Phosphorus Dynamics in Clementine Mandarin

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ABSTRACT

The study sought to investigate the internal cycling of phosphorus (P) in Clementine mandarin (Citrus reticulata Blanco "Clementine"). The biomass formation, P concentration, P uptake and accumulation of different organs (bud, flower, fruit, leaf and branches) identified as active organs and found on 1-year-old shoots on fruit trees of bearing age were periodically examined for 2 years. The biomass value was similar between both production seasons. At the beginning of shoot activity, the biomass of annual shoots had a very low rate in the total biomass (0.4%). The biomass increased from 9.7 kg/tree at the beginning of the production season to 62.8 kg/tree at harvest. The P concentrations were in the ranges of 0.11–0.22% in the branches of <1-year-old shoots throughout the 2 years, 0.07–0.15% in the branches of 1-year-old shoots, 0.17–0.31% in the leaves of <1-year-old shoots and 0.13–0.26% in the fruits of <1-year-old and 1-year-old shoots. The total P accumulation at harvest was 82 and 107 g/tree in the first and second years for <1-year-old shoots, respectively, while it was 44 and 48 g/tree for 1-year-old shoots, in the first and second years respectively. The mean daily P uptake amount was determined as 0.4 g/tree for both production years, and the highest daily P accumulation amount was between the fifteenth and twenty-eighth days for both production seasons.

Introduction

It is known that phosphorus is a mobile element in plants, and thus, development in plants is dependent on internal remobilization and the response of the plant to the availability of P in its growth environment (Zambrosi et al., 2012). Additionally, the possibility of remobilizing P in plants is an important mechanism in fighting against probable and permanent P shortage stress (Fife et al., 2008) and increasing the effectiveness of P usage (Hammond et al., 2004).

In citrus trees, P is mainly stored in the leaves (<6-months-old), new shoots (<1.5 cm diameter) and roots (Mattos et al., 2003). A significant part of it can be remobilized to flowers (Sanz et al., 1987). Therefore, it may be stated that there is a relationship between the total amount of P accumulated and P remobilization rates with sufficient yield values (Zambrosi et al., 2012).

For understanding the P dynamism in citrus trees, studies have been conducted on the P concentrations of different organs. In their study carried out in the province of Izmir in Turkey where Mediterranean climate conditions are dominant, Köseoğlu (1980) reported that in Satsuma mandarin, leaf P concentration was about 0.23% at the beginning of the vegetation period in annual bearing shoots and 0.10% at the end, while these values were respectively 0.23% and 0.11% in non-bearing shoots.

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In their study on 150 orchards of Pummelo citrus (*Citrus maxima*) varying in age from 5 to 8 years found in Indonesia, Thamrin et al. (2014) observed that P concentration had a decreasing trend as tree age increased.

In the greenhouse trial conducted in Brazil with Cleopatra mandarin (*Citrus reshni* hort. ex Tanaka, CM) and Pera sweet orange [*Citrus sinensis* (L.) Osbeck] grafted on Rangpur lime (*Citrus limonia Osbeck, RL*), Zambrosi et al. (2013) applied 4 different P doses (0–20–40 and 80 mg P/kg soil) at 2 different soil depths (0–30 and 31–60 cm). They determined the P concentration of mature leaves on 150–240 days and 330 days following the transfer of the plants into pots, and reported this value to vary in the range of 0.82–1.02 g/kg on the 150th day, 0.54–0.61 g/kg on the 240th day and 0.55–0.61 g/kg on the 330th day.

Kafa et al. (2013) determined the P concentration in Kütdiken lemon leaves as 0.12% in March and April, 0.14% in May, 0.11% in June and July, 0.14% in September and 0.12% in October.

In their study on 135 navel orange trees (*C. sinensis* Osbeck, “Newhall”) in China, Yanli et al. (2015) reported the mean P concentration as 0.15% in mature spring shoots (mid-September shoots).

In plants of Nagpur mandarin whose entire water needs were met, Panigrahi and Srivastava (2016) determined the P concentration of leaves as 0.22%. Sharmaa et al. (2016) reported the P concentration of leaves of Marsh Seedless grapefruit as 0.19%. In Kinnow mandarin, Nasir et al. (2016) determined the P concentration in spring non-bearing shoot leaves (5–7-month-old) as 0.07% in the control group.

In a study on flowers of Valencia orange, P concentration was determined as 0.26% in April (Pestana et al., 2004).

In studies toward determining remobilization in citrus plants, determining biomass constitutes a significant and basic step. Mattos et al. (2003) found the total biomass (on a dry matter basis) in Hamlin orange as 25 kg/tree. In central Florida as well, Morgan et al. (2006) stated that, in mature sweet orange with a yield of 196 kg, the total biomass was 124 kg/tree (in dry weight). In this value, 40% came from shoots and main branches, 24% came from fruits, 23% came from roots, 10% was from leaves and 3% was from the stem.

