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# Nitrogen Partitioning in Young "Julyprince" Peach Trees Grown with Different Irrigation and Fertilization Practices in the Southeastern United States

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**Abstract:** Fertilizer recommendations for peach cultivation in the southeastern United States were developed decades ago and may not reflect the peach trees' needs under current cultivation practices. Adequate fertilization for young peach trees induces a balanced vegetative/reproductive growth, ensures efficient resource use, and is environmentally sound. Droughts in the region are becoming more common. Supplemental irrigation for peaches from the time of field establishment serves as insurance in case drought conditions occur and can increase/advance the yield of young peach trees. Our objective was to determine the influence of different fertilizer levels (25, 50, 100, and 200% of the recommended rate), irrigation levels (irrigated vs. non-irrigated), and irrigation systems (drip vs. micro-sprinkler) on nitrogen partitioning and concentration in different organs of young peach trees. The cumulative nitrogen (N) removal per tree was not affected by the different fertilizer levels. Most of the N allocation was accounted for by summer pruning and defoliation (68% of the total N removed). Irrigated trees had higher cumulative N removal after three years than non-irrigated trees, with differences between irrigated vs. non-irrigated trees in most vegetative removal events (winter and summer pruning, and defoliation). Drip-irrigated trees had higher cumulative N removal after three years than micro-sprinkler-irrigated tress, with differences in N removal found in vegetative and reproductive removal events. Differences in N removal were mainly driven by differences in dry weight rather than the N concentration of the organs. These results suggest that different fertilizer levels did not alter the N partitioning in young peach trees, indicating that reduction in fertilizer applications can be done without negative effects. Furthermore, irrigation induced greater vegetative growth, especially under drought conditions, which may result in greater canopy volume and fruit yield compared to non-irrigated trees. Differences between irrigation systems are not consistent; however, drip is more efficient than micro-sprinkler irrigation, with ~38% water savings.

**Keywords:** *Prunus persica*; allocation; nitrogen concentration; dry weight; pruning; defoliation; fruit yield



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## 1. Introduction

The state of Georgia in the southeastern United States has experienced below average rainfall (drought) in recent years [1]. These droughts can hinder peach tree growth and development. Some growers in the southeastern United States do not irrigate young peach trees until the third year after field establishment. This creates a situation where the non-irrigated trees can experience periods of drought and subsequent stress. As reported by Casamali [2], a lack of water during the first years of field establishment can be detrimental [3–5]. During the first years, young trees' root system and canopy develop to support future growth and fruit yield. Supplemental irrigation from the time of orchard establishment can be an option to overcome periods of drought. Additionally, it induces greater fruit yield, bringing additional revenue for growers [2].

Similarly, interest in optimizing fertilization management has increased. Reasons include: (a) concerns regarding over-fertilization and its effects on the balance between vegetative and reproductive growth; (b) environmental pollution by fertilizer runoff; and (c) inefficient use of financial resources [6]. The Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide [7] provides fertilizer recommendations for peach trees at different ages. However, there are no reports of how current fertilizer recommendations were developed. They may be based on half-century-old studies [8,9]. Understanding the current needs of peach trees and further updating the fertilizer recommendations can result in cost savings and reduction in the orchard's environmental impact. To determine the current needs of nitrogen (N), it is necessary to investigate how N is partitioned among different tree organs in response to irrigation and fertilization treatments.

Prior research has focused on the allocation and partitioning of nutrients in fruit crops in response to N availability, irrigation (regulated deficit), ripening season, and fertilizer source. Rufat and DeJong [10] studied the seasonal N accumulation patterns in organs of mature "O'Henry" peaches grown in either low (0 kg·ha$^{-1}$ N) or high (200 kg·ha$^{-1}$ N) annual N fertilization. They reported that the organs' dry weight (DW) and N concentration increased with N fertilization. Fertilization greatly affected the vegetative growth of the current year in comparison with reproductive organs. Furthermore, annual organs, like fruit, current-year stems, and leaves, had greater responses to N fertilization than perennial organs, like branches and trunk. In another study, Baldi et al. [11] tested the effects of mineral and organic fertilization on nutrient uptake and partitioning in a 1-year-old, potted "Stark RedGold" peach trees. The different mineral and organic fertilizers did not induce differences in the DW of leaves, shoots, stems, or coarse roots. Furthermore, N concentration in fine roots, leaves, and total tree were not different across treatments. Dichio et al. [12] studied the effects of post-harvest regulated deficit irrigation (RDI) on N partitioning and tree growth of "Springcrest" peach trees. Moderate and severe post-harvest RDI reduced the growth of watersprouts and lateral shoots. However, fruiting shoots were not affected by the post-harvest RDI treatments in comparison with the control 100% crop evapotranspiration ($ET_c$) irrigation. Severe post-harvest RDI induced higher N concentrations in roots, branches, and shoots; however, no differences were found in leaves. Furthermore, severe post-harvest RDI reduced fruit yield. Zhou and Melgar [13] investigated how different peach ripening seasons (early, mid, and late) affected nutrient partitioning. They found that mature fruit from early-season cultivars have higher N concentration in comparison with mid- and late-season cultivars. Furthermore, pruning material is where early-season cultivars partition a greater amount of N, followed by defoliated leaves, then harvested fruit. For mid- and late-season cultivars, pruning is still where the trees partition a greater amount of N; however, harvested fruit received more N than defoliated leaves. Policarpo et al. [14] studied N partitioning in early- and late-season peach cultivars throughout the growing season. They found that leaves are the main sinks of N during the entire growing season (from 15 February to 19 October) of early-season cultivars. In contrast, for the late-season cultivar, fine roots are the main N sinks early in the season, followed by leaves, which dominate the sinks until the end of the season (23 March to 14 September). In summary, fertilization, irrigation, and different ripening seasons can affect the trees, inducing differential N allocation patterns. In Georgia, there are no reports of such studies to understand the N partitioning in different organs and removal events.

We performed this study to better comprehend how different irrigation and fertilization treatments induce changes in N allocation in young peach trees since field establishment. The specific objective was to determine how much N is removed from trees during pruning, fruit thinning, harvesting, and fall defoliation. We hypothesized that (1) trees receiving more fertilizer will have greater vegetative growth (as indicated by plant material removed through pruning and fall defoliation); (2) trees irrigated since establishment will grow faster and thus will have more N removed than trees without irrigation; and (3) different irrigation systems will not impact N partitioning.

## 2. Materials and Methods

### *2.1. Plant Material and Field Characteristics*

The experiment was conducted using trees of "Julyprince" peach grafted onto "Guardian™". Both varieties are widely used in the southeastern United States. Trees were planted on 13 July 2015 at a spacing of 4.6 m within rows and 6.1 m between rows (358 trees/ha). The experiment was located at the Dempsey Farm, University of Georgia, Griffin, GA (33°14′55″ N, 84°17′57″ W), with a Cecil sandy loam soil with a slope of 2–6% and organic matter of 1.5%. Prior to planting, amendments of potassium, phosphorus, and lime (to reach pH 6.0) were made following the recommended guidelines published in the Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide [7]. Additionally, pest management also followed the above-cited guidelines. In April 2016, soil samples (0–40 cm depth) were taken from the experimental plot to measure the baseline soil fertility level (Table 1).

**Table 1.** Soil analysis from the experimental field (0–40 cm depth) at the Dempsey Farm, University of Georgia, Griffin, GA. Samples were taken in April of 2016 before any fertilizer treatments were applied (*n* = 48).

| pH | P | K | Mg | Ca | B | Zn | Mn | Fe | Cu | $NO_3$-N | $NH_4$-N | Cation Exchange Capacity (CEC) | Organic Matter (OM) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kg·ha$^{-1}$ | | | | | | | | | | | cmol·kg$^{-1}$ | % |
| 5.95 | 58.9 | 188.4 | 184.8 | 866.4 | 0.5 | 3.3 | 22.4 | 66.2 | 1.4 | 17.0 | 5.4 | 4.84 | 1.51 |

In April 2017, April 2018, and May 2019, soil samples were taken to assess the fertility of the soil in the different fertilizer treatments at two soil depths (0–20 and 20–40 cm), with exception of May 2019 when only 0–20 cm samples were taken.

