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Influence of Three Different Rootstocks on Nutrient Dynamics of Peach Trees

Richardson Bien-Aime and Juan Carlos Melgar

Department of Plant and Environmental Sciences, Clemson University, 105 Collings Street, 204 Biosystems Research Complex, Clemson, SC 29634, USA

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Abstract. **Peach tree cultivation in the southeastern United States faces challenges of inefficiency in fertilization practices, which often leads to overfertilization and environmental pollution. Rootstocks significantly influence nutrient dynamics; however, their impact on nutrient uptake is not well understood. This study evaluated the effects of three peach rootstocks ('MP-29', 'Guardian®', and 'Lovell') on the nutrient composition of peach tree organs (leaf, fruitlet, fruit, and pruned wood) and the total nutrient removal through harvested fruit for 2 years. The study was carried out at an experimental orchard in South Carolina, and comprised 27 'Carored' peach trees on each rootstock in a randomized complete block design. Pruning wood, fruitlets, fruit, and leaves were collected throughout the year, and tissue analyses were performed. Rootstock influenced nutrient uptake and partitioning. Specifically, trees on 'Guardian®' exhibited higher N, P, and Ca, and Mg concentrations in fruitlets than 'MP-29'. Additionally, trees grafted on 'Guardian®' had the highest K concentration in leaves and fruit. The nutrient removal through harvested fruits was lowest for trees on 'MP-29'. These findings highlight the importance of rootstock selection in developing fertilization strategies that optimize nutrient management, improve yield efficiency, and reduce environmental impact.**

Meeting tree nutritional demands is essential for maintaining tree health, growth, and productivity. However, these requirements vary based on orchard-specific factors, including fertilization history, tree age, and cultivar (Melgar et al. 2022). Many studies have been published regarding the influence of rootstocks on nutrient uptake and partitioning in peach trees in different peach-producing regions [Almaliotis et al. (1995) and Roussos et al. (2021) in Greece; Ben Yahmed et al. (2020), Font i Forcada et al. (2020), Jiménez et al. (2008), Mestre et al. (2017), and Zarrouk et al. (2005) in Spain; Mayer et al. (2015) and Padilha Galarça et al. (2015) in Brazil; and Caruso et al. (1999) in Italy]. However, only two studies have addressed this topic in the United States [Reighard et al. (2013) and Shahkoomahally et al. (2020)], with a focus on how rootstocks influence the concentration and content of leaf nutrients and fruit nutrients, but without exploring how rootstocks influence nutrient concentration in other organs that are removed from the tree (i.e., pruning wood, fruitlets, and harvested fruit), which can influence tree requirements and fertilization recommendations. Given the significant influence of rootstocks on nutrient dynamics, understanding their role in nutrient removal through various tree organs is critical for refining fertilization strategies.

The rootstock forms the lower portion of a grafted tree, encompassing the tree root system. In fruit production, rootstocks are crucial in managing tree size and enhancing tolerance/resistance to various abiotic and biotic stresses such as soil physicochemical characteristics (e.g., calcareous or heavy clay soils) (Reighard and Loreti 2008), soil-borne diseases and pests (Beckman et al. 2012), cold temperatures (Layne 1987; Reighard and Loreti 2008), flooding (McGee et al. 2021; Ziegler et al. 2017), or drought (Lordan et al. 2017). By selecting appropriate rootstocks, growers can effectively influence the content and transport of hormones associated with tree growth and vigor and ensure optimal fruit yield and quality by improving parameters such as trunk cross-sectional area, branch angle, biennial bearing, leaf temperature, gas exchange, return bloom, budbreak, crop load, fruit size, and yield efficiency (Lordan et al. 2017).

An example is the 'Guardian®' rootstock, which was codeveloped by scientists at Clemson University and the U.S. Department of Agriculture–Agricultural Research Service in 1993 (Okie et al. 1994) to address the specific challenge of peach tree short life, a disease complex that used to cause severe losses in peach production in the southeastern United States (Beckman et al. 2012). Therefore, 'Guardian®' has become the most used rootstock in the southeastern United States. However, 'Guardian®' is vulnerable to *Armillaria* root rot (Beckman et al. 1997), which has emerged as the leading cause of premature peach tree mortality in the region (Schnabel et al. 2005). A clonal plum × peach interspecific hybrid called 'MP-29' offers not only peach tree short life resistance comparable to that of Guardian but also enhanced resistance to *Armillaria* root rot (Beckman et al. 2012). 'Lovell' rootstock was widely used by peach growers in the southeastern United States before 'Guardian®' and is still used in other parts of the United States due to its adaptability to various soil types and production of uniform seedlings (Beckman et al. 2012; Reighard and Loreti 2008).

