Effect of potassium supply on content of apple leaf phosphorus

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Abstract. Well-balanced mineral nutrition of apple trees is critical for fruit quality and storability. The seasonal changes of phosphorus and potassium leaf content were studied in the pot sand culture during the seasons of 2019 and 2020. The treatments comprised the application of the nutrient solution with different concentrations (0.00; 0.68; 1.36; 1.70; 2.04; 2.72; 3.40 g l⁻¹). Leaves were analyzed on potassium and phosphorus content. The increase in potassium supply led to a striking increase in the content of apple leaf phosphorus above the optimal level. An approach to non-invasive detection of the impact of the nutrient imbalance based on hyperspectral reflectance imaging has been proposed.

1. Introduction
Phosphorus is among the elements essential for plants. It is central to energy and information exchange and storage in the plant cell [1]. It also stimulates seed germination, development of roots, stalk and stem, flower and seed formation; phosphorus supply is a key determinant of crop size and quality [2]. In sand culture, an increased phosphorus supply rate stimulated tree growth, fruit set and yield [3].

Seasonal changes of leaf phosphorus content in different types of apple orchards with various soil nutritional levels are correlated with the phenological stage of tree development. Thus, the largest phosphorus content was typically found in the beginning of growing season followed by a decrease until the end of the season [4]. The dynamics of apple leaf phosphorus was also similar in sand culture experiments with 6-years-old apple trees [5]. Similar pattern of changes in leaf phosphorus was documented in a field trial with 10-year-old apple trees Zhigulevskoye/B396 although some treatments deviated from the common trend depending on the number of fertilizers and their application method [6]. In the other field experiment, Jivan and Sala [7] found little positive correlation between the increase in leaf potassium and phosphorus. Tagliavini et al. [8] reported that an increased phosphorus application rate in the pot greenhouse experiment with peach seedlings induces a striking decline in leaf zinc concentration.

Phosphorus fertilization of apple orchards received less attention of researchers compared to nitrogen and potassium fertilization likely due to a lower number of reports on the positive effect of phosphorus on the yield [9]. The reason may be that the apple tree demand of phosphorus is much
lower than that of nitrogen or potassium [10]. Potassium is crucial for fruit growth and development so a large amount of potassium is fertigated in the second part of the growing season [11]. The imbalance in plant nutrition can largely impact the quality of fruit and development of young trees so we investigated the potassium imbalance impact on the leaf phosphorus concentrations in one-year-old apple trees.

2. Materials and methods
The research was carried out in the laboratory of agronomical chemistry of I.V. Michurin Federal Scientific Centre. One-year-old plants of apple rootstock B118 were planted in 5-L pots filled with sand, one plant per pot. One-year-old trees were planted on 30.04 and taken out from pots on 30.09.2019 and 02.10.2020. The pots were installed in a well-aerated and well-lit room. The nutrient solution composition for fertigation is presented in Table 1.

Table 1. The composition of the nutrient solution, g l⁻¹.

|          | NH₄NO₃ | Ca(NO₃)₂ | FeSO₄ | K₂HPO₄ | KNO₃ | MgSO₄ | Na₂HPO₄ | CaCl₂ | Mn* | Zn** | CuSO₄ | B (Na₂B₄O₇) |
|----------|--------|----------|-------|--------|------|-------|---------|-------|-----|------|-------|-----------|
|          | 1.22   | 0.34     | 0.5   | 1.2    | 0.34 | 1     | 0.02    | 0.48  | 0.0044 | 0.0048 | 0.004 | 0.0116   |

* EDTA chelate - C₁₀H₁₂MnN₂O₈Na₂
**EDTA chelate - C₁₀H₁₂N₂O₈ZnNa₂

Each tree was fertigated weekly with 100 ml of this nutrient solution. Besides, the plants received tap water as the substrate dried. We did not take into account the number of such irrigations. The treatments varied according to potassium concentration.

| Treatments in 2019 | Treatments in 2020 |
|--------------------|--------------------|
| Potash g l⁻¹       | Article I.         |
| 1. Without potassium K0.0 | 0.00 |
| 2. Normal potassium K1.0   | 0.68 |
| 3. Potassium x 2.0 K2.0 | 1.36 |
| 4. Potassium x 2.5 K2.5 | 1.70 |
| 5. Potassium x 3.0 K3.0 | 2.04 |

| Treatments in 2019 | Treatments in 2020 |
|--------------------|--------------------|
| Potash g l⁻¹       | Article I.         |
| 1. Without potassium K0.0 | 0.00 |
| 2. Normal potassium K1.0   | 0.68 |
| 3. Potassium x 2.0 K2.0 | 1.36 |
| 4. Potassium x 2.5 K2.5 | 2.72 |
| 5. Potassium x 3.0 K3.0 | 3.40 |

We enhanced the potassium concentration in the masterbatch in treatments with the maximum nutrient amount to determine the influence of the extreme potash amount on plants. We sampled 10 leaves from each treatment (2 per plant) and determined the reflection spectrum in the range of 300-900 nm on the spectrophotometer Specord 250 Plus (Analitik Jena, Germany). The reflection spectrum was determined on the same part of the upper leaf surface (Fig. 1).

