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Original Research Paper

Evaluation of nutrients removed and recycled in a commercial peach orchard over a 14-years-production cycle

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Abstract: Understanding nutrient dynamics within a peach orchard is fundamental to the development of accurate nutrient management practices. The present study investigated the nutrient uptake and redistribution in a 14-years-old commercial orchard in the Po valley. At the end of the experiment, trees were harvested, biomass and organ nutrient concentration were determined. Skeleton and roots accounted for the highest plant biomass, followed by fruits at harvest, pruned wood and abscised leaves; thinned fruits were less than 1 kg tree^{-1}. The difference between the amounts of nutrients in leaves sampled in summer and in autumn (at abscission) was used to estimate the fraction of nutrients remobilized during the vegetative season inside the tree. The decrease of N, P, S, Cu, Mn and Zn concentration in abscised, compared to summer-sampled leaves was the result of the translocation of nutrients into fruits and storage organs. Nutrient circulation in a commercial nectarine orchard was calculated by determination of the fractions of each nutrient recycled (sum of nutrients in abscised leaves, thinned fruits and pruned wood) and remobilized (sum of nutrients in fruits at harvest, roots and skeleton). In our experimental conditions, on average, nectarine Stark RedGold showed an annual request of (in kg ha^{-1}) 100, 17, 73, 129, 16, and 6 of N, P, K, Ca, Mg and S, respectively. More than half of these quantities were recycled in the orchard and returned back to the soil; consequently, if the nutrient use efficiency is maximized, the fertilization of nectarine requires only small amount of external inputs.

Keywords: *Prunus persica* var. *nucipersica*; nutrient remobilization; macronutrient; micronutrient; compost

1. Introduction

Fertilization is an essential part of fruit tree orchard management, especially under intensive cultivation (Krige and Stassen, 2008; Kangueehi et al., 2011) since through the maintenance of a proper tree nutritional status plants can have equilibrated growth and optimal yield. However, often the supply of nutrients exceeds plant need with negative effects on tree vegetative and productive balance as well as on environmental pollution. Overfertilization may adversely affect fruit yield and quality because of both direct and indirect effects on flowering, fruit set, fruit growth and pathogen pressure (Weinbaum et al., 1992). An excess of nitrogen (N), for example, by stimulating vigorous vegetative growth, could induce shading of fruiting wood, delay of fruit maturity and enhancement of the incidence of fungal diseases (Day, 1997). Nutrient surplus is considered one of the main cause of water pollution (Volk et al., 2009); indeed, in Europe, it was estimated that 55% of water pollution is caused by agricultural practices (Kersebaum et al., 2003). According to global estimates (Galloway et al., 2004), nearly 50% of N applied with fertilizer is removed by crops, 2 to 5% is stored in the soil and the residual 45-48% is lost through leaching in the ground water or emitted into the atmosphere, determining detrimental effects on the environment. The improper management of fertilization, and in particular N, causes serious environmental degradation in terms of increased global warming, soil acidification, and water quality impairment (Han et al., 2017; Li et al., 2018) with detrimental effects on ecological balance and human health (Mencio et al., 2016; Wang et al., 2013).

Consequently, adequate and equilibrated fertilizer supply is essential to guarantee optimal plant growth, fruit yield and quality, holding special attention to environmental issue. This will be achieved only when annual nutrient removal from the tree is known in detail.

In a recent study on peach (El Jendoubi et al., 2013) it was demonstrated that each nutrient was characterized by a precise allocation pattern. Fruits were found to be the largest sink for potassium (K), followed by phosphorous (P) and N,; whereas magnesium (Mg) and calcium (Ca) were mainly accumulated in abscised leaves. In addition, nutrients have a seasonal pattern of accumulation; during the vegetative season, part of the absorbed nutrients is allocated to fruits and removed from the orchard at harvest, while those partitioned to shoots and leaves can be translocated within the tree, or are transferred to the soil via abscised leaves and pruning wood, where they can become available for root uptake again.

According to several authors (Stassen et al., 1981a, b; Caruso et al., 1993; El Jendoubi et al., 2013), most of leaf P and K is transported to the permanent structures before leaves abscission, while Ca and Mg are largely lost. In the literature there are contrasting evidences regarding iron (Fe) re-translocation at leaf fall mainly linked to plant species (Rongli et al., 2011); re-translocation in autumn was not found only in peach trees (El Jendoubi et al., 2013), but also in oak and beech (Abadía et al., 1996).

Estimated peach nutrient requirements are 60-340 g N tree^{-1}, 5-53 g P tree^{-1}, 74-425 g K tree^{-1}, 25-518 g Ca tree^{-1} and 9-74 g Mg tree^{-1} (Stassen, 1987; Krige and Stassen, 2008; El Jendoubi et al., 2013). These wide differences between values is probably due to different environmental conditions, orchard managements and cultivars. According to El Jendoubi et al. (2013), the recycled fraction is of 80-270 g N tree^{-1}, 7-36 g P tree^{-1}, 60-293 g K tree^{-1}, 58-503 g Ca tree^{-1} and 19-66 g Mg tree^{-1} evidencing that most of plants needs could potentially be satisfied by the release of nutrients from tree pruning and leaf fall mineralization.

The sustainable management of nutrition in orchard aims at optimizing the use of internal sources of nutrients and reducing the need for external nutrient inputs and the risk of losses (Hansen et al., 2017; Wang et al., 2020). The knowledge of the distribution of nutrients in different organs could give a precise outlook on plant mineral requirements and thus useful information for setting up precise and environmental friendly fertilization plans.