Orchard management practices such as fruit harvesting, pruning, and thinning contribute to nutrient removal from deciduous fruit trees. Nutrient removal through pruning, thinning, and fruit harvest directly affects soil fertility and fertilization requirements. Understanding how rootstocks affect these processes is essential for optimizing orchard nutrient management. Thus, research examining the influence of various rootstocks on the nutrient composition of aboveground parts of peach trees, such as thinned fruitlets, fruit, and pruned wood, is needed to understand the impact that fertilization programs can have on orchards with different rootstocks. Based on the abovementioned information, the present study aims to evaluate the influence of different rootstocks on the mineral composition of peach aboveground organs and the total amount of nutrients removed from the orchard. We hypothesize that rootstocks differentially influence nutrient uptake and partitioning, which could inform targeted fertilization strategies to improve efficiency and reduce environmental impact.

Materials and Methods

A field study was carried out at the Musser Fruit Research Center (Seneca, SC, USA, 34.61 N, 82.87 W) in 2023 and 2024. An orchard with 8-year-old 'Carored' peach trees budded onto three rootstocks ('MP-29', 'Lovell', and 'Guardian®') and trained in a perpendicular V system was used. Tree spacing was 1.5 m between trees and 6.7 m between rows (equivalent to a planting density of 978 trees/hectare). The orchard contained three rows; each row had three plots of nine trees separated by border trees, with each plot containing three subplots (one per rootstock), with three mature trees on the same rootstock in each subplot (Fig. 1). The plots and subplots were planted in a randomized complete block design to reduce experimental error between rows. Specifically, each row contained a sequence of plots repeated three times: row

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J.C.M. is is the corresponding author. E-mail: jmelgar@clemson.edu.

Border tree	Border tree	Border tree
Carored/MP-29	Carored/Guardian	Carored/Lovell
Carored/MP-29	Carored/Guardian	Carored/Lovell
Carored/MP-29	Carored/Guardian	Carored/Lovell
Carored/Guardian	Carored/Lovell	Carored/MP-29
Carored/Guardian	Carored/Lovell	Carored/MP-29
Carored/Guardian	Carored/Lovell	Carored/MP-29
Carored/Lovell	Carored/MP-29	Carored/Guardian
Carored/Lovell	Carored/MP-29	Carored/Guardian
Carored/Lovell	Carored/MP-29	Carored/Guardian
Border tree	Border tree	Border tree
Carored/MP-29	Carored/Guardian	Carored/Lovell
Carored/MP-29	Carored/Guardian	Carored/Lovell
Carored/MP-29	Carored/Guardian	Carored/Lovell
Carored/Guardian	Carored/Lovell	Carored/MP-29
Carored/Guardian	Carored/Lovell	Carored/MP-29
Carored/Guardian	Carored/Lovell	Carored/MP-29
Carored/Lovell	Carored/MP-29	Carored/Guardian
Carored/Lovell	Carored/MP-29	Carored/Guardian
Carored/Lovell	Carored/MP-29	Carored/Guardian
Border tree	Border tree	Border tree
Carored/MP-29	Carored/Guardian	Carored/Lovell
Carored/MP-29	Carored/Guardian	Carored/Lovell
Carored/MP-29	Carored/Guardian	Carored/Lovell
Carored/Guardian	Carored/Lovell	Carored/MP-29
Carored/Guardian	Carored/Lovell	Carored/MP-29
Carored/Guardian	Carored/Lovell	Carored/MP-29
Carored/Lovell	Carored/MP-29	Carored/Guardian
Carored/Lovell	Carored/MP-29	Carored/Guardian
Carored/Lovell	Carored/MP-29	Carored/Guardian
Border tree	Border tree	Border tree

Fig. 1. Arrangement of different treatments in the field.

1 contained 'Carored'/'MP-29', 'Carored'/'Guardian®', and 'Carored'/'Lovell'; row 2 contained 'Carored'/'Guardian®', 'Carored'/'Lovell', and 'Carored'/'MP-29'; and row 3 contained 'Carored'/'Lovell', 'Carored'/'MP-29', and 'Carored'/'Guardian®'.

