



# Effect of Municipal Mulch and Poultry Litter Amendments on Soil and Tree Parameters of a Mature Peach Orchard in a Humid Subtropical Climate

Brian T. Lawrence<sup>1,2</sup> · Juan Carlos Melgar<sup>2</sup>

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## Abstract

Applying organic matter (OM) amendments in mature peach orchards with low organic matter content (*Prunus persica* (L.) Batsch.) may improve tree nutrient and water status during the growing season and enable growers to reduce synthetic fertilizer inputs. Three treatments were applied to “Juneprince” and “Scarletprince” peach trees: (1) grower standard of bare soil (GS), (2) municipal mulch (M), and (3) poultry litter with municipal mulch (PLM). Synthetic fertilizer was reduced within the M and PLM treatments each year. Soil samples were taken from under the amendments, and the nutrient and water status of the soil and trees were monitored over 3 years. Fruit yield and tree growth measurements were also recorded. Soil OM did not increase, but soil P increased in all three treatments over time. Soil Cu was reduced by adding OM amendments, while PLM increased soil Na and increased leaf K in “Scarletprince” trees. The PLM and M treatments buffered soil water compared to GS, but tree water status between treatments was largely similar. The elevated N status over time from the PLM and M treatments delayed fruit maturity and reduced cumulative yield in “Juneprince” trees. The PLM treatment increased “Scarletprince” fruit size and mass over 3 years, as well as tree size compared to GS. Covering the soil with mulch allowed for reduced synthetic fertilizer use, but further reduction of supplemental synthetic fertilizer or adjustment of amendment rates is needed to limit N and ensure desired fruit harvest windows and long-term production.

**Keywords** Nutrient status · Organic matter · *Prunus persica* · Soil management · Water status

## 1 Introduction

Maintaining soil cover within fruit orchards is a management practice that can improve soil health by reducing soil erosion and potentially increase organic matter (OM) (Britt 1962; Reganold et al. 1987). Across global orchard cultivation, covering the soil using mulch or cover crops has been shown to have positive effects on fruit yield and tree growth (Fang et al. 2022; Liu et al. 2021), but many growers often maintain bare soil within the tree rows and occasionally between rows, resulting in orchards void of any cover.

Historical traditions, such as over-tillage (Keesstra et al. 2016) or maintaining a sense of agricultural cleanliness (Paine and Harrison 1993), can partially explain why some growers choose to maintain bare soil. It is well documented that the control of weed species in the proximity of growing trees reduces nutrient and water competition (Welker and Glenn 1989; Meagher and Meyer 1990; Oliveira et al. 2016), can suppress populations of insect pests (Meyer et al. 1992; Tworokski and Glenn 2008), and provides protection during radiation frost/freeze events (Perry 1998). However, reducing herbicide use and keeping the soil covered decreases soil crusting, nutrient, and water run-off and can improve long-term water, nutrient, and soil conservation (Keesstra et al. 2016; Liu et al. 2021; Mia et al. 2020).

Management practices that apply amendments in orchards are currently being explored in fruit-growing regions of the world and are primarily driven by the prospects of larger production or sustainability goals, such as to reduce agricultural water use in dry climates (Lepsch et al. 2019; Villa et al. 2021), buffer seasonal soil temperature and soil moisture

✉ Brian T. Lawrence  
btl42@cornell.edu

<sup>1</sup> Horticulture Section, School of Integrative Plant Science, Cornell University, Geneva, NY 14456, USA

<sup>2</sup> Department of Plant and Environment Sciences, Clemson University, 105 Collings Street BRC 204, Clemson, SC 29634, USA

(Treder et al. 2004), satisfy organic markets (Granatstein and Mullinix 2008; Reeve et al. 2017), reduce synthetic fertilizer inputs (Baldi et al. 2010a), and capture atmospheric carbon (Baldi et al. 2018; Montanaro et al. 2012; Vicente-Vicente et al. 2016). Cover crops, often used to cover the orchard soil, provide numerous environmental benefits (Demestihias et al. 2017; Morugán-Coronado et al. 2020), but can harbor insect pests which damage fruit (Meyer et al. 1992) and can be difficult to establish due to shade from mature trees.

