Experimental approach in apple tree nutrition

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Summary: Authors present synthesis of experimental work, performed in the last decades, for better understanding nutritional behaviour of apple trees and related problems in fruit quality. There were evidences supporting possible deteriorating role of potassium in feeble physiological status of apples, if applied in excess. More intensive studies proved that higher potassium uptake into leaves and fruits might be also the result of increased sink power of individual fruits. Nevertheless early senescence of apples during storage and also sensibility to bitter pit were successfully related to the increased sink power of fruits, casual relations in excessive NPK fertilization, although increase in sink power need further investigations. Impaired weather conditions during early development of fruits, hostile orchard practices in pruning, thinning, irrigation and also unskilled application of growth regulators may also contribute in the enhancement of sink power and in weakened physiological status of apple fruits.

Key words: storage quality, non-parasitic disorders, fruit load, source-sink relations

Non-parasitic disorders of apple fruits

A number of disorders may appear on apple skin and in the flesh tissue that causes economic losses for the grower. The term "physiological disorder" has been used to refer to the nature of such casualties, where no fungus or other pathogen agent was detected. Initiation of such disorders and their casual relations to physiological processes remained unknown, although many efforts have been taken to determine them. *Faust* et al. (1969) distinguished disorders of carbohydrate metabolism and disorders of corking (*Faust & Shear*, 1968). *Sacher* (1973) emphasised that the decrease in membrane integrity played basic role in senescence of plant tissues. *Wilkinson & Fidler* (1973) reviewed growing practices and climatic conditions in relation to non-parasitic disorders. A number of papers suggested that imbalanced mineral nutrition, especially calcium deficiency might lead to a weakened physiological status (*Hilkenbaumer*, 1966). However the physiological importance of Ca were extensively investigated, (*Faust & Shear*, 1972; *Faust & Klein*, 1973; *Ford*, 1979) the all-over effectiveness of administering this element has not been supported.

Research program and its development

In the Research Institute for Fruitgrowing and Ornamentals a working group, set together by *István Terts* (1972) has dealt with the nutrition and related physiological aspects of deciduous fruit trees since the early sixties of the last century. Acknowledged its multi-disciplinary importance, the nutrition of apple trees was in the centre of studies. The remarkable split-plot designed Jonathan apple plantation for fertilization trial consisted of 140 plots, covered 22 hectares and served for 20 years. Nutritional demand of medium vigorous apple trees, the effect of fertilizers on growth, fruit yield and fruit quality, possible correction methods by the use of foliar nutrients have been the basic aspects of the research. As the effects and side effects of differentiated nutrition became evident, attempts for better understanding the physiology of mineral nutrition, the importance of fruit load in nutritional balance of trees, interrelations among nutritional status, the fruit load and quality parameters of fruits have been made. Evidences, produced by the research work were revised in the experimental of orchard Újfehértó, composed of 10 apple varieties and also in commercial apple plantations.

The aim of the present study is a synthesis of experimental findings, collected in the field of apple tree nutrition. Authors refer on previous publications where description of experimental conditions, material and applied methods were given in detail.

Experimental approach

Yield response in fertilization trials

Single and combined application of N, P and K fertilizers in the long-term trial modified leaf potassium content of Jonathan apple trees. Yield response arrived only after 10 years of fertilization (*Szűcs & Kállay*, 1978, 1979). Although the growth of non-fertilized trees had somewhat retarded, there were no significant differences in crown volume after 13 years of fertilization. Single application of N reduced, NPK fertilizers considerably increased fruit yield. Elevated fertilizer applications resulted in earlier fruiting, however, after a longer producing period, yields of basic application

(N: 130 kg/ha; P: 60 kg/ha; K: 200 kg/ha) became the highest. Reducing effect of N was overtaken by joint phosphorus application. Yield of the different treatments followed a clear saturation pattern in the second 10-year-period. Statistical analysis proved the importance of potassium in yield increase.

