# Relationship between tree nutritional status and apple quality

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**Abstract**

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Development of prediction models for the quality of apples is useful in guiding fruit tree nutrition and in optimising fruit management. The interrelationships between the leaf nutrient contents and some fruit quality indices were studied in five apple cultivars – Generos, Florina, Delicios de Voinesti, Jonathan and Pionier. Highly significant relationships between N and Fe contents ($R^2$ = 0.734; $P$ < 0.01) and between Cu and K ($R^2$ = 0.702; $P$ < 0.01) were found. Acidity was negatively correlated with soluble solids content in the cvs Generos, Delicios de Voinesti and Jonathan, whereas the respective correlation in the apple cv. Pionier was positive. In cv. Florina fruits no significant correlation was found between acidity and soluble solids content. Among macroelements, nitrogen had a considerable contribution to fruit acidity and this allows to predict this index with a high degree of safety ($R^2$ = 0.690; $RMSEP_N$ = 0.105). Microelements have a lower contribution to acidity and a higher one to the sugar accumulation; in case of Zn are $R^2$ = 0.809; $RMSEP_{Zn}$ = 4.250.

**Keywords**: foliar diagnosis; nutrient content; quality indices; prediction model

Nutrient content in apple leaves is a feature of a specific cultivar; it is influenced, within certain limits, by the rootstocks (Ponchia et al. 1997), by soil and climatic conditions (Wehunt, Purvis 1954; Blažek, Hlušičková 2007), by the phase of vegetation (Sadowski et al. 1995; Weinbaum et al. 2001; Holb et al. 2009), and particularly by the orchard management practices, i.e. irrigation and fertilization (Hipps 1997; Nagy, Holb 2006). The different systems of irrigation and fertilization in the orchard (soil application of granular fertilizers or fertigation through drip emitters) or different water rates (1,500 or 3,000 $m^3$/ha/year) resulted in variations of the nutrition status of apple and quality of the fruit. Compared with granular fertilizer, fertigation significantly increased leaf greenness and leaf nitrogen (N) concentration, and reduced phosphorus (P) concentration in the fruits at harvest (Porro et al. 2013). The same authors concluded that the Normalized Difference Vegetation Index (NDVI) values, a measure of canopy growth, were affected by both fertilization and water rate.

More research followed the translocation of nutrients in relation to phenophases of vegetation and accumulation processes of reserve substances in fruits and woody biomass (Rogers et al. 1953; Rogers, Batjer 1954; Wilkinson, Perring 1964; Fallahi et al. 1984a,b; Diamond et al. 1998; Wolk et al. 1998).

Cheng and Raba (2009) found that the concentration of most nutrients in leaves decreased as the growing season progressed, with the exception of Ca, Mg, and Mn showing an increase; the concentration of all nutrients in fruit decreased during fruit development and this indicated a direct correlation between leaf nutrient status and fruit development. In contrast, the total amount of each nutrient in shoots, leaves, fruit and the whole tree increased.

Dris and Niskanen (2004) noted the evolution of the macronutrient content (N, P, K, Ca and Mg) in the apple leaves and fruits during vegetation and fruit development, respectively. They found a significant positive correlation between nutrient concentrations in the early and normally harvested fruits only for P and Ca. Mean K concentration was slightly higher in early harvested fruits. K in early harvested fruits was negatively correlated with leaf K on non-fruit-bearing (NFB) trees in case of the third sampling (leaves sampled on September 22–23). Mg in normally harvested fruits was positively correlated with leaf Mg at the first sampling (July 22–24) of the fruit-bearing (FB) trees and in case of the second sampling (September 1–2) of FB and NBF.

Chundokova (1997) estimated the impact of interrelations of nutrient element contents in apple leaves and 10 indices of the vital activity of a plant and fruit quality. Nitrogen, phosphorus and potassium had the strongest relation to the contents of dry matter as well to the sugar, ascorbic acid and catechols contents in fruits.