The aim of the present experiment was to assess the amount of nutrients removed and recycled in a commercial nectarine orchard during its 14-years life-time.

2. Materials and Methods

2.1. Orchard description and experimental conditions

The investigation was conducted from August 2001 to December 2014 in a commercial nectarine orchard located near Ravenna (44°27’ N; 12°13’ E), in the south-eastern part of the Po valley (Italy), 6 km from the Adriatic Sea coastline. The climate in the area is temperate with an annual precipitation, measured in the period of the experiment, of 465 mm and an average temperature of 14.6 °C (ARPAE, 2021). The orchard was planted in 2001 on a Calcaric Cambisol (FAO, 2015) soil previously described by Baldi and co-authors (2018). The nectarine [*Prunus persica*, Batsch var. *nucipersica* (Bockh.) Schn.] Stark RedGold, grafted on hybrid GF677 (*Prunus persica* × *Prunus dulcis*) was spaced at 5.0 m × 3.8 m frame (526 trees ha^{-1}) and trained to a “delayed-vasette” system. Orchard was managed according to the Integrated Crop Management guideline of the Emilia-Romagna region for pest control (Emilia-Romagna, 2020). Plants were regularly watered with a drip irrigation system to replace the daily evapotranspiration rate. The soil was tilled superficially (0.25 m) in a 2-m-wide strip on the tree row, while alleys were covered with spontaneous grass and mowed three times a year and left on the ground. Since orchard plantation (2001), mineral and organic fertilization were compared as reported in Baldi et al. (2018; 2021) and Toselli et al. (2019).

In detail, mineral fertilization was managed according to Integrated Crop Management Guideline of the Emilia-Romagna region (Emilia-Romagna, 2020), that included P at 100 kg ha^{-1} and K at 200 kg ha^{-1},

applied only at planting and N (70 kg ha^{-1}) applied yearly, split in May (60% of the total rate) and September (40%). In 2004, N application rate was increased to 120 kg ha^{-1} $year^{-1}$ and from 2006 to 130 kg ha^{-1} $year^{-1}$. Compost was supplied at a rate of 10 Mg dry weight (DW) ha^{-1} $year^{-1}$ (corresponding to 240 kg N ha^{-1} $year^{-1}$), split as for mineral fertilization, applied on a 2-m-wide tree row and tilled into the soil to a depth of 0.25 m. Compost was obtained from domestic organic wastes (50%) mixed with pruning material from urban ornamental trees and garden management (50%) after a 3-month stabilization and was characterized by an average N of 21.1 g kg^{-1} DW, organic carbon of 234 g kg^{-1} DW and a C/N ratio of 11.1 (Baldi et al., 2018). Following the traditional farm management, pruned wood was left on the ground and chopped.

2.2. Plant sampling and analysis

Every winter (from 2002 to 2014) trunk circumference was measured 0.20 m above the grafting point and fresh pruned wood weight was recorded. In 2012 and 2014, a sample of fresh pruned wood was oven-dried, milled at 2 mm and analyzed for macro and micronutrient concentration. Nitrogen was determined with the Kjeldahl (Schumann et al., 1973) method. Phosphorus, K, Ca, Mg, sulphur (S), copper (Cu), Fe, manganese (Mn) and zinc (Zn) were determined by plasma spectrometer (ICP-OES; Ametek Spectro, Arcos, Kleve, Germany) after samples mineralization (US EPA Metods 3052; Kingston 1988) in an Ethos TC microwave lab station (Milestone, Bergamo, Italy).

In spring 2011, 2012 and 2014, thinned fruits were collected, weighted and a representative sample of 200 g fresh weigh (FW) was oven dried, milled and analyzed for macro and micronutrients concentration as previously described.

On July 2014, a sample of 40 young fully expanded leaves was collected from the apical part of the shoots and leaf area was measured with a portable area meter (Li-3000, LiCor inc., Lincoln, Nebraska). Leaves were then washed, oven-dried, milled at 2 mm, and analyzed as described for other organs.

Starting from 2004, at harvest, fruit weight per plant was recorded at three fruit picking and total plant yield was calculated as the sum of the three pickings. In 2012 and 2014, on a representative sample of 20 fruits collected at the main picking (the one when most of the fruits were picked), FW and DW of flesh and kernel were measured separately; dried flesh and kernel were separately milled, weighted and analyzed as described before.

In September 2012 and 2014, one tree per plot (eight in total) was enclosed into a plastic net, in order to collect all abscised leaves that were then measured for leaf area, fresh and dry weight. In December 2014, the same eight trees were harvested, and individually divided into roots, trunk, branches (age > 2 years) and current year shoots (twigs) and separately weighted. A sub-sample of this material was oven-dried, milled and analyzed for macro and micronutrients concentration as previously described.

2.3. Data handling and statistical analysis

No statistical differences between treatments were observed in nutrient concentration and plant biomass (Baldi et al., 2018, 2021; Toselli et al., 2019), and for this reason data collected in the mineral and compost plots were pooled together. We estimated: 1) the amount of nutrients removed during the fourteenth year of orchard life and 2) the total amount of nutrients removed during the 14-years of commercial lifetime.

For the first goal, nutrient concentration at the end of the experiment was multiplied by the total dry mass of each organ. The skeleton biomass was calculated as the sum of trunk, branches and twigs older than 2 years (without pruning wood) measured at the end of the experiment. Skeleton and root nutrient content were divided by the age of the orchard (13) assuming a constant annual increase of their weight and nutrient concentration, and considering the increase of the first year (2001) negligible, because the plantation was made at the end of the year.

