Seasonal Variation of Plant Mineral Nutrition in Fruit Trees

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Abstract
This research evaluated the monthly variation of plant mineral nutrition in six kinds of fruit trees over a year. Leaf samples were taken from the fruit trees and mineral content (N, P, K, Ca, Mg, Fe, Zn, Cu, Mn, and Mo) was determined in the leaves at 1-month intervals from April until November for apple, persimmon and peach. Mandarin mineral nutrition was monitored for one year, and grape and fig from May to November. Using this data, the Diagnosis Recommendation Integrated System (DRIS) was also calculated to evaluate the nutrient balance in the plants. The concentration of N and P had seasonal differences, especially in apple and peach, which reached the peak during the summer. Among the fruits, apple, fig, and grape showed ranging greater range in terms of seasonality of mineral nutrition. The P and K levels reached the minimum during the harvesting season. However, the seasonal changes in leaf micronutrient concentrations were not uniform and not affected by phenological stage. The DRIS data demonstrated that mandarin had the best nutrient balance compared to others and that K was the most limiting element among the fruit trees. In summary, the current data suggest the occurrence of a significant seasonality in mineral nutrition in these six fruit trees, especially in temperate ones.

Keywords: Diagnosis Recommendation Integrated System, Fruit Crops, General Plant Nutrition, Nutrient balance.

Introduction
Understanding the physiological aspects of tree nutrition includes studies about the seasonal variation of leaf nutrient contents [1], because the seasonal pattern of nutrient uptake and partitioning is a fundamental portion of fertilizer estimations in fruit orchards. The harmony between the period and fertilizer application rate within the plant’s nutrient demand may lead to maximize yield, and it increases nutrient-use efficiency. In mandarin trees (Citrus reticulata Blanco) the fruiting state had a significant effect on the content of P, K, and Mg in both leaves and stems, because these fruits could act as very strong sinks for potassium and phosphorous; therefore, during the harvesting state the K and P levels in leaves decreased to deficient levels [2].

The variations occurring in plant mineral nutrition can be provoked by their metabolism, depending on plant growth stage and their responses to environmental factors [3]. There are many reports which showed B to have a remarkable role in fruit setting [4,5], suggesting that during flowering and fruiting a B deficiency may lead to fruit abscission and reduce yield and quality [6,7].

Commercial growers of fruit, especially of berries, are encouraged to program their fertilization based on recommended rates of nitrogen, considering also other elements resulting from routine soil and leaf nutrient analysis [8].

The monthly variation of plant-nutrient contents has also been examined with gutation fluid samples from Dieffenbachiae anoena plants, showing that macroelements decreased in winter, and microelements increased [9]. Furthermore, nutrient levels in blackberry (Rubus L.) leaf vary over the growing season and among their cultivars, so a standardization of sampling time for fertilizer recommendation has been established [10].

Under natural conditions, such as in Mediterranean mountain vegetation, the highly variable leaf-quality characteristics based on N content among the seasons create a diverse and changing
chemical landscape in which the local fauna may choose their preferences for diet, according to plant species, at different times and sites [11].

Although many studies have reported nutrient dynamics in fruit trees during the growing season [12,13], the seasonal variation of mineral concentrations in many fruits in the same location needs to be compared. A deep analysis of physiological aspects of tree nutrition also depends on the knowledge of the seasonal variation of leaf nutrient contents [1,2]. These factors are dynamic throughout the year and provide the appropriate recommendation of fertilizer amendment according to the plant growth stage. Therefore, the seasonal pattern of nutrient uptake and partitioning is a fundamental component of fertilizer management in fruit orchards. The present study aims to evaluate the seasonality of macronutrients: Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and micronutrients: Copper (Cu), Iron (Fe), Zinc (Zn), Manganese (Mn) and Molybdenum (Mb) in fruit orchards, including their relationship with plant phenological stages.

Materials and Methods

This study was conducted at Kyoto Prefecture University Experimental Farm, Seika-cho. Root and leaf samples were collected from six fruit crops: Apple (*Malus domestica* “Fuji”), Peach (*Prunus persica* “Benishimizu”), Persimmon (*Diospyros kaki* “Hiratanenashi”), Fig (*Ficus carica* “Masui Dalphine”), Mandarin (*Citrus unshiu* “Satsuma mandarin”) and Grape (*Vitis vinifera* “Fujiminori”), every month for a year. The characteristics of each fruit tree, including their phenological stage and fertilizer application rates, are described in Suppl. Table 1.
Four leaf samples from different trees were taken monthly from the third branch, counting vertically, for the analysis. The fertilization, pesticide application, fruit thinning, and pruning followed the standards in Japanese fruit orchards individually for each kind of fruit.

The leaves were washed, dried for 72 hours at 60 °C, and then the nutrient concentrations were measured. The Kjeldahl method was used to determine the N concentration in fruit leaves after sulfuric acid digestion. P was measured by colorimetry using a spectrophotometer, and K, Mg, Ca and micronutrients (Zn, Mn, Cu, and Fe) by atomic absorption spectrophotometer (AAS). All analyses were performed by the Forest Research Society, Federal University of Vicosa, Brazil. The diagnosis recommendation integrated system (DRIS) was estimated to evaluate the nutrient balance for each fruit tree [14–16].

Statistical analyses of data were performed using SPSS software, where mean values and the standard error were measured, as well as the correlation matrix among the nutrients.

