nutrition has crucial importance for the sink/source balance (*Pieters* et al., 2001). Photosynthetic products may indicate changes in quality (*Doyon* et al., 1991).

On the basis of soil, leaf and fruit analyses and nutrition programs (soil and foliar) we can produce higher quality and quantity of apple fruits.

Material and method

The data were obtained from the orchard located in the Northeast (NE) of Slovenia. The cultivars 'Elstar', 'Jonagold', 'Golden Delicious' and 'Idared' were planted on the M 9 rootstocks in single and double rows and had a reconstructed spindle into solaxe training system. The average age of trees was 18 years. The orchard was not irrigated and the average rainfall from April to September was 400 mm. The results of soil, leaf and fruit analyses presented were from one plot only.

The cultivars were fertilized by the application of standard nutrition through the soil; fertilization depended on the results of soil and fruit analyses and the products' in-take of nutrients.

Standard methods were used for sample collections of the soil, leaves and fruits. The analyses were carried out in the Phosyn laboratories.

In the spring of 2000 the analysed plot was fertilized with 500 kg/ha of Patent kalium (30% K and 10% Mg) and 250 kg/ha KAN (27% N). For foliar nutrition various products from the Phosyn and Greenhas were used.

The exact application is stated by an example of the cv. 'Idared' treated in 2000:

- Zintrac 700 (40% Zn): the first application before leafing and the second one before leaf drop (concentration 1 l/ha),
- Safe-N (28% N): twice, before blooming and before leaf drop (conc. 10 l/ha),
- Bortrac 150 (10.9% B): twice before, once after blooming and before leaf drop (conc. 1 l/ha),
- Seniphos (23.6% P_2O_5, 4.27% CaO, 3% N): three times in the period of fruit cell division (conc. 5 l/ha),
- Oligogreen (3% Mg, 0.5% B, 0.02% CaO, 1% Cu, 2% Fe, 4% Mn, 0.05 Mo, 3% Zn): middle of June and July (conc. 1 kg/ha),
- Hascon M10 AD (15% P_2O_5, 20% K_2O, 0.1% B, 0.1% Mn, 0.01% Mo): three times; July and August (conc. 5 l/ha)
- Calboron (30% CaO, 1% B), 2 times in the period of fruit enlargement (conc. 4 l/ha),
- Calciogreen (34% CaO): 4 times in the period of fruit enlargement (conc. 4 l/ha)
- Drin (amino acids): 4 times; end of June, July and twice in August in the period of drought stress (conc. 1 l/ha).

The fruits were sampled during the time of technological ripeness. The starch test, colour, firmness of fruits and the content of total soluble solids were determined. Each sample consisted of 20 representative fruits. First, the fruit weight and total soluble solids were determined with a refractometer at 20 °C, and then a sample from a cross section was taken for chemical analyses. The contents of individual sugars (glucose, fructose, sucrose), sugar alcohol sorbitol and organic acids (malic, citric, shikimic and fumaric) were evaluated by using the High Performance Liquid Chromatography (HPLC) analyses, according to the modified *Dolenc & Štampar* (1997) method.

Results and discussion

The results of the soil analyses in the cv. 'Idared' stated a shortage of Potassium, Boron and organic matter in 1996 *(Table 1)*. The other main and trace elements were in the optimum, except for P, Mg and Fe, which were on higher levels. The intensive fertilization in the years 1996 and 1997 with a complex PK caused an increase in potassium and partially in Phosphorus in 1998. In 1999, besides ordinary fertilization lime was applied as well and this led to an increased amount of Calcium in the soil. The analysis carried out in 2000 displayed a high use of K. The nutrients remained in the optimum, therefore the soil was fertilized only with K and N.