For the second goal, DW of pruned wood and fruit of all harvests were calculated assuming the same relationship between FW and DW measured in 2012 and 2014. Since abscised leaf biomass was measured only in 2012 and 2014, the linear regression between pruned wood DW and leaf DW calculated in these two years (leaf DW = 0.2471 pruned wood DW + 1.9283; R^2=0.325; P=0.003) was used to estimate leaf DW for all other years. Nutrient concentration in all the years but 2012 and 2014 was estimated as the average concentration measured in 2012 and 2014 in pruned wood, abscised leaves, fruits at harvest and thinned fruits.

The knowledge of annual nutrients content in tree organs allowed us to calculate two fractions of nutrients: recycled and removed. The amount of recycled nutrients up-taken during the growing season and returned to the soil in the fall was calculated as the sum of the fractions in abscised leaves, thinned fruits and pruned wood multiplied by the number of plants per hectare (526 trees ha^{-1}). Removed nutrients up-taken and moved outside the orchard were, calculated as the sum of nutrient content in roots, skeleton, and fruits (stone and flesh), each multiplied by the number of trees per hectare. Total orchard annual demand was calculated as the sum of nutrients removed and remobilized.

Data of leaf nutrients content in summer and at natural abscission (winter) were statistically analyzed with ANOVA as in a complete block design, for the two-sampling times and eight replicates. When analysis of variance showed a statistical effect of sampling time ($P \leq 0.05$), means were separated by Student Newman Keuls test.

All data are shown as means ± standard errors (n=8). The relative distribution of macro and micronutrients in the tree was calculated as percentage of each organ in relation to the whole plant, measured at the end of the investigation.

3. Results

Taking into account the organs produced in 2014, DW of fruits (collected at harvest) was higher than that of pruned wood and abscised leaves (which had a similar biomass around 4 kg $tree^{-1}$), and finally thinned fruits that had the lowest DW (Figure 1A). With regard to the perennial part of the tree, the skeleton was twice the DW of the roots (Figure 1B).

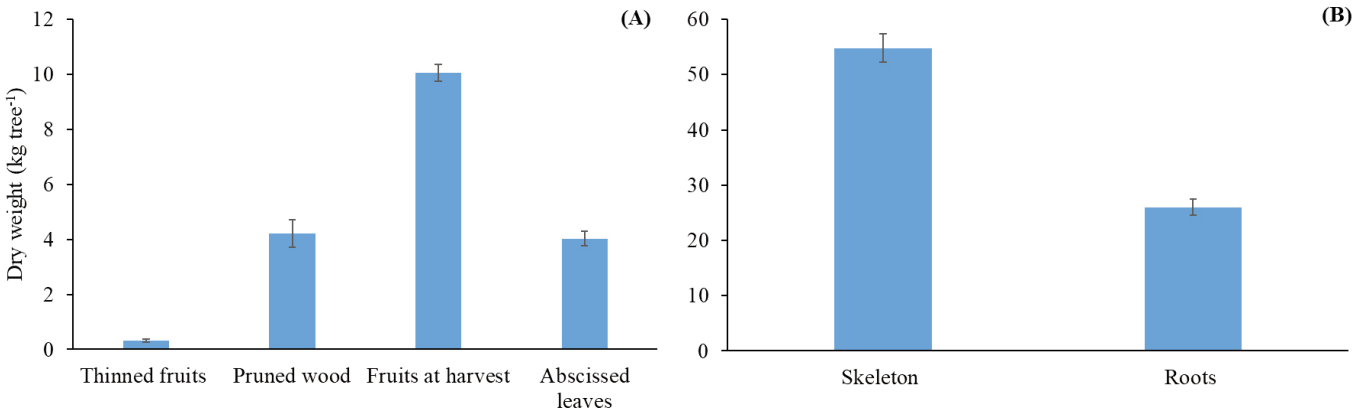

Figure 1. Tree organs dry weight as produced in 2014 season (A) and during the entire lifetime (B). Values are average of eight replicates ± standard error.

Tables 1 and 2 report the annual nutrient demand (recycled and removed) by the 14-years-old nectarine orchard. At the end of the experiment, the highest quantity of N was found in fruits (collected at harvest) and abscised leaves, followed by pruned wood (Table1); the lowest quantity of N was found in thinned fruits (Table 1). The annual fraction of N recycled in the orchard (53.4 kg ha^{-1}) was similar to that removed from the orchard (55.0 kg ha^{-1}). Phosphorous was mainly accumulated in fruits at harvest and abscised leaves, followed by woody organs (pruned wood, skeleton and roots) while thinned fruits had small quantities of P (Table 1). Abscised leaves were the strongest sink for K, while thinned fruits and roots were the weakest (Table 1). As for other macronutrients, abscised leaves accumulated the

highest amount of Ca and Mg; remarkable quantities of these macronutrients were also measured in wooden organs, while fruits (thinned and harvested) accounted for little portions (Table 1). Sulphur was mainly accumulated in leaves, followed by pruned wood and skeleton, while roots and thinned fruits accumulated little quantities of this nutrient (Table 1). In the case of K, Ca, Mg and S, the fraction recycled was higher than that removed from the orchard (Table 1).

Table 1. Annual amount of macronutrients (kg ha^{-1} $year^{-1}$) accumulated in organs of mature (14-years-old) nectarine trees.