All trees were subjected to the same current fertilization guidelines. Granular fertilizer was applied annually before bloom in early March at the rate of 224 kg ha^{-1} 19-19-19 N-P2O5-K2O, and after harvest, in late July, at the rate of 168 kg ha^{-1} 15N–0P_2O_5–40K_2O. These application rates are equivalent to 75.5 kg N ha^{-1}, which align with standard recommendations for commercial peach tree orchards in the southeastern United States (equivalent to 60 to 70 lb of actual N acre^{-1}) (Blaauw et al. 2025). While the orchard has microsprinklers for irrigation, supplemental irrigation was not needed in 2023 and 2024 as rainfall events over the last 3 weeks before harvest (which is when growers typically irrigate peach trees) provided 186 and 141 ml in 2023 and 2024, respectively. The trees were pruned in February each year, before budbreak (17 Feb 2023 and 24 Feb 2024). Summer pruning was not performed in this orchard. Pruning was carried out consistently and uniformly across all trees by the same commercial crew.

Throughout both years of the study, the following samples of vegetative and reproductive organs were collected: wood during winter pruning, fruitlets at thinning, fruit at harvest, and leaves during summer to monitor the nutrient status of the trees. Two types of pruned wood were collected yearly: 1-year-old and 2-year-old twigs. Twelve 1-year-old twigs (4 per tree, 2 per scaffold) between 20 and 25 cm long, and six 2-year-old twigs (2 per tree, 1 per scaffold) between 7.5 and 10 cm long were collected per plot. To ensure commercial fruit size, peach trees were thinned manually following commercial standards (three or four fruit per fruiting twig at a spacing of 15 to 20 cm) in April (18 Apr 2023 and 5 Apr 2024). Each year, thinning was carried out by the same crew to keep uniformity among years. Twenty-four fruitlets were collected yearly per replication (8 per tree, 4 per scaffold). Regarding fruit harvest, it consisted of three pick events every year (16 May, 19 May, and 23 May in 2023; 24 May, 28 May, and 31 May in 2024). At harvest, the weight of commercially ripe fruits from each tree was recorded for each pick. In addition, at the second pick each year, the average weight of a sample of 20 commercially ripe fruits was collected per plot (six to seven fruits per tree) to have an average fruit weight for each plot. These average weights were used after the third pick to be multiplied by the number of marketable dropped fruits counted under each tree of each respective plot to complete the yield for each tree (this number included any marketable fruit that could have fallen in between picks or been accidentally dropped during harvest). From the 20-fruit samples collected, two slices (including the exocarp and mesocarp) were taken from opposite sides of each fruit for nutrient analysis. In regard to leaf sampling for nutrient analyses, mature, fully expanded leaves were picked from the fourth or fifth node of current season shoots from all around the canopy of each tree during sample periods in Summer 2023 and 2024 (12 Jul 2023 and 14 Jun 2024). Finally, 36 leaves, including petioles, were collected per plot (12 per tree, 6 per scaffold).

The fresh weight (FW) of samples collected from each removal event (pruning, thinning, harvesting), as well as leaves from the summer sampling, was recorded; then, samples were oven-dried at 70 °C, and their dry weight recorded. Afterward, these tissues were ground and homogenized until they reached a particle size of ≤1 mm. Samples of 0.25 g of the resultant material were incinerated overnight at 600 °C in a muffle furnace (LE4/11 RC; Nabertherm, Lilienthal, Germany), leaving behind ashes that were subsequently dissolved in 10 mL of 0.1 M HCl and filtered through a 0.42-µm filter. Total N concentration was measured using a revised Dumas method (Harry and Jones 1991) at Clemson University's Agricultural Service Laboratory. P concentrations were assessed using the molybdenum blue colorimetric method (Murphy and Riley 1962). The concentrations of total K, Mg, and Ca were determined using an atomic absorption spectrophotometer (PinAAcle 500; Perkin-Elmer, Waltham, MA, USA).

Using previously recorded sample FW values, the nutrient content of each organ were calculated as by Zhou and Melgar (2019). In brief, the nutrient concentration in the organ was multiplied by its respective dry weight and divided by the sampleFW. Then, the content per tree was calculated by multiplying by the total FW collected from the tree.

