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Changes in Soil Chemical Attributes, Horticultural Performance and Fruit Yield of Peach Cultivars Following Preplant and Annual Applications of Composted Mulch Amendments

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CHANGES IN SOIL CHEMICAL ATTRIBUTES, HORTICULTURAL PERFORMANCE AND FRUIT YIELD OF PEACH CULTIVARS FOLLOWING PREPLANT AND ANNUAL APPLICATIONS OF COMPOSTED MULCH AMENDMENTS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Plant and Environmental Sciences

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by
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ABSTRACT

Southeastern peach orchards often have poor soil quality due to native soil composition, intensive farming practices and generational replanting of trees in the same locations. This study investigated using mulch amendments to improve the chemical and physical quality of soil prior to planting a new peach orchard. At the beginning of the four-year study, a single-ground municipal composted mulch was incorporated into the soil at two different rates and three cultivars of peaches, ‘Rubyprince’, ‘Julyprince’, and ‘BigRed’ were planted on berms. Thereafter, the same mulch product was annually applied to the top of the berms at two different rates to evaluate changes to soil organic matter (OM), cation exchange capacity, soil nutrients, and base saturation throughout the study. Additionally, horticultural parameters including tree growth, leaf nutrients, fruit yield, and fruit quality were assessed. Incorporating either rate of mulch generally had a positive effect on soil chemistry as cation exchange capacity, base saturation, and OM all increased, while soil pH was stabilized closer to 7. Both mulch rates generally enhanced nutrient availability, suggesting the potential benefits for peach growers looking to provide trees with non-synthetic forms of fertility. The trees in mulch-amended soils grew larger and could potentially yield more fruit at younger age from increased tree size, but initial yields only showed no decrease of yield from the treatments. However, continued observation over the orchard lifespan is needed to understand tree productivity and additional work is needed to optimize future application rates to avoid over-fertilization and to understand the farm economy.

ACKNOWLEDGMENTS

I have learned to practice gratitude in life and this single page will not nearly hold the list of individuals that should properly be acknowledged for their help and participation in this educational and research endeavor. So, before any specifics, please know that if you are one of the many that have participated in this project in any way, I am grateful for your assistance in recovering these old and new again truths.

Dr. Guido Schnabel and Dr. Juan Carlos Melgar thank you for the guidance, and generous time and resources spent on this project. Dr. Brian Lawrence the same, and for providing endless help in statistics and editing. I am grateful for the help from the Musser Fruit Research Center Team – Dave Ouellette, Luke Dallmann, Marcie Dallmann, Coleman Parker, Charlie Burrell, Sarah Harding and Seth Mayo. Dr. Matt Hersom, thank you for your generous support and encouragement. Finally, without the endless support from my family this would not have been possible. Thank you, Laura, and the Hopkins for your long-suffering sharing of my time with this educational journey. Let’s go on a hike this weekend!

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CHAPTER ONE

CHANGES IN SOIL CHEMICAL ATTRIBUTES FOLLOWING PREPLANT AND ANNUAL APPLICATIONS OF COMPOSTED MULCH AMENDMENTS TO A PEACH ORCHARD

Introduction

Peaches (*Prunus persica* (L.) Batsch) are an economically important fruit crop in the United States, with a production value of over $650 million (USDA, 2022) and are closely tied to the regional identity of the southeastern states. In South Carolina, peaches have significant economic importance, with the peach farm gate value totaling $152,229,000 in 2022 (SC Cooperative Extension, 2022) and nearly 15,500 acres currently under production (USDA, 2022). Moreover, the peach industry contributes to the state's economy through direct and indirect employment opportunities. Not only are South Carolina fresh-market peaches renowned for their high quality and taste but are marketed and coveted by consumers primarily on the east coast of the United States, attracting visitors to support a growing agritourism industry revolving around the fruit. Considering the economic impact of peach production, much research has been conducted to improve yield for growers and fruit quality for consumers. Many of these studies have focused on improving commercial cultivar production (Gasic et al., 2015), cutting costs of fertilizer and irrigation inputs (Fresnedo-Ramirez et al., 2016; Zhou and Melgar, 2019), improving fruit quality and lowering preharvest losses (Anthony and Minas, 2022) and postharvest losses (Adaskaveg and Förster, 2023).

Orchard replant issues associated with poor orchard soils limit the potential productivity and number of suitable growing sites for current and future peach cultivation. Late spring frost risk is a primary consideration prior to orchard establishment and historically profitable production locations are limited to a few key geographic regions within the state. Thus, orchards are frequently replanted on the same location and often suffer from disorders centered around detrimental soil quality changes occurring over the lifetime of the orchard, such as organic matter (OM) reduction (Lawrence et al., 2023) and/or “Peach Tree Short Life” (Okie et al., 1994). Although peach trees are a perennial crop, the average commercial lifespan is only 13 years in commercial orchards. Thus, increasing the lifespan of orchards could be economically beneficial for growers and environmentally beneficial to reduce soil disturbance during orchard removal and establishment. Moreover, identifying orchard establishment strategies which improve soil and long-term tree health despite frequent replanting of orchards may help avoid long-term orchard problems.

Soil properties have historically been categorized into three distinct categories: physical, chemical, or biological, although all three interact and govern the others. Considering the complexity of understanding soil, many studies have examined one of the three soil components individually, as described below. One of the challenges is that each of these three soil components are usually considered independent scientific specialties. Prior orchard soil research has focused on the physical parameters such as soil compaction (Glenn et al., 1994), water infiltration, and erosion (Glenn and Welker, 1989); along with chemical parameters, such as the extractable nutrients required for plant growth. Most studies which examine agricultural soils have focused on the inorganic forms of nitrogen (N), potassium (K), and phosphorus (P) as plants have a large response from their presence or absence (Johnson, 2008; Melgar, et al., 2022) Comparatively, little soil research has been dedicated to the biological components of soil, until more recent times (Baldi et al., 2005). Adding to the complexity, all three components of soil: physical, chemical, and biological interact closely with one another and the appropriate balance is required to ensure healthy soil and create long-lasting changes to biological soil properties (Coyne et al., 2022). For example, increasing OM in soils can increase the cation exchange capacity (CEC), a measurement of the soil to retain and exchange nutrients such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}).

Previous studies investigating the effect of soil amendments in other climatic conditions and in other fruit species have shown promising results regarding adding OM (Thompson et al., 2017; Thompson et al., 2019; Baldi et al., 2006). In each study, increasing the amount of OM in soils by adding organic material improved the natural, synergistic functioning of each category of the soil including the physical, chemical, and biological components. Similarly, topically applying mulch made of various organic materials to the surface of the soil generally improved ground cover management, reducing soil, nutrient, and water runoff in other fruit growing regions (Liu et al., 2022). Some preliminary work using food waste compost has been completed in peach orchards in the southeastern U.S. (Lawrence and Melgar, 2023); however, the role of mulch amendments on peach production systems to improve orchard soil and the effect of these applications in southeastern peach production is still relatively unknown. This study aims to investigate the progressive change of peach orchard soil quality, including the amount of OM, CEC, and available nutrients after mulch amendments are incorporated and annually applied to soil compared to soil under standard practice in the upstate of South Carolina. Thus, the first focus of this study is predominantly tracking soil chemical changes over time. There are soil studies addressing the other two soil components running parallel with this study, but not included in this document.

We addressed this knowledge gap of using mulch as an amendment to southeastern orchards by creating a new soil orchard management system, and analyzed the effects of adding composted mulch to peach orchard soils and tracking the changes to the soil composition. The objective of this study was to assess the OM and chemical constituents of orchard soil after incorporating and amending with mulch annually. We hypothesized that chemical properties of orchard soils can be improved, such that both macronutrient and micronutrient concentration would be increased, by using soil amendments in comparison to standard commercial practices.

Materials and Methods

Orchard conditions, treatment design, and mulch application

A new peach orchard on a replant site was established for this project at the Clemson University Musser Fruit Research Center (MFRC), Seneca, SC (lat. 34˚36’22” N, long. 82˚52’39” W). The location had been previously planted in nectarines (*Prunus persica* var. *nucipersica*, ‘Juneprincess’ on Guardian® rootstock) for approximately 20 years prior to tree removal in 2017. The soil is of the Appling series and classified as clayey, kaolinitic, thermic, typic hapludult, common in the upstate of SC. The initial soil composition, sampled in fall of 2019, yielded a sandy loam (loamy sand by Ye in a second evaluation) (69% sand, 25% silt, and 6% clay) as determined by a jar test. The orchard topography is less than 1% slope east to west.

A 9-row peach orchard (6.7 m on center and 4.9 m apart) was installed in 2020 following 3 years of native sod cover, using a randomized split block design with two factors (soil amendment and cultivar). There were 3 mulch treatments (one per row) replicated three times with 3 cultivars per row (Table 1.1). The following three mulch treatments were used per full row: 1) Untreated control (grower standard, bare soil); 2) 1x mulch (composted mulch incorporated at planting plus mulch top dressed annually, rate 1 (see below)); and 3) 2x mulch (composted mulch incorporated at planting plus mulch top dressed annually, rate 2 (see below)). All trees were planted on berms and not excavated. The control rows received no mulch prior to tree planting. Composted mulch was incorporated into the existing soil when creating berms, before planting trees (Fig. 1.1). The mulch amendments were installed volumetrically per full row of the experiment to a width of 2.4 m (8 ft) wide, which matched the width of the herbicide strip in the untreated control. Specifically, the 1x mulch incorporation rate was 0.34 m^3 of mulch per 1 m of tree row (0.11 m^3 [4.0 ft^3] of composted mulch per linear foot). The 2x preplant rate was 0.68 m^3 of mulch per 1 m of tree row (0.23 m^3 [8.0 ft^3] of composted mulch per linear foot).

The soil amendment used was a composted, single ground, municipal mulch from the Oconee County Landfill, Seneca, SC. The mulch was comprised of mixed species, which were piled and turned twice per year for 4 years following a 2014 storm. During decomposition years prior to 2019, the temperature in the pile was hot enough to self-combust and the fire had to be extinguished several times. After four years, the mulch was well composted and cold and only larger wood pieces were still identifiable. Although incorporated and applied as a mulch, much of the product appeared as dark, friable organic compost.

Berms were created in fall 2019 after the preplant mulch was applied. Incorporation of the composted mulch into the soil was completed to a depth of 0.4 m using a 3-point hitch, 3 shank, V-type subsoiler with 0.8 m shanks pulled behind a tractor. A standard 2 m wide offset disk harrow was then used to complete the incorporation and smooth the soil before using an upfitted Amco LJ6 levee plow (Yazoo City, MS) with a bed packing wheel to create raised berms. The final berms were 0.3 m tall and 1 m wide and 6.7 m apart from the center of the berms. The berms were oriented NW to SE to fit within the predetermined field space. Planting peach trees on berms is part of the current disease management strategy in fields that have a history of oak root rot (*Desarmillaria caespitosa*). In the winter after the second leaf, the trees are typically excavated to expose the root crown to atmospheric conditions not favorable to fungal spread that causes tree mortality, extending the life of the orchard by several years. There is a history of oak root rot in this field. However, the trees were not excavated in this experiment, as it would complicate consistent data collection of soil properties.

Figure 1.1. Arial photograph showing the orchard after the initial incorporation of the 1x and 2x rates of composted single ground municipal mulch replicated three times. The broad lines in the orchard (from left to right, lighter to darker color) show unamended soil which served as the control, the 1x mulch treatment, and the 2x mulch treatment.

Immediately after the berms were created row middles were smoothed with a Unverferth Perfecta field cultivator and planted with a Pasture Pleaser 2007 drill at 2.1m wide with a cover crop mixture of oats (*Avena sativa* L.), crimson clover (*Trifolium incarnatum* L.), arrow leaf clover (*Trifolium vesiculosum* Savi), and hairy vetch (*Vicia villosa* Roth).

After cover crop establishment, additional mulch was applied to the surface of the 1x and 2x treatment berms in year 1 and annually during each spring following the first year. The surface-applied annual application rate for the 1x treatment was 0.11 m^3 per 1 m of tree row (1.33 ft^3 linear $foot^{-1}$ of row) while the surface-applied annual application rate for the 2x treatment was 0.23 m^3 per 1 m of tree row (2.66 ft^3 linear $foot^{-1}$ of row).

One-year-old bare root trees of three cultivars on Guardian® rootstock were used for the study: 'Rubyprince' (early-season cultivar ripening in June), 'Julyprince' (mid-season cultivar ripening in July), and 'Big Red' (late-season cultivar ripening in August). Each row comprised three, randomized, 5-tree blocks. Rows 1, 4, and 7 were untreated controls, receiving no mulch incorporation or topical mulch application; rows 2, 5, and 8 were treated with 1x mulch; and rows 3, 6, and 9 were treated with 2x mulch (Table 1.1).

Table 1.1. The randomized split block design of the 9-row orchard used in the study with entire rows comprised of one of the three mulch treatments (negative control, no mulch; 1x rate of mulch; or 2x rate of mulch) and divided by the cultivars Rubyprince (Rp), Julyprince (Jp), or Big Red (BR).

Control Row 1	1x Row 2	2x Row 3	Control Row 4	1x Row 5	2x Row 6	Control Row 7	1x Row 8	2x Row 9
Rp Rp Rp Rp Rp	Jp Jp Jp Jp Jp	BR BR BR BR BR	Jp Jp Jp Jp Jp	Rp Rp Rp Rp Rp	BR BR BR BR BR	Rp Rp Rp Rp Rp	Jp Jp Jp Jp Jp	Rp Rp Rp Rp Rp
Jp Jp Jp Jp Jp	BR BR BR BR BR	Rp Rp Rp Rp Rp	BR BR BR BR BR	Jp Jp Jp Jp Jp	Jp Jp Jp Jp Jp	BR BR BR BR BR	Rp Rp Rp Rp Rp	Jp Jp Jp Jp Jp
BR BR BR BR BR	Rp Rp Rp Rp Rp	Jp Jp Jp Jp Jp	Rp Rp Rp Rp Rp	BR BR BR BR BR	Rp Rp Rp Rp Rp	Jp Jp Jp Jp Jp	BR BR BR BR BR	BR BR BR BR BR

Fertilizer and lime were applied according to soil sample results and commercial standards (CUASL, 2023; Blaauw et al., 2024). During the study, the soil was limed twice, once with dolomitic lime ($CaMg(CO_3)_2$) and once with calcitic lime ($CaCO_3$) The first lime application was dolomitic lime prior to planting trees and was broadcast at 4483 kg ha^{-1} (2 tons $acre^{-1}$). The second lime application was calcitic agricultural lime applied in January 2021 and broadcast at 3363 kg ha^{-1} (1.5 tons $acre^{-1}$). Fertilizer (10-10-10) was broadcast in March 2020 and June 2020 at 0.45 $tree^{-1}$ (1lb $tree^{-1}$). Then, in March 2021, 2022, and 2023, 19-19-19 fertilizer was broadcast banded under the trees with a tractor mounted pendulum type fertilizer spreader at a rate of 17.23 kg N $acre^{-1}$ (38lbs N $acre^{-1}$).

Soil Analysis

A baseline soil sample was taken during the fall of 2019, then a total of 5 times over the study during fall 2020, spring 2021, spring 2022, fall 2022, and spring 2023. During 2020 and 2021, soil samples were taken as a composite of 12 cores within each row of trees, regardless of cultivar, resulting in 9 total samples (9 rows). In 2022 and 2023, 12-core composites were made from the middle three trees of each 5-tree cultivar block in each row, resulting in a total of 27 soil samples (9 rows by 3 cultivar blocks). Regardless of the number of samples or date, core samples were taken to a depth of 0.15 m and half occurred at the top center of each berm and half were taken on the side slope of the berm. The soil sampler used was a Collect-N-Go Soil Sample Collection Kit (CNG1, collectngonow.com, Opelika, AL). Aggregate samples were sent to the Clemson University Agriculture Service Center of Clemson University and analyzed for OM, CEC, total base saturation (BS), pH, nitrate nitrogen (NO_3^-), and extractable P, K, magnesium

(Mg), calcium (Ca), zinc (Zn), manganese (Mn), copper (Cu), boron (B), and sodium (Na) using the Mehlich 1 extraction method (CUASL, 2023).