In April 2018, the samples were taken two days after fertilizer application, resulting in higher values relative to values of 2017 and 2019. This sampling was used to quantify the immediate effect of the fertilizer treatments on the level of nutrients in the soil right after fertilization. Annual precipitation records from the Dempsey Farm weather station for 2016, 2017, 2018, and the historical average during the period 1981–2010 are shown in Table 2.

**Table 2.** Precipitation (mm) from January to December in 2016, 2017, and 2018 and the historic normal (average from 1981 to 2010) at the Dempsey Farm, Griffin, GA.

| | January | February | March | April | May | June | July | August | September | October | November | December | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2016 | 110 | 125 | 66 | 174 | 67 | 77 | 66 | 69 | 159 | 1 | 69 | 159 | 754 |
| 2017 | 247 | 66 | 53 | 97 | 91 | 194 | 91 | 112 | 130 | 207 | 28 | 79 | 952 |
| 2018 | 103 | 98 | 133 | 118 | 145 | 134 | 103 | 106 | 84 | 132 | 164 | 267 | 940 |
| 1981–2010 | 112 | 104 | 146 | 113 | 96 | 96 | 150 | 131 | 91 | 83 | 99 | 99 | 947 |

### *2.2. Experimental Design and Treatments*

Experimental design and field set-up were fully described previously [2]. Briefly, the experiment was comprised of three factors: (1) irrigation levels (non-irrigated vs. irrigated); (2) irrigation systems (drip vs. micro-sprinkler irrigation); and (3) fertilization rates (25, 50, 100, and 200%). Non-irrigated trees only received water from rain events. Irrigation was controlled automatically by an irrigation network that would activate the irrigation as needed to keep the soil moisture levels above the thresholds established as follows: (1) irrigation off from January to early May; (2) volumetric water content (VWC) threshold of 25% from early May to early August; (3) VWC threshold of 20% from early August to mid-September; (4) VWC threshold of 15% from mid-September to late September; and (5) irrigation off from late September to December. Each combination of fertilizer levels and irrigation systems was irrigated separately. Figures 1–3 show the VWC of the soil for different treatments and the rain events for 2016, 2017, and 2018, respectively. To test different irrigation systems, trees were either drip or micro-sprinkler irrigated.

Four fertilizer levels were defined based on the current recommendations. Currently, the Southeastern Peach, Nectarine, and Plum Pest Management and Culture Guide [7] recommends 65, 95, and 98 kg·ha$^{-1}$ N for 1-, 2-, and 3-year-old trees, respectively. These rates are denoted as 100% in this experiment. Three other rates (25, 50, and 200%) were chosen based on the recommended rate, generating four N fertilizer rates for the experiment: 16, 33, 65, and 129 kg·ha$^{-1}$ N for 1-year-old trees; 23, 48, 95, and 191 kg·ha$^{-1}$ N for 2-year-old trees; and 24, 49, 98, and 195 kg·ha$^{-1}$ N for 3-year-old trees. Granular fertilizer was applied by hand: one application of 10.0N-4.4P-8.3K (in March) and two applications of 15.5N-0P-0K (in May and July) for 1- and 2-year-old trees; and one application of 10.0N-4.4P-8.3K (in March) and one application of 15.5N-0P-0K (in August) for 3-year-old trees. Fertilizer 10.0N-4.4P-8.3K had N form as 10.0% ammoniacal nitrogen (Farmers Favorite Fertilizer; Agri-AFC, Evergreen, AL, USA), and fertilizer 15.5N-0P-0K had N form as 1.0% ammoniacal nitrogen + 14.5% nitrate nitrogen (Yara Liva Tropicote; Yara, Tampa, FL, USA).

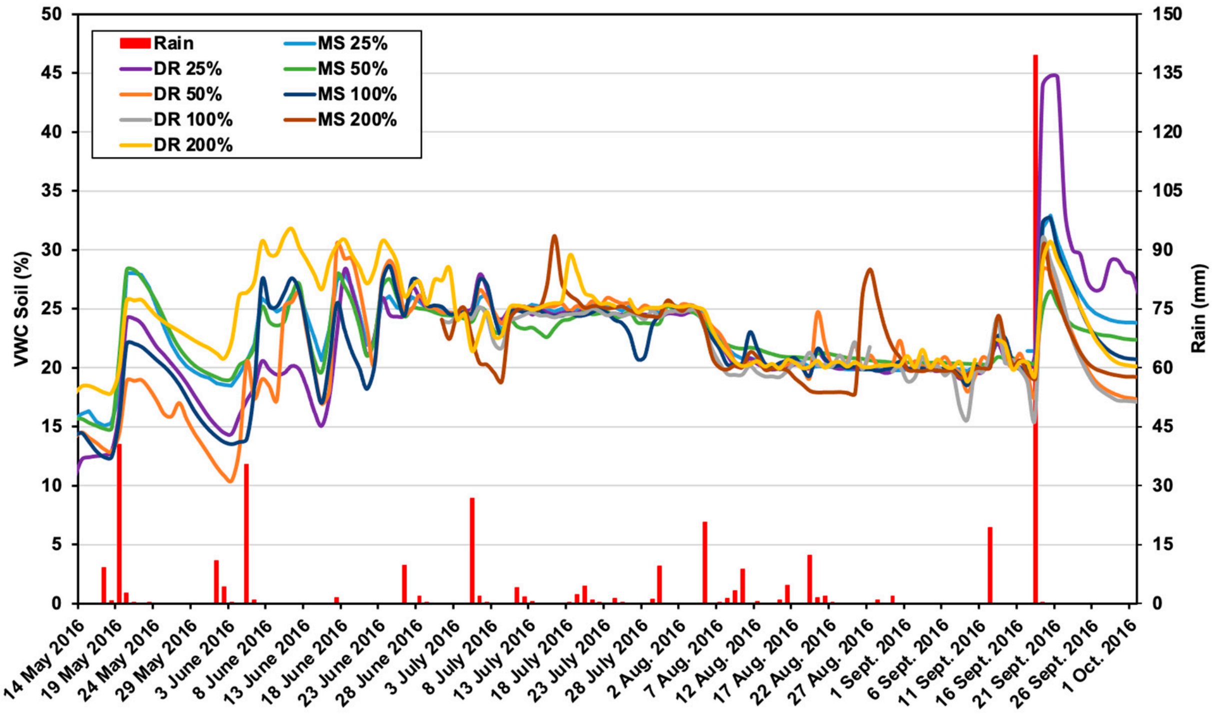


**Figure 1.** Soil volumetric water content (VWC) for the different combinations of drip (DR) and micro-sprinkler (MS) irrigation with different fertilizer levels (25, 50, 100, and 200%) in 2016. Rain events are shown as vertical bars. From 14 May 2016 to 22 June 2016, the irrigation system was being tested and the irrigation was controlled by hand, trying to keep the VWC above 25%. After 23 June 2016, the automated irrigation network was turned on, following the thresholds established (from early May to early August: VWC threshold of 25%; from early August to mid-September: VWC threshold of 20%; from mid-September to late September: VWC threshold of 15%; late September to December: irrigation off). Values are the average of four sensors (two at 20 cm and two at 40 cm depth).