The statistical analyses of the current study followed a randomized complete block design. The one-way analysis of variance test was used to analyze the factor's effect on the parameters. Tukey's honestly significant difference mean separation test was performed for multiple treatment comparisons. The data were analyzed using Excel (version 18.2405.1221.0; Microsoft, Redmond, WA, USA) and JMP® statistical software (version 16.0.0; SAS Institute, Cary, NC, USA).

Results

Rootstocks did not influence nutrient concentrations in pruned wood, except for 2-year-old wood from trees on 'MP-29', which had higher N concentration than wood from 'Guardian®' in 2023, and pruned 1-year-old wood from trees on 'Lovell', which showed higher K concentration than wood from trees on 'Guardian®' in 2024 (Table 1). However, these differences were not consistent across

Table 1. N, P, K, Ca, and Mg concentrations (% DW) of different tissues from ‘MP-29’, ‘Lovell’, and ‘Guardian’ rootstocks.

		Nutrient (% DW)[i]									
		N (%)		P (%)		K (%)		Ca (%)		Mg (%)	
Removal activity	Rootstock	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
Pruned wood at 1 years old	MP-29	1.36 a	1.03 a	0.19 a	0.14 a	1.28 a	**0.97 ab**	1.52 a	1.62 a	0.25 a	0.16 a
	Lovell	1.41 a	0.94 a	0.20 a	0.14 a	1.25 a	**1.02 a**	1.38 a	1.66 a	0.26 a	0.17 a
	Guardian	1.31 a	0.83 a	0.18 a	0.15 a	1.29 a	**0.94 b**	1.50 a	1.73 a	0.26 a	0.17 a
Pruned wood at 2 years old	MP-29	**0.43 a**	0.64 a	0.11 a	0.14 a	0.37 a	0.44 a	0.47 a	1.28 a	0.07 a	0.14 a
	Lovell	**0.40 ab**	0.82 a	0.12 a	0.14 a	0.38 a	0.39 a	0.49 a	1.15 a	0.07 a	0.14 a
	Guardian	**0.38 b**	0.63 a	0.13 a	0.14 a	0.37 a	0.40 a	0.46 a	1.16 a	0.08 a	0.16 a
Thinned fruitlets	MP-29	**2.27 b**	2.83 a	**0.47 b**	0.37 a	**1.40 b**	2.76 a	0.04 a	**0.12 b**	**0.28 b**	**0.20 b**
	Lovell	**2.36 ab**	2.64 a	**0.49 ab**	0.39 a	**1.57 a**	2.92 a	0.05 a	**0.14 a**	**0.34 a**	**0.22 a**
	Guardian	**2.54 a**	3.00 a	**0.53 a**	0.38 a	**1.39 b**	2.74 a	0.05 a	**0.14 a**	**0.34 a**	**0.21 ab**
Harvested Fruits	MP-29	1.07 a	1.03 a	0.39 a	0.20 a	**0.99 b**	**1.00 b**	0.01 a	0.02 a	0.13 a	0.10 a
	Lovell	1.11 a	1.04 a	0.43 a	0.19 a	**0.92 b**	**1.14 a**	0.01 a	0.02 a	0.15 a	0.10 a
	Guardian	1.18 a	1.16 a	0.41 a	0.21 a	**1.18 a**	**1.07 ab**	0.01 a	0.02 a	0.14 a	0.10 a
Summer leaves	MP-29	2.22 a	2.51 a	0.34 a	**0.26 ab**	5.16 a	**3.93 b**	2.10 a	1.65 a	**0.67 b**	**0.49 b**
	Lovell	2.20 a	2.57 a	0.36 a	**0.27 a**	5.45 a	**4.28 ab**	2.39 a	1.63 a	**0.84 a**	**0.58 a**
	Guardian	2.26 a	2.44 a	0.38 a	**0.25 b**	5.00 a	**4.36 a**	2.39 a	1.72 a	**0.92 a**	**0.61 a**

[i] Bold values with different letters within columns and for each removal activity indicate significant differences among rootstocks using Tukey’s honestly significant difference mean separation test ($\alpha = 0.05$). The same letters indicate there is no significant difference between treatments.
DW = dry weight.

rootstocks or nutrients in both years. In contrast, rootstocks had a significant impact on all nutrient concentrations in thinned fruitlets: ‘Guardian®’ trees accumulated more N (2023), *P* (2023), Ca (2024), and Mg (2023) than ‘MP-29’. Rootstocks also had a considerable influence on K concentration of fruits and summer leaves, with trees on ‘MP-29’ having lower fruit K concentrations than trees on ‘Guardian®’ or ‘Lovell’.