Organ	N	P	K	Ca	Mg	S
Thinned fruits	4.04±0.67*	0.439±0.08	1.43±0.26	0.346±0.07	0.161±0.03	0.148±0.03
Pruned wood	17.5±2.17	2.68±0.30	7.57±0.80	18.1±2.11	1.61±0.17	1.07±0.11
Abscised leaves	31.9±1.98	4.59±0.46	35.7±2.04	88.8±6.48	10.4±0.72	2.43±0.16
RECYCLED	*53.4±4.17*	*7.71±0.56*	*44.7±2.56*	*107±7.03*	*12.2±0.78*	*3.65±0.24*
Fruits at harvest	38.7±1.98	5.40±0.20	28.3±10.0	1.25±0.04	2.51±0.08	1.48±0.04
Skeleton	7.09±0.76	2.90±0.24	8.71±0.65	30.5±2.32	2.67±0.22	1.29±0.08
Roots	9.20±0.72	2.52±0.17	2.95±0.22	11.6±0.97	1.73±0.15	0.23±0.01
REMOVED	*55.0±2.12*	*10.8±0.50*	*40.0±1.46*	*43.4±2.10*	*6.91±0.235*	*3.00±0.10*
TOTAL	108±5.65	18.5±1.02	84.7±3.58	150±8.11	19.1±0.846	6.65±0.325

* mean ± standard error (n=8)

Iron was the most accumulated micronutrient in trees (Table 2) and the organs with the highest quantity were roots and skeleton, followed by fruits at harvest and abscised leaves; thinned fruits accumulated little quantities of Fe in comparison to other organs (Table 2). The highest quantity of Cu was measured in pruned wood, followed by the skeleton, fruits at harvest, abscised leaves and thinned fruits (Table 2). Manganese was mainly accumulated in abscised leaves, fruits and roots followed by the skeleton; the smallest quantity was measured in thinned fruits (Table 2). Skeleton accounted for the highest Zn concentration followed by pruned wood, leaves, fruits, roots and thinned fruits (Table 2). The fraction of Fe, Mn and Zn removed from the orchard was higher than the fraction recycled; an opposite trend was observed for Cu with a lower quantity removed than recycled (Table 2).

Table 2. Amount of micronutrients (g ha^{-1} $year^{-1}$) accumulated in organs of mature (14-years-old) nectarine trees.

Organ	Cu	Fe	Mn	Zn
Thinned fruits	2.96±0.55*	4.85±0.92	1.44±0.25	4.23±0.76
Pruned wood	284±30.5	96.0±10.8	17.5±2.04	74.2±7.95
Abscised leaves	19.7±1.64	258±18.9	51.7±6.86	72.1±5.70
RECYCLED	*307±31.0*	*359±20.5*	*70.6±7.96*	*151±7.79*
Fruits at harvest	41.1±1.78	236±18.0	37.3±1.44	43.4±1.13
Skeleton	66.6±6.71	594±98.1	27.0±2.94	136±12.5
Roots	7.62±1.24	1538±193	45.0±5.26	18.3±1.72
REMOVED	*115±7.42*	*2368±179*	*109±4.77*	*198±13.9*
TOTAL	422±31.5	2727±170	180±6.78	349±20.6

* mean ± standard error (n=8)

Tables 3 and 4 report the total nutrient demand of the orchard during its 14-year lifetime, divided in fraction recycled and removed. Fruits at harvest and abscised leaves showed the highest quantity of N,

followed by pruned wood, while the lowest amount of N was found in the skeleton (Table 3). In the 14-year period studied, the fraction of N recycled in the orchard (686 kg ha^{-1}) was similar to that removed from the orchard (611 kg ha^{-1}). Phosphorous mainly accumulated in fruits at harvest and abscised leaves, followed by the woody organs (pruned wood, skeleton and roots) while thinned fruits showed small quantities of this nutrient (Table 3). Abscised leaves accounted for the highest quantity of K, while thinned fruits and roots the lowest (Table 3). Similarly, to other macronutrients, abscised leaves accumulated the highest amount of Ca and Mg; noteworthy amounts of these macronutrients were also in wooden organs, while fruits (thinned and harvested) accounted for little quantities (Table 3). Sulphur was mainly accumulated in leaves, followed by pruned wood and skeleton, while roots and thinned fruits accumulated little quantities (Table 3). Potassium, Ca, Mg and S in the recycled fraction was higher than that removed from the orchard, while P showed an opposite trend with a higher amount removed than recycled (Table 3).

Table 3. Macronutrients (kg ha^{-1}) accumulated in tree organs in a 14-years period.

Organ	N	P	K	Ca	Mg	S
Thinned fruits	144±8.02*	15.4±1.05	50.4±2.97	12.0±0.79	5.71±0.37	5.21±0.37
Pruned wood	225±14.1	35.0±2.46	99.2±6.27	234±12.8	21.0±0.95	14.0±0.95
Abscised leaves	317±12.8	45.9±4.74	353±6.67	876±20.4	102±1.41	24.3±0.53
RECYCLED	*686±26.4*	*96.3±6.61*	*503±12.5*	*1121±23.4*	*128±1.17*	*43.5±1.39*
Fruits at harvest	400±22.2	55.6±2.03	291±8.83	12.9±0.614	25.9±0.857	15.2±0.491
Skeleton	92.1±9.84	37.6±3.06	113±8.47	396±30.2	34.7±2.93	16.8±1.01
Roots	119±9.41	32.8±2.21	38.4±2.91	151±12.6	22.5±1.95	2.98±0.13
REMOVED	*611±29.4*	*126±6.61*	*442±17.6*	*559±27.4*	*83.1±3.35*	*35.0±1.41*
TOTAL	1297±50.9	222±12.2	945±29.4	1680±40.4	211±3.70	78.5±2.64