Assessing nutrient content through foliar diagnosis in apple tree is necessary to establish the nutrition level of fruit trees, in order to guide nutrition through fertilisation and to ensure the sustainability of the production system (Han et al. 2011).

In this research the relationships between the nutritional status of apple trees, assessed through foliar diagnosis, and the apple fruit quality represented by acidity and soluble solids content were monitored and the predictive models for quality indices were developed.

## MATERIAL AND METHODS

**Location**. Research was carried out at the Didactic Experimental Station of the Banat's University of Agricultural Science and Veterinary Medicine of Timișoara, Romania – the Fruit Tree Centre. The experiment field is located in the plot LL 474, topographical coordinates are 45°78'83''N and 21°21'70''E.

**Soil and climatic conditions**. The soil in the experiment plot is characterised by a neutral pH in the horizon 0–20 cm (pH = 6.90) and slightly acidic in the 20–40 cm horizon (pH = 6.39). Humus content (H) amounted to 1.95% in the 0–20 cm horizon and 1.73% in the 20–40 cm horizon. Total nitrogen ($N_t$) is 1.16% and 1.13%, respectively. Available phosphorus content is 32.55 ppm in the 0–20 cm horizon and 29.4 ppm in the 20–40 cm horizon. Available potassium (K) content is 172.0 ppm in the upper, 0–20 cm horizon and 161.5 ppm in the underlying, 20–40 cm horizon.

Climatic conditions are specific to the temperate continental climate with Mediterranean influences, i.e. characterised by the average (many-years') precipitations of 603.3 mm and a mean temperature of 10.9°C. During the last years the rainfalls were very variable, resulting in temporary deficits, associated also with high temperatures. These situations frequently coincided with the period of max. consumption of water by the apple trees, i.e. in June to August. Under these conditions the supply of water and nutrients to the trees could be disturbed. This motivated our research on the guidance of foliar fertilization.

**Plant material and orchard management**. The plant material was represented by five apple cultivars – Generos, Florina, Delicios de Voinesti, Jonathan and Pionier. The orchard was 12 years old, trees were grown on a medium-vigourous rootstock MM 110, with a semi-intensive management system – spaces at 4.0 × 2.0 m and trained to a free palmetto crown type.

Soil in the orchard was maintained with permanent grassing and repeated mowing. To the soil complex fertilizer (NPK, 15:15:15) was applied at a dose of 60 kg/ha active substance.

**Experimental design**. The experiments consisted of nine treatments for each apple cultivar. The guidance of the nutrition was done through foliar fertilisation. The experimental treatments were:

$T_0$ – control;
$T_1$ – Uwafol (0.4%) + Foliarel (0.1%);
$T_2$ – Uwafol (0.4%) + Foliarel (0.1%) + Calcio Plus (0.2%);
$T_3$ – Waterfert (0.5%) + Foliarel (0.1%);
$T_4$ – Waterfert (0.5%) + Foliarel (0.1%) + Calcio Plus (0.2%);
$T_5$ – Biocomplex900 (0.2%) + Foliarel (0.1%);
$T_6$ – Biocomplex900 (0.2%) + Foliarel (0.1%) + Calcio Plus (0.2%);
$T_7$ – Megafol (0.2%) + Foliarel (0.1%);
$T_8$ – Megafol (0.2%) + Foliarel (0.1%) + Calcio Plus (0.2%).

Foliar fertilisers were applied in three treatments with an atomiser to ensure even distribution in the leaves. Between experimental variants isolation space (two trees) was assured.