Mulch Analysis

The initial incorporation of mulch in 2019, and the 2020 and 2021 annual mulch applications were all sourced from the same batch of single ground municipal mulch. The 2022 and 2023 mulch samples were sourced from different batches of mulch, which were collected from the Oconee County landfill and composted for less than one year (Table 1.2). Composted mulch samples were collected from corresponding years of application and submitted for analysis. In 2019, 2020 and 2021, samples were taken from the pile prior to application and dried before submitting for analysis. In 2022 and 2023 samples were taken from the field after application. Samples were submitted to the Clemson University Agricultural Services Lab and analyzed for nitrate nitrogen (NO_3^-), total nitrogen, total carbon, carbon to nitrogen ratio (C:N), P, K, Ca, Mg, S, Zn, Cu, Mn, Iron (Fe), Na, aluminum (Al), OM, soluble salts, and pH. The samples were submitted for analysis as Landscape Mulch to the Clemson University Ag Services Lab and are reported in Table 1.2

Table 1.2. Mulch composition from samples taken in 2019-2021, 2022, and 2023 on dry basis (d.w.) including total nitrogen (Total N), total carbon (Carbon), carbon:nitrogen ratio (C:N); the macronutrients phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S); the micronutrients zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), sodium (Na), and aluminum (Al); organic matter (OM), electrical conductivity (EC) and pH. Macronutrients and OM are shown as % of dry sample, while micronutrients are shown as ppm. EC is shown as dS m^{-1}.

Year	Mulch measurement					
	OM (%)	EC (dS m^{-1})	pH	Total N (%)	Carbon (%)	C:N
2019-2021	37.1	0.07	5.2	0.64	22.0	34.3
2022	66.5	0.04	5.4	0.73	39.5	54.2
2023	87.4	0.06	6.0	0.65	44.7	68.4
	Macronutrient (% d.w. sample)					
	P	K	Ca	Mg	S	
2019-2021	0.06	0.17	1.03	0.15	0.06	
2022	0.09	0.30	1.11	0.14	0.08	
2023	0.15	0.31	0.77	0.13	0.08	
	Micronutrient (ppm d.w. sample)					
	Zn	Cu	Mn	Fe	Na	Al
2019-2021	183	42	176	10849	30	15168
2022	69	23	241	5961	173	9133
2023	89	30	310	3409	338	4663

Statistical Design

The orchard was designed as a randomized split block, with the mulch treatments (3) replicated three times in order across 9 rows of peach trees and cultivars (3) randomly assigned as 5-tree blocks over each row. Due to the two different methods of soil sampling, the soil sample data in 2020 and 2021 were explored using analysis of variance between the three mulch treatments with three replications. In 2022 and 2023, data were explored using analysis of variance (ANOVA) by following a 3x3 factorial model, examining the mulch treatments, cultivars, and their interaction as main effects with the statistical program JMP® (Version 16.2. SAS Institute Inc., Cary, NC, USA). Significant main effects and/or their interaction were further explored using Tukey's honest significant difference (HSD) *post hoc* test for mean separation.

Results

Between the two main effects of the study (mulch and cultivar), there were significant differences in soil parameters due to the mulch treatments, but no differences were found due to the cultivars nor the interaction between mulch treatment and cultivar for any of the soil parameters measured in 2022 and 2023 (Table 1.3). Similarly, across all measurement dates, discriminate analysis showed clear separation between the three mulch treatments (Figure 1.2A) but no separation between the three cultivars (Figure 1.2B).

Table 1.3. Analysis of variance of the factorial model used during the spring of 2022 and 2023 by main effects of mulch treatment (M) and cultivar (C), and their interaction (M x C) on the soil parameters (organic matter, OM; cation exchange capacity, CEC; base saturation, BS; pH; nitrate nitrogen, NO_3^-, phosphorus, P; potassium, K; calcium, Ca; magnesium, Mg; zinc, Zn; manganese, Mn; copper, Cu; boron, B; sodium, Na). Astericks *, **, and *** correspond to *P* values ≤0.05, ≤0.001, and ≤0.0001, respectively. N.S. = non-significant differences at *P* values ≤0.05

Sample Date	**Main effect**	**OM**	**CEC**	**BS**	**pH**	**NO_3^-**	**P**	**K**	**Ca**	**Mg**	**Zn**	**Mn**	**Cu**	**B**	**Na**
Spring 2022	M	-	-	-	-	*	*	**	***	***	NS	***	***	***	NS
	C	-	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	M x C	-	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fall 2022	M	***	***	***	***	NS	***	***	***	*	***	***	***	***	***
	C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	M x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Spring 2023	M	***	***	***	***	NS	***	***	***	***	***	***	***	***	NS
	C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	M x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

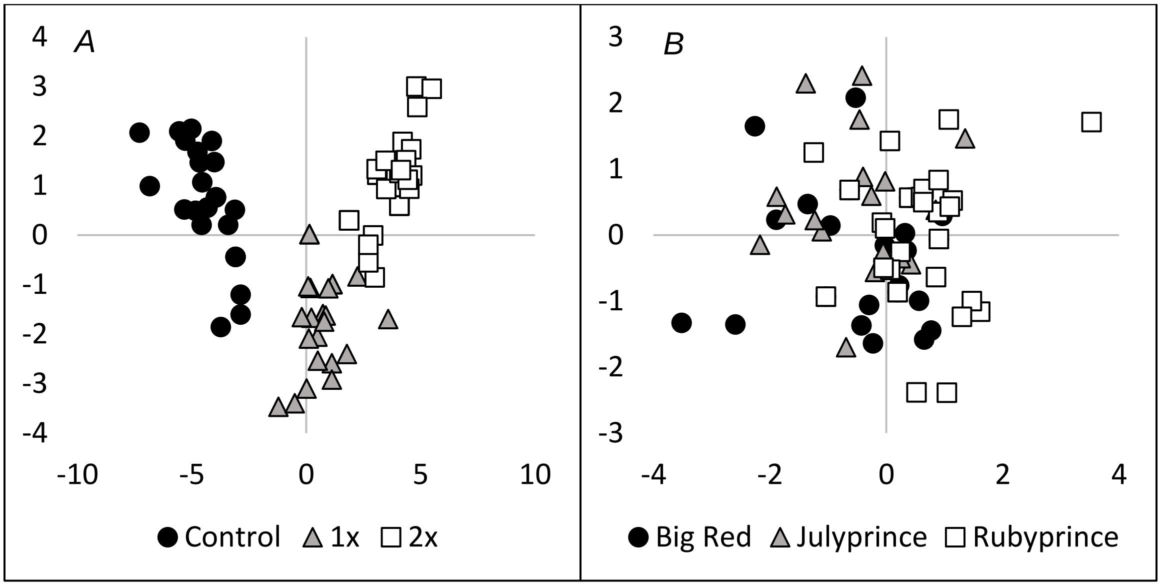

Figure 1.2. Discriminant analysis shows strong separation of the three mulch treatments (A) but no separation of cultivar (B) over the 2022 and 2023 sample dates.

Soil OM, cation exchange capacity, base saturation, and pH

Following the initial incorporation and surface applied mulch in 2019, both the 1x and 2x treatments had greater OM, CEC, BS, and pH values than the control soil for each subsequent sampling time of the study (Figure 1.3, A-D; Appendix A). During individual sampling dates, the OM was consistently highest in the 2x treatment, followed by the 1x treatment, and both were higher than the control during the fall of 2020 ($F = 106.5$, $P \leq 0.0001$), spring of 2021 ($F = 75.0$, $P \leq 0.0001$), fall of 2022 ($F = 46.4$, $P \leq 0.0001$), spring of 2023 ($F = 64.9$, $P \leq 0.0001$) and fall of 2023 ($F = 46.1$, $P \leq 0.0001$; Figure 1.3, A). The values of CEC were also consistently higher in the 1x and 2x soil samples compared to the control in the fall of 2020 ($F = 89.3$, $P \leq 0.0001$), the spring of 2021 ($F = 33.0$, $P \leq 0.0001$), the spring of 2022 ($F = 30.3$, $P \leq 0.0001$), fall of 2022 ($F = 85.6$, $P \leq 0.0001$), spring of 2023 ($F = 177.8$, $P \leq 0.0001$) and fall of 2023 ($F = 53.2$, $P \leq 0.0001$; Figure 1.3, B). Total base saturation was also higher within both mulch treatments compared to the control soil in the fall of 2020 ($F = 110.3$, $P \leq 0.0001$), the spring of 2021 ($F = 15.8$, $P \leq 0.0001$), fall of 2022 ($F = 116.7$, $P \leq 0.0001$), spring of 2023 ($F = 63.2$, $P \leq 0.0001$) and fall of 2023 ($F = 15.2$, $P \leq 0.0001$; Figure 1.3, C). The soil pH was consistently higher within the 1x and 2x treatments than the control soil during the fall of 2020 ($F = 53.5$, $P \leq 0.0001$), the spring of 2021 ($F = 27.5$, $P \leq 0.0001$), the spring of 2022 ($F = 24.5$, $\mathrm{P} \leq 0.0001$), the fall of 2022 ($F = 56.3$, $P \leq 0.0001$), the spring of 2023 ($F = 33.2$, $P \leq 0.0001$) and the fall of 2023 ($F = 4.4$, $P \leq 0.05$; Figure 1.3, D).

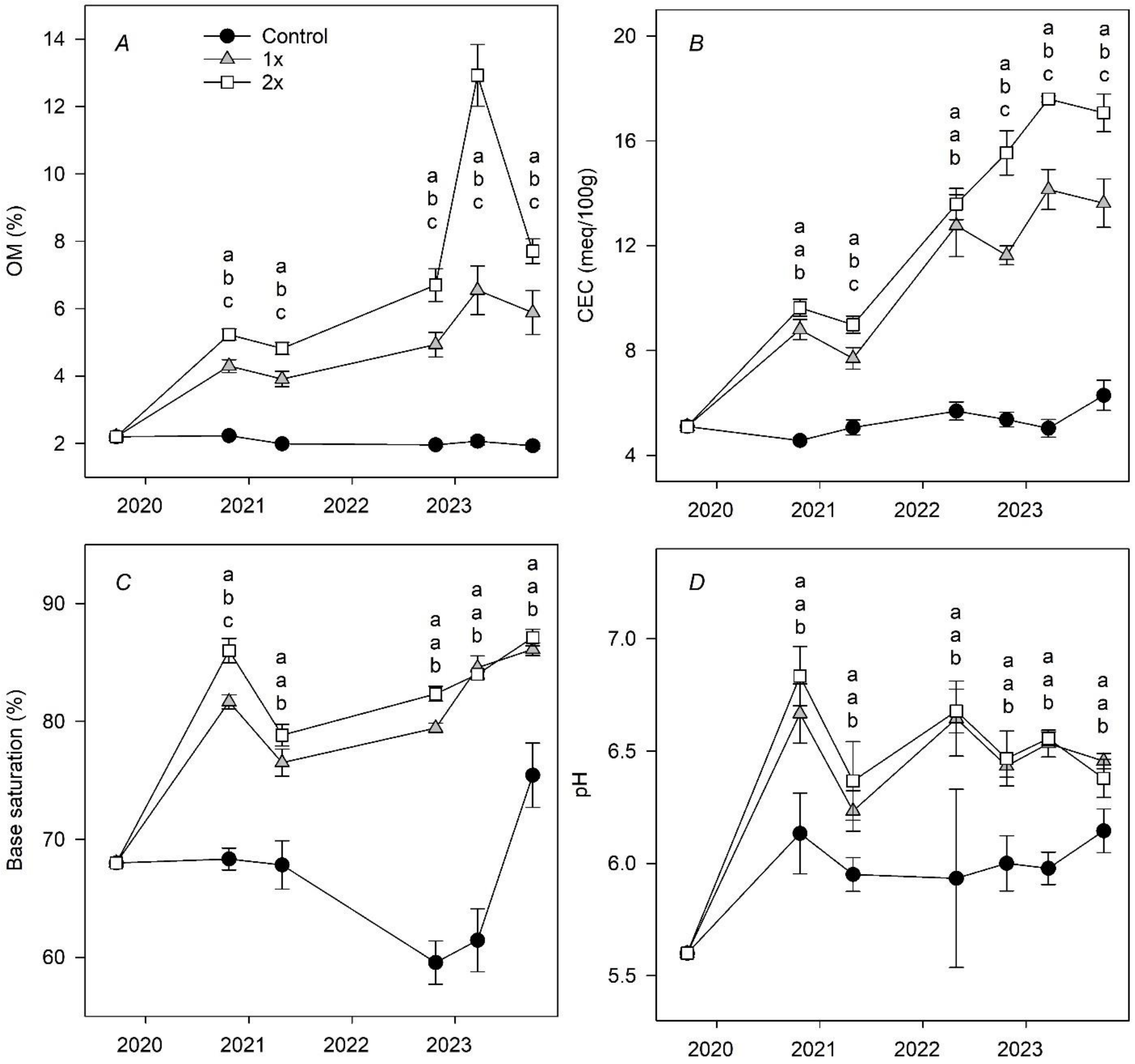

Figure 1.3. Soil properties over the study including: (*A*) organic matter (%), (*B*) cation exchange capacity (CEC, meg/100 g), (*C*) base saturation (%), and (*D*) pH, between the control (no mulch, black circles), 1x (gray triangles), and 2x mulch treatments (white squares). The single point during fall of 2019 shows the baseline value. Different letters show statistical differences according to HSD mean separation test ($P \leq 0.05$).

Soil macronutrients and micronutrients

The mulch treatments affected the quantity of extractable macronutrients and micronutrients during sample periods (Table 1.4). Soil NO_3^- was similar between treatments during the spring of 2021 and statistically higher in the 2x treatment compared to the 1x and control mulch treatments during the spring of 2022 ($F = 6.1$, $P \leq 0.01$) and fall of 2022 ($F = 28.1$, $P \leq 0.0001$). During the spring of 2023 and fall of 2023, soil NO_3^- was not different between the treatments. Soil P was higher within the 2x treatment compared to the control and 1x mulch treatment during fall of 2020 ($F = 8.3$, $P \leq 0.001$), and the spring of 2021 ($F = 5.0$, $P \leq 0.05$), but was higher within the control soil compared to both 1x and 2x mulch treatments during the spring of 2022 ($F = 6.0$, $P \leq 0.01$). P was similar between mulch treatments in the fall of 2022, spring of 2023, and fall of 2023. Soil K was consistently higher in the 1x and 2x mulch treatments compared to the control soil in the fall of 2020 ($F = 272.3$, $P \leq 0.0001$), spring of 2021 ($F = 204.9$, $P \leq 0.0001$) and spring of 2022 ($F = 10.0$, $P \leq 0.001$), fall of 2022 ($F = 64.5$, $P \leq 0.0001$), spring of 2023 ($F = 56.3$, $P \leq 0.0001$), and fall of 2023 ($F = 12.7$, $P \leq 0.0001$). Soil Ca was higher in the 1x and 2x mulch treatments compared to the control the fall of 2020 (103.8, $P \leq 0.0001$), spring of 2021 ($F = 23.1$, $P \leq 0.0001$) and spring of 2022 ($F = 26.4$, $P \leq 0.0001$). However, during the fall of 2022 ($F = 88.1$, $P \leq 0.0001$), spring of 2023 ($F = 149.\ 9$, $P \leq 0.001$), and fall of 2023 ($F = 49.23$, $P \leq 0.0001$), all three treatments were different as the 2x mulch treatment had higher soil Ca than the 1x mulch treatment, which was higher than the control soil. Soil Mg was significantly different in each of the mulch treatments, with the lowest Mg within the control soil, followed by the 1x mulch, and the highest Mg within the 2x mulch treatment in the fall of 2020 ($F = 57.1$, $P \leq 0.0001$), spring of 2021 ($F = 32.6$, $P \leq 0.0001$), spring of 2022 ($F = 31.1$, $P \leq 0.0001$), fall of 2022 ($F = 101.9$, $P \leq$

0.0001) and spring of 2023 ($F = 145.8$, $P \leq 0.0001$). During the fall of 2023, soil Mg was higher within the 1x and 2x mulch treatments compared to the control ($F = 37.3$, $P \leq 0.0001$).