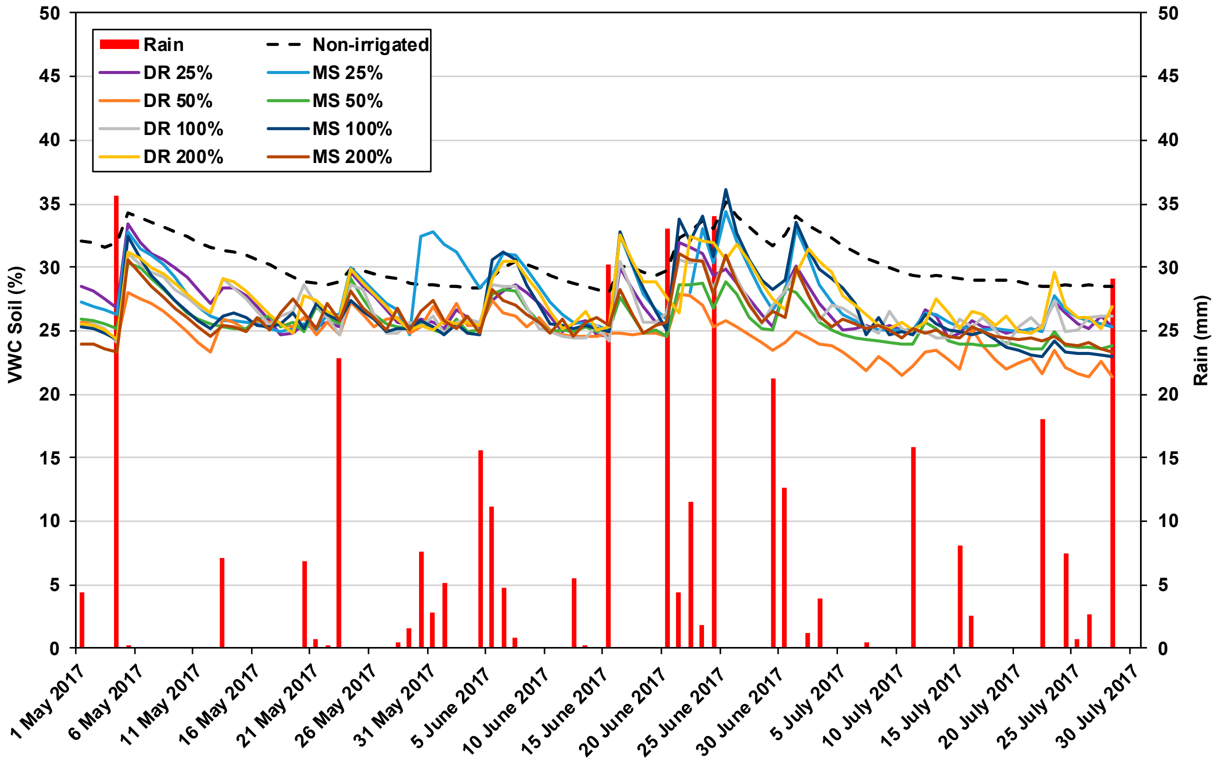


**Figure 2.** Soil volumetric water content (VWC) for the non-irrigated treatments and for the different combinations of drip (DR) and micro-sprinkler (MS) irrigation with different fertilizer levels (25, 50, 100, and 200%) in 2017. Rain events are shown as vertical bars. The automated irrigation network was activated in 12 May 2017, with the intent of following the thresholds established (from early May to early August: VWC threshold of 25%; from early August to mid-September: VWC threshold of 20%; from mid-September to late September: VWC threshold of 15%; from late September to December: irrigation off). The system was damaged and deactivated after 28 July 2017 because of a lightning strike. For the irrigated treatments, the values are the average of four sensors (two at 20 cm and two at 40 cm depth). For the non-irrigated, values the are averages of 32 sensors (16 at 20 cm and 16 at 40 cm depth).

### 2.3. Process to Collect Samples and Analyze the N Content of Plant Tissues

A total of 64 trees, representing all treatment combinations, were randomly selected (2 irrigation systems × 2 irrigation levels × 4 fertilization levels × 4 blocks). Each treatment combination had one tree evaluated per block. For each tree's removal event (pruning, fruit thinning, harvesting, and defoliation), the fresh weight (FW) and the DW of the material were either measured or calculated (see detailed description below) for the 64 trees. DW was measured after drying the material at 65 °C until constant weight was achieved. The total amount of N removed by the removal events was calculated by multiplying DW by N concentration in the tissues of the material. Nitrogen concentration from all tissues was assessed using the Kjeldalh method by a commercial laboratory (Waters Agricultural Laboratories; Camilla, GA, USA). Each removal event is described below. The total amount of N removed by pruning, fruit thinning, harvesting, and defoliation combined was calculated by adding up the amounts of N removed in each of these individual removal events.

#### 2.3.1. Winter Pruning

Trees were winter-pruned following commercial procedures for an open-vase training system in February 2017 and February 2018. In February 2017, pruned material FW, DW, and N concentration were assessed. In February 2018, the trees were winter pruned following the same procedure described for the winter pruning in February 2017, with one modification due the trees' size. Total pruned material FW was recorded, and a sub-sample of known weight was taken and dried instead of all pruned material as in 2017. The FW, DW, and

N concentration were determined for this subsample and estimated for the total pruned material based on its FW.

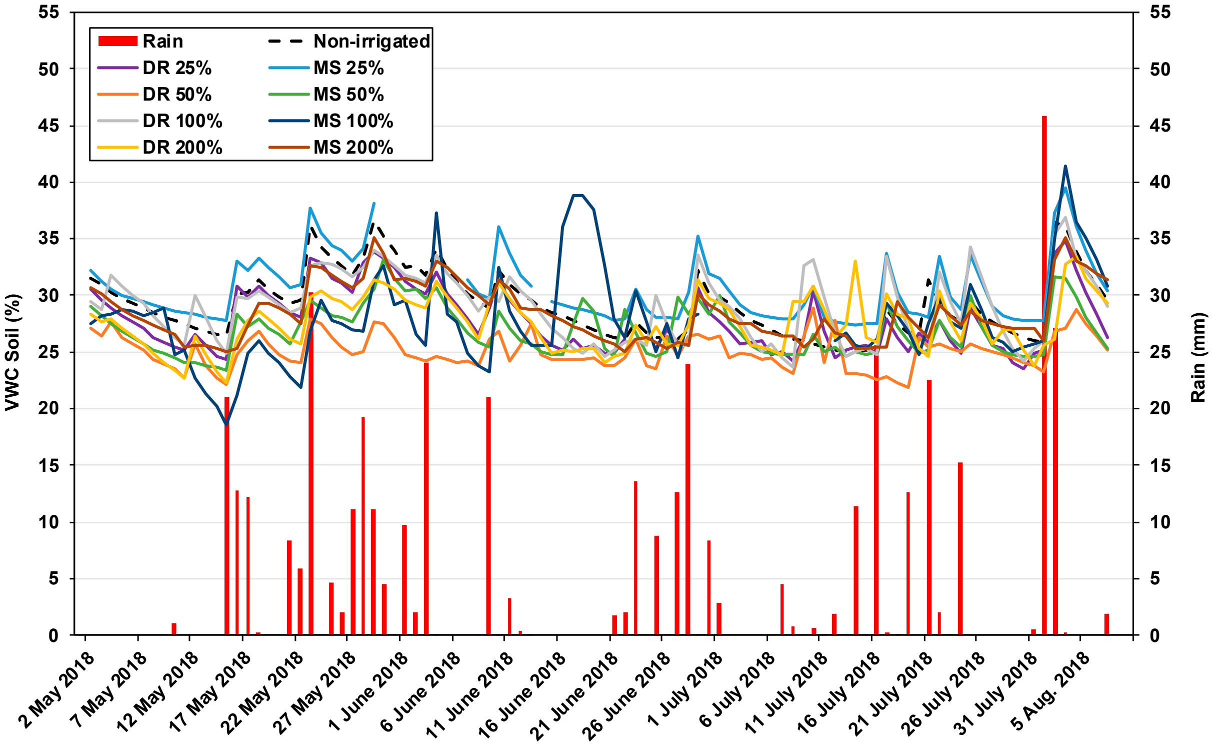


**Figure 3.** Soil volumetric water content (VWC) for the non-irrigated treatments and for the different combinations of drip (DR) and micro-sprinkler (MS) irrigation with different fertilizer levels (25, 50, 100, and 200%) in 2018. Rain events are shown as vertical bars. The automated irrigation network was activated on 7 May 2018, with the intent of following the thresholds established (from early May to early August: VWC threshold of 25%; from early August to mid-September: VWC threshold of 20%; from mid-September to late September: VWC threshold of 15%; from late September to December: irrigation off). However, the system was damaged and the data were not recorded from 8 August 2018 to 5 September 2018. For the irrigated treatments, the values are the average of four sensors (two at 20 cm and two at 40 cm depth). For the non-irrigated treatment, the values are the average of 32 sensors (16 at 20 cm and 16 at 40 cm depth).

### 2.3.2. Fruit Thinning

Fruit were thinned following commercial procedures. In April 2017, the trees were thinned following commercial standards (three or four fruit per fruiting twig at a spacing of 15–20 cm). Fresh weight, DW, and N concentration were assessed. In 2018, the trees were not thinned because of an advective freeze that reduced the fruit load. The number of fruitlets left on the trees after the freeze did not merit additional thinning.