Uwafol (S.C. CristianGrup, Bucharest, Romania) is a product containing: N (6.13%), $P_2O_5$ (9.05%), $K_2O$ (4.5%), B (0.006%), Cu (0.02%), Fe (0.045%), Mn (0.015%), Zn (0.02%), Mo (0.0015%); Waterfert (Biolchim, Medicina, Italy) containing: N (8%), $P_2O_5$ (12%), $K_2O$ (24%), MgO (3%), $SO_3$ (32%), B (0.01%), $Cu_{EDTA}$ (0.01%), $Fe_{EDTA}$ (0.02%), $Mn_{EDTA}$ (0.01%), $Zn_{EDTA}$ (0.01%), Mo (0.005%); Megafol (Valagro, Atessa, Italy) containing: aminoacids (35%), $N_t$ (5.6%), $C_{org}$ (18.7%), $K_2O$ (3.8%); Foliarel (Societá Chimica Lorderello, Milano, Italy) containing: B (0.7%), $Cu_{EDTA}$ (0.3%), $Fe_{EDTA}$ (7.0%), $Mn_{EDTA}$ (3.0%), $Zn_{EDTA}$ (2.3%), Mo (0.2%); Biocomplex900 (EKO GEA, Celje, Slovenia), containing: polyuronic acids, iodine, trace elements and salts; Calcio plus L. (BioKimia International, Castel Guelfo di Bologna (BO), Italy) containing: Ca (15.9%).

The area of single experimental plots was 72 $m^2$ and included 9 trees. Each treatment was replicated 3 times on every cultivar.

**Parameters monitored**. To assess the nutritional status, the content of mineral nutrients (N, P, K, Fe, Cu, and Zn) in the leaves was determined as total forms. Leaves were sampled in the third week of July, after the last foliar treatment. To assess the quality of apples, sugar content was estimated by determination of soluble solids upon fruit harvesting. Acidity of fruits was determined at the same time.

**Analytical methods**. The leaf samples were dried in a drying closet at 70°C (Heraterm; Thermo Scientific, Schwerte, Germany). Later, the dried material was processed to analyse macro- and microelements (N, P, K, Fe, Cu, and Zn – total forms). $N_t$ was determined through the Kjeldahl method (Velp Scientific UDK 127 Distillation Uni; VELP Scientifica, Usmate, Italy), and total phosphorus, colorimetrically, with molybdenum blue (Spectrophotometer UV-VIS Cintra 101, series V3793; GBC Scientific Equipment, Hampshire, USA). Potassium and micro-elements (K, Fe, Cu, Zn – total forms) were determined through atomic absorption flam spectophotometry (Varian AA 240, fast sequential atomic absorption spectrophotometer; Varian, Palo Alto, USA). Sugar content was determined through the refractometric method and acidity through the titrimetric method (KOH in the presence of phenolphthalein).

**Analysis of experimental data**. Experimental results were analysed and processed statistically with an Excel module of the Office 2007 suite. The authors determined the relationship between the parameters monitored through correlations and regressions. Also, prediction functions of some parameters were deducted based on interrelationships identified. The safety level of measurements and predictions were assessed and checked through the RMSEP correlation coefficient, level of significance ($P$) and statistical-mathematical parameter (Davies, Fearn 2006; Esbensen 2010). The analysis of the individual contribution of each element assessed based on correlation coefficients and on individual RMSEP values, supplied information on the share of elements of the quality indices.

## RESULTS AND DISCUSSION

The apple cultivars studied utilized the macro- and micro-nutrients administered by foliar way, at the same condition of soil fertility, in different way. Experimental results concerning the values of the parameters determining nutrition status and fruit quality are presented in Table 1.

### Leaf nutrient contents and their relationships

Apple cultivars studied accumulated nutrients in different way. The correlations between them were identified with different levels of significance.

The relationship between N and Fe in apple leaves was positive; this means that increase of the leaf nitrogen content was associated with the increase of the leaf iron content.

The values of the correlation coefficients for leaf N and leaf Fe were significant for all cultivars studied (Table 2).

The analysis of regression, based on mean values of five apple cultivars studied and 9 treatments applied showed a significant positive correlation between N and Fe leaf contents ($R^2 = 0.734$; $P < 0.01$). The relationship between the contents of these two nutrients was expressed by the equation of regression: $Fe = 30.682N^2 - 57.597N + 85.29$. The distribution of particular values is presented in Fig. 1.