* mean ± standard error (n=8)

Among the micronutrients, Fe was the one that most accumulated in trees during orchard lifetime (Table 4), the organs showing the highest content were roots and skeleton, followed by fruits at harvest and abscised leaves; thinned fruits accumulated little quantities of Fe in comparison to other organs (Table 4). Copper was mainly found in pruned wood, followed by skeleton, fruits at harvest, abscised leaves and thinned fruits (Table 4). Manganese was mainly accumulated in roots and abscised leaves, fruits and roots followed by skeleton; the smallest quantity was measured in thinned fruits (Table 4). Skeleton was the main Zn sink followed by pruned wood, leaves, fruits, roots and thinned fruits (Table 4). The fraction of Fe, Mn and Zn removed from the orchard was higher than the fraction recycled; an opposite trend was observed for Cu (Table 4).

Table 4. Micronutrients (g ha^{-1}) accumulated in plant organs in a 14-years period.

Organ	Cu	Fe	Mn	Zn
Thinned fruits	105±13.4*	172±12.8	51.2±2.99	149±9.84
Pruned wood	3802±315	1254±75.6	227±14.7	970±46.1
Abscised leaves	195±13.4	2551±115	501±42.1	726±62.0
RECYCLED	*4102±318*	*3977±140*	*779±48.5*	*1845±63.3*
Fruits at harvest	422±13.9	2417±148	384±67.0	448±17.0
Skeleton	866±87.2	7718±1275	351±38.2	1766±162
Roots	99.1±16.1	19992±2515	585±68.4	238±22.4
REMOVED	*1387±92.9*	*30127±2381*	*1320±67*	*2452±180*
TOTAL	5489±286	34104±2326	2099±60.8	4297±221

* mean ± standard error (n=8)

Leaf N, P and S (Figure 2A-B) content, as well as, Cu, Mn and Zn (Figure 2C) decreased in abscised leaves in comparison to leaves sampled in summer; an opposite trend was observed for Ca (Figure 2A) and Fe (Figure 2C); no significant differences among sampling dates were observed for K and Mg (Figure 2A-B).

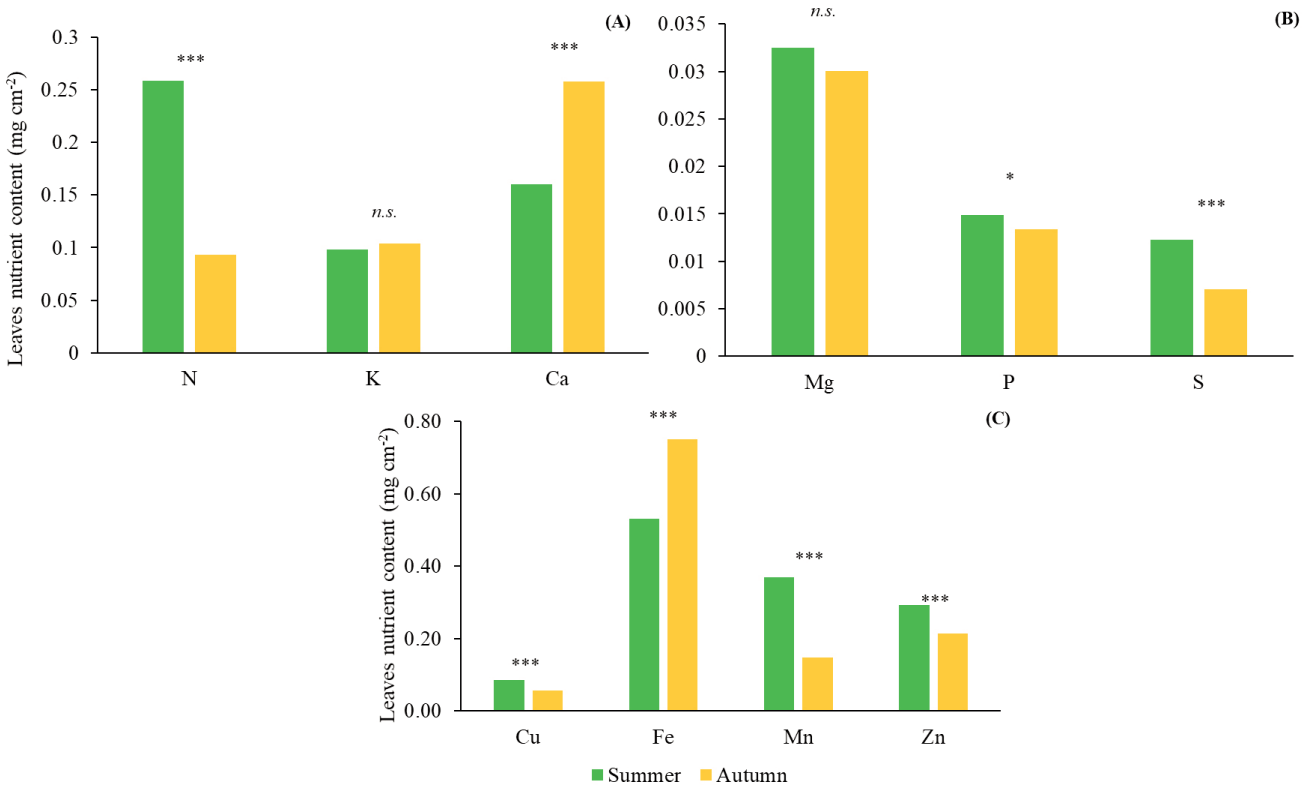

Figure 2. Effect of sampling time on macro (A-B) and micro (C) nutrients content in leaves of mature nectarine trees. n.s., *, ***: effect not significant, significant at P≤0.05, and P≤0.001, respectively.