Table 1 Soil analyses in the years 1996, 1998, 1999 and 2000. Content of main and trace elements are in mg/kg of soil

Analysis	Guideline level	test level			
		1996	1998	1999	2000
Phosphorus	26.0 ppm	40.0	44.0	37.0	54.0
Potassium	181.0 ppm	133.0	202.0	151.0	101.0
Sulphur	10.0 ppm	13.0	10.0	14.0	18.0
Calcium	1600.0 ppm	1903.0	1737.0	2212.0	1512.0
Magnesium	120.0 ppm	256.0	207.0	333.0	167.0
Boron	0.80 ppm	0.6	0.9	0.6	0.7
Copper	2.5 ppm	4.3	6.5	3.5	5.6
Iron	250.0 ppm	754.0	624.0	693.0	630.0
Manganese	20.0 ppm	351.0	244.0	249.0	242.0
Molybdenum	0.6 ppm	0.4	0.1	0.2	0.1
Zinc	5.0 ppm	4.8	7.4	4.2	9.0
Organic Matter	3.0 %	1.6	1.8	1.7	2.1
pH	6.0	6.1	6.3	6.7	6.9

The leaf analyses were carried out too late to be used in the correction of the application of foliar nutrition plan in 1996 and 1997 *(Table 2)*. There were no significant deviations in the contents of main and trace elements from the optimal contents in the years 1998 and 2000. The leaf analyses showed good ratios between the nutrients. There was only a shortage of Fe, despite the fact that there was too much of it in the soil. Such excellent results of foliar analyses prove that the foliar fertilization was optimal as well as the foliar plan in that period.

The yields produced in the years from 1998 to 2000 were extremely high *(Figure 1)* and exceeded the average production in Slovenia by 100%. A higher yield was made possible by the use of a new training system – solaxe, which has a double crown volume, compared to a spindle training system. The yields increased every year from 1998 to 2000

Table 2 Leaf analyses in % or ppm in cv. 'Idared'

Analysis	Guideline level	test level			
		9. 8. 1996	26. 8. 1997	11. 6. 1998	2. 6. 2000
Nitrogen	2.5%	1.83	2.31	2.60	2.96
Phosphorus	0.2%	0.15	0.15	0.24	0.31
Potassium	1.2%	0.90	0.76	1.22	1.3
Calcium	1.3%	1.07	1.09	1.46	1.48
Magnesium	0.2%	0.23	0.23	0.34	0.39
Sulphur	0.1%	0.07	0.07	0.08	0.23
Boron	35.0 ppm	15.0	31.6	34.3	34.5
Copper	5.0 ppm	6.6	6.6	8.0	9.2
Iron	150.0 ppm	43.0	130.0	75.0	79.0
Manganese	35.0 ppm	166.0	63.0	65.0	67.0
Molybdenum	0.1 ppm			0.2	0.1
Zinc	35.0 ppm	36.3	32.8	22.6	25.3

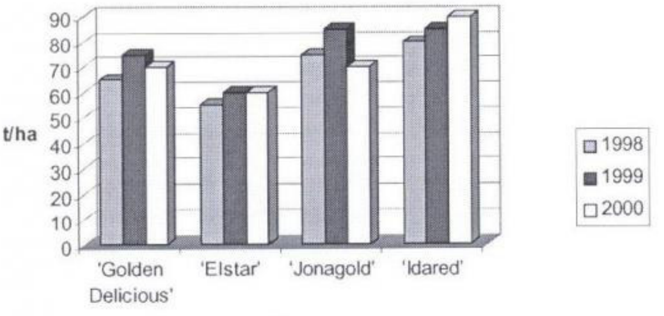

Figure 1 Average yield in t/ha in different cultivars in the years 1998 to 2000.

in cvs. 'Golden Delicious', 'Elstar' and 'Idared' and were up to 70 tons/ha on average. Such high yields were undoubtedly a consequence of the proper foliar nutrition which enabled a high yield in the current year and good differentiation of bearing buds in the following year.

The contents of sucrose, fructose, glucose, sorbitol, soluble solids and total acids are presented in *Table 3*. Despite of an increased yield the contents of sugars were similar to the contents of sugars in orchards with lower yields which were not treated with foliar fertilization (*Štampar* et al., 1999; *Štampar* et al., 2000). The content of soluble solids was in the year 1999 higher than in the year 1998 in all observed cultivars *(Table 3)*. The contents of soluble solids in 1998 were on the bottom level of demanded ones (in September there was a lot of rainfall and the temperatures were lover than average). In 1999 the contents in all cultivars were higher, as it was stated by *Herregods* et al. (1993). According to *Herregods* et al. (1993) the apple quality is the best when apples exhibit more than 4.2 g/l acidity expressed as malic acid and more than 13° Brix (total soluble solids). The results of the experiment show that the contents of acids during both years were higher than it is demanded by European standard.