In studies conducted on P uptake amount and its distribution by utilizing the biomass and concentration values to present the P dynamism in citrus trees, Roy and Gardner (1946) determined the highest uptake of P in orange between October and November. Mattos et al. (2003) determined the P amount in Hamlin orange as 29 g/tree. Within this amount, 5 g was carried by leaves, 7 g was in shoots, and 10 g was in fruits. The remaining amount was collected in the stem and roots. In their study with Satsuma mandarin (*Citrus unshiu* Marc.) carried out in Turkey, Barlas (2017) examined the trends of nutritional element uptake. As a result of the study, it was determined that 122 g/tree of P accumulation took place in the active organs throughout the vegetative period (late March – mid-December). Moreover, the periods where P accumulation was the most intense were found during flowering (14th–27th days) and onset of faster fruit growth (44th–81st days) periods respectively as 20 and 17 g/tree. Most studies conducted for understanding the internal P cycling in citrus trees focused on determining concentrations in different organs, and these studies were on a limited scope in terms of comprehending the dynamism of P. This study aimed to present the P dynamics in Clementine mandarin based on the course of biomass formation and P uptake.

**Materials and Methods**

**Description of the Study Material and Soil Characteristics**

In this the study, we used buds, flowers, fruits, leaves and branch samples found on the shoots (<1-year-old and >1-year-old) belonging to Clementine mandarin at the productive age (20–30 years) grafted on sour orange (*Citrus aurantium*) (Figure 1).

Sampling was performed between 2014 and 2016 in the Soke district of the province of Aydın in Turkey where agricultural activities are carried out. Phosphorus was applied at 80 g P₂O₅/tree throughout the production season.
The soil of study site was mildly alkaline (pH = 7.1) in both production seasons, and no problem was encountered in terms of total water-soluble salts (0.04%). It was observed that the sandy loam soil was insufficient in terms of organic matter (1.8%) but sufficient in terms of P (17 mg/kg).

Plant Sampling

In both production seasons, sampling started when the shoot growth started. The observations on the sampling days and the vegetation period are presented for both years below (Table 1).

The <1-year-old and 1-year-old shoots were sampled based on the period at intervals shown in Table 1 with the organs on them (bud, flower, fruit, leaf and branch), separated into organs at the laboratory and made ready for analysis according to the method described by Chapman (1964).

Phosphorus Analysis in Plants

After extraction of plants with a mixture of HClO₄:HNO₃ (1:4) (Kacar and Inal, 2008), the P concentration in the plant samples was determined with vanadomolybdo phosphoric acid colorimetric method. Intensity of yellow color at a wavelength of 430 nm was found using a spectrophotometer (Kacar, 1972).

Table 1. Plant sampling periods and some observations on the periods.

| Observations                                      | Year 1 (2014–2015) | Year 2 (2015–2016) | Days after shoot flush |
|---------------------------------------------------|---------------------|---------------------|------------------------|
| Onset of shoot activity                          | 3/15/2014           | 3/22/2015           | 0                      |
| Flowering period                                 | 3/30/2014           | 4/5/2015            | 0                      |
| End of flowering – onset of fruit setting        | 4/11/2014           | 4/19/2015           | 15                     |
| Fruit setting                                    | 5/3/2014            | 5/2/2015            | 69                     |
| Fruit growth                                     | 5/23/2014           | 5/23/2015           | 62                     |
| Before full size in fruits                       | 6/8/2014            | 6/5/2015            | 75                     |
| Color formation in fruits and onset of fall shoot activity | 7/12/2014       | 7/4/2015            | 119                    |
| Onset of harvest                                 | 8/10/2014           | 8/7/2015            | 148                    |
| Harvest                                           | 9/7/2014            | 9/12/2015           | 176                    |
| Dormancy period                                  | 10/12/2014          | 10/10/2015          | 211                    |
| End of winter dormancy period                    | 11/8/2014           | 11/3/2015           | 238                    |
| Onset of spring shoot activity                   | 12/6/2014           | 12/5/2015           | 266                    |
| Harvest                                           | 1/2/2015            | 1/3/2016            | 293                    |

Figure 1. A picture of experiment grove in Turkey.
Biomass Calculation

The biomass value was calculated as described by Barlas (2017). The biomass was determined by separating 4 trees from the trial orchard in both production seasons, and no sampling was performed on these trees throughout the trial.