Trees on ‘Guardian®’ also accumulated higher concentrations of Mg (in 2023 and 2024) and K (2024) in leaves than on ‘MP-29’ but had lower leaf P concentration (2024) than trees on ‘Lovell’. Annual leaf analysis (summer leaves; Table 1) showed that Ca and Mg (only in 2024) were within the sufficiency range, while K concentrations were much higher than the recommended sufficient level across all rootstocks (Johnson 2008). Meanwhile, N was within (2023) or just above (2024) the deficiency range. Trees on ‘Lovell’ and ‘Guardian®’ rootstocks also showed Mg concentrations higher than the recommended sufficiency level, whereas those on ‘MP-29’ remained within the sufficiency range in 2023.

Considering peach tree yield across both years, nutrient removed (kg/tree) through fruit was significantly lower for trees on ‘MP-29’ compared with those on ‘Lovell’ and ‘Guardian®’. Trees on ‘MP-29’ produced significantly lower yields than those on ‘Guardian®’ or ‘Lovell’, which had similar yield performance (Table 2). Consequently, trees on ‘Guardian®’ and ‘Lovell’ consistently removed similar—and higher—amounts of macronutrients per tree in both years compared with those on ‘MP-29’ (Table 3), with N and K being the primary nutrients removed regardless of rootstock, followed by P, Mg, and Ca.

Table 2. Average yield from trees on ‘MP-29’, ‘Lovell’, and ‘Guardian’ rootstocks in 2023 and 2024.

	Average yield (kg/tree)[i]	
Rootstock	2023	2024
MP-29	**15.9 b**	**20.4 b**
Lovell	**22.0 a**	**24.8 a**
Guardian	**22.7 a**	**26.7 a**

[i] Bold values with different letters within columns and for each removal activity indicate significant differences among rootstocks using Tukey’s honestly significant difference mean separation test ($\alpha = 0.05$). The same letters indicate there is no significant difference between treatments.

Discussion

Rootstocks influenced the nutrient concentrations of the aboveground organs collected at different removal events throughout the year. Our results showed that rootstocks primarily influenced nutrient concentration of thinned fruitlets and harvested fruit; specifically, trees on ‘MP-29’ had significantly lower fruitlet concentrations of N, P, Ca, and Mg than those on ‘Guardian®’ and lower fruitlet K and Mg than trees on ‘Lovell’. Similarly, fruit from trees on ‘MP-29’ had numerically lower N concentration than those from trees on ‘Guardian®’ (nonsignificant but consistent for both years), as well as lower K concentration than ‘Guardian®’ (2023) and ‘Lovell’ (2024).

In general, previous studies on peach (Mestre et al. 2015; Zarrouk et al. 2005), plum (Mestre et al. 2017), cherry (Moreno et al. 2001), and apricot (Rosati et al. 1997) rootstocks report that less vigorous rootstocks show lower leaf nutrient concentrations, suggesting that dwarfing rootstocks could be less efficient in absorbing nutrients from the soil (Mestre et al. 2017). The mechanisms behind rootstock influence on nutrient uptake and partitioning are not well known; most rootstock studies for *Prunus* species focus on the effects on survivability, growth, yield, and yield efficiency, and there is a need to study root system’s architecture of *Prunus* rootstocks (Lesmes-Vesga et al. 2002). ‘MP-29’, a semidwarfing plum × peach interspecific hybrid (Beckman et al. 2012), has anatomical and morphological differences compared with ‘Guardian®’ or ‘Lovell’, for instance, visual observations indicate that ‘MP-29’ trees have finer roots than ‘Guardian®’ or ‘Lovell’; however, the influence of root morphology, size, and growth on nutrient uptake and partitioning is yet to be studied in *Prunus* rootstocks. Over the last decades, most studies comparing semidwarfing rootstocks and rootstocks with less vigor than traditional ones concluded semidwarfing and reduced-vigor rootstocks were less efficient in nutrient uptake (Rosati et al. 1997; Ystaas 1990).