The contents of individual minerals in fruits of the cv. 'Idared' are displayed in *Table 5*. At the beginning of the application of the foliar nutrition in 1996 the contents of Ca, B, P, Zn and K in fruits were on the lowest levels of recommended values. There was too much of N, which is not surprising as the trees in that period were at the beginning of reconstruction of the training system and their vegetative growth was very active. In 1999 and 2000 the growth of trees was moderate. The content of Ca, P, K, in fruits was optimal. There was a little more of Mg and Zn and there should have been more from N. In 2000 higher values of N were expected as a consequence of additional foliar fertilization with N. However, due to the drought stress the content of N remained on the same level as it had been in 1999. The effect of the drought was reduced especially with the Drin nutrition (amino acids).

The results of the study prove the fact that when the yields increased there were no decrease in fruit quality. This was true in the cases when the additional foliar nutrition applied. An appropriate supply with the minerals influences the quantity and quality of the yield. A higher yield, which appears due to the improved flower bud formation, good fruitfulness of trees at enlarged volume of trees is not followed by a decrease in the contents of soluble solids, individual sugars and organic acids. At an optimal treatment of trees including foliar nutrition the internal quality of fruits stays on the same level as with lower yields. The results obtained during the experiment indicate a positive trend towards a more economical and stable apple production.

Table 3 Average content of sucrose, glucose, fructose and sorbitol in g/kg of fresh fruits and soluble solids in % in cv. 'Idared'

Cultivar	Year	Sucrose	Glucose	Fructose	Sorbitol	Soluble solids
'Golden Delicious'	1998	46.9±5.8	55.5±2.7	13.4±4.5	2.1±1.3	12.6±0.6
	1999	42.0±7.3	57.2±7.2	15.1±4.6	4.0±3.5	13.6±1.2
'Elstar'	1998	54.1±6.9	51.7±5.3	7.4±1.7	2.7±1.3	12.0±1.2
	1999	59.7±10.5	48.1±3.8	7.1±1.4	3.2±1.4	12.8±1.1
'Jonagold'	1998	53.1±7.0	39.2±3.5	7.5±1.3	2.7±1.4	12.4±1.1
	1999	45.2±6.2	43.2±5.3	15.2±4.6	3.9±1.0	14.2±1.2
'Idared'	1998	41.1±3.8	58.5±4.5	8.9±2.3	1.3±0.7	12.6±1.0
	1999	42.1±4.9	50.1±4.4	15.1±3.9	3.2±1.3	13.8±1.3

Table 4 Average content of malic and citric acids in g/kg of fresh fruits in cv. 'Idared'

Cultivar	Year	Citric acid	Malic acid
'Golden Delicious'	1998	0.5±0.2	14.8±1.9
	1999	0.8±0.3	14.8±1.4
'Elstar'	1998	0.5±0.3	14.0±1.2
	1999	0.7±0.1	15.7±1.3
'Jonagold'	1998	1.1±0.6	16.7±2.5
	1999	1.1±0.8	15.5±1.1
'Idared'	1998	0.9±0.6	13.7±1.5
	1999	1.0±0.8	14.1±1.4

Table 5 Fruit analyses in mg/100 g in cv. 'Idared'

Analysis	Guideline level	test level		
		1996	1999	2000
Calcium	> 5.0	4.8	6.3	7.9
Boron	0.2–0.6	0.106	0.22	0.38
Phosphorus	10–12	8.1	8.4	8.5
Zinc	> 0.025	0.077	0.07	0.07
Potassium	100–120	105.0	110.0	107.0
Magnesium	< 5.0	4.4	5.60	5.30
Nitrogen	40–50	72.0	31.0	30.0

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