Regarding soil micronutrients, there was less soil Zn within the control soil compared to the 1x and 2x mulch treatments during the fall of 2020 ($F = 13.0$, $P \leq 0.0001$) and spring of 2021 ($F = 5.1$, $P \leq 0.05$), but was similar between treatments during the spring of 2022. Soil Zn in the 2x mulch treatment was higher than the control during the fall of 2022 ($F = 5.0$, $P \leq 0.05$), spring of 2023 ($F = 29.5$, $P \leq 0.0001$), and fall of 2023 ($F = 15.6$, $P \leq 0.0001$). Soil Mn was consistently different in each of the treatments with the highest Mn measured in the 2x mulch treatment, followed by the 1x mulch treatment, and finally the control soil in the fall of 2020 ($F = 38.5$, $P \leq 0.0001$), spring of 2021 ($F = 123.3$, $P \leq 0.0001$), spring of 2022 ($F = 40.0$, $P \leq 0.0001$), fall of 2022 ($F = 22.2$, $P \leq 0.0001$), the spring of 2023 ($F = 71.7$, $P \leq 0.0001$). However, during the fall of 2023, soil Mn was higher within the 1x and 2x mulch treatments compared to the control ($F = 10.9$, $P \leq 0.001$). Soil Cu was consistently higher within the control soil than the 1x and 2x mulch treatments during the fall of 2020 ($F = 100.5$, $P \leq 0.0001$), spring of 2021 ($F = 70.8$, $P \leq 0.0001$), spring of 2022 ($F = 50.9$, $P \leq 0.0001$), fall of 2022 ($F = 15.1$, $P \leq 0.0001$), spring of 2023 ($F = 30.1$, $P \leq 0.0001$), and fall of 2023 ($F = 20.8$, $P \leq 0.0001$). Soil B was different in each of the treatments with the highest B measured in the 2x mulch treatment, followed by the 1x mulch treatment, and finally the control soil in the fall of 2020 ($F = 177.8$, $P \leq 0.0001$), spring of 2021 ($F = 64.3$, $P \leq 0.0001$), spring of 2022 ($F = 92.5$, $P \leq 0.0001$), fall of 2022 ($F = 128.8$, $P \leq 0.0001$), spring of 2023 ($F = 112.3$, $P \leq 0.0001$), and fall of 2023 ($F = 110.9$, $P \leq 0.0001$). Soil Na was similar between treatments in the fall of 2020 and spring of 2022 but was higher in the 2x mulch treatment than the control soil in the spring of 2021 ($F = 4.8$, $P \leq 0.05$), and higher in the 1x and

2x mulch treatments compared to the control soil during the fall of 2022 ($F = 10.8$, $P \leq 0.001$) and spring of 2023 ($F = 11.0$, $P \leq 0.001$). During the fall of 2023, the control soil had less Na than the 2x mulch treatment ($F = 4.2$, $P \leq 0.05$).

Table 1.4. Soil macronutrients (kg ha^{-1}) and micronutrients (kg ha^{-1}) measured during the fall of 2020, spring of 2021, spring of 2022, fall of 2022, spring of 2023, and fall of 2023, between three mulch amendment treatments: control (no mulch), 1x, and 2x. Different letters between mulch treatments within a single date and nutrient show statistical differences using HSD mean separation test ($P \leq 0.05$).

Date	Mulch Treatment		Macronutrient				Micronutrient				
		NO_3^-	P	K	Ca	Mg	Zn	Mn	Cu	B	Na
Fall 2019	n.a.		78.5	149.1	1166.8	181.6	8.7	28	4.5	0.4	10.1
Fall 2020	Control		44.1 b	57.5 c	1006.1 b	207.4 c	7.0 b	17.9 c	2.2 a	0.3 c	19.1
	1x		49.7 b	122.9 b	2582.4 a	340.4 b	12.3 a	31.8 b	1.4 b	1.0 b	19.1
	2x		63.1 a	183.8 a	2920.2 a	409.9 a	12.9 a	38.5 a	1.0 c	1.3 a	19.4
Spring 2021	Control	10.5	58.8 b	103.9 c	1293.8 b	128.9 c	7.6 b	20.9 c	2.6 a	0.4 c	20.7 b
	1x	10.3	62.0 b	150.0 b	2221.9 a	218.4 b	13.1 a	38.9 b	1.6 b	0.9 b	23.4 ab
	2x	10.3	90.0 a	202.1 a	2625 a	285.3 a	13.2 a	50.4 a	1.4 b	1.3 a	25.4 a
Spring 2022	Control	18.6 b	101.4 a	191.4 b	1278.3 b	174.0 c	11.9	20.7 c	2.9 a	0.1 c	7.1
	1x	18.9 b	75.0 b	151.2 b	4234.7 a	353.6 b	15.3	29.6 b	0.9 b	1.2 b	12.1
	2x	31.0 a	67.9 b	257.5 a	4287.4 a	483.0 a	20.1	41.2 a	0.6 b	2.2 a	9.3
Fall 2022	Control	0.5 b	79.1	98.9 c	1143.8 c	145.3 c	9.6 b	49.2 c	3.6 a	0.4 c	7.7 b
	1x	1.2 b	85.2	136.9 b	3416.2 b	387.8 b	15.1 ab	64.0 b	1.9 b	1.5 b	10.0 a
	2x	11.2 a	97.4	205.7 a	4710.3 a	547.2 a	20.5 a	85.6 a	1.5 b	2.4 a	11.3 a
Spring 2023	Control	0.1	91.4	89.0 c	1135.0 c	135.7 c	8.8 b	30.3 c	3.2 a	0.5 c	11.2 b
	1x	1.9	109.8	160.7 b	4530.5 b	450.3 b	18.4 a	66.6 b	1.0 b	1.8 b	12.3 a
	2x	0.9	111.7	248.7 a	5380.1 a	672.4 a	21.5 a	91.5 a	0.5 b	3.0 a	13.2 a
Fall 2023	Control	5.1	136.7	130.0 b	1744.4 c	209.7 b	9.0 b	62.9 b	5.3 a	0.1 c	14.8 b
	1x	0.7	122.4	175.5 b	4401.5 b	460.8 a	18.8 a	88.3 a	2.9 b	1.2 b	16.3 ab
	2x	5.4	125.7	226.3 a	5632.6 a	547.0 a	24.9 a	109.5 a	2.4 b	2.1 a	16.9 a

Discussion

Soil OM, CEC, Buffering Capacity, and pH

Changing orchard management in the southeast by incorporating composted mulch and later applying mulch topically to peach berms rapidly increased and consistently maintained elevated Soil OM (SOM) compared to the standard practice without mulch application. The increase of SOM occurred in a rate-dependent manner and the 1x and 2x treatments continued to increase in SOM during the four years of mulch applications. In the hot and humid conditions of the southeastern United States, SOM rapidly degrades (Jones et al. 2020) and few studies have explored how to best apply organic materials to orchards in this region (Lawrence et al., 2023). The rapid and consistent increase following the application of the composted mulch is different but not entirely in contrast to a previous study at the MFRC location by Lawrence and Melgar (2023), which showed significant accumulation of SOM in a peach orchard by initially incorporating and annually applying 10- and 20-tons acre^{-1} food waste compost after two years. The amendment rates used by Lawrence and Melgar (2023) were much reduced compared to the current study, and it took several years to increase SOM within the 20 tons acre^{-1} treatment verses the rapid increase of the current study. Both Lawrence and Melgar (2023) along with the present study, examine amendments applied during orchard establishment and the preplant incorporation of OM at planting followed by post-plant topical applications used in the current study, would be the most appropriate method for young trees. The benefit of compost incorporation on soil C, N and bulk density has been demonstrated in other tree species such as apple (*Malus domestica*)

(Thompson, et.al, 2017, 2019) and redosier dogwood (*Cornus sericea* L. ssp. *Sericea)* (Cogger et al. 2008).

Orchard management decisions are ultimately governed by the farm economy and incorporation of amendments during tree establishment have yet to be fully analyzed in the southeastern context. The higher rate of mulch applied to the soil, the greater the chemical changes of the soil for the macronutrients of K, Ca, Mg and the micronutrients Mn and B. However, the differences in soil mineral concentration between the 1x and 2x were smaller than between the control and the 1x treatment. Therefore, the rates used in this study suggest a point of diminishing return and moving towards a possible OM saturation of the soil. While the composted mulch was viable source of OM addition to the soil, more was not necessarily better. Three sources of single ground municipal mulch were used for the study, and the mulch initially used between 2019 and 2021 had numerically similar macronutrients to the later mulch used in 2022 and 2023. However, the micronutrients extracted from the soil of the 2019-2021 plots were much higher in Zn, Fe, and Al, and lower in Na than in 2022 and 2023. Therefore, special attention is needed when applying different sources of OM amendments, and testing of the amendments is necessary for growers to understand the nutritive value of the application. Not only should growers pay attention to the soil test nutrient level as it may create excessive levels in the soil leading to toxicity symptoms in crops, but testing could identify appropriate rates to supplement with synthetic fertilizers.

Incorporating composted mulch to peach orchard soils before planting and post plant topical applications also increased soil CEC, suggesting that a greater concentration of cations would be bioavailable for orchard trees. This result is similar to a study which reported an increase of CEC after applying a green waste compost amendment to almond orchards in California (Villa et al. 2021), although the increase of CEC was greater (90%) in a loam soil compared to a sandy soil (25%). The loamy sand soils of the current study witnessed a CEC increase of over 200% compared to the control by the end of the study, suggesting the 1x and 2x treatments supply more nutrients to trees which require a large supply of cations, especially K to produce fruit. Soils in the upstate of South Carolina are clayey ultisols, low in OM and often low in native CEC. Considering the control rows had between 1/2 and 1/3 the CEC of the 1x or 2x rows, the composted mulch greatly increased CEC in our soil type. However, similar to the numeric differences of the OM, double the rate of soil amendments from the 1x to the 2x rate did not double the CEC, suggesting that there is a point of saturation or diminishing return associated with the rates of mulch application. Furthermore, soils with a low CEC may require more frequent fertilization as they cannot retain nutrients as well as soils with a high CEC that can retain and supply more nutrients to plants over a longer period. Understanding OM decomposition and nutrient release over time requires many years, but the increase of CEC observed after several years of composted mulch application could allow growers to reduce the amount of fertilizer applied during orchard establishment (Baldi et al. 2005).

Similar to OM and CEC, the soil pH increase following the composted mulch treatments suggests that incorporation and annual topical applications may reduce or replace the need for regular orchard liming. Remarkably, how OM buffers soil pH is not entirely understood (Zhi-An, 2008) but the increase of CEC, humic substances, and microbial activity all resist ionic changes by absorbing and releasing hydrogen ions (H^+) and hydroxide ions (OH^-). The previously mentioned increase of CEC resulting from adding OM in the 1x and 2x treatments also could have increased and stabilized pH (Petit, 2004). Although this study did not measure humic substances or microbial life, the well composted amendment must have increased that amount of fulvic acids and humic acids, which can form complexes with minerals in the soil and help buffer pH. Many studies have shown how adding OM can support diverse microbial communities in orchard soil (Sofo et al. 2020; Yang et al. 2020). Microbial communities play a role in nutrient cycling, influence pH dynamics (Petit, 2004) and produce organic acids which buffer soil pH during OM decomposition (Wang, 2022). These factors collectively contribute to improving and maintaining a relatively stable soil pH over time.

Lime was applied once preplant and once post plant for this study for pH management in keeping with industry standards. However, no more lime will be applied for the rest of the orchard life to track the legacy effect of mulch application on soil pH. From what has been observed so far, there should be a significant legacy effect, keeping pH stabilized between pH 6.0 and. 6.5 within the recommendation for peach production (Johnson, 2008). The number of years this influence lasts within the orchard will require a long-term study, but it is possible no future pH adjustment would be needed. Physical changes to the soil which lead to increased aggregation, and water infiltration may also have improved conditions for microbial activity.

Soil Nutrients

Composted mulch incorporated and topically applied proved to be a viable source of soil nutrients in this study. Since the material was composted prior to incorporation or application, there was an initial uncertainty if N immobilization would occur. Mulch amendments which are not decomposed can immobilize plant available N, and according to our NO_3^- analysis, this may have occurred the first season. Only by the spring of 2022 was the 2x rate higher in nitrate than the control, perhaps due to previous years mulch decomposing and slowly releasing N. While the composted mulch eventually proved to be a viable source of soil NO_3^-, N sources for trees under alternative management which use OM amendments is complicated, while combining inorganic and organic sources further complicates the ability to quantify total and seasonal N. Moreover, microbial community changes can determine N cycling processes (Wang et al. 2020) and as plant residue decomposition is finalized, the N stored in microbial biomass becomes largely plant available again (Johnson, 1989).

Contrary to the hypothesis, which surmised all soil macronutrients would increase due to the composted mulch application, soil P was generally not elevated by adding composted mulch at either the 1x or 2x rate. Compost sourced from animal waste is known to have significant P levels (Komiyama et al., 2019), whereas this mulch was all from decomposed plant material with much reduced P levels from animal sources. Previous work by Lawrence and Melgar (2023) showed that food waste compost increased soil P within a replant orchard site, but not within a location which had not had peach production previously and this may have been a function of prior land use. Other work which applied mulch to young pecan trees suggested P released from the mulch amendment was responsible for increased tree growth (Smith et al. 2000), however, they measured P using foliar analysis. Adding OM alters the biological communities and subsequent mycorrhizal fungi, and while the soil analysis did not reveal an increase of extractable P from the Melich 1 procedure, the trees may have had elevated P due to increased tree root-hyphal associations (Sheldrake, 2018).

Regarding other macronutrients, balancing soil cations to avoid excessive K is necessary to prevent fruit quality issues (Lawton, 2021), however sufficient K is also required for desired yields. Large quantities of K are removed from orchards each harvest (Zhou and Melgar, 2019) and the decomposing mulch may have helped retain K in the orchard system (Andrews et al. 2021). One important factor of K uptake from plant residues or soil particles is soil moisture, but soil moisture was not measured due to funding limitations. It is known that increasing OM within the soil can increase water holding capacity (Libohova et al. 2018) and adding plant residues or mulch has also been shown to conserve soil moisture (Moore et al. 2019). During orchard establishment, few commercial growers provide irrigation to young trees, yet avoiding periods of moisture stress could be beneficial for tree growth. There are studies that show that tree water stress may reduce K uptake in other tree species (Qi et al., 2019). Thus, any improvement to soil moisture may allow for higher K uptake. Other cations, such as Ca, move through the transpiration stream (xylem) and whether the current rates of composted mulch added to young peach orchards result in cation antagonism will need to be studied in further work. Nonetheless, the composted mulch contained about 1% Ca on a dry weight basis and a clear positive effect on soil Ca was demonstrated with soil analysis, and Ca became more abundant in soil tests year-on-year within the 2x rate due to previous amendment decomposition (Duryea, 1999). However, the well-composted and decomposed mulch product immediately increased extractable soil Ca following the incorporation in 2020. This was also observed within the CEC readings.