Soil to leaf, leaf to fruit relations in mineral nutrition

The loamy clay soil of the experimental plantation contained 3% humus, about 14% lime, pH 7.9 in average. Due to repeated fertilizations, soil nutrient content in 60cm layer varied among treatments without modifying physical parameters. Basic phosphorus application resulted in 30mg/kg increase above the original 80mg/kg P_2O_5 content; the double application doubled the soil phosphorus content. The original 140mg/kg K_2O content went up to two-fold at basic application and to three-fold at doubled fertilization. Those findings underlined evidences on selective adsorption capacity of the given soil.

Lime content of soil varied in a 5 to 27 % range; however there was little if any effect visible in leaf nutrient content of leaves. As a tendency, leaf nitrogen and phosphorus increased, potassium and calcium decreased on plots, higher in $CaCO_3$.

Fertilization treatments influenced intensively leaf K content but had little, if any effect on the other micro- or macro elements. The negative correlation of Mg to K content was evident, however not proved statistically. The well-known K uptake was limited by some unknown factors *(Figure 1)*. As the soil potassium content increased, as a general rule, the leaf K content and also the fruit K content responded positively, but after a peak, both plant organs refused further uptake (*Szűcs & Kállay*, 1988). Fertilization had no significant influence on leaf P and Ca content.

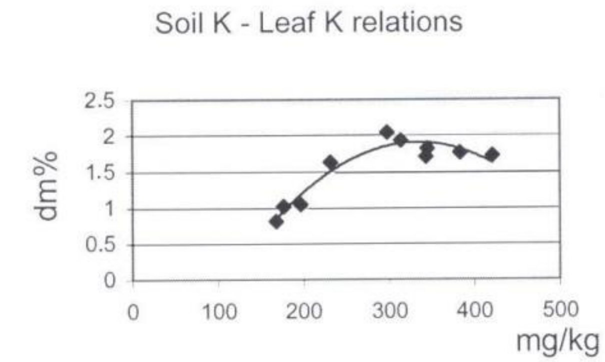

Figure 1 Leaf potassium content on elevated soil potassium conditions in a long-term fertilization experiment (Averages of 6 consecutive years)

N content in fruit was highest in single N treatment; additional P and K fertilization reduced fruit N. Apple fruits from non-fertilized trees accumulated a medium nitrogen level. Phosphorus content was the highest in apples from non-fertilized plots, either single or in combination with PK fertilizers, N reduced P uptake of fruits. The potassium uptake pattern in fruits was very much similar to that of the leaves. *(Figure 2, Figure 3)* Single N application reduced fruit K and leaf K too. The highest K content was measured in doubled NPK treatment. Fruit Ca content varied from year to year at a magnitude of 5 to 10 mg/100g fresh weight. Magnesium in fruits varied little and there were no signs of K-Mg antagonism. Microelements showed year-to-year variations without correlation to fertilization treatments.

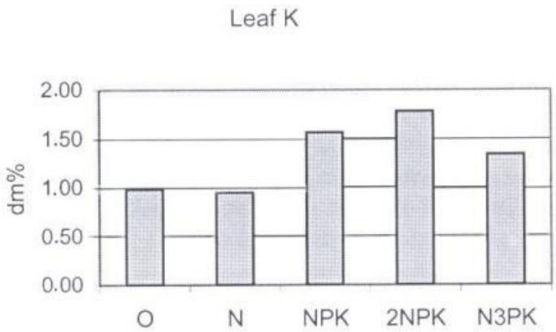

Figure 2 Leaf potassium content in a long-term fertilization experiment (Averages of 6 consecutive years)

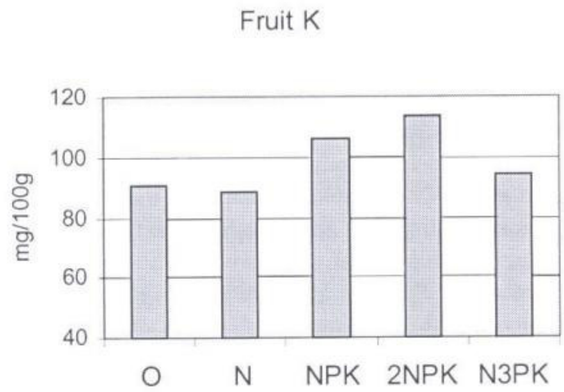

Figure 3 Fruit potassium content in a long-term fertilization experiment (Averages of 6 consecutive years)