Fruit thinning is essential to manage competition for carbohydrates in fruit growth (Bussi et al. 2005). The differences among cultivars in nutrient concentrations of thinned fruitlets were similar to the differences observed among cultivars reported by El-Jendoubi et al. (2013) or between trees of different ages (Zhou and Melgar 2019, 2020). Also, the values reported by El-Jendoubi et al. (2013) and Zhou and Melgar (2019, 2020) correspond to fruitlet and fruit from trees on other rootstocks (‘GF677’, ‘Bailey’, and ‘Tennessee Natural’), which might also explain some of these differences. Fruitlets had some of the largest nutrient concentrations among all organs, but the total weight of thinned fruitlets is small compared with that of fruit at harvest. As a consequence, the estimated nutrient content removed during thinning is between around 10 to 20 times smaller than that of fruit at harvest (Zhou and Melgar 2019, 2020). Nevertheless, while thinning time or crop load does not significantly affect leaf nutrient concentration (Blanco et al. 1995; Drogoudi et al. 2009), the effect of these factors on fruit nutrient concentration and tree nutrient status have not been studied. Based on our results on thinned fruitlet concentrations and, considering similar or higher amounts of fruitlets removed on ‘Guardian®’ compared with ‘MP-29’ (due to ‘Guardian®’ vigor and size being larger than ‘MP-29’), trees on ‘Guardian®’ will need more N, P, Ca, and Mg for a similar crop load due to higher fruitlet nutrient removal.

Table 3. Total amount of removed N, P, K, Ca, and Mg estimated in harvested fruits from 'MP-29', 'Lovell', and 'Guardian' rootstocks in 2023 and 2024.

	Total elements removed from harvested fruits (g/tree)									
	N		P		K		Ca		Mg	
Rootstock	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
MP-29	23.0 b	28.4 b	8.5 b	5.38 b	21.3 c	27.4 b	0.29 b	0.52 b	2.92 c	2.59 b
Lovell	37.4 a	37.2 a	13.6 a	6.84 a	29.1 b	40.8 a	0.43 a	0.64 a	4.84 a	3.79 a
Guardian	33.2 a	40.7 a	12.4 a	7.20 a	35.4 a	37.3 a	0.43 a	0.70 a	4.08 b	3.69 a

Values with different letters within columns and for each removal activity indicate significant differences among rootstocks using Tukey's honestly significant difference mean separation test ($\alpha = 0.05$). The same letters indicate there is no significant difference between treatments.

Regarding fruit, differences between years are often observed in fruit mineral concentrations, particularly in N, Ca, and Mg, regardless of the treatments applied (Fallahi et al. 2002). This variation is frequently attributed to fluctuations in crop load from one year to the next, which can affect the consistency of treatment effects. Similar observations have been reported by other researchers, such as Perring and Pearson (1989) and Poling and Oberly (1979), who also noted the common occurrence of year-to-year variations in nutrient concentrations. Interestingly, while leaf nutrient concentrations were within or above the sufficiency ranges, there were oscillations between years, and the differences in leaf nutrient concentrations due to rootstocks (P, K, and Mg sampled in mid-July) did not align with the differences observed in fruitlet or fruit nutrient concentrations (sampled in mid-April and mid-to-late May, respectively), which highlights the complex interactions between rootstock, annual conditions, and nutrient uptake. These discrepancies between fruit and leaf for the different minerals can be due to different fruit and leaf sampling times ('Carored' is an early-season cultivar, and fruit was harvested in May, while leaves were sampled in midsummer), nutrient mobility, as well as rootstock effects on nutrient partitioning due to their hydraulic conductivity, xylem anatomy, and ability to uptake nutrients (Valverdi et al. 2019).

Overall, trees on 'Guardian®' rootstocks were found to have higher nutrient concentrations in fruits than trees on 'MP-29'. Since fruit is the only organ that is permanently removed from the orchard, higher nutrient concentration in fruit translates into a need for providing nutrients at higher quantities for 'Guardian®' than for 'MP-29'. The differences in fruit N, P, and Ca concentrations among cultivars were also similar to those observed by El-Jendoubi et al. (2013) and Zhou and Melgar (2019, 2020), although K and Mg concentrations in harvested fruit were lower than in those studies. It is important to recognize that nutrients lost through thinning, pruning, and the resorption and further drop of leaves during fall season remain in the orchard, allowing growers to recycle these nutrients through leaving these materials decompose in the orchard, as well as mulching or composting. However, since the fruit is the only organ leaving the orchard, the nutrients lost during harvest represent a permanent removal from the system. It has been widely documented that various rootstocks can influence vegetative growth rates and yield efficiency (Fallahi and Rodney 1992; Roose et al. 1989; Wheaton et al. 1991).