In addition to macronutrients, sufficient levels of micronutrients Zn and B are necessary for peach tree productivity (Johnson, 2008). Typically, Zn is added through applications of Zn-containing fungicides or an annual foliar spray or through granular fertilizer additions. The range from deficiency to toxicity for B can be quite narrow depending on the species of plant, and phytotoxic effects can occur if B is applied on the soil around peach trees. For this reason, growers often apply B using foliar sprays (Shu et al. 1994). However, adding composted mulch to orchards appeared to have provided additional amounts of both Zn and B as the soil of the 1x and 2x treatments was significantly higher in both micronutrients versus the control, thus, decreasing the need for these supplemental nutrients to be applied.

The only mineral consistently lower in the soil following the addition of the 1x or 2x mulch treatments was Cu, suggesting it may have been bound or absorbed to the added exchange sites following increases of OM and CEC within the soil. Additional Cu-based fungicide sprays were likely prevented from leaching downward from the mulch layer on top of the soil. Exploring the influence of OM on Cu for commercial peach production has application beyond the mineral nutrient for plant growth, as Cu is sprayed for bacterial control (Adaskaveg et al, 2008). Cu is a heavy metal and has a documented detrimental effect to invertebrates and may contribute to poor soil health along with slow tree growth (Rodrigo, 2020). Adding mulch which increases the soil OM may offset some of these negative effects of Cu on soil life. Whether or not the decomposition of the OM over time would release bound Cu back into the soil would need to be explored.

Conclusion

In conclusion, adding OM created significant changes to the chemical composition of orchard soil, but this was a time consuming and expensive process and ongoing decomposition in the hot and humid climate necessitated continual application. Further system studies need to be conducted to determine the best application timing, method, and the inflection point of the input of this organic material to soil benefit. For example, the annual 1x treatment shared most of the same effects observed in the annual 2x treatment with half of the input rate. Perhaps a 0.5x rate, or a biannual mulch application or just a preplant and one post plant mulch application for the life of the orchard would sufficiently continue the trend. As the farm economy will drive the implementation of this system, we need to determine the point of greatest efficiency, receiving the most benefit with the least input with consideration of the treatment legacy effects on the soil.

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CHAPTER TWO

HORTICULTURAL PERFORMANCE AND FRUIT YIELD OF PEACH CULTIVARS FOLLOWING PREPLANT AND ANNUAL COMPOSTED MULCH AMENDMENT APPLICATIONS DURING ORCHARD ESTABLISHMENT

Introduction

In the southeastern region of the United States, peach (*Prunus persica* (L.) Batsch) growers face unique challenges in the humid, subtropical climate such as depleted soils with poor soil structure, crusting, erosion, and replant disease issues. Soils of the region are often low in organic matter (OM) and the standard practice of removing vegetation with herbicide and mowing between tree rows provides little soil cover to prevent erosion. Orchard replant issues linked to suboptimal orchard soils persist, constraining potential productivity and suitable growing sites for future peach cultivation (Manganaris, et al. 2022). Despite being perennial, commercial peach orchards have an average lifespan of only 13 years in the region. Due to late spring frost risk and limited profitable production sites, orchards are replanted frequently, leading to soil quality challenges over generations of orchards, including OM reduction (Lawrence et al., 2023) and "Peach Tree Short Life" (Okie et al., 1994). While numerous rootstock options allow growers to avoid several major disease complexes (Beckman et al., 2019; Lemes-Vesga et al. 2022; Reighard et al., 2022), prolonging orchard lifespan by improving soil properties and tree health holds potential economic and environmental benefits. Depending on the goal of the grower, utilizing alternative management practices to retain or maintain OM, such as mulch to cover the soil, have long been understood to improve the orchard agroecosystem (Haynes, 1980) and possibly improve tree growth and performance during orchard establishment (Lawrence and Melgar, 2023).

Previous research has addressed strategies to improve yields for growers and fruit quality for consumers. These studies have ranged from improving synthetic fertilization or irrigation programs (Zhou and Melgar, 2019; Casamali et al. 2021), tree architecture and spacing (Anthony and Minas, 2021; Layne et al. 2001), to improving commercial cultivars (Gasic et al. (2015); Iezzoni et al. (2015)) and reducing losses from preharvest disease and postharvest losses (Schnabel et al. 2022) but nearly all studies neglect the importance of improving orchard soils. Studies which have explored the impact of adding OM mulch products to the orchard soil surface have been completed in other climates on other types of fruit trees. Factors such as plant nutrients (Baldi et al., 2010), carbon dynamics (Montanaro et al., 2012), and water dynamics, including infiltration and availability (Lordan et al., 2015) can all be positively impacted by increasing OM or by using organic mulches in orchards. Other studies are based around organic agriculture. The major tool in the organic grower's toolbox is to improve soil to help trees be productive as they have less options than conventional growers to help against insects, disease, and fertility. Thus, previous organic research studies have looked at using cover crops and bio-organic sources to improve soil health and ultimately tree health (Sanchez, 2006; Singh, 2010). The intent of this study is to incorporate the best of both organic and conventional techniques to benefit the soil and the trees.

As there is a need for expanding lifespan and performance of peach orchards and improvement of soil OM can have a positive impact on the different factors mentioned above, this chapter will look at the impact of two rates of composted mulch on the horticultural attributes and performance during the establishment of peach trees in the southeast, over three growing seasons. While the previous chapter explored changes to soil organic matter and soil chemistry following the addition of two rates of composted mulch during orchard establishment, the objective of the present chapter was to evaluate how the two mulch rate treatments change tree growth, phenology, leaf nutrient content, and fruit yield and quality (acidity, soluble solids, firmness, size, and mass) through the fourth leaf. We hypothesized that increasing orchard soil OM and improving soil quality will improve the horticultural performance including growth of peach trees during establishment and larger trees will produce higher yields.

Materials and Methods

Orchard conditions, treatment design, and mulch application

The following study took place in the same orchard at the Clemson University Musser Fruit Research Center (MFRC) in Seneca, South Carolina, USA and followed the same treatment design described previously in chapter 1. A new peach orchard was established on a replant site for this project at the MFRC (lat. 34˚36’22” N, long. 82˚52’39” W), and the study conducted between the years of 2019 and 2023._The location had been previously planted in nectarines (*Prunus persica* var. *nucipersica*, ‘Juneprincess’ on Guardian® rootstock) for approximately 20 years prior to tree removal in 2017. The soil was of the Appling series and classified as clayey, kaolinitic, thermic, typic hapludult, common in the upstate of SC. The initial soil composition, sampled in fall of 2019, yielded a sandy loam (loamy sand by Ye in a second evaluation) (69% sand, 25% silt, and 6% clay) as determined by a jar test. The orchard topography was less than 1% slope east to west.

A 9-row peach orchard (6.7 m on center and 4.9 m apart) was installed in 2020 following 3 years of native sod cover, using a randomized split block design with two factors (soil amendment and cultivar). There were 3 mulch treatments (one per row) replicated three times with 3 cultivars per row (Table 2.1). The following three mulch treatments were used per full row: 1)

Untreated control (grower standard, bare soil); 2) 1x mulch (composted mulch incorporated at planting plus mulch top dressed annually, rate 1 (see below)); and 3) 2x mulch (composted mulch incorporated at planting plus mulch top dressed annually, rate 2 (see below)). All trees were planted on berms. The control rows received no mulch prior to tree planting. Composted mulch was incorporated into the existing soil when creating berms, before planting trees (Fig. 2.1). The mulch amendments were installed volumetrically per full row of the experiment to a width of 2.4 m (8 ft) wide, which matched the width of the herbicide strip in the untreated control. Specifically, the 1x mulch incorporation rate was 0.34 m^3 of mulch per 1 m of tree row (0.11 m^3 [4.0 ft^3] of composted mulch per linear foot). The 2x preplant rate was 0.68 m^3 of mulch per 1 m of tree row (0.23 m^3 [8.0 ft^3] of composted mulch per linear foot).

The soil amendment used was a composted, single ground, municipal mulch from the Oconee County Landfill, Seneca, SC. The mulch was comprised of mixed species, which were piled and turned twice per year for 4 years following a 2014 storm. During decomposition years prior to 2019, the temperature in the pile was hot enough to self-combust and the fire had to be extinguished several times. After four years, the mulch was well composted and only larger wood pieces were still identifiable. Although incorporated and applied as a mulch, much of the product appeared as dark, friable organic compost.

Berms were created in fall 2019 after the preplant mulch was applied. Incorporation of the composted mulch into the soil was completed to a depth of 0.4 m using a 3-point hitch, 3 shank, V-type subsoiler with 0.8 m shanks pulled behind a tractor. A standard 2 m wide offset disk harrow was then used to complete the incorporation and smooth the soil before using an upfitted Amco LJ6 levee plow (Yazoo City, MS) with a bed packing wheel to create raised berms. The final berms were 0.3 m tall and 1 m wide and 6.7 m apart from the center of the berms. The berms were oriented NW to SE to fit within the predetermined field space. Planting peach trees on berms is part of the current disease management strategy in fields that have a history of oak root rot (*Desarmillaria caespitosa*). In the winter after the second leaf, the trees are typically excavated to expose the root crown to atmospheric conditions not favorable to fungal spread that causes tree mortality, extending the life of the orchard by several years. There is a history of oak root rot in this field. However, the trees were not excavated in this experiment, as it would complicate consistent data collection of soil properties.

Figure 2.1. Arial photograph showing the orchard after the initial incorporation of the 1x and 2x rates of composted single ground municipal mulch replicated three times. The broad lines in the orchard (from left to right, lighter to darker color) show unamended soil which served as the control, the 1x mulch treatment, and the 2x mulch treatment.

Immediately after the berms were created row middles were smoothed with a Unverferth Perfecta field cultivator and planted with a Pasture Pleaser 2007 drill at 2.1m wide with a cover crop mixture of oats (*Avena sativa* L.), crimson clover (*Trifolium incarnatum* L.), arrow leaf clover (*Trifolium vesiculosum* Savi), and hairy vetch (*Vicia villosa* Roth).

After cover crop establishment, additional mulch was applied to the surface of the 1x and 2x treatment berms in year 1 and annually during each spring following the first year. The surface-applied annual application rate for the 1x treatment was 0.11 m^3 per 1 m of tree row (1.33 ft^3 linear $foot^{-1}$ of row) while the surface-applied annual application rate for the 2x treatment was 0.23 m^3 per 1 m of tree row (2.66 ft^3 linear $foot^{-1}$ of row).

One-year-old bare root trees of three cultivars on Guardian® rootstock were used for the study: 'Rubyprince' (early-season cultivar ripening in June), 'Julyprince' (mid-season cultivar ripening in July), and 'Big Red' (late-season cultivar ripening in August). Each row comprised three, randomized, 5-tree blocks. Rows 1, 4, and 7 were untreated controls, receiving no mulch incorporation or topical mulch application; rows 2, 5, and 8 were treated with 1x mulch; and rows 3, 6, and 9 were treated with 2x mulch (Figure 2.1).

Table 2.1. The randomized split block design of the 9-row orchard used in the study with entire rows comprised of one of the three mulch treatments (negative control, no mulch; 1x rate of mulch; or 2x rate of mulch) and divided by the cultivars Rubyprince (Rp), Julyprince (Jp), or Big Red (BR).

Control Row 1	1x Row 2	2x Row 3	Control Row 4	1x Row 5	2x Row 6	Control Row 7	1x Row 8	2x Row 9
Rp	Jp	BR	Jp	Rp	BR	Rp	Jp	Rp
Rp	Jp	BR	Jp	Rp	BR	Rp	Jp	Rp
Rp	Jp	BR	Jp	Rp	BR	Rp	Jp	Rp
Rp	Jp	BR	Jp	Rp	BR	Rp	Jp	Rp
Rp	Jp	BR	Jp	Rp	BR	Rp	Jp	Rp
Jp	BR	Rp	BR	Jp	Jp	BR	Rp	Jp
Jp	BR	Rp	BR	Jp	Jp	BR	Rp	Jp
Jp	BR	Rp	BR	Jp	Jp	BR	Rp	Jp
Jp	BR	Rp	BR	Jp	Jp	BR	Rp	Jp
Jp	BR	Rp	BR	Jp	Jp	BR	Rp	Jp
BR	Rp	Jp	Rp	BR	Rp	Jp	BR	BR
BR	Rp	Jp	Rp	BR	Rp	Jp	BR	BR
BR	Rp	Jp	Rp	BR	Rp	Jp	BR	BR
BR	Rp	Jp	Rp	BR	Rp	Jp	BR	BR
BR	Rp	Jp	Rp	BR	Rp	Jp	BR	BR

Fertilizer and lime were applied according to soil sample results and commercial standards (Blaauw et al., 2024; CUASL, 2023). During the study, the soil was limed twice, once with dolomitic lime ($CaMg(CO_3)_2$) and once with calcitic lime ($CaCO_3$). The first lime application was dolomitic lime prior to planting trees and was broadcast at 4483 kg ha^{-1} (2 tons $acre^{-1}$). The second lime application was calcitic agricultural lime applied in January 2021 and broadcast at 3363 kg ha^{-1} (1.5 tons $acre^{-1}$). Fertilizer (10-10-10) was broadcast in March 2020 and June 2020 at 0.45 $tree^{-1}$ (1lb $tree^{-1}$). Then, in March 2021, 2022, and 2023, 19-19-19 fertilizer was broadcast banded under the trees with a tractor mounted pendulum type fertilizer spreader at a rate of 17.23 kg N $acre^{-1}$ (38lbs N $acre^{-1}$).

Soil Analysis

A baseline soil sample was taken during the fall of 2019, then a total of 5 times over the study during fall 2020, spring 2021, spring 2022, fall 2022, and spring 2023. During 2020 and 2021, soil samples were taken as a composite of 12 cores within each row of trees, regardless of cultivar, resulting in 9 total samples (9 rows). In 2022 and 2023, 12-core composites were made from the middle three trees of each 5-tree cultivar block in each row, resulting in a total of 27 soil samples (9 rows by 3 cultivar blocks). Regardless of the number of samples or date, core samples were taken to a depth of 0.15 m and half occurred at the top center of each berm and half were taken on the side slope of the berm. The soil sampler used was a Collect-N-Go Soil Sample Collection Kit (CNG1, collectngonow.com, Opelika, AL). Aggregate samples were sent to the Clemson University Agriculture Service Center of Clemson University and analyzed for OM, CEC, total base saturation (BS), pH, nitrate nitrogen (NO_3^-), and extractable P, K, magnesium (Mg), calcium (Ca), zinc (Zn), manganese (Mn), copper (Cu), boron (B), and sodium (Na) using the Mehlich 1 extraction method (CUASL, 2023).

Mulch Analysis

The initial incorporation of mulch in 2019 and the 2020 and 2021 annual mulch applications were all sourced from the same source of single ground municipal mulch. The 2022 and 2023 mulch samples were sourced from different sources of mulch, which were collected from the Oconee County landfill and composted for less than one year (Table 2.2). Composted mulch samples were collected from corresponding years of application and submitted for analysis. In 2019, 2020 and 2021, samples were taken from the pile prior to application and dried before submitting for analysis. In 2022 and 2023 samples were taken from the field after application. Samples were submitted to the Clemson University Agricultural Services Lab and analyzed for nitrate nitrogen (NO_3^-), total nitrogen, total carbon, carbon to nitrogen ratio (C:N), P, K, Ca, Mg, S, Zn, Cu, Mn, Iron (Fe), Na, aluminum (Al), OM, soluble salts, and pH. The samples were submitted for analysis as Landscape Mulch to the Clemson University Ag Services Lab and are reported in Table 2.2.