Nitrogen, P and K were mainly found in abscised leaves (35%, 28.6% and 46.2%, respectively) and fruit flesh (36%, 31.3%, 35.5%, respectively). Nitrogen accounted for 10.2%, 7.8%, 6.6% and 4.4% of the total for roots, skeleton, fruit stone and thinned fruits, respectively (Figure 3). Potassium accounted for 11.2% in skeleton, 3.9% in roots, 1.8% in thinned fruits and 1.3% in fruit stones (Figure 3). Phosphorous was allocated in similar percentages in roots (16.1%) and skeleton (18.2%), while a small fraction was measured in thinned fruits (2.7%) and fruit stone (3.2%). In addition, low-mobile macronutrients such as Ca and Mg, along with the relatively mobile S were mainly found in abscised leaves (66.7%, 59.1%, 43.4% for Ca, Mg and S, respectively) and in the skeleton (23.1% for Ca and S and 15.3% for Mg). Fruit flesh accounted for high percentages of S (23.1%) and Mg (12.2%) but low of Ca (0.74%). Roots (9.0%, 10.1% and 4.2% for Ca, Mg and S, respectively), thinned fruits (0.26% Ca, 0.9% Mg and 2.57% S) and fruit stone (0.20%, 2.40% and 3.63% for Ca, Mg and S, respectively) accumulated low quantities of immobile macronutrients (Figure 4).

Regarding micronutrients, Cu and Zn were accumulated in the skeleton (48% and 49% for Cu and Zn, respectively), in abscised leaves (14% and 27% for Cu and Zn, respectively) and in fruit flesh (23% and 13% for Cu and Zn, respectively). Fruit stone (6.74% and 2.75% for Cu and Zn, respectively), roots (5.54% and 6.76 for Cu and Zn, respectively) and thinned fruits (2.12% and 1.49% for Cu and Zn, respectively) accounted for a small portion of these micronutrients. Iron and Mn were accumulated in roots (57% of Fe and 28.1% of Mn) and skeleton (23% of Fe and 17% of Mn) and abscised leaves (10.3% and 31.4% for Fe and Mn respectively). Fruits flesh (2% Fe and 14.2% Mn), fruit stone (7.3% and 8.9% for Fe and Mn, respectively) and thinned fruits (0.20% Fe and 0.90% Mn) accounted for smaller portions of these nutrients (Figure 4).