A high correlation between N and Fe leaf content found in this study can be attributed to specific interrelation of these two nutrients in plant tissues. Numerous studies were focused at these issues. Marschner (1995) stated that nitrogen (N) is one of the most important inorganic nutrients in plants because it is a major constituent of proteins, nucleo-

Table 1. Experimental results in the apple cultivar Generos – mean values 2011–2012

| Cultivar/ variant | Leaf nutrient content – total forms | | | | | | Fruit quality index | |
|---|---|---|---|---|---|---|---|---|
| | N | P | K | Fe | Cu | Zn | acidity | SS |
| | (%) | | | (ppm) | | | (%) | |
| **Generos** | | | | | | | | |
| T0 | 1.52 | 0.17 | 1.35 | 60 | 10.4 | 17.8 | 0.35 ± 0.01 | 8.00 ± 0.26 |
| T1 | 1.70 | 0.17 | 1.33 | 57 | 10.9 | 18.4 | 0.42 ± 0.02 | 8.01 ± 0.06 |
| T2 | 1.96 | 0.18 | 1.35 | 61 | 10.8 | 18.2 | 0.39 ± 0.02 | 7.48 ± 0.32 |
| T3 | 1.92 | 0.17 | 1.36 | 65 | 11.2 | 18.4 | 0.61 ± 0.03 | 7.39 ± 0.25 |
| T4 | 2.10 | 0.19 | 1.39 | 60 | 11.3 | 18.8 | 0.42 ± 0.03 | 7.19 ± 0.27 |
| T5 | 2.01 | 0.18 | 1.37 | 61 | 11.7 | 18.6 | 0.40 ± 0.03 | 7.62 ± 0.21 |
| T6 | 2.02 | 0.18 | 1.41 | 65 | 11.2 | 19.0 | 0.51 ± 0.02 | 7.35 ± 0.40 |
| T7 | 1.90 | 0.18 | 1.47 | 64 | 11.9 | 19.4 | 0.53 ± 0.02 | 7.53 ± 0.06 |
| T8 | 2.23 | 0.17 | 1.50 | 69 | 12.3 | 19.3 | 0.41 ± 0.03 | 7.69 ± 0.10 |
| SD | ± 0.22 | ± 0.01 | ± 0.06 | ± 3.7 | ± 0.6 | ± 0.5 | – | – |
| **Florina** | | | | | | | | |
| T0 | 1.20 | 0.17 | 1.48 | 77 | 11.5 | 18.9 | 0.38 ± 0.03 | 18.933 ± 0.15 |
| T1 | 2.15 | 0.17 | 1.52 | 89 | 12.7 | 19.5 | 0.40 ± 0.03 | 17.967 ± 0.21 |
| T2 | 2.08 | 0.18 | 1.51 | 95 | 12.8 | 19.9 | 0.520 ± 0.06 | 18.000 ± 0.46 |
| T3 | 1.99 | 0.18 | 1.58 | 94 | 12.7 | 19.2 | 0.373 ± 0.04 | 18.233 ± 0.42 |
| T4 | 2.01 | 0.19 | 1.58 | 99 | 12.2 | 19.9 | 0.407 ± 0.04 | 18.167 ± 0.23 |
| T5 | 2.12 | 0.18 | 1.55 | 106 | 12.5 | 19.8 | 0.390 ± 0.02 | 18.400 ± 0.30 |
| T6 | 2.15 | 0.18 | 1.59 | 101 | 12.8 | 19.5 | 0.383 ± 0.03 | 18.100 ± 0.36 |
| T7 | 2.21 | 0.19 | 1.56 | 104 | 12.9 | 19.1 | 0.393 ± 0.04 | 18.233 ± 0.31 |
| T8 | 1.89 | 0.19 | 1.60 | 108 | 13.5 | 19.5 | 0.503 ± 0.03 | 18.733 ± 0.31 |
| SD | ± 0.31 | ± 0.01 | ± 0.04 | ± 9.67 | ± 0.5 | ± 0.4 | – | – |
| **Delicios de Voinesti** | | | | | | | | |
| T0 | 1.79 | 0.17 | 1.39 | 105 | 10.5 | 18.7 | 0.25 ± 0.01 | 22.13 ± 0.96 |
| T1 | 1.99 | 0.18 | 1.41 | 120 | 10.3 | 19.0 | 0.31 ± 0.01 | 20.63 ± 0.91 |
| T2 | 2.33 | 0.18 | 1.43 | 122 | 11.2 | 19.3 | 0.33 ± 0.01 | 20.30 ± 0.66 |
| T3 | 2.20 | 0.17 | 1.44 | 130 | 11.8 | 19.9 | 0.29 ± 0.01 | 21.70 ± 0.63 |
| T4 | 2.29 | 0.18 | 1.46 | 134 | 11.5 | 19.5 | 0.31 ± 0.04 | 20.33 ± 2.08 |
| T5 | 2.21 | 0.18 | 1.48 | 130 | 11.9 | 19.8 | 0.33 ± 0.03 | 20.00 ± 1.00 |
| T6 | 2.75 | 0.18 | 1.49 | 134 | 12.2 | 19.9 | 0.33 ± 0.04 | 20.27 ± 2.05 |
| T7 | 2.40 | 0.19 | 1.51 | 141 | 12.4 | 20.4 | 0.27 ± 0.02 | 21.50 ± 1.50 |
| T8 | 2.39 | 0.19 | 1.50 | 140 | 12.6 | 20.6 | 0.25 ± 0.01 | 21.97 ± 1.00 |
| SD | ± 0.27 | ± 0.01 | ± 0.04 | ± 11.3 | ± 0.8 | ± 0.6 | – | – |
| **Jonathan** | | | | | | | | |
| T0 | 2.48 | 0.16 | 1.40 | 117 | 10.8 | 18.6 | 0.60 ± 0.03 | 12.93 ± 0.21 |
| T1 | 2.61 | 0.17 | 1.44 | 138 | 11.4 | 18.2 | 0.61 ± 0.02 | 12.83 ± 0.21 |