Table 2.2. Mulch composition from samples taken in 2019-2021, 2022, and 2023 on dry basis including total nitrogen (Total N), total carbon (Carbon), carbon:nitrogen ratio (C:N); the macronutrients phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S); the micronutrients zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), sodium (Na), and aluminum (Al); organic matter (OM), electrical conductivity (EC) and pH Macronutrients and OM are shown as % of dry sample, while micronutrients are shown as ppm. EC is shown as dS m^{-1}.

Year	Mulch measurement					
	OM (%)	EC (dS m^{-1})	pH	Total N (%)	Carbon (%)	C:N
2019-2021	37.1	0.07	5.2	0.64	22	34.3
2022	66.5	0.04	5.4	0.73	39.5	54.2
2023	87.4	0.06	6.0	0.65	44.67	68.4
	Macronutrient (% of sample)					
	P	K	Ca	Mg	S	
2019-2021	0.06	0.17	1.03	0.15	0.06	
2022	0.09	0.3	1.11	0.14	0.08	
2023	0.15	0.31	0.77	0.13	0.08	
	Micronutrient (ppm of sample)					
	Zn	Cu	Mn	Fe	Na	Al
2019-2021	183	42	176	10849	30	15168
2022	69	23	241	5961	173	9133
2023	89	30	310	3409	338	4663

Tree growth, leaf analysis, and phenology measurements

Tree size was measured annually. Trunk cross sectional area (TCSA, cm^2) was taken during the dormant season by calculating the area of a circle from a single diameter reading taken at a 10 cm height above the graft union of each tree. During dormancy, tree height (m) was measured with a surveying rod held at the base of the tree to the tallest shoot while canopy width (m) was measured as an average of the width parallel and perpendicular to the row using the same rod. Total pruning weight (kg) was also recorded during winter pruning events.

To measure leaf nutrient concentration, leaf samples were collected from the 3 middle trees within each 5-tree cultivar block by row during July in 2021, 2022, and 2023. In 2020, leaves were sampled late during the growing season, during November, because of the pandemic. Regardless of year, leaves were collected from all sides of the trees at 1.5 m height from the ground and were the youngest full-sized leaves (5-7th node from shoot terminus on non-fruiting branches). The middle three trees of each set of cultivars were compiled into a single sample and each row yielded 3 composite samples within each soil amendment treatment row resulting in a total of 27 samples (3 samples per row x 9 rows). All samples were analyzed for total nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), and sodium (Na) at the Clemson University Ag Services Lab. Total N was measured by combustion using a LECO FP528 Nitrogen Combustion Analyzer and all other nutrients were measured using a wet ash procedure and inductively coupled plasma mass spectrometry.

Regarding tree phenology, spring bloom was measured by Julian date for an estimated 10, 50 and 90% open flowers each year. Similarly, senescence was also estimated as a percentage of leaves fallen from trees each fall.

Fruit yield, quality, and efficiency

The middle three trees of the 5-tree cultivar blocks within each row were harvested at commercial maturity and totaled in 2022, and 2023. A random sample of 20 fruit was weighed during the middle harvest date from each tree to calculate average fruit weight, later used to calculate the weight of dropped fruit, which were tallied at the end of each harvest and added to the total yield value. Fruit quality and texture analysis occurred during the middle of the ripening window where fruit diameter size (cm), weight (g), and firmness (kg cm^{-2}) were all measured using a fruit texture analyzer; total (FTA, GÜSS Manufacturing (Pty) Ltd., South Africa). Total soluble solids (TSS, %) was measured by digital refractometry (Atago 3810 PAL-1, Atago, Bellewue, WA, USA), and titratable acidity (as malic acid, %) was measured by NaOH titration (862 Compact Titrosampler, Metrohm, Riverview, FL, USA). Yield efficiency was calculated as average total yield by the average TCSA of each soil treatment, cultivar, and their interaction.

Statistical Design

The study was designed as a randomized split block, with mulch treatments as blocks (control, 1x and 2x) and cultivar (‘Rubyprince’, ‘Julyprince’, and ‘BigRed’) dividing each of the blocks. Single rows were divided by soil treatment and 5-tree cultivar blocks were randomly assigned within each row. Most measurements were taken from the middle three trees of each 5-tree cultivar block and replicated three times over the three mulch treatment rows. While data were averaged by tree for most measurements, the leaf nutrients were combined across the three trees, resulting in 3 replicates per treatment and cultivar combination and the fruit quality measurements were averaged from the same 3 trees in each 5-tree cultivar block. Thus, a 3x3 factorial model was used to explore mulch treatment, cultivar, and their interaction using analysis of variance (ANOVA) differences and either Student’s least significant difference *post hoc* test (LSD) or Tukey’s honest significant *post hoc* test (HSD) was used to separate means with an alpha of 0.05. Repeated measures analysis (MANOVA) was used to analyze phenological differences between mulch treatments and cultivars. All data were analyzed using the statistical program JMP (Version 16.2 Version 16.2. SAS Institute Inc., Cary, NC, USA).

Results

Tree growth

There were significant differences in TCSA each year by mulch amendment (Table 2.1). Following the 2020 growing season, trees receiving the single rate mulch treatment (1x) had larger TCSA than the control and 2x mulch treatments (F = 48.4, $P \leq 0.0001$). Following the 2021 growing season, 1x treatment TCSA was larger than the 2x treatment, and TCSA of both 1x and 2x were larger than the control TCSA (F = 28.0, $P \leq 0.0001$). Following the 2022 growing season, the 1x treatment TCSA was larger than the 2x treatment, and TCSA of both 1x and 2x were larger than the control TCSA (F = 27.6, $P \leq 0.0001$). In 2023, both the 1x and 2x mulch TCSA were both larger than the control TCSA (F = 34.9, $P \leq 0.0001$) (Table 2.3).

There were also TCSA differences by cultivar following the 2020, 2021 and 2022 growing seasons (data not shown). After 2020, there were significant differences in trunk size between cultivars in 2020 (F = 7.2, $P \leq 0.01$), as ‘Rubyprince’ (26.0 cm^2) was larger than ‘Julyprince’ (23.3 cm^2) and ‘Big Red’ (21.7 cm^2). After the 2021 growing season, ‘Rubyprince’ was significantly larger (89.7 cm^2) in trunk size than 'Big Red' (78.6 cm^2) and 'Julyprince' (74.8 cm^2) ($F = 9.2$, $P \leq 0.001$). After the 2022 growing season, 'Rubyprince' trees (137.2 cm^2) were larger than 'Big Red' (128.3 cm^2), and both were larger than 'Julyprince' (105.8 cm^2) ($F = 28.5$, $P \leq 0.0001$). After the 2023 growing season, the 'Rubyprince' trees (206.7 cm^2) and 'Big Red' trees (197.5 cm^2) were larger in TCSA than 'Julyprince' trees (156.4 cm^2; $F = 27.6$, $P \leq 0.0001$).

The mulch treatments also generally increased tree height over the study years (Table 2.3), and trees in 2020, the 1x treatment trees were taller than the control trees, and both the 1x and control trees were taller than the 2x treatment trees ($F = 11.6$, $P \leq 0.0001$). In 2021, the 1x treatment trees were taller than the control trees and the 2x treatment trees ($F = 11.6$, $P \leq 0.0001$). After the 2022 growing season, there were no differences in tree height by mulch treatment. In 2023 the 1x and 2x treatment trees were both taller than the control trees ($F = 14.2$, $P \leq 0.0001$).

The effect of cultivar also had a significant effect on tree height (data not shown). During the 2020 season ($F = 29.4$, $P \leq 0.0001$), the 'Rubyprince' trees were taller (2.45 m) in comparison to 'Julyprince' (2.28 m), both of which were taller than 'Big Red' (2.11 m). The effect of cultivar had a significant effect on tree height during the 2021 season ($F = 46.3$, $P \leq 0.0001$), with 'Rubyprince' trees being higher (3.65 m) in comparison to 'Julyprince' (3.43 m), both of which were higher than 'Big Red' (3.17 m). Tree height was not compared in 2022 as 'Rubyprince' was pruned in the fall. In 2023, 'Rubyprince' was taller than the 'Julyprince', and both were taller than 'Big Red' ($F = 42.4$, $P \leq 0.0001$). There was no interaction between mulch treatment and variety any year of measurement.

Regarding tree width, there was a significant effect of mulch treatment on tree width (Table 2.3). In 2020, 1x trees were wider than the control and 2x trees ($F = 60.71$, $P \leq 0.0001$). In 2021, the 1x trees were wider than the 2x trees, and both 1x and 2x trees were larger than the control trees (F = 26.0, $P \leq 0.0001$). Following 2022 and 2023, the 1x and 2x trees were larger than the control trees (F = 11.9, $P \leq 0.0001$; F = 25.5, $P \leq 0.0001$; respectively).

There were significant differences in tree width between cultivars (data not shown) after the 2020 season (F = 38.0, $P \leq 0.0001$) as 'Julyprince' (2.17 m) and 'Rubyprince' (2.16 m) were larger in size than 'Big Red' (1.87 m). There were significant differences in tree size by cultivar following the 2021 growing season (F = 37.7, $P \leq 0.0001$) as 'Julyprince' (3.84 m) and 'Rubyprince' (3.88 m) trees were wider than 'Big Red' (3.36 m) trees. 'Rubyprince' trees were pruned prior to when width measurements were taken in 2022 for a parallel study, and no comparisons were made. In 2023, 'Rubyprince' were larger in width than 'Big Red' (F = 6.0, $P \leq$ 0.01).

The pruning weights of trees were highest within the 1x treatment compared to the control, which was subsequently higher than the 2x treatment in 2020 (F = 49.4, $P \leq 0.0001$). In 2021, the pruning weights were higher in the 1x treatment compared to the control and 2x treatments (F = 8.3, $P \leq 0.001$). In 2022, pruning weight of the 1x and 2x treatments were both higher than the control (F = 8.6, $P \leq 0.001$). The pruning weights were also different by cultivar (data not shown), with 'Rubyprince' (4.2 kg) and 'Julyprince' (3.9 kg) having greater amount of pruning wood in 2020 than 'BigRed' (3.1 kg, F = 4.3, $P < 0.05$). In 2021, 'Rubyprince' (18.9 kg) was higher in pruning wood weight than 'Julyprince' (16.2 kg), and both were greater than 'BigRed' (13.6 kg, F = 24.7, $P < 0.0001$). As 'Rubyprince' were pruned earlier in the season before dormancy, no comparisons of cultivar pruning weights were made in 2022.

Table 2.3. Annual horticultural measurements of tree trunk cross sectional area (TCSA, cm^2), tree height (m), and tree width (m) between the three mulch treatments including: control (no mulch), 1x (single rate mulch), and 2x (twice rate mulch) following the growing seasons of 2020, 2021, and 2022. Different letters between treatments each year show significant differences using Student's LSD test (n = 27, $P \leq 0.05$).

Measurement	Mulch treatment	Year			
		2020	2021	2022	2023
TCSA (cm^2)	Control	21.0 b	67.6 c	106.3 c	152.2 b
	1x	30.0 a	94.9 a	137.4 a	205.5 a
	2x	20.1 b	80.6 b	127.6 b	203.0 a
Tree height (m)	Control	2.2 b	3.3 b	3.2	3.8 b
	1x	2.5 a	3.6 a	3.3	4.1 a
	2x	2.1 c	3.4 b	3.4	4.1 a
Tree width (m)	Control	1.9 b	3.5 b	4.3 b	5.1 b
	1x	2.3 a	3.9 a	4.7 a	5.5 a
	2x	2.0 b	3.7 c	4.7 a	5.6 a
Pruning weight (kg)	Control	3.4 b	14.5 b	9.8 b	-
	1x	5.3 a	18.0 a	12.2 a	-
	2x	2.5 c	16.1 b	12.7 a	-

Leaf analysis

The main effect of mulch treatment had an influence on each of the leaf macronutrients measured during the four years of analysis (Figure 2.2). Leaf N was lower in the 2x treatment compared to the control and 1x treatment in 2020 ($F = 5.3$, $P \leq 0.05$), but then lower in the control treatment compared to the 1x and 2x treatments in 2021, 2022, and 2023 ($F = 10.9$, $P \leq 0.05$; $F = 7.5$, $P \leq 0.01$; $F = 31.2$, $P \leq 0.0001$, respectively). Leaf P was lower in the control treatment compared to the 1x and 2x treatments in 2020 ($F = 6.49$, $P \leq 0.01$), all three treatments were different in 2021, with the 2x treatment having the highest P and the control having the lowest P ($F = 39.8$, $P \leq 0.0001$). Treatments were similar in 2022, but both 1x and 2x treatments had more

P than the control in 2023 ($F = 10.9$, $P \leq 0.001$). Leaf K increased after 2020 in all three treatments but was higher in the 1x treatment than the control and 2x treatment in 2020 ($F = 3.9$, $P \leq 0.05$), then consistently higher in the 1x and 2x treatments compared to the control in 2021, 2022, and 2023 ($F = 57.3$ $P \leq 0.0001$; $F = 10.7$, $P \leq 0.0001$; and $F = 25.5$, $P \leq 0.0001$; respectively). Leaf Ca was similar between treatments in 2020, but higher in the 1x treatment compared to the 2x treatment in 2021 ($F = 3.6$, $P \leq 0.05$) and 2022 ($F = 3.3$, $P \leq 0.05$). All three treatments were different in 2023, with the 1x treatment having the highest Ca and the 2x treatment having the lowest Ca ($F = 21.3$, $P \leq 0.0001$). Leaf Mg was higher within the control and 2x treatments compared to the 1x treatment in 2020 ($F = 5.9$, $P \leq 0.01$), higher in the control treatment compared to the 1x and 2x treatment in 2021 ($F = 42.8$, $P \leq 0.0001$), and higher within the control and 1x treatment compared to the 2x treatment in 2022 ($F = 4.4$, $P \leq 0.05$). In 2023, the three treatments were different by leaf Mg, with the control having the highest Mg and the 2x treatment having the lowest ($F = 12.1$, $P \leq 0.001$). Leaf S decreased across all treatments between 2020 and 2023. S was higher within the control and 1x treatments compared to the 2x treatment in 2020 ($F = 7.1$, $P \leq 0.01$), similar in 2021 and 2022, and higher in the 2x treatment compared to the control in 2023 ($F = 3.6$, $P \leq 0.05$).