Figure 1. Reflection spectrum detection point

The hyperspectral imaging of sampled leaves was carried out only in the season of 2020. The images containing hyperspectral reflection coefficients were captured using a frame-type hyperspectrometer IQ (Specim, Finland). The reflection spectrum was recorded for each pixel of the hyperspectral image (spectral range 400-1000 nm; spectral resolution 1 nm) against a Spectralon plate as the 100% reflectivity standard under artificial illumination with two 150 W incandescent lamps. The index CI₆₇₈ was calculated for each spectrum in the hyperspectral image using the original
software “Gelon” (https://github.com/AlexanderMipt/Gelion). It was calculated according to Formula 1:

$$CI_{678} = \frac{R_{800}}{R_{678}}$$  \hspace{1cm} (Formula 1)

where $R_{800}$ – the near-infrared reflectance coefficient (NIR), which is not affected by light absorption by pigments; $R_{678}$ – the reflection coefficient in the red maximum absorption of Chl. We analyzed these leaves to determine leaf phosphorus – by the phosphomolybdenum blue method with $\text{SnCl}_2$ staining and detecting at 750 nm on photometer KFK 3.01 (ZOMZ, Russia) [13]. We calculated the least significant difference (LSD) between various treatments (P<0.05). The differences that were higher than the computed LSD value were considered significant.

3. Effect of potassium supply on seasonal changes of leaf potassium

Apple leaf phosphorus concentrations strongly depended on potassium supply levels in 2019 (Fig. 2). Seasonal changes in leaf phosphorus concentrations in the K0.0, K1.0, and K2.0 treatments were similar: the largest phosphorus content was recorded in the end of May, later it decreased until the end of July. The optimal leaf phosphorus concentrations attainable by the end of May are 0.2–0.3% d.m. [14] or 0.3–0.4% d.m. [7]. The leaf phosphorus concentration in the K2.0 treatment exceeded the optimum at the end of May but further decreased until the end of September. The main difference among the above-mentioned treatments was in the value of leaf phosphorus content.

The leaf phosphorus in the K2.5 and K3.0 treatments was significantly higher and more variable than that in other treatments throughout the season. The largest leaf phosphorus concentration in the K2.5 treatment was found in the end of May. It decreased until the end of June, then slightly increased and levelled off by the end of the season. The variations in the leaf phosphorus concentrations in the K3.0 treatment were not significant.

![Figure 2. Seasonal pattern of changes in leaf phosphorus concentrations on the different levels of potassium supply.](image)

The seasonal change pattern of leaf phosphorus in 2020 was generally similar to those in 2019. The treatments formed two distinct groups according to the potassium supply rates. The most significant difference was displayed by the plants in the K4.0 and K5.0 treatments which eventually died in the beginning of September. The largest leaf phosphorus concentration was in treatment K5.0 at the end of July with a slight trend to decrease.

The pattern of leaf phosphorus under condition of field experiment with fruit-bearing trees was similar to those documented in the K1.0 and K2.0 treatments [5, 7]. A similar dynamics was also in the K0.0 treatment, but the leaf phosphorus content was too low in the second part of the growing season. The leaf phosphorus of plants grown in the sand culture depended on the potassium nutrition level and rootstock-graft combination [15]. In the above-mentioned research, the increase in potassium supply led to a decrease of leaf phosphorus concentration in A2 rootstock in the middle of August. The leaf phosphorus content in fruit-bearing trees of cv. 'Idared' grafted on the A2 also decreased with the increase of potassium supply. Still the leaf phosphorus, as a rule, increases in other woody plant
species as a result of enhanced potassium supply [16]. The revealed interactive patterns of potassium and phosphorus should be taken into account, together with the rootstock-graft combinations, in the development of fertilization (fertigation) programs.

In this study, we also employed Visible-Near Infrared (Vis-NIR) spectroscopy which is now a widespread tool emerged from the field of remote sensing. Recent advancements in instrumentation and data analysis paved the way for the advent of affordable hyperspectral reflectance imaging (HRI) technology. The spectra of healthy leaves featured typical spectral details attributable to absorption by photosynthetic pigments—chlorophylls and carotenoids [17]. The leaf regions affected by the potassium and phosphorus imbalance generally displayed a lower reflectance in the NIR along with a higher reflectance in red chlorophyll absorption band. These changes resulted in a decline of the CI678 index manifesting the onset of leaf chlorosis in response to the nutrient imbalance. Notably, a decline in leaf chlorophyll also took place in the control due to a normal leaf senescence but in the high-potassium treatments (K.3–K.5) chlorophyll declined at a faster rate (Fig. 3).

Figure 3. The onset of apple leaf chlorosis during leaf aging (K1.0) or as an effect of the excessive potassium and phosphorus (K2.0–K5.0).

4. Conclusion
Increased concentrations of potassium in nutrient solutions led to an increase in leaf phosphorus content under our experimental conditions. An increase over 2.72 g l⁻¹ led to plant death, likely due to the general nutritional imbalance including the excess of phosphorus. A spectacular manifestation of the nutrient imbalance was constituted by the leaf chlorosis which can be monitored non-invasively by the leaf reflectance imaging. The obtained data are important to better understand the maintenance of proper nutritional balance during application of single-component fertilizers in apple-trees.

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