Fruit quality as related to fertilization treatments

Influence of fertilization on fruit maturity, ripening and senescence was studied in a consecutive storage experiment of 6 months. Fruit samples were collected at 130, 140 and 150 days after full bloom. Sub-samples were examined immediately after picking and during storage, in 30-day intervals. Evidences were carried out upon database of 6 consecutive years. There were no apparent differences in ground colour or cover colour of fruits, neither in fruit size or weight when parameters were related to fertilization treatments. However, flesh firmness, sugar and acid content were influenced by fertilization treatments. Apples from N treatment were less firm, contained less sugar and free acidity than apples from non-fertilized control, or fruits from any treatment where potassium was involved *(Figure 4, Figure 5)*.

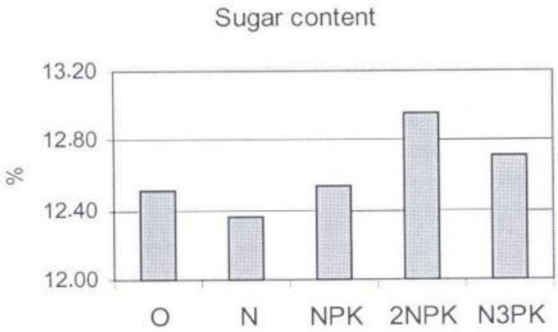

Figure 4 Sugar content of apples from a long-term fertilization experiment (Averages of 6 consecutive years)

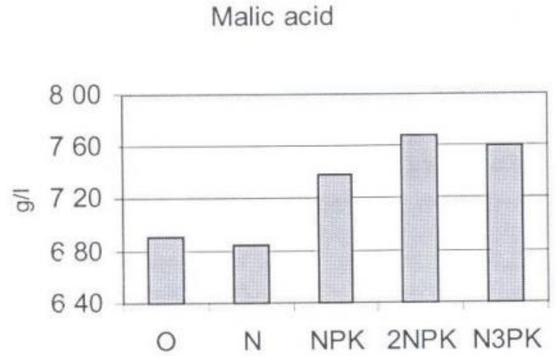

Figure 5 Malic acid content of apples from a long-term fertilization experiment (Averages of 6 consecutive years)

Fruits from massive potassium fertilization treatments softened faster in cold store (*Szűcs & Kállay*, 1978) and had shortened storage life (*Szűcs & Kállay*, 1979). Senescence disorders as Jonathan spot, lenticell spot, internal breakdown or wilting limited storage life. The magnitude of storage losses varied widely from year to year. In a 6-year-examination period, storage losses were steadily the smallest in control samples, appearance of senescence disorders were about one month earlier in fertilized treatments *(Figure 6)*.

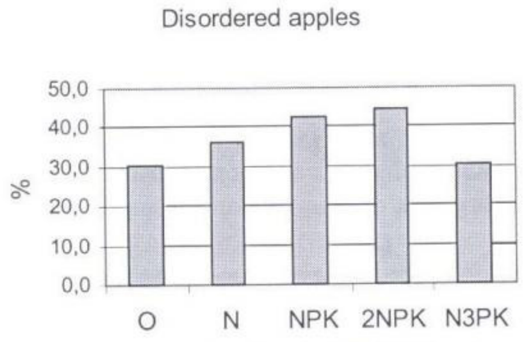

Figure 6 Percent of fruits displaying physiological disorders, cumulated during six months in coldstore (Averages of 6 consecutive years)