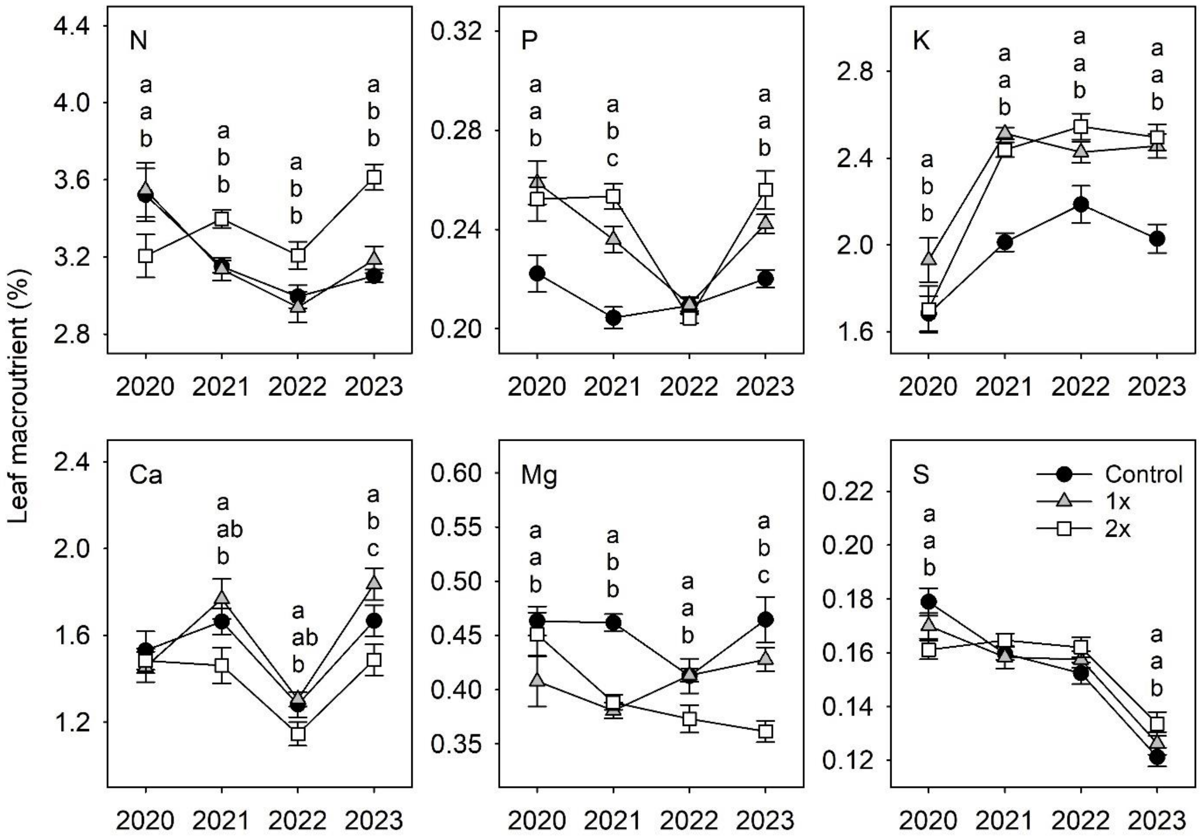

Figure 2.2. Leaf concentration (%) of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) following three mulch treatments including no mulch (control, black circles), 1x mulch (grey triangles), or 2x mulch (white squares), across three cultivars: 'Rubyprince', 'Julyprince', and 'Big Red' during 2020, 2021, 2022, and 2023. Leaf nutrients were sampled in November of 2020, and during July 2021, 2022, and 2023. Different letters show significant differences between mulch treatments for a given nutrient and year using Student's LSD test (n = 9, $P \leq 0.05$).

The mulch treatments also changed the level of micronutrients across the three peach cultivars (Figure 2.2) Leaf B was only measured in 2022 and 2023, but the control and 2x treatments had higher B than the 1x treatment ($F = 6.1$, $P \leq 0.01$) in 2022. In 2023, all three treatments were different, with the 1x having the highest B followed by the 2x treatment and then the control ($F = 29.7$, $P \leq 0.0001$). Leaf Cu was similar in 2020 between the treatments, but higher in the 1x and 2x treatments compared to the control in 2021 ($F = 7.6$, $P \leq 0.01$). In 2022, leaf Cu was again similar, but higher within the 2x treatment compared to the control and 1x in 2023 (F = 15.1, $P \leq 0.001$). Leaf Fe was higher in the control treatment than the 2x treatment in 2020 (F = 5.4, $P \leq 0.05$), similar between the treatments in 2021 and 2022. In 2023, the 2x treatment had higher Fe than the control (F = 3.4, $P \leq 0.05$). Leaf Mn decreased rapidly following the first year of sampling for all three treatments, but also showed treatment differences each year. In 2020 and 2021, the control treatment had higher Mn than the 1x and 2x treatments (F = 4.6, $P \leq 0.05$; F = 15.4, $P \leq 0.0001$; respectively), and all three treatments showed statistical difference in 2022, with the control having the highest Mn and the 2x treatment showing the least Mn (F = 17.9, $P \leq 0.0001$). In 2023, both the control and 1x treatment had higher Mn than the 2x treatment (F = 9.7, $P \leq 0.01$). Regarding leaf Zn, a single interaction between mulch treatment and cultivar occurred in 2020, as ‘Big Red’ trees with the 2x mulch treatment had higher Zn, while the control and 1x treatment ‘Big Red’ trees had lower Zn. Leaf Zn was higher in the 2x treatment compared to the control and 1x treatment in 2021 and 2023 (F = 4.7, $P \leq 0.05$; F =14.5, $P \leq 0.01$; respectively), but similar in 2022. No differences were found between the mulch treatments regarding leaf Na (Appendix B).

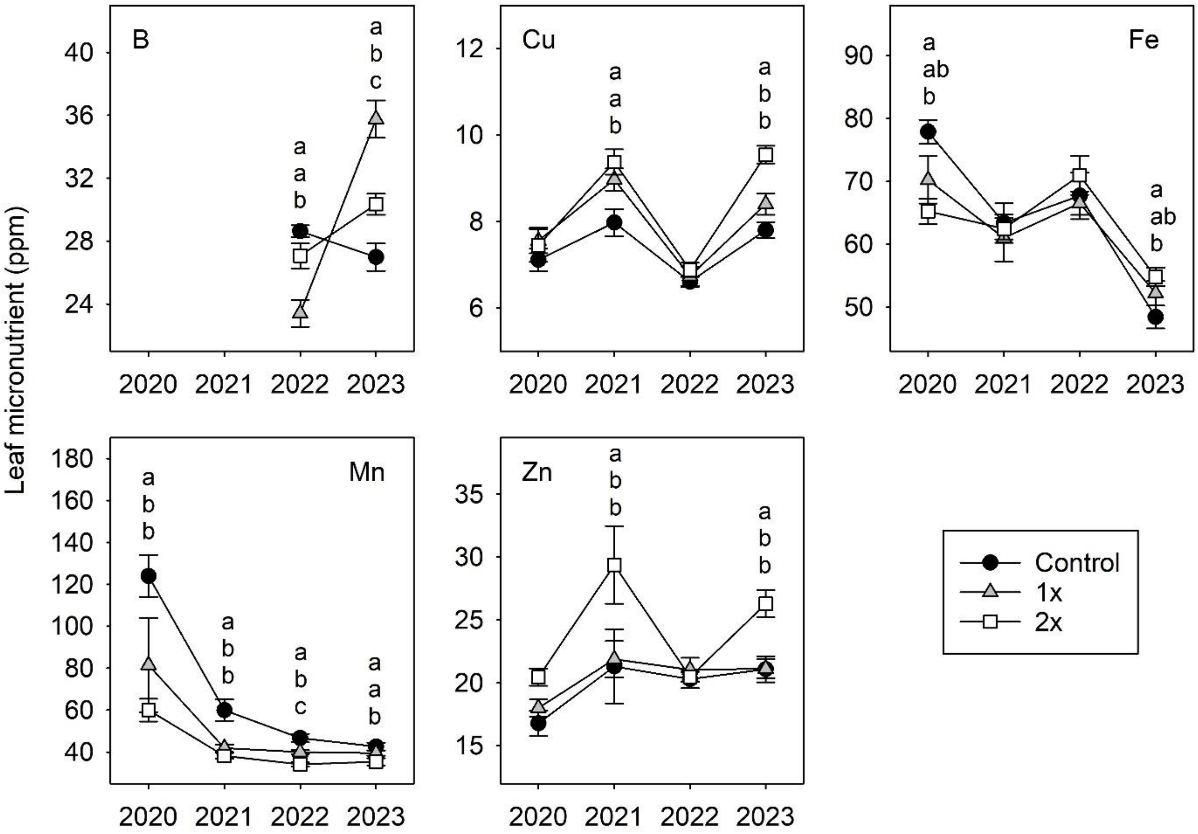

Figure 2.3 Leaf concentration (ppm) of boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) following three mulch treatments including no mulch (control, black circles), 1x mulch (grey triangles), or 2x mulch (white squares), across three cultivars: ‘Rubyprince’, ’Julyprince’, and ‘Big Red’ during 2020, 2021, 2022, and 2023. Leaf nutrients were sampled in November of 2020, and during July 2021, 2022, and 2023. Different letters show significant differences between mulch treatments for a given nutrient and year using Student's LSD test (n = 9, $P \leq 0.05$).

Regarding leaf nutrient differences between cultivars (Table 2.4), no differences were found in 2020 or 2021, except for leaf Cu, which was higher in ‘Big Red’ and ‘Julyprince’ compared to ‘Rubyprince’ ($F = 3.8$, $P \leq 0.05$). Multiple leaf nutrients analyzed including P, Zn, Fe, and Na were not different between cultivars during the study ($P > 0.05$). However, in 2022, ‘Julyprince’ had higher leaf N than ‘Big Red’ or ‘Rubyprince’ ($F = 11.8$, $P \leq 0.001$), and ‘Julyprince’ had higher leaf N than ‘Rubyprince’ in 2023 ($F = 5.4$, $P \leq 0.05$). Leaf K was higher in ‘Big Red’ and

‘Rubyprince’ compared to ‘Julyprince’ in 2022 ($F = 5.6$, $P \leq 0.05$), and higher in ‘Big Red’ compared to ‘Julyprince’ in 2023 ($F = 14.2$, $P \leq 0.001$). Leaf Ca was higher in ‘Big Red’ and ‘Julyprince’ compared to ‘Rubyprince’ in 2023 ($F = 3.9$, $P \leq 0.05$). Leaf Mg was higher in ‘Julyprince’ than ‘Big Red’ and ‘Rubyprince’ in 2023 ($F = 14.2$, $P \leq 0.001$). Leaf S was higher in ‘Julyprince’ compared to ‘Big Red’ and ‘Rubyprince’ in 2022 ($F = 9.5$, $P \leq 0.01$). Leaf Mn was different between all three cultivars in 2023, with ‘Julyprince’ having the highest Mn concentration, followed by ‘Big Red’ and finally ‘Rubyprince’ ($F = 12.8$, $P \leq 0.001$).

Table 2.4. Leaf nutrients of ‘Rubyprince’ (Rp), ’Julyprince’(Jp) and ‘Big Red’ (BR) peach tree cultivars across soil amendment treatments in 2020 and 2021. Significant differences resulting from Student’s LSD post hoc test are shown using letters (n = 9, $P \leq 0.05$).

Year	Cultivar	Macronutrient (%)						Micronutrient (ppm)					
		N	P	K	Ca	Mg	S	Zn	Cu	Mn	Fe	Na	B
2020	Rp	3.39	0.24	1.78	1.54	0.45	0.17	18.11	7.33	84.33	71.67	27.44	
	Jp	3.46	0.24	1.84	1.37	0.41	0.17	19.22	7.11	97.33	73.89	27.11	
	BR	3.53	0.25	1.77	1.57	0.45	0.17	17.78	7.78	79.22	68.11	31.56	
2021	Rp	3.22	0.23	2.34	1.59	0.42	0.16	22.43	8.19 b	42.51	62.78	22.49	
	Jp	3.20	0.23	2.29	1.66	0.40	0.16	27.71	9.08 a	50.81	61.47	55.13	
	BR	3.26	0.24	2.34	1.65	0.41	0.16	22.42	9.04 a	46.64	62.60	34.30	
2022	Rp	2.91 b	0.20	2.46 a	1.24	0.42	0.15 b	20.29	6.48	39.59	72.63	157.50	26.21
	Jp	3.24 a	0.21	2.23 b	1.21	0.41	0.17 a	21.25	6.93	40.57	65.09	162.28	26.38
	BR	3.02 b	0.21	2.47 a	1.28	0.38	0.15 b	20.27	6.80	40.62	67.43	160.81	26.51
2023	Rp	3.20 b	0.23	2.32 ab	1.45 b	0.39 b	0.12	22.92	8.64	34.84 c	49.74	27.99	31.75
	Jp	3.42 a	0.25	2.22 b	1.80 a	0.46 a	0.13	24.95	8.54	43.25 a	52.68	36.63	28.82
	BR	3.28 ab	0.24	2.44 a	1.75 a	0.40 b	0.13	20.62	8.56	39.42 b	53.02	34.68	32.49

Discriminate analysis of measured leaf nutrients across all measurement dates revealed clear groups and separation between the three mulch treatments for each of the nutrient variables (Figure 2.4A) but unclear classification between the three cultivars, as the three cultivars separated clearly by eigenvalues, but individual variables were not grouped (Figure 2.4B).

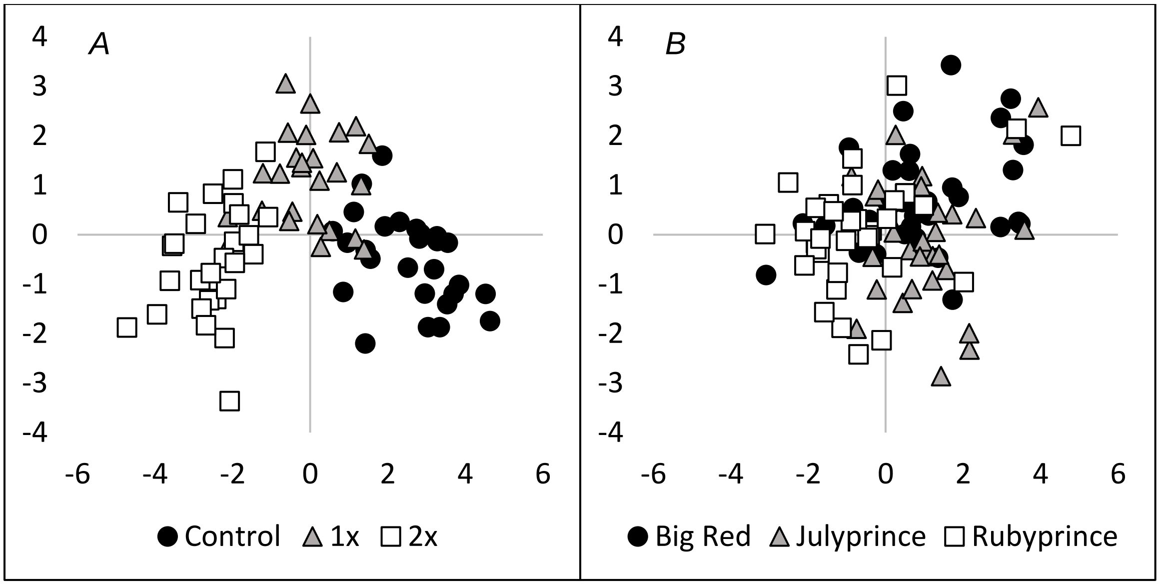

Figure 2.4. Discriminate analysis of leaf nutrients for mulch treatments (A) and the three cultivars (B) between 2020 and 2023.

Phenology measurements

Average bloom dates were analyzed using repeated measures analysis and found to be different by mulch treatment each year but were not consistent over the study (Figure 2.5). In 2021, the 1x trees bloomed sooner ($F = 11.6$, $P \leq 0.0001$), than control or 2x trees. In 2022, the 1x and control trees both were similar and bloomed earlier than 2x trees ($F = 8.7$, $P \leq 0.01$). In 2023, the control treatment trees bloomed earlier than the 1x or 2x trees ($F = 12.2$, $P \leq 0.001$).

Leaf senescence in 2020 was similar between mulch treatments but occurred earlier in the 1x treatment compared to the control and 2x treatment in 2021 ($F = 19.4$, $P \leq 0.0001$) and 2022 ($F = 21.1$, $P \leq 0.0001$) (Figure 2.6).