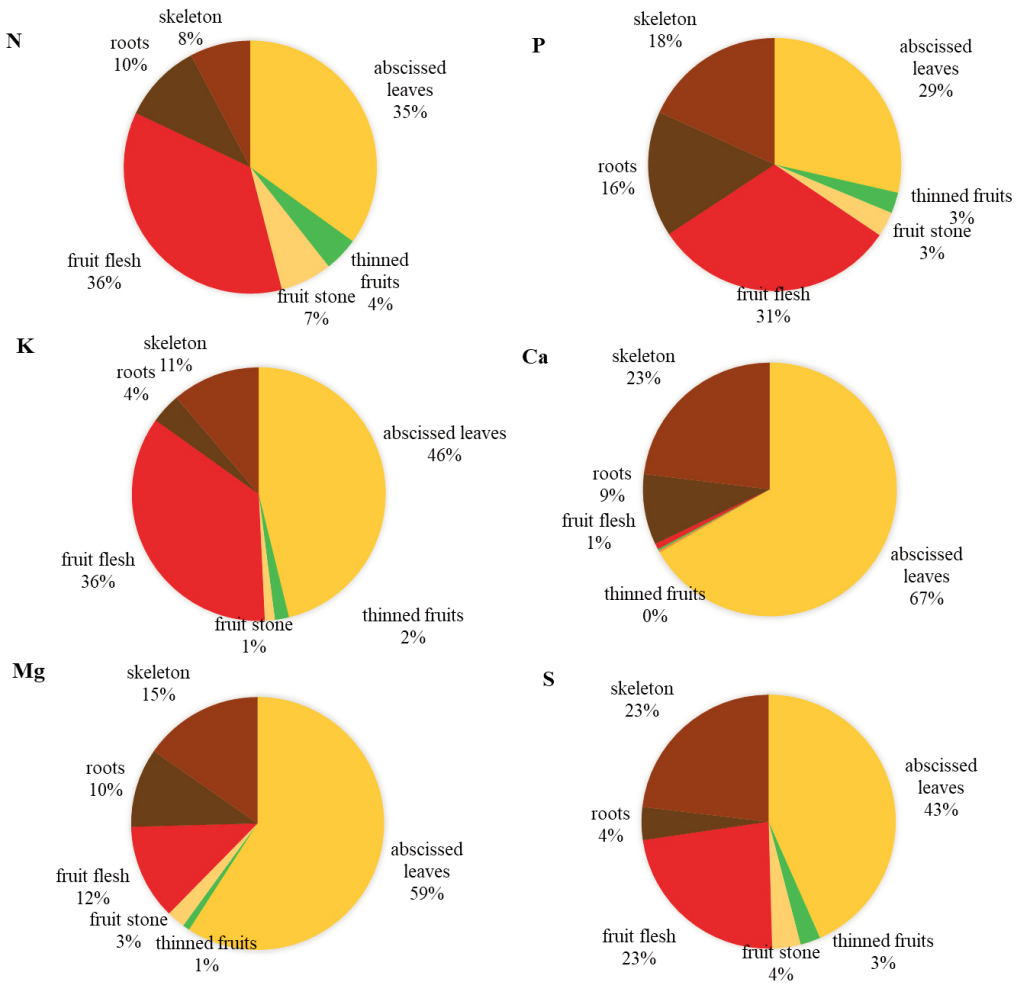

Figure 3. Relative partitioning of macronutrients (N, P, K, Ca, Mg and S) in plant organs at the end of the orchard commercial life (2014).

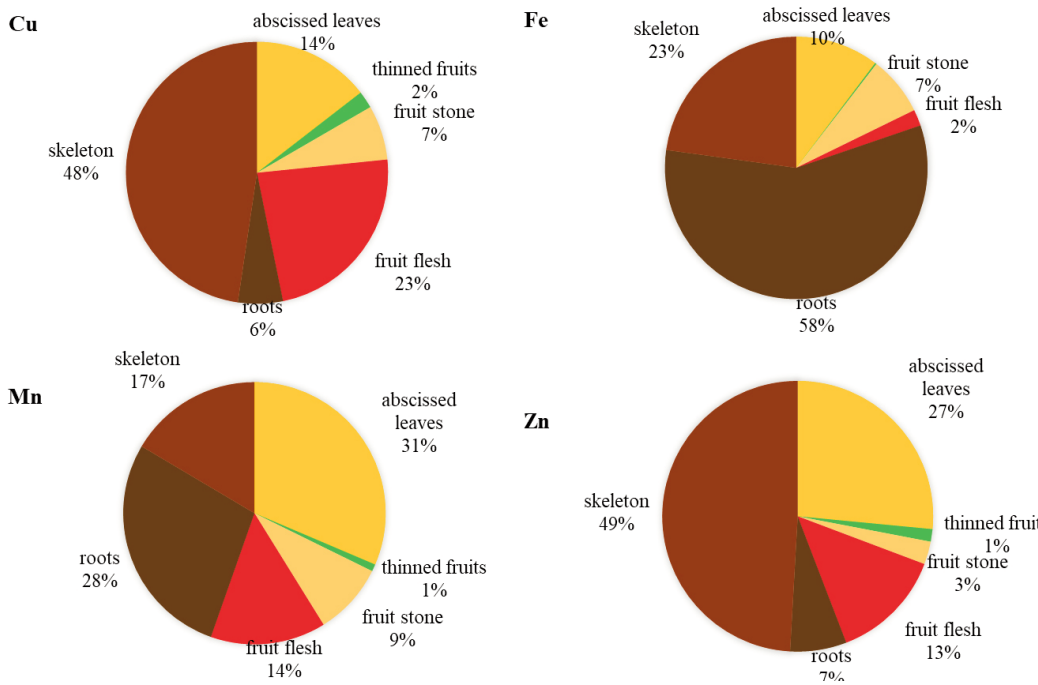

Figure 4. Relative partitioning of micronutrients (Cu, Fe, Mn and Zn) in plant organ at the end of the orchard commercial life (2014).

4. Discussion

The fraction of nutrients remobilized during the vegetative season inside the plant was estimated by the difference between the amount of nutrients in leaves sampled in summer and at natural abscission (Figure 2). The decrease of the concentration of N, P, S, Cu, Mn and Zn in abscised, compared to summer-sampled leaves was the result of the translocation of nutrients into other organs, like fruits and also into storage compartments (branches, trunks and roots), for the development of new tissues in the following spring. This behaviour is well known and studied for N (Millard and Grelet, 2010), whereas minor attention was reserved to P, K and micronutrients (Marschner, 1995). As reported for almonds (Muhammad et al., 2015), our investigation evidenced an unchanged K and Mg leaf content in summer and autumn and an accumulation of Ca during the season. Calcium and Fe were almost entirely found in abscised leaves in line with previous studies (Marschner, 1995; Kalcsits et al., 2020). The higher content of Fe in autumn than in summer indicates that leaves are an active sink for Fe during the entire season. The accumulation of Fe is promoted by a good N nutritional status, since high protein concentration decreases Fe mobilization and translocation (Marschner, 1995) along with the formation of the Fe chelators (Shi et al., 2012). As also previously observed in peach (El Jendoubi et al., 2013) macronutrients are mainly allocated in abscised leaves and fruits (Figure 3), while micronutrients in woody organs like roots and skeleton (Figure 4).