### 2.3.3. Summer Pruning

Trees were summer-pruned following commercial procedures for an open-vase training system in July 2016, June 2017, and June 2018. In July 2016, six samples out of the 64 trees were randomly selected to determine the proportion of leaves vs. stems (temporary branches of 1- or 2-year-old) in the pruning material. The percentage of leaves and stems was 57.1 and 42.9% fresh material, respectively. The stems and leaves from these samples were separated. The fresh weight and DW of leaves and stems were recorded. These proportions were also used for the summer pruning of 2017 and 2018 seasons calculations. The FW of pruned material was recorded for the 64 trees for all seasons. In 2016, all 64 trees had the fresh-pruned material dried to estimate the DW. In 2017 and 2018, the subsamples of the total pruned material were dried. Based on the proportion of leaves vs. stems estimated (as described above), the DW of leaves and stems was calculated. Dried samples of leaves and stems were submitted for N analysis.

#### 2.3.4. Harvested Fruit

Fruit were harvested following commercial procedures. In July 2017 and 2018, mature fruit were harvested, and FW was recorded. A sub-sample of fruit of known weight was taken, and the DW and N concentration were assessed.

#### 2.3.5. Defoliation

Different techniques were utilized every year because of the increasing size of the trees. Furthermore, samples for nutritional analysis were taken before natural leaf senescence. Therefore, the values of N concentration reported in this study likely overestimated the real N concentration of defoliated leaves. Zhou and Melgar [13] reported values of N concentration in peaches around 1.5% after leaves have senesced. In October 2016, to estimate the N removed via fall defoliation, one significant scaffold (permanent large branches coming from the trunk) of each of the 64 trees was selected and the total number of leaves in the scaffold was counted. FW, DW, and N concentration were assessed on a sub-sample of 100 leaves of each 64 trees. In October 2017, one scaffold per tree from a subsample of eight trees (one tree from each irrigation level * fertilizer level treatment combination) was selected and the total number of leaves in the scaffold was counted. An average number of leaves per scaffold was calculated based on the eight trees. Additionally, the number of scaffolds per tree for all 64 trees were counted for both years. An estimate of the total number of leaves per tree was obtained by multiplying the number of leaves in one scaffold by the number of scaffolds in a tree. FW, DW, and N concentration were assessed on a sub-sample of 100 leaves and calculated for the total number of leaves of each tree. In October 2018, all 64 trees had the number of scaffolds counted. Subsequently, seven trees were randomly selected. Their canopy was wrapped with bird nets to collect all the fallen leaves. The fresh weight of the fallen leaves for each tree was recorded. The total number of leaves on those seven trees was estimated based on a correlation between the total FW and the FW of a 100-leaf sub-sample. This 100-leaf sub-sample was dried, and the average DW of one leaf was estimated. An average number of leaves per scaffold was determined based on the seven trees. The total number of leaves per tree on the 64 trees were estimated by multiplying the number of scaffolds per tree by the average number of leaves per scaffold. By knowing the total number of leaves per tree and the average DW of a single leaf, the total DW of the pruning material for the 64 trees was estimated. A sub-sample of 100 leaves taken in November 2018 from all 64 trees were sent for N concentration analysis.

### *2.4. Physiological Measurements*

Leaf and stem water potential were measured using a pressure chamber (1505D-EXP PMS Instrument Company; Albany, OR, USA), as previously described [2]. Briefly, a fully developed leaf was selected and placed (stem water potential) or not placed (leaf water potential) inside an aluminum foil bag for ~20 min and then placed inside the pressure chamber for measurement. Measurements were performed on a clear, sunny day, around solar noon.

### *2.5. Statistical Analysis*

SAS 9.4 (SAS Institute Inc., Cary, NC, USA) was used to compare the treatment means and interactions, using PROC GLIMMIX. Means were separated using Tukey's Honest Significant Difference method with a significance level at $P \leq 0.05$. Interactions between factors are not shown because most were not significant. When present, the interactions did not have biological meaning. Therefore, only the main factors were reported. N = 4 for all treatments tested and measurements performed.

## 3. Results

### 3.1. Fertilizer Levels

The soil analyses performed in 2017, 2018, and 2019 showed the nutritional status of the soil during the research period (Table 3). Variations in P and K were reported because the first fertilizer application of each year (in March) was an application of 10.0N-4.4P-8.3K. The second and third fertilizer applications were 15.5N-0P-0K (as described in the material and methods section). In 2017 and 2019, the analyses were performed before fertilization, resulting in less variation in the soil nutritional levels among different fertilizer levels. In 2017, soil receiving 200% fertilizer had the highest amount of $NO_3$–N (48.3 kg·ha$^{-1}$) and P (105.4 kg·ha$^{-1}$). Soils receiving 25 and 50% of fertilizer had the lowest amount of $NO_3$–N, whereas soil receiving 25% of fertilizer had the lowest amount of P (Table 3). Samples taken from 0–20 cm had a higher amount of P (107.9 kg·ha$^{-1}$) and K (161.1 kg·ha$^{-1}$) than 20–40 cm samples (46.2 and 137.5 kg·ha$^{-1}$ for P and K respectively). In 2018, the soil samples were taken after fertilization, resulting in large differences in soil nutritional levels among the highest and lowest fertilizer levels. Soil from the 200% fertilizer level had 123.0, 63.6, 165.8, and 322.6 kg·ha$^{-1}$ of $NH_4$–N, $NO_3$–N, P, and K, respectively, whereas soil from the 25% fertilizer level had 15.5, 37.3, 69.7, and 183.3 kg·ha$^{-1}$ of $NH_4$–N, $NO_3$–N, P, and K, respectively (Table 3). When present, differences between sample depths showed that nutrients were present in higher concentrations in the top layer than in the deep layer of the soil (Table 3). In 2019, soil receiving 200% fertilizer had the highest P amount (194.0 kg·ha$^{-1}$) and soil receiving 25% of fertilizer had the lowest P amount (89.9 kg·ha$^{-1}$) (Table 3).

**Table 3.** Soil analyses for $NH_4$–N, $NO_3$–N, P, and K for the different fertilizer levels (25, 50, 100, and 200%) and sample depth (0–20 and 20–40 cm) in 2017, 2018, and 2019 from the Dempsey Farm, University of Georgia, Griffin, GA. In 2017 and 2019, soil samples were taken before fertilizer application (recommended practice). In 2018, soil samples were taken two days after fertilizer application, displaying elevated values relative to the samples taken in 2017 and 2019, because of the sampling time.

| Nutrient | Fertilizer Level | | | | Sample Depth (cm) | | *P* Value | |
|---|---|---|---|---|---|---|---|---|
| | 25% | 50% | 100% | 200% | 0–20 | 20–40 | Fertilizer Level | Sample Depth |
| | kg·ha$^{-1}$ | | | | | | | |
| | **April 2017** | | | | | | | |
| $NH_4$–N | 2.3 | 2.4 | 4.7 | 7.6 | 4.8 | 3.7 | 0.091 | 0.523 |
| $NO_3$–N | 17.2 b $^{z}$ | 22.4 b | 30.9 ab | 48.3 a | 31.4 | 28.0 | **<0.001** | 0.533 |
| P | 57.7 c | 60.0 bc | 85.0 ab | 105.4 a | 107.9 a | 46.2 b | **<0.001** | **<0.001** |
| K | 155.1 | 144.1 | 141.6 | 156.4 | 161.1 a | 137.5 b | 0.223 | **<0.001** |
| | **April 2018** | | | | | | | |
| $NH_4$–N | 15.5 c | 43.5 bc | 47.7 b | 123.0 a | 86.1 a | 28.7 b | **<0.001** | **<0.001** |
| $NO_3$–N | 37.3 b | 45.6 ab | 47.7 ab | 63.6 a | 45.0 | 52.1 | **0.019** | 0.230 |
| P | 69.7 c | 87.5 c | 123.2 b | 165.8 a | 155.3 a | 67.8 b | **<0.001** | **<0.001** |
| K | 183.3 c | 224.6 bc | 245.2 b | 322.6 a | 289.4 a | 198.5 b | **<0.001** | **<0.001** |
| | **May 2019$^{y}$** | | | | | | | |
| $NH_4$–N | 7.3 | 6.7 | 7.9 | 8.4 | 7.6 | N/A | 0.592 | N/A |
| $NO_3$–N | 4.4 | 2.9 | 6.7 | 2.1 | 4.0 | | 0.058 | |
| P | 89.9 c | 104.8 bc | 138.3 b | 194.0 a | 131.8 | | **<0.001** | |
| K | 146.7 | 151.1 | 163.0 | 160.9 | 155.4 | | 0.548 | |

$^{z}$ Means followed by the same letter within a row and treatment effect (fertilizer levels or sample depth) are not significantly different by Tukey's honestly significant different test, $P \leq 0.05$. Means without letters indicate non-statistical differences, $P > 0.05$. $^{y}$ Samples were collected only from the 0–20 cm soil profile.