Table 1. to be continued

| Variant/ cultivar | Leaf nutrient content – total forms | | | | | | Fruit quality index | |
|---|---|---|---|---|---|---|---|---|
| | N | P | K | Fe | Cu | Zn | acidity | SS |
| | (%) | | | (ppm) | | | (%) | |
| T2 | 2.50 | 0.17 | 1.48 | 135 | 11.5 | 18.2 | 0.63 ± 0.03 | 12.50 ± 0.26 |
| T3 | 2.59 | 0.18 | 1.48 | 143 | 11.9 | 18.5 | 0.59 ± 0.03 | 13.70 ± 0.40 |
| T4 | 2.68 | 0.18 | 1.49 | 147 | 12.2 | 18.9 | 0.61 ± 0.03 | 13.00 ± 0.27 |
| T5 | 2.59 | 0.17 | 1.49 | 146 | 12.4 | 19.0 | 0.63 ± 0.02 | 12.73 ± 0.25 |
| T6 | 2.60 | 0.18 | 1.49 | 142 | 12.8 | 18.9 | 0.60 ± 0.02 | 12.53 ± 0.32 |
| T7 | 2.55 | 0.18 | 1.51 | 139 | 12.7 | 18.2 | 0.62 ± 0.03 | 12.00 ± 0.26 |
| T8 | 2.66 | 0.17 | 1.52 | 145 | 12.9 | 18.4 | 0.61 ± 0.04 | 12.20 ± 0.27 |
| SD | ± 0.07 | ± 0.01 | ± 0.04 | ± 9.2 | ± 0.7 | ± 0.3 | – | – |
| **Pionier** | | | | | | | | |
| T0 | 2.38 | 0.17 | 1.46 | 139 | 10.8 | 18.5 | 0.53 ± 0.02 | 12.70 ± 0.30 |
| T1 | 2.65 | 0.17 | 1.53 | 144 | 11.6 | 19.0 | 0.57 ± 0.04 | 12.80 ± 0.17 |
| T2 | 2.54 | 0.18 | 1.51 | 153 | 11.8 | 19.4 | 0.58 ± 0.02 | 13.00 ± 0.46 |
| T3 | 2.69 | 0.18 | 1.50 | 149 | 11.8 | 19.9 | 0.55 ± 0.01 | 12.93 ± 0.15 |
| T4 | 2.67 | 0.17 | 1.57 | 152 | 12.4 | 19.7 | 0.57 ± 0.05 | 13.00 ± 0.30 |
| T5 | 2.78 | 0.18 | 1.59 | 155 | 12.6 | 20.2 | 0.57 ± 0.02 | 13.01 ± 0.30 |
| T6 | 2.70 | 0.18 | 1.58 | 157 | 12.7 | 20.7 | 0.60 ± 0.04 | 13.21 ± 0.24 |
| T7 | 2.80 | 0.18 | 1.61 | 154 | 12.6 | 20.9 | 0.60 ± 0.01 | 13.25 ± 0.46 |
| T8 | 2.60 | 0.18 | 1.62 | 155 | 12.9 | 21.5 | 0.63 ± 0.04 | 13.30 ± 0.12 |
| SD | ± 0.27 | ± 0.01 | ± 0.04 | ± 11.3 | ± 0.8 | ± 0.6 | – | – |