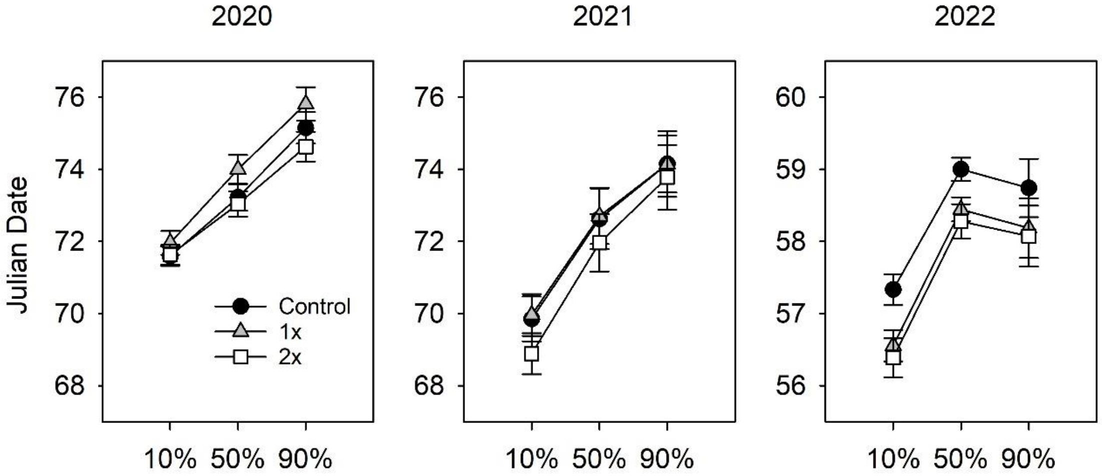

Figure 2.5. The average Julian date of 10, 50, and 90% bloom between the control (black circles), 1x mulch (grey triangles), and 2x mulch (white square) treatments across three cultivars in the spring of 2020 – 2022. Bloom occurred earlier in 2022 than the previous two years.

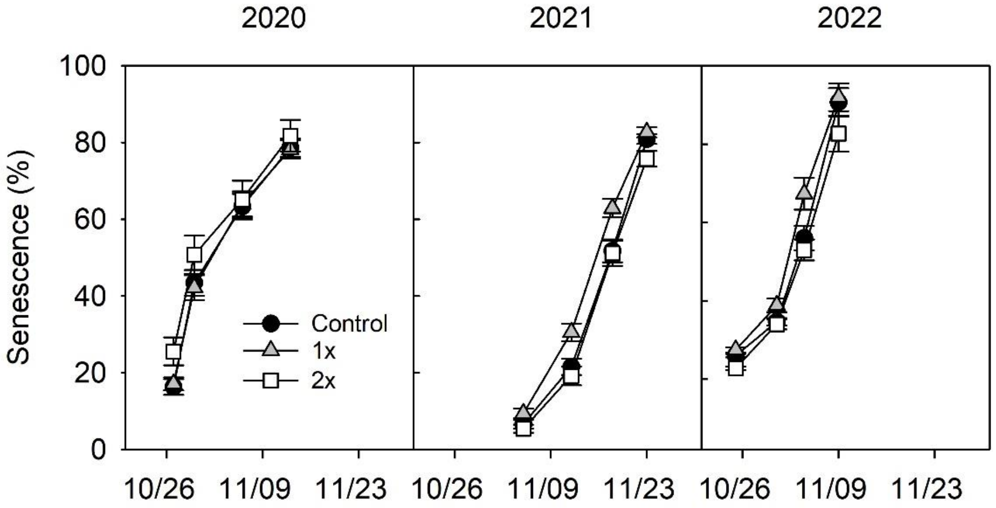

Figure 2.6. Average peach tree senescence (%) between control (black circles), 1x mulch (grey triangles), and 2x mulch (white square) treatments across three cultivars during the end of October (10/26, month/day) and November (11/23) in 2020-2022.

Fruit yield, quality, and efficiency

The mulch treatment had a significant effect on fruit yield and fruit quality measurements over the three years of fruit harvest (Table 2.5). Across treatments, few fruit were harvested in 2021 since the trees were only in their second leaf, compared to 2022 and 2023, and fruit quality measurements were not taken. Regardless, the 1x mulch treatment had higher yield ($F = 6.7$, $P \leq 0.0001$) than the control or 2x mulch treatment in 2021 (Table 2.5). In 2022, the 1x mulch treatment and the control had higher yield ($F = 8.9$, $P \leq 0.001$) than the 2x mulch treatment. In 2023, following the theft of ‘Big Red’ fruit, no differences in fruit yield were found between the mulch treatments due in part to a large degree of yield variability. When analyzing differences between mulch treatments by cultivar, ‘Rubyprince’ and ‘Big Red’ had greater fruit yield in the 1x treatment than the 2x treatment in 2022 ($F = 7.8$, $P \leq 0.01$ and $F = 5.1$, $P \leq 0.05$, respectively), while yield in all other years were similar between mulch treatments ($P > 0.05$).

There were cultivar differences in yield over the three years of study (data not shown). The second year after planting in 2021, the cultivars were allowed to produce fruit and ‘Julyprince’ (6.3 kg) produced more than ‘Rubyprince’ (4.7 kg), both of which yielded more than ‘Big Red’ (2.5 kg; $F = 16.7$, $P \leq 0.0001$). In 2022, there were significant differences by cultivar ($F = 102.6$, $P \leq 0.0001$) with ‘Julyprince’ (45.5 kg) producing more than ‘Big Red’ (23.0 kg) and ‘Rubyprince’ (19.7 kg). In 2023, cultivars were not examined due to the theft of ‘Big Red’. Due to the theft in 2023 and heavy pruning of ‘Rubyprince’ during the fall 2022, the cultivars were not examined statistically.

The mulch treatments also changed fruit quality and texture analysis in 2022 and 2023 (Table 2.5). In 2022, ‘Rubyprince’ fruit had higher soluble solid content in 1x treatment fruit than 2x treatment fruit ($F = 61.7$, $P \leq 0.0001$); while the 1x and 2x treatments were firmer than the control fruit ($F = 9.4$, $P \leq 0.0001$). The ‘Julyprince’ fruit in the 2x treatment were also firmer than the control fruit ($F = 3.4$, $P \leq 0.05$) in 2022. The ‘Big Red’ fruit had higher acidity in the control and 1x mulch treatments than the 2x mulch treatment ($F = 7.9$, $P \leq 0.01$); greater firmness in the 2x fruit compared to the 1x treatment, which was subsequently greater than the control ($F =25.2$, $P \leq 0.0001$); and the size and mass of the control fruit were larger than the 1x and 2x fruit ($F = 14.0$, $P \leq 0.0001$; and $F = 11.5$, $P \leq 0.0001$, respectively) in 2022.

In 2023, there were more differences in fruit quality measurements between the mulch treatments. The ‘Rubyprince’ fruit in the 1x treatment were larger in size ($F = 8.4$, $P \leq 0.001$) than the control and 2x treatment, and the 1x treatment was larger in mass ($F = 6.9$, $P \leq 0.01$) then the 2x treatment. The ‘Julyprince’ 2x treatment fruit were firmer than the control and 1x treatment ($F = 11.8$, $P \leq 0.0001$) and the 1x and 2x treatment were larger than the control fruit in size and mass ($F = 3.5$, $P \leq 0.05$ and $F = 5.8$, $P \leq 0.01$, respectively). In 2023, ‘Big Red’ 1x and 2x treatment fruit had higher acidity than the control fruit ($F = 21.2$, $P \leq 0.001$); and higher firmness ($F = 12.7$, $P \leq 0.0001$), size ($F = 13.9$, $P \leq 0.0001$) and mass ($F = 13.0$, $P \leq 0.0001$) in the 1x treatment than the control and 2x treatments.

Excluding ‘Big Red’ from cumulative yield analysis due to fruit theft, after the first two years of harvest (2021, 2022), ‘Julyprince’ (164.7 kg tree^{-1}) was much higher ($P < 0.0001$) than ‘Rubyprince’ (39.7 kg tree^{-1}), but there were no cumulative yield differences by the mulch treatments.

Table 2.5. Yield (kg tree $^{-1}$) and fruit texture analysis including titratable acidity (as malic acid, Acidity, %), total soluble solids (Brix, %), firmness (kg/cm^2), fruit diameter size (cm), and mass (g) from three cultivars of peach trees, ‘Rubyprince’, ‘Julyprince’, and ‘Big Red’ grown with three mulch treatments including control (no mulch), 1x rate of mulch and 2x rate of mulch. Differences between mulch treatments for a given year are shown by different letters according to Tukey’s honest significant mean separation test (n = 15 for yield; all other measurements: n = 18 in 2022, n = 9 in 2023, $P \leq 0.05$).

		Mulch treatment - 2022			Mulch treatment - 2023		
Cultivar	Measurement	Control	1x	2x	Control	1x	2x
Rubyprince	Yield	19.3 ab	24.3 a	15.5 b	22.4	18.9	18.7
	Acidity	1.31	1.37	-	0.75	0.82	0.77
	Brix	10.6 ab	11.1 a	9.7 b	8.0	8.4	7.4
	Firmness	3.7 b	4.6 a	4.2 a	3.6	3.5	3.3
	Size	72.7	72.3	73.5	72.2 b	75.1 a	71.0 b
	Mass	183.2	176.4	181	184.5 ab	198.0 a	169.6 b
Julyprince	Yield	47.3	47.0	42.1	110.0	114.8	133.0
	Acidity	0.56	0.57	0.53	0.71	0.66	0.76
	Brix	-	-	-	9.3	9.4	10.2
	Firmness	4.3 b	4.9 ab	5.1 a	2.9 b	3.4 b	4.1 a
	Size	81.9	79.7	80.5	81.9 b	84.1 a	84.6 a
	Mass	258.9	233.7	244.4	275.2 b	303.5 a	308.2 a
Big Red	Yield	22.5 ab	28.7 a	17.7 b	-	-	-
	Acidity	1.10 a	1.16 a	0.91 b	0.86 b	1.00 a	1.06 a
	Brix	15.3	15.83	15.48	12.5	12.1	13.1
	Firmness	3.2 c	4.5 b	5.7 a	3.8 b	4.7 a	4.0 b
	Size	89.4 a	85.6 b	84.2 b	84.6 b	89.2 a	86.7 b
	Mass	328.4 a	293.2 b	280 b	309.0 b	355.9 a	329.4 b

Yield efficiency (Table 2.6), the ratio of kg fruit to TCSA, appeared higher within the control and 1x trees compared to the 2x trees across cultivars in 2022, but there was an interaction between mulch treatment and cultivar ($F = 3.4$, $P \leq 0.05$), during which the

‘Julyprince’ had differences by efficiency by mulch treatments while the other two cultivars were similar. In 2023, the control trees were more efficient than the 1x and 2x trees (*F* = 12.3, *P* ≤ 0.0001), and the ‘Julyprince’ trees were greater than the ‘Big Red’ trees, both of which were greater than the ‘Rubyprince’ trees (*F* = 145.2, *P* ≤ 0.0001). Increasing the mulch rate decreased yield efficiency in 2023.

Table 2.6. Yield efficiency (kg fruit/cm^2 TCSA) between the three mulch treatments and three peach cultivars in 2022 and 2023.

Mulch Treatment	Cultivar	Mulch Treatment * Cultivar	Yield Efficiency	
			2022	2023
Control	-		0.31	0.53 a
1x	-		0.26	0.35 b
2x	-		0.21	0.36 b
Mulch treatment significance			NS	***
-	Rubyprince		0.15	0.10 c
-	Julyprince		0.45	0.80 a
-	Big Red		0.18	0.34 b
Cultivar significance			NS	***
		Control* Rp	0.16 c	0.13
		1x * Rp	0.17 c	0.08
		2x *Rp	0.11 c	0.09
		Control* Jp	0.56 a	0.95
		1x * Jp	0.42 b	0.71
		2x *Jp	0.37 b	0.75
		Control* BR	0.20 c	0.52
		1x * BR	0.20 c	0.24
		2x *BR	0.14 c	0.25
Interaction significance			*	NS

Discussion

Tree Growth

This study is the first to demonstrate that the addition of large quantities of composted single-ground municipal mulch, initially incorporated into the berms and later to cover the soil annually can significantly impact peach tree growth, nutrient status, and yield during tree establishment in the Southeast USA. A similar study in organic apples looked at various cover crops on yield, growth and fertility and determined that there were benefits to cover crops, yet adding additional fertilizers were necessary to sustain growth and yield (Sanchez, 2006). Another study also in apples that blended organic and inorganic fertility treatments determined that adding fertility treatments to high density apples may not increase unwanted tree growth and that compost additions can improve many soil properties (Thompson, 2017). A study in apricots (*Prunus armeniaca L.*) that combined bio-organic and inorganic nutrient sources improved many soil and horticulture parameters of an existing apricot orchard (Singh, 2010). The end goal of a peach production system is to have planted trees fill their allotted space with high quality fruiting potential and to efficiently produce high yields (Marini and Reighard, 2008; Reighard, 2008). In this study, the addition of OM led to changes to the orchard soil and the horticultural parameters measured reflect these changes. All three cultivars of the study showed phenotypic plasticity according to the mulch treatments, growing larger in amended soil than the control by the end of the study. Adding OM increased available nutrients required for plant growth, especially N, and covering the soil may have contributed to increased moisture availability during periods of water stress, although this was not measured directly.

Previous studies have shown that covering the soil with mulches and organic materials can prevent nutrient leaching, increase soil moisture, improve the physical, chemical, and biological properties of soil, and enhance growth in many different crops (Kaur et al., 2017). In the current study, the influence of N on tree growth was markedly different during the first growing season, as the 2x trees were much smaller and had less foliar N compared to the control and 1x trees. The 2x rate of preplant composted mulch application may have resulted in soil N immobilization due to undigested large wood pieces still in the compost leading to reduced tree growth (TCSA, tree height and width). However, by the time trees were producing fruit during the third year, yields of 1x and 2x trees were similar to each other and numerically higher than the control trees and whether smaller size trees during the first growing season would have long-lasting influence on cumulative yield cannot yet be understood. Also, it is also possible the unsettled soil of the berms after mulch incorporation may have had large air gaps and allowed the soil to dry out faster during dry weather conditions than other treatments during the first growing season and lack of soil moisture may have prevented trees from accessing available N. Furthermore, heavy rains during the spring immediately after planting brought heavy rains that led to short-term saturated soils, particularly in the heavily mulched rows as water infiltration was greatly improved in those rows. Regardless, most concerning for growers if they were to add composted municipal mulch was that several (3) 2x trees collapsed from an inability to uptake enough N, saturated soils, or overly dry soils or the combination of all, and were replanted with potted same-age trees. The dead trees were evaluated for cause of death and on the lower roots there were blackened rotting roots typical of flooding. The shallower roots were living but failing to grow. These trees may have recovered if not pulled out for evaluation. Since these trees were pulled during the growing season, potted trees of the same age, type, and lot were replanted in their place.

More confounding to the N story regarding tree growth was the mulch analysis initially suggested little N available. Since both the 1x and the 2x trees grew larger and faster than the control, the mulch treatments improved the soil environment beyond just adding important macronutrients needed for rapid plant growth. Interestingly, tree height was reduced from 2021 to 2022 due to the pruning out of the central leader after measuring in 2021 to transition the trees to an open vase system. The control trees also were also reduced in size when transitioning to the open vase habit. Standard summer pruning was used evenly across treatments, but the 1x and 2x trees grew beyond standard management practices recommended for maintaining the desired fruiting wood. Adding the mulch may have increased the amount of N directly available and indirectly available through increased microbial volume. These excessive nutrients can adversely affect growth and fruit quality. While larger trees may have the potential to increase yields early in the orchard life, vigorous trees without fruiting wood due to increased shading and blind wood are inefficient (Weinbaum et al., 1992). Summer pruning and improving light penetration on young peach trees can increase yield the following season (Miller, 1987), but multiple summer pruning events due to overly vigorous trees would be cost prohibitive. Moreover, the ‘Rubyprince’ trees experienced a light crop in 2023 due to spring frost and without competition of photosynthetic resources between fruits and growing shoots, the mulch treatments resulted in excessive vegetative growth and shading. Additional studies in this orchard could measure the development of blind wood, flower buds, and fruit quality. Larger TCSA has been historically used to convey a larger yield potential (Lepsis et al., 2006), but the larger trees of the study in the 1x and 2x treatments did not necessarily produce more fruit. Between the two treatments, the 1x exhibited steady growth, without first-year mortality or potentially N immobilization, while the 2x rates had issues the first season of growth. Future studies need to address the possible issue of overfertilization following the mulch treatments in addition to the recommended standard rates of synthetic fertilizers (Blaauw et al., 2024). Both mulch treatments visually had greater vegetative growth, delayed ripening, and inner canopy shading out of fruiting wood in comparison to the control, all symptoms of excessive fertilization. Nonetheless, the concern over tree growth on fruit production perhaps is best understood with longer studies and cumulative yield evaluations.