After the harvest and before pruning, all <1- and 1-year-old shoots found on a quarter of these 4 specified trees were cut and counted, and their weights were determined. The following formula was utilized in biomass calculation.

\[
\text{Biomass}_{\text{tree}} = \frac{g}{A} = (A \times B) + (C \times D) + (E \times F)
\]

A = Weight of bearing shoot (g)
B = Number of bearing shoots
C = Weight of non-bearing shoots (g)
D = Number of non-bearing shoots
E = Weight of shoots > 1-year-old (g)
F = Number of shoots > 1-year-old

Theoretical Approach

In planning the study, the basis was the theoretical approach that in fruit trees at fully productive age, the growth in roots-stem and main branches becomes almost dormant. That is why increase in biomass occurs at a very low level (Spigel-Roy and Goldschmidt, 1996). For this reason, roots, stem and main branches were not considered in this study.

Results

Biomass Formation And Distribution

The total biomass showed a variation from the beginning of the vegetative period to harvest (266th day) in 6.6–57.9 kg/tree for first year and 12.8–67.6 kg/tree for the second year. Biomass formation was similar in both years throughout the production season (Figure 2).

It was observed that the highest share in the biomass value was in the leaves <1-year-old in the first and second years respectively as 23.3 and 29.1 kg/tree (Figure 3).

Phosphorus Concentration Trends

The P concentrations in the <1- and 1-year-old shoots were similar in both years in all organs (Figure 4). On the other hand, the progress that was observed throughout the year showed some differences depending on the age of the shoot and whether it was a bearing or non-bearing shoot.

In <1-year-old shoots, it was observed that the P concentration was higher in both years in the organs of the non-bearing shoots (wood and leaf) in comparison with the bearing shoots. There were similar changes throughout the vegetative period in the bearing and non-bearing shoots in terms of the P concentration, and in this context, there were reductions in the woody portion and increases in the leaves especially until the harvesting period. It is believed that the existence of a competition between the leaves and fruits in terms of P uptake was apparent in this case.

The highest P concentration values in the leaves and fruits were determined in the harvesting period respectively averaged as 0.23% and 0.24% for both years. In both years, the P concentration varied in the wood and leaves of bearing and non-bearing shoots in the ranges of 0.11–0.22% and 0.17–0.31%, respectively, while this range was 0.13–0.26% for the
fruits. In 1-year-old shoots, the P concentration followed highly different patterns based on organs (wood, leaf and fruit) and vegetative period. At the beginning of vegetative period, the P concentration in the woody part was about 0.08%. In parallel with the progress of the vegetative period, it initially showed a partial increase, and then, a decrease. The P concentration with the highest value of 0.14% before harvesting decreased down to the value of 0.10% at the end of the production season. The P concentration in the leaves was similar to the P concentration of the woody part at the beginning of the season. The leaf P concentration showed a variable course throughout the vegetative period. It was observed that there were low reductions in the P concentration at the end of harvesting-beginning of the winter stage and following periods.

The fruit P concentration was higher than the P concentrations of the leaf and wood parts. The fruit P concentration showed an increase from the beginning of the vegetation period (0.14%) to the end of harvesting (0.20%).

Figure 2. Biomass formation trends.

Figure 3. Biomass distribution in different organs.
The P uptake in the organs of <1-year-old shoots showed a similar course in both years. While it varied in the range of 5.6–126.1 g/tree in the first year at the beginning of the vegetative period and continuing toward the end of harvesting, and it varied in the range of 13.3–154.0 g/tree in the second year.

The period with the highest daily P uptake was the period from flowering (15\textsuperscript{th} day) to the beginning of fruit setting (28\textsuperscript{th} day) in both years, and it was found as 2.06 and 2.38 g/tree/day for the 1\textsuperscript{st} and 2\textsuperscript{nd} years, respectively (Figure 5).
The total P accumulation amount determined in the harvesting period averaged 140 g/tree for both years, and the shares of the leaves, fruits and shoots in this value were 89, 32 and 19 g/tree, respectively. The ranking of different organs in the P accumulation amount at harvest is given in Figure 6.

**Figure 5.** Phosphorus uptake trends in different organs (B = Branch, L = Leaf, F = Fruit).
Discussion

It was observed that the total P amount accumulated throughout one production season was 140 g/tree, and 23% of this belonged to the fruits. The periods where the P uptake was the greatest were between the 15th and 28th days corresponding to flowering and onset of fruit setting.

Considering the difference among the P amount that is applied, the availability of the fertilizer with P and the amount that is accumulated, it is understood that remobilization has an important role in the cycle of nutritional elements. In terms of more accurately presenting the nutritional element amounts provided by remobilization, it is believed that studies to be conducted with radioactive elements will provide clarity for this issue.

Disclosure Statement

The authors have not declared any conflict of interest.

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