SS – soluble solids content; SD – standard deviation

tides, as well as chlorophyll and numerous other metabolites and cellular components. According to the same author, among the factors which may limit assimilation, iron (Fe) plays a crucial role, being a metal co-factor of enzymes of the reductive assimilatory pathway nitrate reductase (NR), nitrite reductase (NiR) and glutamate synthase (GOGAT), all requiring Fe as Fe-heme group or Fe-S cluster. Potentially, both assimilation and Fe acquisition could compete for reducing equivalents; thus a limited uptake could favour the reduction-based mechanism of Fe uptake or, alternatively, since reduction is carried out by Fe-containing enzymes (i.e. NR and NiR), Fe deficiency could alter the cytosolic concentration leading to a restriction of its uptake mechanisms (Nikolic et al. 2007). From microarray data some information is available concerning the Fe-deficient-dependent expression of genes related to

Table 2. Relationship of causality N-Fe in the apple leaves

| Cultivar | The regression equations for Fe-leaf content (ppm, d.m.), depending on N-leaf content (%, d.m.) | Correlation coefficient ($R^2$) | $P$-value |
|---|---|---|---|
| Generos | $Fe = 1.684N^2 + 7.608N + 42.003$ | 0.717 | 0.02 |
| Florina | $Fe = -7.966N^2 + 54.43N + 22.801$ | 0.748 | 0.016 |
| Delicios de Voinesti | $Fe = -53.14N^2 + 272.2N + 211.84$ | 0.803 | < 0.01 |
| Jonathan | $Fe = -722.4N^2 + 3,831N - 4,932.6$ | 0.788 | < 0.01 |
| Pionier | $Fe = -115.7N^2 + 637N - 721.79$ | 0.877 | < 0.01 |

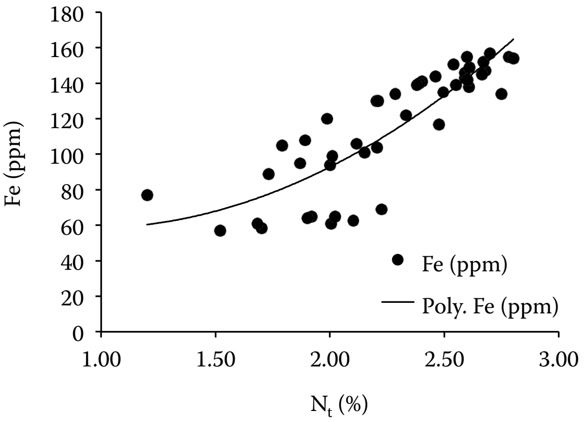


Fig. 1. Total iron content depending on total nitrogen content in apple leaves: relationship based on mean values for five studied cultivars and nine treatments compared Poly. – polynomial regression function for Fe in relation to N