Based on fruit yield in our study, we found that trees on 'MP-29' rootstocks produced significantly lower yields than those on 'Guardian®' and 'Lovell' rootstocks. 'MP-29' are semidwarfing rootstocks and trees on 'MP-29' have lower vigor and size than those of 'Guardian®' or 'Lovell' (Minas et al. 2022) and could, therefore, be planted at a higher density to maintain orchard productivity. While all trees in this study were subjected to the same current fertilization guidelines, nutrient removal through harvested fruit was significantly lower in trees on 'MP-29' rootstock compared with those on 'Lovell' and 'Guardian®'.

These results indicate that fertilizer adjustments could be made based on rootstock genotypes; for instance, less nutrients are removed through thinning and harvesting from trees on 'MP-29' compared with 'Guardian®' and 'Lovell', which indicates that trees on 'MP-29' may require lower levels of nutrients to maintain their nutrient balance. While we did not analyze nutrient concentrations in roots, trunks, and primary scaffold branches, we cannot rule out similar uptake but increased nutrient storage as reserves in these organs; nevertheless, if that was the case, these nutrients would be available for future remobilization, and still less fertilizer would be required for trees on 'MP-29'. In contrast, trees on 'Guardian®' and 'Lovell' consistently showed higher nutrient removal than 'MP-29', particularly of N and K, meaning growers using these rootstocks should prioritize replenishing these macronutrients after harvest to maintain tree productivity and soil health. Similarly, the use of calcitic or dolomitic lime by peach growers in the southern United States to adjust soil pH (Clemson University Agricultural Soils Lab 2023), which also supplies Ca and Mg, can be strategically adjusted based on rootstock-specific nutrient needs. For instance, trees on 'MP-29' rootstock lost significantly less Ca through thinning and harvesting than 'Lovell' or 'Guardian®', indicating that 'MP-29' may require less Ca supplementation overall. In contrast, 'Guardian®' rootstock trees used higher Ca and Mg levels, implying a greater need for these nutrients. Therefore, for 'MP-29' rootstocks, growers could consider using calcitic lime (which primarily provides Ca) rather than dolomitic lime to avoid excess Mg and prevent overapplication of Ca (e.g., if they applied calcitic lime, they might not need another Ca fertilizer, especially for 'MP-29'). If, based on leaf and/or soil analysis, Mg is needed, it could be applied separately. Dolomitic lime is recommended for 'Guardian®' or 'Lovell' rootstocks, as it will supply both Ca and Mg, which aligns with their higher nutrient losses through thinning and harvesting.

Conclusions

This study proves that peach rootstocks significantly influence nutrient concentrations and partitioning in various tissues. 'Guardian®' rootstock generally had higher N, P, Ca, and Mg levels in thinned fruitlets than 'MP-29', which showed the lowest concentrations. Rootstock influenced K in both leaf and fruit tissues, with trees on 'Guardian®' and 'Lovell' showing the highest concentrations. Nutrient loss through fruit was lowest in 'MP-29' across all nutrients, while 'Guardian®' and 'Lovell' had similar losses, with N and K being the most removed nutrients. Additionally, nutrient removal through fruit was significantly lower for 'MP-29' trees than for those on 'Lovell' and 'Guardian®', with N and K as the primary nutrients removed from the orchard, followed by P, Mg, and Ca. These findings suggest that nutrient management should be tailored to these nutrient removal patterns. Future studies could focus on developing rootstock-specific nutrient management strategies to optimize fertilization and improve yield efficiency, particularly by investigating tailored protocols for 'MP-29', 'Guardian®', and 'Lovell'. Research on nutrient cycling of pruning and thinning residues left in the orchard, specifically their decomposition, nutrient release to the soil, and uptake rates by different rootstocks, could also provide valuable insights on the tree–soil nutrient balance for the optimization of fertilizer orchard needs. Further, an extension to other climatic zones may provide region-specific performance data for rootstocks.

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