Mineral composition of Jonathan apples

In the continental climate condition of the Carpathian basin, low air humidity may be the limiting factor of photosynthesis in apple leaves, however respiration and transpiration processes are active on hot sunny days. Such arid conditions enhance calcium uptake into leaves and also fruits. The pattern of Ca uptake was proportional of fruit growth pattern (*Kállay & Szűcs*, 1982), resulting more than 7mg/100g Ca concentration in average. High Ca content did not correlate with fruit keeping quality. As N and P content in apple fruit was related to storage ability of apples, the smaller the $N.P^{-1}$ ratio occurred, the better storage results were obtained. Moderate and elevated N and NPK fertilization reduced fruit P content and increased $N.P^{-1}$ ratio. As the potassium content of fruit was in strong correlation with K content of leaf and soil, there were some tendencies to nominate potassium as a casual agent in weak storage potential. Although positive correlations of K content of fruits and of higher and earlier occurrence of senescence disorders in apples had been proved in a great number of statistical analyses, the data obtained were not sufficient to clarify possible interactions of potassium in fruit life.

Physiological status of apples as related to mineral nutrition

Determining storage ability of apples before storage has been a controversy in scientific life since long. Parameters to be measured are very much variety-dependent, variability from year to year makes the comparative analysis difficult. Among ingredients, the acidity of apples has drawn some attention. Variations in potassium uptake were related to titratable acidity and a strong, positive correlation was found, as K concentration in fruit increased, the higher acidity was titrated. Further analysis showed that the Henderson-Haselbach equation was effective in apple cell sap (*Richmond* et. al., 1964; *Kállay*, 1980), however potassium was only the major, but not the only one cation taking part in dissociation. Physiological status of apples might be characterised by measuring pH of freshly processed apple juice. In spite of net increase in free acidity, apples of higher K content had always-higher pH in juice, as well. Since it has been well known that pH factor of cells increases by ageing or senescence and that the oxidative processes of decayed tissue enhance rise in pH, involvement of elevated K concentrations in weak physiological status of fruits might have been supposed *(Figure 7)*.

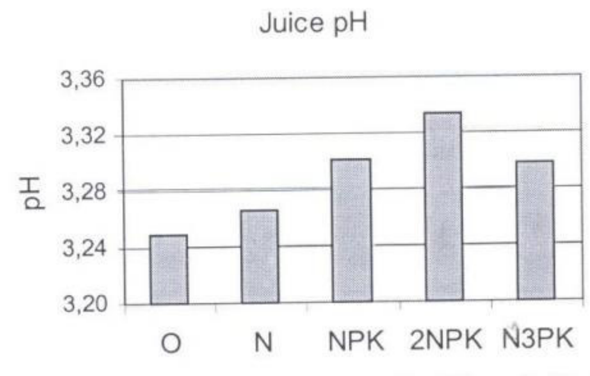

Figure 7 Hydrogen ion activity in apple juice from different fertilization treatments (Averages of 6 consecutive years)

In 1979, due to cold weather conditions at blooming time, a number of apples showed internal breakdown on one side of the fruit only, the other half remained intact. Comparative measurements on attacked and intact halves did not prove direct involvement of K concentration in the development of disorder *(Table 1)* Evidences of equal potassium ion activities on both decayed and healthy half of fruit excluded any direct deteriorating effect of that important cation, although the role of potassium in physiological status of apples remained obscure. What are the factors contributing in the weakened physiological status of apples and also in elevated uptake of potassium, producing the syndrome together?

Table 1 Hydrogen ion activity, acidity and potassium ion activity in disordered and healthy halves of Jonathan apples

Apple half	pH	pH*	Acidity	cK
			10^{-2} gequ/l	10^{-2} gion/l
Healthy	3.43	3.22	12.24a	3.053
Breakdown	3.82a	3.63a	6.77	3.081
SD 5%	0.11	0.12	1.46	—

pH* Calculated value upon cK and acidity gequ/l

Phenomena of the impaired source sink relations in apple fruit

Weak fruit load in orchard practices

Storage quality of apples may vary from year to year. There are possibly a great number of factors involved, among them orchard practices and the weather events can be mentioned. Effectiveness of hostile orchard practices are limited for given plantations and the weather can cause deteriorations in wide regions. Analysing orchard practices as pruning, thinning or summer pruning, unskilled work may weaken fruit load of trees, and as a consequence, the storage potential of fruits may decrease. Extreme fertilization may cause imbalance in fruit tree nutrition and fruiting capacity. Repeated sprayings across the fertilization treatments with either mineral or organic Ca salts resulted in higher Ca content in leaves and somewhat in fruits, without noticeable effect on physiological status of fruits. Similarly, in a field trial in a commercial orchard on over-fertilized sandy soil repeated Ca sprayings did not have any curative effect on feeble fruit quality. In both cases the fruit Ca was high.