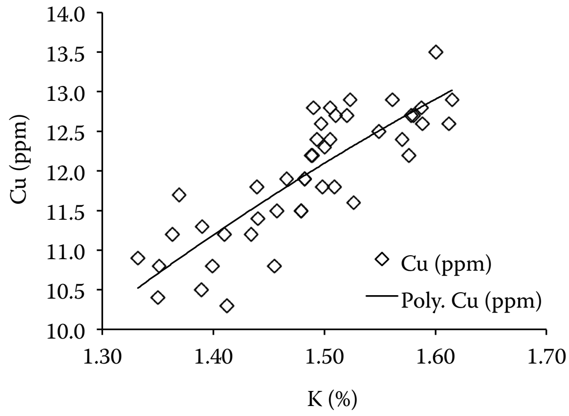


Fig. 2. Total copper content depending on total potassium content in apple leaves; relationship based on mean values for five studied cultivars and nine treatments applied Poly. – polynomial regression function for Cu in relation to K

N metabolism in *Arabidopsis* (Meiser et al. 2011). Zocchi (2006) and Vigani (2012) noted that the metabolic Fe deficiency level induced several changes, mainly concerning carbon (C) and nitrogen (N) metabolism, because the metabolism of these two elements (C, N) are strongly interrelated. Borlotti et al. (2012) reported that Fe deficiency had a differential effect on N metabolism in roots and leaves, with particular adaptive mechanisms to nutritional constraint acting at the whole plant level.

Nitrogen showed a less pronounced correlation with the other macro- and micro-elements studied. There was a positive but rather low correlation between phosphorus and potassium ($R^2$ = 0.388). Relatively higher correlations were found between the leaf Cu and P contents ($R^2$ = 0.501; $P$ < 0.01); interrelationship between these two nutrients was expressed in form of equation of regression: $Cu = -2,399P^2 + 948.3P - 80.66$.

There was also a strong relationship found between the leaf Cu and K contents ($R^2$ = 0.702; $P$ < 0.01); equation of regression: $Cu = -4.788K^2 + 22.934K - 11.53$.

The relationship between these two nutrients is also presented in Fig. 2. The correlation between Cu and P identified in this research can be attributed to the participation of copper in various enzymatic processes in the plant, which influences the phosphorus regime. Van Assche and Clijsters (1990) and Harrison et al. (1999) noted that copper is an essential element, as it is involved in a number of physiological processes such as the photosynthetic and respiratory electron transport chains and as a co-factor or as a part of the prosthetic group of many key enzymes involved in different metabolic pathways, including ATP synthesis.

The relationships between the other nutrients in apple leaves were rather weakly expressed in this study.

### Fruit quality indices

The balance sugars/acidity in apples is an index specific to the cultivar. However, it can be modified by certain conditions of growing and particularly by the nutrition rate (Hecke et al. 2006).

In our study, the determination of soluble solids (SS) content was used as an estimation of sugar content in apples. The measurement of the two quality indices (SS and acidity) in each apple cultivar and the analysis of regression between them and the leaf contents of different mineral nutrients revealed different correlations. The apple cv. Generos showed a negative correlation between acidity and soluble solids, at a low level of significance ($R^2$ = 0.235; $P$ = 0.14). In the apple cv. Delicios de Voinesti a negative correlation between acidity and SS was found at a high level of significance ($R^2$ = 0.913; $P$ < 0.01). In cv. Jonathan apples a negative correlation between acidity and soluble solids was noted at a low significance ($R^2$ = 0.481; $P$ = 0.1). In cv. Pionier apples, a positive correlation between acidity and soluble solids content was recorded with high level of significance ($R^2$ = 0.810; $P$ < 0.01). In cv. Florina no significant correlation was found between acidity and soluble solids content.