Application of OM to the soil surface has the potential to increase soil OM content (Khalsa et al. 2021). Increasing OM within orchard soils can greatly improve soil properties, such as aggregate structure and water storage, as well as encourage soil microorganism communities and soil fertility (Oliveira et al. 2016; Reganold et al. 1987). Growers can acquire sources of OM from composting programs in municipalities or from regional industries, and specific OM amendments are often readily available in fruit-growing regions (Khalsa and Brown 2017). Municipal compost products have been shown to meet the nutrient demands of fruit trees (Baldi et al. 2014) and increase soil organic carbon (Baldi et al. 2018), while hardwood mulch products can improve soil OM and nutrient availability when applied to apple orchards over multiple seasons (Atucha et al. 2011). Surface application of mulch has also been shown to improve tree water status, leading to increased yields when soils are limited in Spain (Lordan et al. 2015). Historically, animal manures and composted manure products were used to fulfill nutrient requirements and increase OM in orchard soils (Baldi and Toselli 2021) but are less common in modern commercial orchard management. Composted dairy manure has been used as a surface mulch to reduce water stress in young almond (*Prunus amygdalus* Batsch.) trees in California (Lepsch et al. 2019), and olive (*Olea europaea* L.) oil waste products have been mixed with poultry litter and applied to olive orchards in Italy (Montemurro et al. 2016). Poultry litter has also been used to supply nutrients in peach orchards (Preusch and Tworkoski 2003) and reduce soil-borne pathogens (Pokharel and Reighard 2015).

Although many amendments are being tested as soil covers in orchards, they do not always improve tree or fruit production in the short term compared to current management practices. A study that added yard waste compost and poultry litter to young apple (*Malus domestica* Borkh.) trees in Virginia concluded positive effects on soil fertility parameters and bacterial communities (Sharaf et al. 2021), but the amendments did not result in improved tree growth after 3 years (Thompson and Peck 2017). Surveys among growers in Europe and within California have also revealed hesitation or barriers to adopting for using manure as a soil amendment or source of fertilizer for numerous reasons, including potential risk to food safety, timing of nutrient release, farm size, and difficulty of application (Fangueiro et al. 2021; Khalsa

and Brown 2017). However, growers are also aware of the numerous benefits of adding OM and that various manure sources can be inexpensive and improve soil structure for future production (Fangueiro et al. 2021). Similar to other regions worldwide which have been intensively managed for fruit trees, large amounts of soil have been lost in the southeastern USA due to prior land use, resulting in low OM content and highly eroded soil (Franzluëbbers 2005). While some work has explored OM amendments over multiple growing seasons on young orchard trees in subtropical conditions (Lawrence and Melgar 2023), there is little information to how OM applications made to mature trees change soil and tree parameters.

The purpose of this study was to examine the effects of two soil cover OM amendments on water and nutrient dynamics in a mature peach tree orchard and how they would impact tree growth and productivity over 3 years. We hypothesized that annual surface application of composted single-ground municipal mulch or the same mulch with poultry litter would increase OM, increase CEC (thus increase extractable soil nutrients essential for plant growth), and buffer soil moisture compared to the standard practice of bare soil. Due to soil changes by adding OM amendments, we hypothesized that trees growing with mulch or mulch with poultry litter would also exhibit increased shoot growth, improved water status during periods of water deficit, increased foliar nutrient concentration, and greater fruit yield compared to trees growing without either amendment. Our objectives were to measure how the two OM amendments would alter (1) the soil environment in terms of water availability, OM, cation exchange capacity (CEC), and nutrients and (2) tree parameters in terms of vegetative growth, water status, nutrient status, fruit quality, and yield.

## 2 Materials and Methods

### 2.1 Location, Treatments, and Weather Conditions

The study took place at the Musser Fruit Research Center of Clemson University in Seneca, SC (lat. 34° 36' 22" N, long. 82° 52' 39" W) between 2019 and 2022. An orchard of perpendicular V-trained peach trees (*Prunus persica* (L.) Batsch) which were 5 years old at the beginning of the study and planted at 1.5 × 6.7 m spacing (5 × 22 feet) was used. The soil of the orchard is of the Appling series, being an eroded and well-drained gravelly loamy sand with approximately 52% sand, 18% silt, and 30% clay from the soil surface to 15 cm deep, and 35% sand, 15% silt, and 50% clay from 15 to 45 cm (Soil Survey Staff 2022). The initial OM ranged from 1.4 to 3.1% in the top 0–15 cm depth. The site had no previous history of orchard cultivation. The study involved three rows of peach trees, with each row divided

into three treatment sections consisting of 10 trees each: (1) maintained with bare soil similar to the current peach; (2) covered with composted single-ground municipal mulch, which was primarily yard-waste debris (M); or (3) with poultry litter added and immediately covered with the same yard-waste debris mulch (PLM). Each treatment section was further divided between 5 “Juneprince” and 5 “Scarletprince” trees, both grafted onto Guardian® rootstock, which were planted together as individual plots. Single border trees were placed between each section and at the end of each row.

A rate of 6725 kg ha<sup>-1</sup> dw (3 tons acre<sup>-1</sup>) of poultry litter, sourced from nearby poultry production, was applied annually in the study, whereby each treatment area received 0.2 m<sup>3</sup> of the litter. The litter had a moisture content between 31 and 35% and an estimated N availability of 29 ± 2 kg ha<sup>-1</sup> between 2020 and 2022 (Supplementary Table 1). These estimates were provided by the Clemson Agricultural Service Lab. In spring 2020, the litter was mixed into the top 15 cm of mulch, while in the spring of 2021 and 2022, it was covered under 8 cm of mulch. However, the available nutrients were assumed to be lower compared to if the litter had been incorporated into the soil beneath the amendments, where most of the peach roots existed when the trial began.