Physiological interpretation of fruit load

Interaction between fruit load and nutritional capacities of trees is widely known. It was more apparent on alternate yielding varieties than on modern varieties, although significance of fruit load on fruit physiology became more pronounced in our days. It is also evident that fruit from weakly charged trees are often subjected to physiological disorders like bitter pit, cork spot, crinkle, water core and internal breakdown. In commercial growing, as well as in our long-term fertilization trial such extremities occur seldom. Fruit yield increased with the increase in fertilization but the fruiting surface of trees remained unaltered. As the storage potential of fruit decreased with fertilization, a conflict became evident in traditional interpretation of fruit load versus and fruit quality relation. It became obvious that with simple estimation of fruit yield per tree or fruit per trunk circumference, the term fruit load did not have any physiological meaning. When interaction of fruit yield and nutritional status of tree was envisaged along the variability of mineral nutritive content of leaves the scope became much clearer. In the physiological interpretation of fruit load the actual fruit crop is interrelated to foliar analysis data. The higher the K and P, and the lower the Ca level in the leaves make the physiological status of fruits worse, even when the visually estimated fruit load seems satisfactory. In a reverse constellation, with lower potassium and phosphorus content but with elevated calcium concentrations in leaves, the fruit storage potential is improved even on weakly loaded trees. Surprisingly high statistical proofs have supported physiological interpretation of fruit load.

Physiological interpretation of fruit load on apple trees led to estimate cropping capacities of apple trees (*Szűcs & Kállay*, 1990) through determination of DRIS indices of apple trees (*Szűcs* et al., 1989). Multi-factorial analysis showed that categories as "optimal nutritive concentrations" or "optimal ranges" widely recommended in commercial growing, containing figures that occurred most frequently in lab analysis. As it was shown, nutritional status of the fruit tree may be determined through multi-factorial evaluation of foliar nutrients together with the actual fruit crop (*Szűcs & Kállay*, 1999). Single evaluation of a given element would mislead conclusions.

Factors influencing sink power

Effect of weather on developing fruit has been less studied, however in continental climate not only the fruit quality but even the total crop might be ruined. Since the most dangerous period for fruit life and fruit quality is at blooming, the influence of chilling was studied on artificially cooled apple trees (*Kállay* et al., 1987). Pre-bloom cooling with cold-water wetting caused retardation in early development of Jonathan fruitlets and increased sink-power during fruit growth. Influence of pre-bloom treatment was apparent 140 days later, as water core occurrence increased at harvest and internal breakdown after two months of storage. One may conclude that inadequate orchard practices, as well as unpleasant weather may harm fruit quality via imbalanced fruit load. However, in case of weak fruit load, impaired nutrition may happen, if remaining fruits perform with elevated sink power. In the elevated sink power phenomena growth hormones and also growth retardants may interact in case of the application of inadequate amount. There were experimental evidences that application of ethephon on premature Golden Delicious apples provoked sink power and contributed to the appearance of Bitter pit disorder (*Kállay*, 1983). Similar results were obtained by the use of phosphorus-calcium foliar nutrient mixtures.

Concluding remarks

A sensible apple variety (Jonathan) was experienced in arid climatic conditions and at elevated nutrition. Those experimental circumstances to understand better the nutritional behaviour of apple trees and fruits. Impaired source-sink relations are correlated to weakened fruit storage potential and resulted in higher potassium uptake, if available. Role of excess potassium in increased sink power of fruits was not clearly understood, however its significance in carbohydrate metabolism was underlined.

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