Results

In our analyses, we found that seasons affected P concentration more than N concentration (Figures 1 and 2). The N values were stable over the year for almost all the fruits analyzed in this study, except apple, peach, and grape. In peach, the N concentration had a peak in May and in September. Moreover, persimmon and mandarin had a peak of N in August and September (Figure 1).

Intriguingly, the N concentration decreased in persimmon, fig, and apple from July to August, a period when these fruit crops showed a peak of AMF colonization. In peach trees, the values of N increased in summer, but this crop only reached the peak of N in September (Figure 1). Persimmon, grape, and peach were the most variable for P concentration, while mandarin was the most stable for P concentration over the year (Figure 2). Considering all these data it is possible
to confirm that the concentration of N in leaves showed seasonal differences in apple and peach, while P varied for all fruits, except mandarin.

Other macro-elements, K, Ca and Mg, did not have similar patterns. Their variation over the year depended on the fruit, and special attention could be given to Ca in mandarin and fig, and Mg only in fig, where there was a higher level compared to others (Suppl. Fig. 1). For the micronutrients, there were not many differences among the plants over the year, except for Cu and Zn, which were low in mandarin during the spring. Moreover, the Mn and Mb concentrations were remarkably higher in persimmon and fig, respectively. An increase in the content of the same element was observed throughout the year, except in August, when these fruits start fruit set and harvesting, respectively. Although higher concentrations of this microelement were reported in fig, these concentrations decreased throughout the year (Suppl. Figs 2 and 3).

The DRIS results indicated that mandarin followed by grape had the best NBI, which indicates that these fruit crops were well balanced for nutrients compared to other crops. Peach was most limited by K, and persimmon by N and K. Figs were limited by Zn, whereas Cu was in excess for most fruit crops, except mandarin. However, apple had no limitations in terms of nutrients (Table 2).

Discussion

The results of this study reveal that the fruit trees studied differed in their chemical characteristics between species and times. As seasonality also has genetic components [17] that depend on the plant species, we analyzed data from six different species. The monthly variation in the nutrient concentration for these fruit trees suggests a significant effect of this trait. The highest difference was found between spring and summer for the temperate fruit trees, whereas with the mandarin such variations were not so significant. Seasonal chemical changes are usually a well-
known cause of variation within species [11], especially nitrogen concentration and tannins. Carbohydrate storage was also found as a major difference among seasons within the same species [18].

Soil health, which includes P concentration and the phenological stage of the fruit tree, can affect plant mineral nutrition. Consequently, soil protection and improvement of physical properties, such as viability of organic matter, offer a finer texture and help the formation of soil aggregates to keep up soil porosity [19]. The current research detected variation by season; however, the site and cultivars of the same fruit species should be considered too.

It is notable that the amount of P in the soil inhibits absorption of other nutrients, such as Fe and Mn [20]. Therefore, the low levels of this nutrient in the leaves of some fruit crops, for example, persimmon, may be explained by environmental factors, phenological stages, and soil properties. In the case of nutrient balance among the trees, a deficiency in N and K in peach and persimmon was found, with an excess of Zn and Mb for most of the trees. The low content of organic matter in soils could explain these data [21,22]. Generally, soils with low organic matter that receive high dosages of P may exhibit an excess of Zn, as this element is proportional to P in soils. In addition, Fe availability could be reduced in a season of heavy rainfall [22], so peach, persimmon, fig and grape might be unable to uptake Fe during this strong rain. However, it might not affect the yield itself, because other nutrients also influence the final production and fruit quality.

Leaf N and S levels declined throughout the floricane-fruiting season in blackberry [10,23]. This decline might be due to dilution, and/or translocation to fruit that is relatively high in N. In addition, the leaf K may decrease during fruit development in caneberries [8,24].

For citrus trees, the development of new organs may affect the uptake and distribution of nitrogen in spring and autumn [25]. The leaf P contents also may decrease after fruit set in mandarin.
[2,26], and this also seen in olive trees [1]. The current study showed some stability of K content in leaves throughout the year, except for apple and persimmon, but in most of the fruit trees, a decrease occurred after harvesting. Corroborating these data, other authors also found the same decrease in olive and pistachio [26,27]. The dynamics of K indicate that it is a very mobile macronutrient [4]. Therefore, the supply of K for fruit trees at the time of fruit set is crucial in reaching high fruit quality, a very important requirement in the fruit market in Japan, where appearance is much prized.

The amount of Mg, in leaves was significantly affected by the phenological stage, especially during the flowering and fruit set. The patterns of seasonal changes in these elements were corroborated in previous studies carried out with mandarin [26] and pistachio [28]. The concentrations of Mg in fruit trees could be linked to their functions, such as numerous enzymatic reactions involving energy provision [4]. In the present study, leaf Fe and Mn contents were not affected by seasonality, except in persimmon, with a slight decrease during the summer. This phenomenon may result because the fruit does not act as a sink for these elements.

Conclusions

This study reported that in five temperate fruit trees (Apple, Peach, Persimmon, Fig and Grape) and one evergreen fruit tree (Satsuma mandarin) there was a significant seasonal variation in their nutrients. The amounts of P and K were affected by fruit setting, where the fruit could be sinks for P and K. These two elements might be involved in flowering, so the management of these two fertilizers is likely to affect yield and fruit quality.

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**Literature Cited**


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