No differences were found among fertilizer levels for the total amount of N removed from trees during the three years of the experiment ($P$ = 0.17). The average removal across the fertilizer levels was 583.7 g/tree (Figure 4). The analysis of the percentage of N partitioning in the three years revealed that defoliation and summer pruning accounted for most of the N removal (68% of the total N removed). For the individual removal events, most of the differences in N removal among fertilizer treatments were found only for summer pruning in June 2017 and winter pruning in February 2018 (Figure 4). For the summer pruning in June 2017, the greatest amount of N was removed from trees receiving 100% fertilizer (55.3 g/tree), followed by trees receiving 200 and 25% fertilizer (51.5 and 47.3 g/tree, respectively), and lastly by trees receiving 50% fertilizer (42.1 g/tree). For the winter pruning in February 2018, trees receiving 100% fertilizer had the greatest amount of N removed (83.8 g/tree), followed by trees receiving 200% fertilizer (70.1 g/tree), and then followed by trees receiving 25 and 50% fertilizer (66.2 and 57.9 g/tree, respectively) (Figure 4).

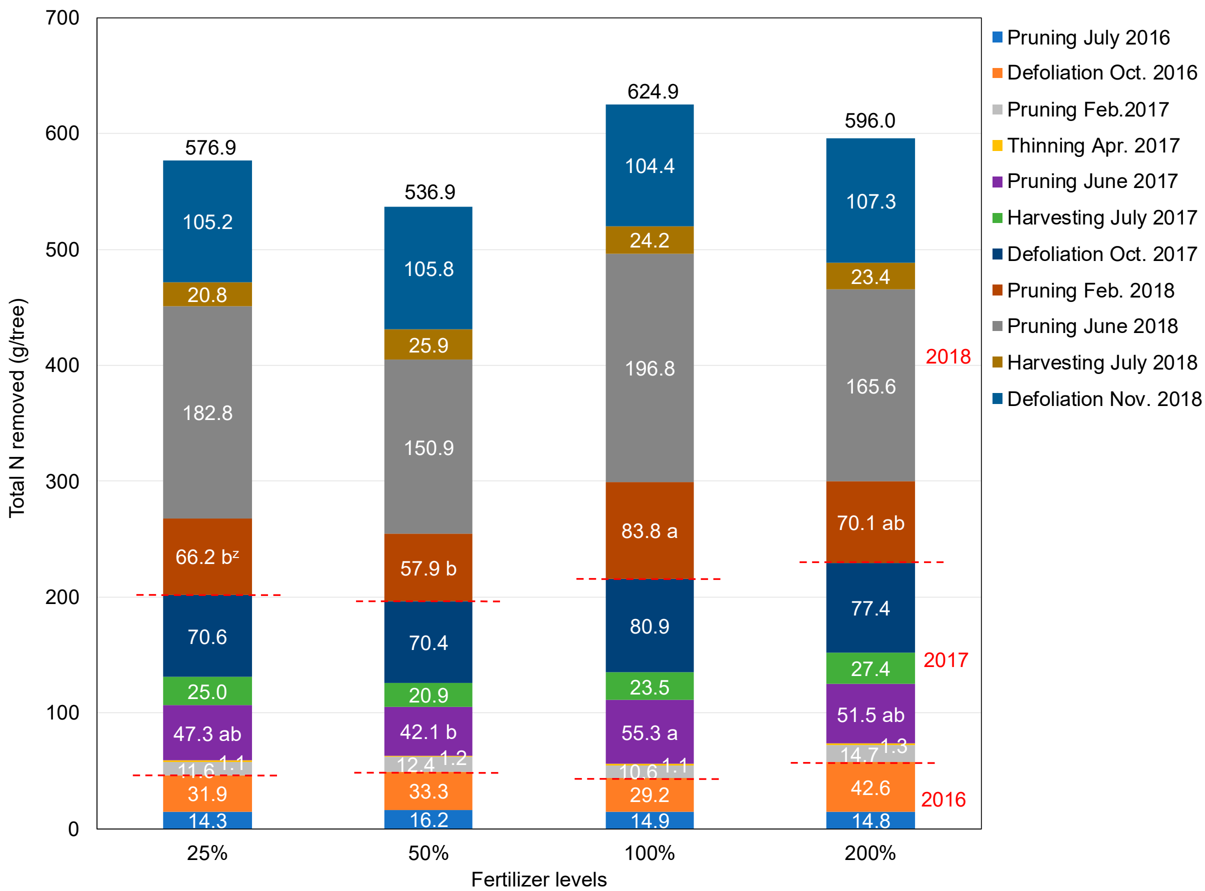


**Figure 4.** Total N removed per tree for the different fertilizer levels (25, 50, 100, and 200%) of the "Julyprince" peaches in 2016, 2017, and 2018. For each removal event (different colors), the means are shown inside the bars. $^{z}$ Means followed by a different letter within a removal event are significantly different by Tukey's honestly significant different test, $P \leq 0.05$. Means without letters indicate non-statistical differences, $P > 0.05$.

For the specific cases of summer pruning in June 2017 and winter pruning in February 2018, significant differences were found for the DW of the material (Table 4). The means separation followed a very similar pattern than those from the total amount of N removed from those two removal events—greater values for 100%, followed by 200 and 25%, and lastly by 50% (Table 4). The N concentration analysis among fertilizer rates within every removal event indicated significant differences only for the leaves removed from the summer pruning in July 2016 ($P = 0.013$) and fruit harvested in July 2017 ($P < 0.001$) (Table 4).

**Table 4.** Dry weight (DW) and N concentration in the different removal events for the different fertilizer levels (25, 50, 100, and 200%) for trees of "Julyprince" peaches in 2016, 2017, and 2018.