The analysis of annual nutrient circulation in a commercial nectarine orchard was done by the determination of the fractions of each nutrient recycled and remobilized. The first one is the result of the sum of nutrients found in abscised leaves, in thinned fruits and in pruned wood, that in 2014 accounted for 53 kg ha^{-1}, 8 kg ha^{-1}, and 45 kg ha^{-1} for N, P, K, respectively (Table 1). Among the nutrients examined, the amount of Ca recycled was the highest, mainly because its high percentage (67%) in abscised leaves. On the other hand, Mg and S recycled fractions were lower than other macronutrients and accounted for approximatively 12 kg ha^{-1}, and 4 kg ha^{-1}, respectively. Micronutrient recycled magnitude was around 300 g Cu ha^{-1}, 360 g Fe ha^{-1}, 70 g Mn ha^{-1} and 150 g Zn ha^{-1} (Table 2). With the exception of Cu that showed a recycled fraction higher than that removed, all the other micronutrients were stocked in high quantities in perennial organs like skeleton and roots. Consequently, since they are not re-mobilized in the following spring, they should be provided with annual fertilization. The large amounts of nutrients recycled with pruning and thinning, together with leaf abscission, largely contribute to improve soil fertility. Abscised leaves accounted for the largest portion of macronutrients recycled by nectarine trees and incorporation into the soil could represent a significant increase of nutrients, that after organic matter decomposition, can become available for root uptake (Granatstein and Sánchez, 2009). In northern Italy, the decomposition of peach leaves releases mineral elements (Ventura et al., 2010) in different ways. The release of Nitrogen and S starts in the second year and continues in the third year, when most (80%) of the original amounts is mineralized. Potassium release occurs rapidly and approximately 70-80% of the K from abscised leaves is available in the soil in the following spring. Phosphorous is mineralized mainly in winter of the first two years; Mg is mainly released in the first 18 weeks, while Ca is gradually released and its residual content decreases linearly with time (Ventura et al., 2010). Micronutrients in abscised leaves accounted for a small percentage and, consequently, their release through decomposition is negligible. Along with senescent leaves, also pruned wood and thinned fruits contributed to the return of nutrients to the soil. However, the release of nutrients depends on quality and mainly on C/N ratio of the organic material. Carbon to N ratio is negatively correlated to the organic litter decomposition rate (Zhang et al., 2015; Marcolini et al., 2016), so pruned wood (C/N=38) decomposes more slowly than leaves (C/N=19) and thinned fruits (C/N=11). In a mature peach orchard, abscised leaves, thinned fruits and pruned wood of different ages coexist on the soil surface and therefore, each year, a large quantity of nutrients deriving from litter degradation is expected to return to the soil and potentially be available for plant uptake. However, it is difficult to evaluate the entity of the nutrients mineralized each year and re-absorbed. According to Ventura et al. (2010) each year, 80-90% of the

nutrients contained in the abscised leaves are expected to return to the soil and potentially be available for subsequent root and/or microbial uptake.

Nutrient yearly uptake can be calculated as the sum of recycled and removed and, based on the last year of tree growth, in our study it was quantified in 108 kg N ha^{-1}, 19 kg P ha^{-1}, 85 kg K ha^{-1}, 150 kg Ca ha^{-1}, 19 kg Mg ha^{-1}, 7 kg S ha^{-1}, 422 g Cu ha^{-1}, 2.27 kg Fe ha^{-1}, 180 g Mn ha^{-1} and 349 g Zn ha^{-1} (Tables 1 and 2), reaching values in line with previous research (Rufat and DeJong, 2001; Tagliavini et al., 1996; El Jendoubi et al., 2013) that established nutrient requirement for peach of 45-130 kg N ha^{-1}, 10-54 kg P ha^{-1}, 60-80 kg K ha^{-1} and 10-62 kg Mg ha^{-1}, depending on tree training system, age, productivity and soil fertility. These values are similar to those obtained by dividing the total amount of nutrient up-taken by the tree during its commercial life. In fact, dividing the values reported in Tables 3 and 4 by 13 years (we do not consider the first year since planting was done late in the season), we obtained a total amount of nutrients (removed + recycled) similar to those measured the fourteenth year and accounting for (in kg ha^{-1}): 100, 17, 73, 129, 16, 6, for N, P, K, Ca, Mg and S, respectively. The Integrated Crop Management guidelines of the Region (Emilia-Romagna, 2020) suggest, for orchard with a yield of 20-30 t ha^{-1}, the supply of 100 kg N ha^{-1}; 8-25 kg P ha^{-1} and 40-125 kg K ha^{-1}; the rate of nutrients can be increased up to 150 kg N ha^{-1}; 35 kg P ha^{-1} and 170 kg K ha^{-1} if the expected fruit yield is higher than 30 t ha^{-1}. The values established as limit are in line with peach nutrient demand; however, they do not take into consideration the relevant fraction of nutrient released thought litter decomposition (47, 9.7 and 34 kg ha^{-1} for N, P and K, respectively). Consequently, in the light of these results, fertilization programs should reduce external inputs by 20 to 40%. The supply of organic matter, if done properly, could be a win-win solution able to maintain adequate soil fertility and plant yield without exceeding with soil mineral N (Toselli et al., 2019). Indeed, in the same experiment (Toselli et al., 2019) the supply of 240 kg N ha^{-1} with compost induced the release of the same quantities of mineral N in soil as for mineral fertilization that provided 120 kg N ha^{-1}. Consequently, when planning a fertilization strategy, beside plants need and pedoclimatic conditions, the source of mineral elements should be accurately selected.

5. Conclusions

In the experimental conditions of northern Italy coastline climate, nectarine Stark RedGold showed a limited annual request of macro and micronutrients, of which more than half was recycled and returned back to the orchard. Potentially, nutrient use efficiency can be maximized, consequently the fertilization of nectarine requires a small amounts of chemical inputs, lower than those suggested by the Integrated Crop Management guidelines of the Region. In conclusion, the data obtained in the present experiments provide farmers and technicians with information helpful to set up their fertilization plans avoiding detrimental excess of nutrients.

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