Yield

For growers, the most important result of the study was the positive potential effect of the mulch treatment on yield. However, following two years of harvest it is too early to understand the full significance of the mulch treatments on yield. Understanding and making future trend predictions from the two years of yield data is further complicated due to extenuating circumstances, notably the spring frost which reduced the ‘Rubyprince’ yield and the theft of ‘Big Red’ in 2023. However, numerically higher values in the 1x and 2x rates may be a factor of greater tree sizes, and potentially greater cumulative yields over the orchard lifetime. Additional years of harvest data will help determine the long-term influence of the mulch treatments on yield. The study by Thompson et al. (2017) showed their compost additions improved many soil properties but did not lead to improved orchard productivity within the first 3 years or the orchard. These two studies agree on this outcome. Also monitoring tree health and pathogen pressure as these trees age will be important variables to factor into cumulative orchard yields as any increase to the average orchard age by treatment could justify the cost of mulch purchase and application.

In the southeastern United States, the majority of peach growers maintain trees pruned to an open vase and yield efficiency is not often commercially used to understand tree performance. After the first three years in 2023, yield efficiencies were lower in both mulch treatments than the control but this was largely an effect of the much larger size TCSA in the 1x and 2x treatments. While larger trees may produce more fruit over the first several years of orchard establishment, annual pruning maintains a particular size according to the grower equipment and standards, and excessive tree growth is undesirable. As of now, both the 1x and 2x treatments had reduced efficiency but had a neutral or positive effect on total yields in comparison to the control, since the 2x rate improved in 2023 compared to 2022 over the control.

Leaf Nutrients

The addition of OM to peach orchards has been known to provide fruit trees with sufficient mineral nutrients required for growth (Baldi et al., 2010). In the present study, both the 1x and 2x treatments were able to maintain, and often increased the level of macro and micronutrients measured in the leaf tissue. However, all treatments of the study also received the standard rate of fertilizers annually (Blaauw et al., 2024) and adjusting the rates of synthetic fertilizers needs to occur in the future to avoid excessive macronutrient accumulation within the orchard. Both mulch treatments provided large amounts of both macro and micronutrients to the growing trees, and this is reflected in the leaf nutrients levels over time. Nutrients became either more or less available as the OM decomposed. The dominant chemical indicator of larger tree growth was the significantly higher leaf tissue N in the 2x treatment compared to the 1x and control. While the initial amount of N was low in 2020, once the mulch decomposed further over time and/or the berms settled, the 2x trees grew faster and were equal in size to the 1x and the control by 2021. For example, N was much higher in the 2x rate but similar between the 1x and control after the first year, whereas both the 1x and 2x rates were frequently higher compared to the control for leaf P, K, Ca, and S. While various forms of OM can provide similar levels of foliar nutrients (Baldi et al., 2010), the goal is not to increase the amount of nutrients over sufficiency ranges, as it would be unhelpful for the goal of fruit production. The current study showed leaf nutrients which exceeded the sufficiency range (e.g. N: 2x in 2023) or were deficient (e.g. Ca: 1x and 2x in 2020; 2x in 2021; C, 1x, and 2x in 2022; 2x in 2023. Zn: C and 1x in 2020. Fe: C, 1x and 2x in 2023.) according to the standard guidelines (CUASL 2024) but no nutrient except Ca in 2x was consistently outside the guideline thresholds year-on-year. In other studies, mulch treatments caused the opposite effect for nutrients, such as Mg, which was lower compared to grower standard treatments. For micronutrients, the 2x mulch treatment also frequently increased nutrients compared to the control, but not for Mn, which was consistently higher in the control and could be a result of increased soil pH (Noor, 2023). Through complex biochemical soil processes, the bioavailability of heavy metals can be higher in soils with higher OM, as the CEC increases (Kim et al., 2015). However, in this study there was no increase in Cu concentrations in leaf tissue in the mulched rows with higher OM, there was an actual decrease in several years that also follows the lower soil Cu concentrations in the mulched rows. Due to the differences in foliar nutrients, optimizing both the rates of fertilizer and particular formulas of fertilizers with mulch will be necessary to avoid nutrient imbalances over time. Secondary and micronutrients of particular interest for peach growers in the southeastern USA regarding fruit quality are Ca, B, and Zn (Johnson, 2008). The addition of 1x mulch rates did not appear to restrict these nutrients to the growing trees and was improved consistently over multiple years in the case of Ca and Zn. Therefore, the study suggests that growers with difficult soil conditions who need to increase the amount of Ca should consider adding the 1x rate of composted mulch to young orchards as a possible way to increase Ca status in orchard trees. A similar suggestion may be given for B, as improving soil quality and stabilizing pH, may hypothetically increase the availability of B for trees, although a previous Canadian study determined that there was no significant relationship found between soil pH and soil B in their study (Neilsen, (1985)). However, whether or not the mulch treatments increase or reduce fruit quality consistently and provide nutrients to maintain sufficiency levels will need to be shown by additional years of analysis.

A discriminant analysis was used to broadly understand the influence of the mulch treatments on nutrient status of the leaf tissue and showed clear separation by soil treatment, similar to the discriminate soil nutrient analysis from the previous chapter. The separation of the three cultivars using similar analysis is probably an artifact of harvest time (Zhou, 2019) and yield damaging spring frosts events in 2023 for ‘Rubyprince’, but the patterns of each nutrient by cultivar were not consistently clustered, unlike the effect of mulch treatment.

Tree phenology

Like other orchard species, peaches in the southeast are at risk of spring frost and warmer fall temperatures can disrupt natural patterns of internal nutrient recycling. The recent addition of planting berms in the southeast have been suggested to change the phenology of both young and old trees, and new management including the addition of OM may change plant behavior (Gasic, personal communication, 2023). Both bloom timing and senescence timing differences between mulch treatments were not consistent, but repeated measurement analysis suggests that some minor differences occurred. In the case of spring bloom timing, the largest difference was observed in 2023, when both mulch treatments bloomed sooner. Unlike previous research which has suggested covering the soil may insulate the soil from warming and delay blooming (Tworkoski, 2008) the darker color of the mulch compared to bare soil may have absorbed more radiation and increased soil temperature. A study in West Virginia spread coal dust under peach trees to evaluate the effect of soil microclimate differences and a similar cumulative effect was reported (Sharratt, 1988). Although there were statistical differences observed, it is unknown whether there would be practical difference between the treatments, as the maximum difference in bloom phenology was 1.5 days and dates between senescence of leaves were essentially equal. Continued observations, especially regarding how covering the soil may lead to an increased spring frost risk and warmer soil from the darker substrates may place trees at higher risk for earlier bloom or lower the risk due to the release of more stored heat during cold events should be studied.

Future directions

Adding OM to peach orchards in the southeastern United States, especially at the scale of the current study have not largely been performed. Ongoing exploration of the orchard system, using horticultural, pathological, and economical studies will need to accompany the current study before having a complete understanding. Although not reported in the current study, one of the initial long-term objectives was to understand how common orchard pathogens would be influenced by the mulch treatments during orchard establishment. Whether trees with higher amounts of OM would have greater resilience to pathogens, particularly bacterial canker (*Pseudomonas syringae* pv. *syringae*), remains unknown. Nonetheless, several 'Rubyprince' trees were pruned early, prior to senescence, in October 2022 just before a long rain event to inoculate the trees intentionally and naturally with bacterial canker. No differences were observed for this pathogen the following spring in terms of canker incidence and severity (data not shown). An additional pathogen, bacterial spot (*Xanthomonas arboricola* pv. *pruni*), which is a disease that reduces fruit quality, tree productivity, and reduces yield was also purposely inoculated on leaves during the third growing season, but the results were inconclusive (data not shown). In October 2023 this whole orchard was pruned unseasonably early to exacerbate potential bacterial canker infection, but no data has been collected from this pruning event yet. Regardless, future work should consider the pathological changes in bacterial canker and other pathogens in the orchard, especially as soil biology changes over time. The long-term objective of this study is to determine if improved soils lead to healthier plants that lead to prolonging productive orchard lifespan and cumulative fruit yield. As the composted mulch continues to decompose and change the composition of the soil profile, shifting microbiology species diversity could affect pathogen presence and severity. This was already observed in seeing a positive shift from pathogenic to beneficial populations of nematodes for a parallel study in this orchard (data not shown). Alternatively, excess N can increase the rate of disease and insect susceptibility in other stone fruit orchards (Daane, 1995). Without reducing current synthetic fertilizer rates in conjunction with the mulch application, elevated N in the orchard system which increases pest or disease pressure may completely negate any other benefit from using amendments.

One of the most common hesitations for the use of mulch in fruit orchards is the expense of purchasing and application. This study benefited from having the mulch amendment in close proximity to the location and several years of natural decomposition before incorporation in 2019. Various amendments added may have a range of benefits or drawbacks for growers in the short and long-term but little data exists in the region on differences between amendments. Specifically, a long-term analysis of cost-to-benefit variables will need to be constructed at the conclusion of the orchard used for the current study. The composted mulch acts not only as a fertilizer source for soil and tree life but influences both biotic and abiotic factors impacting tree performance over the long-term and this will require long-term observation. The complexity provides both challenge and opportunity for future study, and any positive economic valuation while decreasing costs of other inputs, such as fertilizer, water, and pest control measures could result in regional growers shifting from current management strategies and incorporating similar techniques.

Conclusion

The initial incorporation and annual application of mulch to the replanted orchard increased tree growth and larger trees may have the potential to yield more fruit, agreeing with the initial hypothesis. To a peach grower, the value of this alternative management system would be realized as cumulative tree and orchard yield, a measurement which is impossible to obtain from only two years of fruit harvest. Nonetheless, the initial harvest measurements show that mulch did not decrease yield compared to the control, but whether trees may produce more fruit over the lifetime of the orchard will need to be explored in later studies. While the mulch amendments increased concentration of many measured foliar nutrients, one of the challenges moving forward will be to accurately project nutrient availability from the amendments to not over fertilize the orchard. Justifying the use of alternative management practices in peach orchards will be possible if growers reduce costs and/or labor with the addition of increased yield and desirable fruit quality. Only by continuing the current experiment for the typical orchard lifespan of 13 years and determining if there are tree longevity benefits will final production value be realized.

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APPENDICES

Appendix A. Organic matter (%), cation exchange capacity (CEC, meg/100 g), base saturation (BS, %), and soil pH between the control (no mulch), 1x, and 2x mulch treatments during spring and fall soil sampling times. The fall of 2019 served as a baseline while different letters show differences according to Tukey's honest significant difference mean separation test ($P \leq 0.05$) during individual sampling times.

Sampling Time	Mulch Treatment	OM	CEC	Base Saturation	pH
Fall 2019	n.a.	2.2	5.1	68	5.6
Fall 2020	Control	2.2 c	4.6 b	68.3 c	6.1 b
	1x	4.3 b	8.8 a	81.7 b	6.7 a
	2x	5.2 a	9.6 a	86 a	6.8 a
Spring 2021	Control	2.0 c	5.1 c	67.8 b	6.0 b
	1x	3.9 b	7.7 b	76.5 a	6.2 a
	2x	4.8 a	9.0 a	78.8 a	6.4 a
Spring 2022	Control		5.7 b		5.9 b
	1x		12.8 a		6.6 a
	2x		13.6 a		6.7 a
Fall 2022	Control	2.0 c	5.4 c	59.6 b	6.0 b
	1x	4.9 b	11.6 b	79.4 a	6.4 a
	2x	6.7 a	15.5 a	82.3 a	6.5 a
Spring 2023	Control	2.1 c	5.0 b	61.4 b	6.0 b
	1x	6.6 b	14.1 a	84.6 a	6.5 a
	2x	12.9 a	17.6 a	84.0 a	6.6 a

Appendix B. Leaf macronutrients (N, P, K, Ca, Mg, and S %) and micronutrients (Zn, Cu, Mn, Fe, Na, and B ppm) of peach leaves grown under three mulch treatments including no mulch (control), 1x mulch, or 2x mulch, across three cultivars: ‘Rubyprince’, ’Julyprince’, and ‘Big Red’ during 2020, 2021, 2022, and 2023. Leaf nutrients were sampled in November of 2020, and during July 2021, 2022, and 2023. Different letters show significant differences between mulch treatments for a given nutrient and year using Student's LSD test (n = 9, *P* ≤ 0.05).

Year	Soil Treatment	Macronutrient (%)											Micronutrient (ppm)
		N	P	K	Ca	Mg	S	Zn	Cu	Mn	Fe	Na	B
2020	Control	**3.52 a**	**0.22 b**	**1.68 b**	1.53	**0.46 a**	**0.18 a**	16.78	7.11	**124 a**	**77.89 a**	29.44	
	1x Mulch	**3.66 a**	**0.26 a**	**1.99 a**	1.46	**0.39 b**	**0.17 a**	17.89	7.67	**76.89 b**	**70.56 ab**	29.56	
	2x Mulch	**3.21 b**	**0.25 a**	**1.70 b**	1.48	**0.45 a**	**0.16 b**	20.44	7.44	**60 b**	**65.22 b**	27.11	
2021	Control	**3.15 b**	**0.20 c**	**2.01 b**	**1.66 ab**	**0.46 a**	0.16	**21.31 b**	**7.97 b**	**59.97 a**	63.37	34.85	
	1x Mulch	**3.14 b**	**0.24 b**	**2.51 a**	**1.77 a**	**0.38 b**	0.16	**21.88 b**	**8.97 a**	**41.84 b**	61	23.96	
	2x Mulch	**3.40 a**	**0.25 a**	**2.44 a**	**1.46 b**	**0.39 b**	0.16	**29.37 a**	**9.37 a**	**38.16 b**	62.48	53.11	
2022	Control	**2.99 b**	0.21	**2.19 b**	**1.28 ab**	**0.41 a**	0.15	20.29	6.61	**46.67 a**	67.7	162.76	**28.62 a**
	1x Mulch	**2.97 b**	0.21	**2.43 a**	**1.31 a**	**0.41 a**	0.16	21.05	6.73	**39.98 b**	66.52	161.26	**23.40 b**
	2x Mulch	**3.21 a**	0.20	**2.55 a**	**1.15 b**	**0.37 b**	0.16	20.47	6.88	**34.13 c**	70.95	156.57	**27.06 a**
2023	Control	**3.10 b**	**0.22 b**	**2.03 b**	**1.67 b**	**0.46 a**	**0.12 b**	**21.08 b**	**7.80 b**	**42.65 a**	**48.44 b**	30.56	**26.97 c**
	1x Mulch	**3.19 b**	**0.24 a**	**2.46 a**	**1.84 a**	**0.43 b**	**0.13 a**	**21.12 b**	**8.40 b**	**39.51 a**	**52.20 ab**	34.14	**35.75 a**
	2x Mulch	**3.61 a**	**0.26 a**	**2.50 a**	**1.49 c**	**0.36 c**	**0.13 a**	**26.28 a**	**9.54 a**	**35.35 b**	**54.80 a**	34.61	**30.34 b**