| Removal Event | Dry Weight (g/tree) | | | | | | | | *P* Value |
|---|---|---|---|---|---|---|---|---|---|
| | 25% | | 50% | | 100% | | 200% | | |
| Pruning Leaf July 2016 | 360.9 | | 382.6 | | 355.3 | | 340.9 | | 0.888 |
| Pruning Stem July 2016 | 270.8 | | 287.5 | | 270.1 | | 256.0 | | 0.895 |
| Defoliation October 2016 | 1080.9 | | 1121.4 | | 980.6 | | 1413.8 | | 0.181 |
| Pruning February 2017 | 875.2 | | 992.4 | | 811.4 | | 1055.0 | | 0.342 |
| Thinning April 2017 | 39.6 | | 41.3 | | 38.0 | | 41.2 | | 0.978 |
| Pruning Leaf June 2017 | 968.6 | ab [z] | 854.9 | b | 1149.7 | a | 1054.6 | ab | **0.028** |
| Pruning Stem June 2017 | 798.8 | ab | 725.8 | b | 965.8 | a | 894.9 | ab | **0.026** |
| Harvesting July 2017 | 1778.3 | | 1616.1 | | 1642.7 | | 2017.3 | | 0.179 |
| Defoliation October 2017 | 2070.4 | | 2003.2 | | 2355.0 | | 2204.7 | | 0.124 |
| Pruning February 2018 | 3169.4 | ab | 2761.9 | b | 3901.7 | a | 3400.5 | ab | **0.007** |
| Pruning Leaf June 2018 | 3766.1 | | 3159.9 | | 3944.2 | | 3425.1 | | 0.326 |
| Pruning Stem June 2018 | 3138.3 | ab | 2523.7 | b | 3650.7 | a | 2805.6 | ab | **0.038** |
| Harvesting July 2018 | 1829.7 | | 2276.7 | | 1929.3 | | 2014.4 | | 0.752 |
| Defoliation November 2018 | 3622.9 | | 3557.6 | | 3606.6 | | 3639.2 | | 0.986 |
| Total | 23,769.9 | | 22,304.9 | | 25,601.0 | | 24,563.0 | | 0.121 |
| | N Concentration (% DW) | | | | | | | | *P* Value |
| | 25% | | 50% | | 100% | | 200% | | |
| Pruning Leaf July 2016 | 3.29 | b | 3.46 | ab | 3.43 | ab | 3.59 | a | **0.013** |
| Pruning Stem July 2016 | 0.96 | | 0.99 | | 0.93 | | 0.97 | | 0.891 |
| Defoliation October 2016 | 2.92 | | 2.96 | | 2.95 | | 2.99 | | 0.808 |
| Pruning February 2017 | 1.33 | | 1.29 | | 1.37 | | 1.36 | | 0.369 |
| Thinning April 2017 | 2.78 | | 2.92 | | 2.82 | | 3.05 | | 0.201 |
| Pruning Leaf June 2017 | 3.97 | | 3.98 | | 3.93 | | 4.00 | | 0.662 |
| Pruning Stem June 2017 | 1.11 | | 1.11 | | 1.09 | | 1.07 | | 0.709 |
| Harvesting July 2017 | 1.41 | a | 1.30 | b | 1.44 | a | 1.35 | ab | **0.001** |
| Defoliation October 2017 | 3.43 | | 3.51 | | 3.43 | | 3.52 | | 0.335 |
| Pruning February 2018 | 2.11 | | 2.08 | | 2.12 | | 2.07 | | 0.807 |
| Pruning Leaf June 2018 | 3.95 | | 3.89 | | 3.97 | | 3.94 | | 0.808 |
| Pruning Stem June 2018 | 1.08 | | 1.06 | | 1.08 | | 1.09 | | 0.697 |
| Harvesting July 2018 | 1.16 | | 1.14 | | 1.24 | | 1.16 | | 0.262 |
| Defoliation November 2018 | 2.89 | | 2.96 | | 2.88 | | 2.95 | | 0.646 |

[z] Means followed by the same letter within a row (removal event) are not significantly different by Tukey's honestly significant different test, $P \leq 0.05$. Means without letters indicate non-statistical differences, $P > 0.05$.

### *3.2. Irrigation Levels and Systems*

Figures 1–3 represent the VWC of the soil and how the Sensorweb system maintained the VWC above the thresholds established for irrigation (see Materials and Methods). Additionally, rain events are represented. In 2016, non-irrigated trees had lower water potential than irrigated trees. In July 2016, the leaf water potential of non-irrigated trees was −2.56 MPa, lower than −2.16 MPa of irrigated trees ($P < 0.001$). In August 2016, the stem water potential of non-irrigated trees was also lower than irrigated trees (−1.99 vs. −1.25 MPa, $P < 0.001$). Drought stress in trees was caused by below average rainfall in 2016 (Table 2). In 2017 and 2018, no major differences in stem water potential were found between irrigated vs. non-irrigated trees (average stem water potential of −0.64 MPa across treatments from May to October 2017, and −0.72 MPa from June to October 2018). Precipitation was comparable to the historical average, not resulting in drought stress in the trees in 2017 and 2018 (Table 2).

A greater amount of N was removed from the irrigated trees (656.8 g/tree) when compared with the non-irrigated trees (510.6 g/tree) ($P < 0.001$, Figure 5). Defoliation and summer pruning accounted for most of the N removal in a given year. Irrigation induced greater N removal than non-irrigation for most of the removal events (Figure 5). Differences were found within all the pruning practices (winter or summer) and most of the defoliations.

The amounts of N removed from events related to fruit (thinned and harvested fruit) were not different between irrigated and non-irrigated trees (Figure 5).

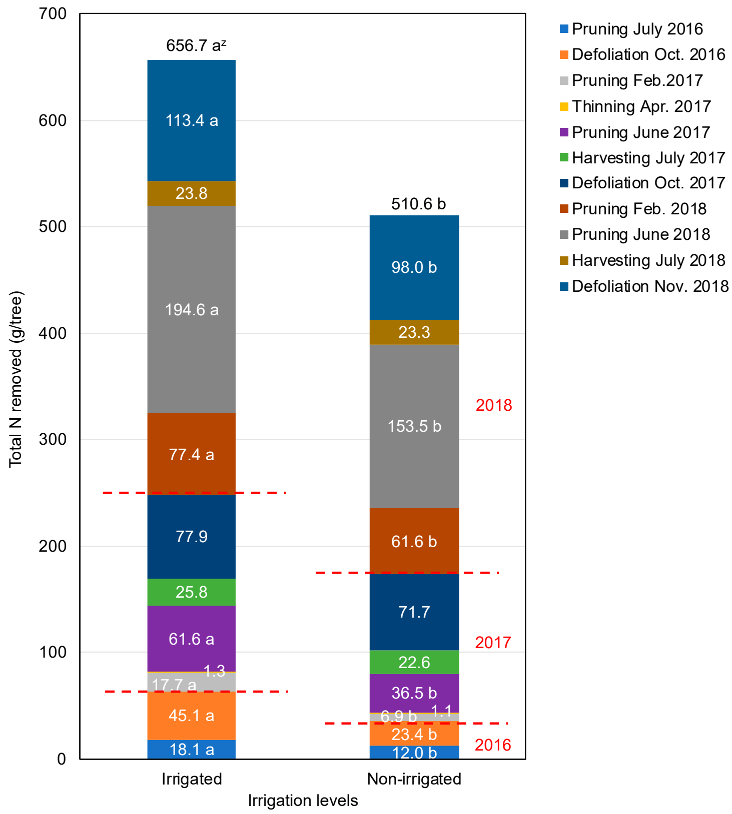


**Figure 5.** Total N removed per tree for the different irrigation levels (irrigated vs. non-irrigated) of "Julyprince" peaches in 2016, 2017, and 2018. For each removal event (different colors), the means are shown inside the bars. $^{z}$ Means followed by a different letter within a removal event are significantly different by Tukey's honestly significant different test, $P \leq 0.05$. Means without letters indicate non-statistical differences, $P > 0.05$.

Irrigating trees induced greater DW from most of the removal events, except for fruit thinning, fruit harvesting, and defoliation in 2017, and fruit harvesting in 2018 (Table 5). Non-irrigated trees had higher N concentration than irrigated trees for summer pruning in June 2018 ($P = 0.034$ and 0.014 for leaves and stems, respectively) and fruit harvested in 2018 ($P = 0.043$, Table 5).

**Table 5.** Dry weight (DW) and N concentration in the different removal events for irrigated vs. non-irrigated for trees of "Julyprince" peaches in 2016, 2017, and 2018.

| Removal Event | Dry Weight (g/tree) | | | | *P* Value |
|---|---|---|---|---|---|
| | Irrigated | | Non-Irrigated | | |
| Pruning Leaf July 2016 | 428.3 | a $^{z}$ | 291.6 | b | **<0.001** |
| Pruning Stem July 2016 | 323.2 | a | 219.0 | b | **<0.001** |
| Defoliation October 2016 | 1502.3 | a | 796.0 | b | **<0.001** |
| Pruning February 2017 | 1350.0 | a | 517.0 | b | **<0.001** |
| Thinning April 2017 | 42.4 | | 37.6 | | 0.441 |
| Pruning Leaf June 2017 | 1274.5 | a | 739.5 | b | **<0.001** |
| Pruning Stem June 2017 | 1070.1 | a | 622.6 | b | **<0.001** |