Table 3. Prediction of acidity and soluble solids content, based on leaf nutrients

| | Element | Assessment and prediction of acidity and soluble solids content | Correlation coefficient | Synthetic index[1] | Individual synthetic index[2] |
|---|---|---|---|---|---|
| Acidity (A) | N | $A = 0.1253N^2 - 0.3681N + 0.6461$ | 0.690 | | 0.105 |
| | P | $A = -417.92P^2 + 144.77P - 12.048$ | 0.093 | 0.0925* | 0.121 |
| | K | $A = -3.651K^2 + 11.211K - 8.1062$ | 0.231 | | 0.119 |
| | Fe | $A = -7 \times 10^{-6} Fe^2 + 0.0029Fe + 0.239$ | 0.463 | | 0.114 |
| | Cu | $A = -0.0006Cu^2 + 0.051Cu - 0.0498$ | 0.183 | 0.103** | 0.119 |
| | Zn | $A = 0.0007Zn^2 - 0.0448Zn + 1.0668$ | 0.041 | | 0.122 |
| Soluble solids (SS) | N | $SS = -0.5623N^2 + 2.3189N + 12.23$ | 0.003 | | 4.706 |
| | P | $SS = 4.239.2P^2 - 1{,}219P + 97.37$ | 0.634 | 4.269* | 4.437 |
| | K | $SS = 55.219K^2 - 141.26K + 102.2$ | 0.713 | | 4.412 |
| | Fe | $SS = 9 \times 10^{-5} Fe^2 + 0.0332Fe + 0.3881$ | 0.588 | | 4.378 |
| | Cu | $SS = -0.4773Cu^2 + 12.65Cu - 68.186$ | 0.247 | 4.132** | 4.581 |
| | Zn | $SS = 0.1584Zn^2 - 3.6539Zn + 26.014$ | 0.809 | | 4.250 |

[1]synthetic index per groups of macro- and microelements (*$RMSEP_{macro}$, **$RMSEP_{micro}$); [2]($RMSEP$)

### Prediction of quality indices, based on leaf nutrients content

Acidity and soluble solids content was different in particular apple cultivars. Some significant correlations were found between these quality indices and the contents of particular nutrients in the leaves. Regression analysis allowed estimation of the acidity and sugars content (expressed as soluble solids); the level of significance and the safety degree of the prediction based on the nutrients analysed is indicated in Table 3. The prediction models for the two quality indices were obtained based on the leaf nutrient content. The prediction error of the models obtained (i.e. safety) was assessed through the parameter *RMSEP* that gives direct estimates of the prediction error and the modelling error in Y and is expressed in the original measurement units (Esbensen 2010). The lowest values of the *RMSEP* parameter point to the safest models.

Based on the results of the analysis of the relationship between leaf nutrient contents and fruit quality indices (acidity and soluble solids content), the share of nutrient contribution per groups of macro- and microelements to acidity and sugar content in apples can be assessed. Chundokova (1997) also obtained close relationships between nitrogen, phosphorus and potassium in the leaves and dry matter content and sugar content, respectively.

The overall analysis of the two groups of nutrients showed that macroelements had a larger share ($RMSEP_{macro} < RMSEP_{micro}$) in development of the fruit acidity, while microelements have a larger share ($RMSEP_{macro} > RMSEP_{micro}$) in accumulation of sugars (expressed as soluble solids).

Among macroelements, total nitrogen (N, %) showed the highest value of the correlation coefficient ($R^2$ = 0.690) and the lowest value of *RMSEP* ($RMSEP_N$ = 0.105), of all the elements analysed in the measurement and prediction of acidity.

Phosphorus ($R^2$ = 0.634) and potassium ($R^2$ = 0.712) had a higher contribution to the soluble solids (apparently mainly sugar) content. Microelements had a larger share of ($RMSEP_{micro}$ = 4.132). Among microelements, Zn had the largest share in sugar (soluble solids) accumulation and enabled the prediction of this quality index with a higher safety degree ($R^2$ = 0.809; $RMSEP_{Zn}$ = 4.250).

Based on the model and related functions, it is possible to predict values of apple quality indices with multiple practical advantages. Making use of the predictive values of quality indices, production of apples for direct consumption as well as for processing may be improved. Apple quality indices (sugar content and acidity) may be modified by foliar fertilization with the mineral elements that have a positive effect on them.

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