**Table 5.** *Cont.*

| Removal Event | Dry Weight (g/tree) | | | | *P* Value |
|---|---|---|---|---|---|
| | Irrigated | | Non-Irrigated | | |
| Harvesting July 2017 | 1870.3 | | 1656.9 | | 0.136 |
| Defoliation October 2017 | 2258.2 | | 2058.4 | | 0.074 |
| Pruning February 2018 | 3709.4 | a | 2907.4 | b | **<0.001** |
| Pruning Leaf June 2018 | 4067.6 | a | 3080.1 | b | **0.004** |
| Pruning Stem June 2018 | 3404.3 | a | 2654.9 | b | **0.010** |
| Harvesting July 2018 | 2119.9 | | 1905.2 | | 0.481 |
| Defoliation November 2018 | 3818.7 | a | 3394.4 | b | **0.011** |
| Total | 27,239.1 | a | 20,880.4 | b | **<0.001** |
| | **N Concentration (% DW)** | | | | ***P* Value** |
| | **Irrigated** | | **Non-Irrigated** | | |
| Pruning Leaf July 2016 | 3.45 | | 3.43 | | 0.695 |
| Pruning Stem July 2016 | 0.98 | | 0.94 | | 0.452 |
| Defoliation October 2016 | 2.98 | | 2.93 | | 0.365 |
| Pruning February 2017 | 1.32 | | 1.35 | | 0.384 |
| Thinning April 2017 | 2.94 | | 2.85 | | 0.351 |
| Pruning Leaf June 2017 | 3.93 | | 4.00 | | 0.098 |
| Pruning Stem June 2017 | 1.09 | | 1.11 | | 0.420 |
| Harvesting July 2017 | 1.38 | | 1.37 | | 0.507 |
| Defoliation October 2017 | 3.46 | | 3.48 | | 0.600 |
| Pruning February 2018 | 2.08 | | 2.11 | | 0.600 |
| Pruning Leaf June 2018 | 3.88 | b | 3.99 | a | **0.034** |
| Pruning Stem June 2018 | 1.05 | b | 1.11 | a | **0.014** |
| Harvesting July 2018 | 1.14 | b | 1.21 | a | **0.043** |
| Defoliation November 2018 | 2.96 | | 2.87 | | 0.081 |

[z] Means followed by the same letter within a row (removal event) are not significantly different by Tukey's honestly significant different test, $P \leq 0.05$. Means without letters indicate non-statistical differences, $P > 0.05$.

Drip irrigation delivered 3065 L/tree of water, averaged over fertilizer levels and totaled over the three years of the experiment, whereas micro-sprinkler irrigation delivered 4743 L/tree. This accounts for a reduction of 35% by using drip-irrigation. Drip-irrigated trees had more N removed (720.9 g/tree) in comparison with micro-sprinkler-irrigated trees (592.6 g/tree) ($P = 0.004$) (Figure 6). These differences were mainly driven by differences found in the amount of N removed from defoliation in 2016 and 2018, summer pruning in 2018, fruit harvested in 2017 and 2018, and fruit thinning in 2017 (Figure 6).

Similar to the other treatments, most of the material removed each year was from summer pruning and defoliation. Drip irrigation induced greater DW removal than micro-sprinkler irrigation for fruit thinning in April 2017 ($P = 0.028$) and summer pruning in June 2018 ($P = 0.019$ and 0.004 for leaves and stems, respectively) (Table 6). In contrast, micro-sprinkler irrigation induced greater DW removal for harvested fruit in 2018 ($P = 0.036$). Drip-irrigated trees had a higher N concentration than micro-sprinkler-irrigated trees for the defoliation in 2016 ($P = 0.016$) and 2018 ($P = 0.002$) and stems from summer pruning in 2018 ($P = 0.009$) (Table 6).

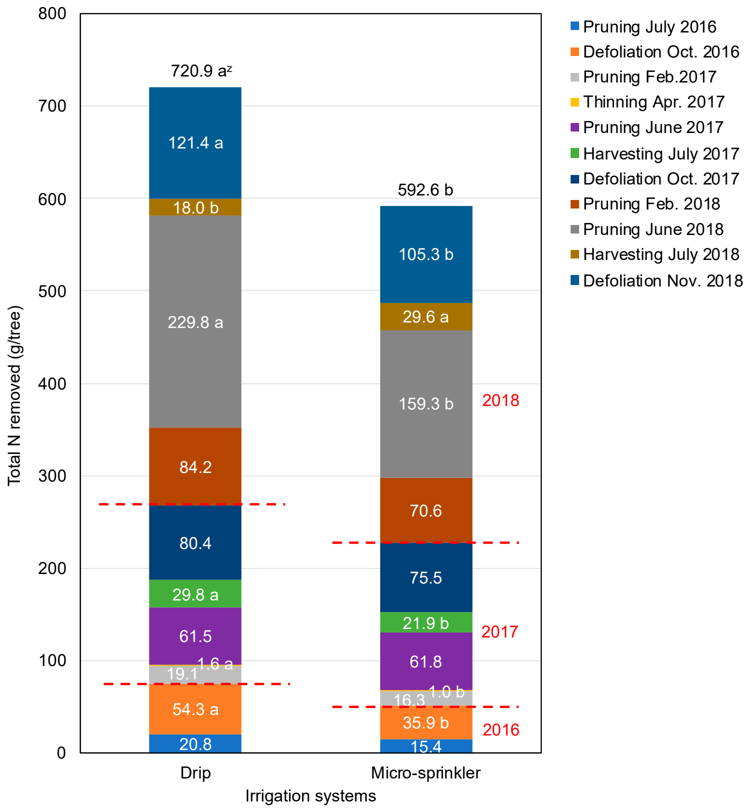


**Figure 6.** Total N removed per tree for the different irrigation systems (drip vs. micro-sprinkler) of "Julyprince" peaches in 2016, 2017, and 2018. For each removal event (different colors), the means are shown inside the bars. $^{z}$ Means followed by a different letter within a removal event are significantly different by Tukey's honestly significant different test, $P \leq 0.05$. Means without letters indicate non-statistical differences, $P > 0.05$.

**Table 6.** Dry weight (DW) and N concentration in the different removal events for drip- vs. micro-sprinkler-irrigated for trees of "Julyprince" peaches in 2016, 2017, and 2018.

| Removal Event | Dry Weight (g/tree) | | | | *P* Value |
|---|---|---|---|---|---|
| | Drip | | Micro-Sprinkler | | |
| Pruning Leaf July 2016 | 486.7 | | 369.9 | | 0.135 |
| Pruning Stem July 2016 | 365.7 | | 280.6 | | 0.153 |
| Defoliation October 2016 | 1716.1 | | 1288.6 | | 0.086 |
| Pruning February 2017 | 1505.8 | | 1194.2 | | 0.392 |
| Thinning April 2017 | 53.3 | a $^{z}$ | 31.5 | b | **0.028** |
| Pruning Leaf June 2017 | 1272.2 | | 1276.7 | | 0.973 |
| Pruning Stem June 2017 | 1058.4 | | 1081.7 | | 0.825 |
| Harvesting July 2017 | 2076.6 | | 1663.9 | | 0.087 |
| Defoliation October 2017 | 2315.0 | | 2201.5 | | 0.432 |
| Pruning February 2018 | 3962.9 | | 3455.8 | | 0.116 |
| Pruning Leaf June 2018 | 4674.7 | a | 3460.6 | b | **0.019** |
| Pruning Stem June 2018 | 4074.4 | a | 2734.2 | b | **0.004** |
| Harvesting July 2018 | 1586.4 | b | 2653.3 | a | **0.036** |
| Defoliation November 2018 | 3933.0 | | 3704.5 | | 0.360 |
| Total | 29,081.2 | a | 25,397.0 | b | 0.015 |

**Table 6.** *Cont.*

| | N Concentration (% DW) | | | | *P* Value |
|---|---|---|---|---|---|
| | Drip | | Micro-Sprinkler | | |
| Pruning Leaf July 2016 | 3.53 | | 3.38 | | 0.190 |
| Pruning Stem July 2016 | 0.99 | | 0.98 | | 0.929 |
| Defoliation October 2016 | 3.16 | a | 2.80 | b | **0.016** |
| Pruning February 2017 | 1.28 | | 1.37 | | 0.072 |
| Thinning April 2017 | 2.93 | | 2.95 | | 0.912 |
| Pruning Leaf June 2017 | 3.93 | | 3.94 | | 0.922 |
| Pruning Stem June 2017 | 1.09 | | 1.08 | | 0.752 |
| Harvesting July 2017 | 1.45 | | 1.32 | | 0.109 |
| Defoliation October 2017 | 3.48 | | 3.43 | | 0.484 |
| Pruning February 2018 | 2.11 | | 2.05 | | 0.587 |
| Pruning Leaf June 2018 | 3.92 | | 3.83 | | 0.410 |
| Pruning Stem June 2018 | 1.16 | a | 0.94 | b | **0.009** |
| Harvesting July 2018 | 1.15 | | 1.13 | | 0.611 |
| Defoliation November 2018 | 3.09 | a | 2.84 | b | **0.002** |

[z] Means followed by the same letter within a row (removal event) are not significantly different by Tukey's honestly significant different test, $P \leq 0.05$. Means without letters indicate non-statistical differences, $P > 0.05$.

## 4. Discussion

### *4.1. Fertilizer Levels*

The total amount of N removed per tree is a combination of the DW of the tree material removed and the N concentration of those tissues. Different fertilizer rates did not affect the total amount of N removed by the trees in the three years of the experiment. This disagrees with previous findings [10], reporting an increased N content (greater potential of N removed) in fertilized peach trees vs. trees not fertilized for three years before the experiment. In that study, the lack of fertilization significantly reduced the N in the trees, negatively affecting the DW and the N concentration. In contrast, our lowest fertilizer level, the 25% rate, did not affect the DW or the N concentration in comparison to the recommended rate. This basal fertilizer application was able to maintain tree growth and development. One of the reasons for this maintenance capacity is the recycling of nutrients in the orchard [13]. Most of the plant removal events (pruning, fruit thinning, and defoliation) do not remove the nutrients from the orchard. The fresh material is removed from the trees but immediately returned to the soil surface. There, the material can be mowed, decomposed, and re-incorporated into the soil profile, allowing for nutrient recycling. Therefore, the only plant removal event that actually removes material and nutrients from the orchard is harvesting. Zhou and Melgar [13] estimated that N removal from harvesting was 19.0, 20.8, and 27.4 kg·ha$^{-1}$ for the early, mid-, and late cultivars of peaches grown in South Carolina, respectively. Tagliavini et al. [15] reported that N removal in fruit from mature peach trees in Italy ranges from 12 to 36 kg·ha$^{-1}$. In our research, N removal in harvested fruit averaged 8.7 kg·ha$^{-1}$ in 2017 and 8.4 kg·ha$^{-1}$ in 2018. It is important to highlight that 2017 was the first year of harvesting, and in 2018, trees were severely affected by a late freeze, which reduced the fruit load. Our research is the first report of N partitioning for young peach trees in the southeastern United States.

Evaluations of individual removal events showed differences in N removal among fertilizer levels only for winter or summer pruning events. The differences were caused solely by variations in DW of the material and not related to the N concentration in the tissues. These findings agree with Rufat and DeJong [10], who reported a greater DW of peach leaves and branches (which can be associated with pruning) in treatments receiving 200 kg·ha$^{-1}$ N vs. 0 kg·ha$^{-1}$ N. Additionally, 200 kg·ha$^{-1}$ N treatment induced a slightly greater N concentration in leaves, but no differences between treatments were found for the N concentration in branches. Statistical differences in N concentration among fertilization treatments were found only for leaves from the summer pruning in July 2016 and fruit harvested in 2017. However, they were not consistent throughout the experiment and may not hold a biological meaning. Nevertheless, the result of greater N concentration in leaves in July 2016 in higher fertilizer levels agrees with Rufat and DeJong [10].

### 4.2. Irrigation Levels and Systems

The total amount of N removed from irrigated trees was greater than that of non-irrigated trees for the three years. This difference started during the 2016 season and continued in the 2017 and 2018 seasons. In 2016, a severe drought took place during most of the spring and summer seasons, as shown by the below average rainfall in comparison with the historical average (Table 2). Similarly, as reported by Casamali [2], water potential measurements indicated that non-irrigated trees were exposed to drought in 2016, but not in 2017 or 2018 (data not shown).

The evaluation of the individual removal events reveals that most of the events induced greater N removal for irrigated vs. non-irrigated trees. These results were consistent with the analysis of canopy volume and trunk cross-sectional area of the trees in this experiment indicating that plant growth was affected by the drought and trees did not recover during the three years of research [2]. All other pruning events and defoliation in 2018 also showed more N removed from irrigated vs. non-irrigated trees. This illustrates how one year of drought (2016) can negatively affect peach tree growth and development in following years. Differences in total N removed between irrigated and non-irrigated trees are the result of differences in DW of removed material. Irrigated trees had more DW removed for most events in comparison with non-irrigated trees. This agrees with prior findings for peach stems and leaves DW [16]. Boland et al. [17] reported reductions in summer but not winter pruning FW when peach trees experienced deficit irrigation. This distinct behavior might be attributed to the different composition of summer and winter pruning material. We estimated that for summer pruning, leaves accounted for 57.1% and stems for 42.9%, while winter pruning material consists of 100% dormant stems. The N concentration of the removal events was affected by the irrigation levels mostly in 2018. Summer pruning material and harvested fruit from 2018 had greater N concentration if trees were non-irrigated. This response was not observed in 2016 and 2017, therefore it may not hold a biological meaning.

Drip irrigation resulted in greater N removal from trees than micro-sprinkler irrigation. Differences between drip and micro-sprinkler irrigation were found in N removal from fruit thinning, summer pruning, harvested fruit, and defoliation events. For most cases, drip irrigation induced higher N removal than micro-sprinkler irrigation. These differences were driven majorly by differences in DW, with the exception of defoliation, where drip-irrigated trees had a higher N concentration than the micro-sprinkler-irrigated trees. The difference in N removal between irrigation systems differed from the other main treatments (fertilization or irrigated vs. non-irrigated) where differences in total N removal were mainly driven by differences in N removal from pruning and defoliation events (vegetative material) instead of fruit thinning and harvest fruit (reproductive organs). Differences in DW between drip vs. micro-sprinkler for individual removal events were reported only for fruit thinning in 2017, and summer pruning and harvested fruit in 2018. The differences in fruit thinning DW can be explained by the greater canopy volume of drip-irrigated trees in September 2016 [2]. Greater canopy volume allows for a more fruit production, which was the case in our study [2]. A greater number of fruit was produced in drip-irrigated trees and some were removed during fruit thinning in 2017. For the case of summer pruning in 2018, a possible explanation comes from an advective freeze that affected the orchard in March 2018. The freeze killed a significant number of flowers and fruitlets of the drip-irrigated trees only, because of the topography of the experimental plot. After having a great number of flowers and fruitlets removed, the competition for photoassimilates was reduced. Thus, the dry matter and nitrogen partitioning was shifted towards vegetative growth instead of reproductive growth. Similarly, Zhou and Melgar [13] and Policarpo et al [14] reported greater vegetative growth after harvest in early-season cultivars in comparison to late-season cultivars, because of the removal of fruit (sinks). The reduced number of fruit from the drip-irrigated trees in comparison to micro-sprinkler-irrigated trees possibly resulted in increased N concentration in the stems in June 2018 and in the leaves from defoliation in 2018, since the nutrients did not have to be allocated to fruit production. Differences in N concentration between irrigation systems were found for defoliation in 2016, possibly because of the severe drought in 2016. In September 2016, drip-irrigated trees had a greater canopy volume than micro-sprinkler-irrigated trees [2]. Therefore, drip-irrigated trees were growing at a different rate than micro-sprinkler-irrigated trees. It is possible that because of the differences in growth, micro-sprinkler-irrigated trees were already reallocating nutrients from leaves to permanent organs in preparation for fall defoliation.

## 5. Conclusions

Different fertilization rates did not show any negative effects in terms of the dynamics of DW and N concentration among different organs of peach trees. This suggests that young peach trees need less fertilizer than currently recommended. Peach trees receiving reduced levels of fertilizer can still allocate enough assimilates and N for satisfactory tree growth and development. At the same time, reductions in fertilization are environmentally sound and decrease the production costs. The long-term sustainability of reduced fertilization is being monitored. Irrigation induces greater vegetative growth in general, especially under drought conditions. The greater canopy did not translate to the greater DW of harvested fruit or nitrogen removed in harvested fruit. However, it is important to highlight that the fresh fruit yield was greater for irrigated vs. non-irrigated trees in 2017 [2]. In our experiment, differences between drip and micro-sprinkler irrigation appears to be more related to the environment than an irrigation treatment effect.

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