The composted single-ground municipal mulch was acquired from Oconee County, SC, USA. The mulch material was obtained once in 2018, stored on site, and was reused repeatedly from the same pile during the years of the trial period. The material was tested twice during the study. In 2020, it had a carbon-to-nitrogen (C:N) ratio of 35.8, an OM content of 25.5%, and a moisture content of 42.8%. In 2022, the litter had a C:N ratio of 24.3, an OM content of 30.8%, and a moisture content of 58.6%. The mulch was initially applied to the soil surface at a depth of 15 cm in November 2019. Additional applications were made on top of the existing mulch in March 2021 and 2022, to a depth of 8 cm using a Millcreek row mulcher (304RM, Millcreek Mfg. Co., Lancaster County, PA, USA). The M and PLM treatments covered the area beneath trees traditionally maintained as bare soil, with dimensions of 6 m × 16.5 m. In 2020, they received 5.1 m<sup>3</sup> of mulch, and in subsequent years, they received 2.5 m<sup>3</sup> each year. The same mulch depths and volumes were used when covering the poultry litter treatment sections.

In 2020, all treatments received a recommended fertilization rate of 0.25 kg N tree<sup>-1</sup> using 19–19–19 (Blaauw et al. 2022). From 2021 onwards, the control treatment (GS) continued to receive the standard amount of fertilizer, while the M treatment received 25% less fertilizer (0.19 kg N tree<sup>-1</sup>) during the spring of 2021 and 2022. The PLM treatment did not receive additional fertilization during the spring of 2021 and 2022. After harvest, the GS treatment received an additional 0.16 kg N tree<sup>-1</sup> in 2020, 2021, and 2022. The M and PLM treatments received 0.16 kg N tree<sup>-1</sup> in July

2021 and 2022, as indicated by foliar N analysis that showed nutrient levels within the optimum range and consistent crop production.

Prior to the establishment of the treatments, herbicide was applied to maintain a weed-free area 1 m wide on both sides of the tree rows. Throughout the trial, herbicides were used to control weeds within all treatments, and the row middles were regularly mowed. Monthly temperature and rainfall data were collected from a weather station located 100 m from the orchard (Vantage Pro, Davis Instruments, Hayward, CA; weather underground station KSCSENEC14). During fruit development and after fruit harvest during periods of dry weather, supplemental irrigation at a rate of 2.5 cm week<sup>-1</sup> was applied equally to all the treatments.

## 2.2 Soil Nutrient Analysis

Baseline soil characteristics were measured during the fall of 2019 at a depth of 15 cm before the first mulch application. Subsequent soil samples were taken at 15 cm depth in September 2020, February 2021, September 2021, and February 2022. Additionally, soil samples were collected at a depth of 45 cm in February 2021, September 2021, and February 2022. All soil samples were extracted from the original soil beneath the mulch layer and the OM amendments (M or PLM). To collect the samples, the amendments were carefully removed using a garden hoe. A 2.5-cm drill bit attached to a power drill was used for the 15 cm depth samples, while a 5-cm telescoping soil auger (AMS Inc., American Falls, ID, USA) was used for the 45 cm depth samples. Composite samples were created by combining and mixing eight cores for the 15 cm depth samples and six cores for the 45 cm depth samples from each treatment and row. Therefore, a total of three soil samples for each depth during each measurement date were used for the comparisons between treatments. All soil analyses, including nitrate (NO<sub>3</sub><sup>-</sup>), P, K, Ca, Mg, zinc (Zn), manganese (Mn), copper (Cu), boron (B), and sodium (Na) as well as pH, base saturation of cations, CEC and OM, were conducted by the Clemson University Agricultural Service Laboratory in Clemson, SC, USA.

## 2.3 Soil and Tree Moisture Status Measurements

Soil moisture (measured as soil water tension,  $h_m$ ) was monitored at a depth of 15 cm using two soil moisture probes (Model 200SS, Irrrometer Company Inc., Riverside, CA, USA) per M and PLM treatment, while a single probe was used in the control treatment throughout the trial starting from October of 2020. Additionally, three additional probes were placed at a depth of 45 cm depth (one in each treatment). Probes at corresponding depths and treatments were averaged together for comparison. Mid-day stem water potential (SWP) measurements were taken throughout the

growing season using a Scholander bomb (PMS Instrument Co., Albany, OR, USA; Scholander et al. 1965). To measure SWP, aluminum foil “Walnut” bags (9 cm × 17 cm; PMS Instrument Co., Albany, OR, USA) were placed over one leaf per tree in the morning before taking measurements between the hours of 11:30 AM to 2:00 PM. Two trees from each cultivar within each treatment and row were measured for a total of six replicates.

## 2.4 Tree Growth, Organ Nutrient, And Fruit Analysis

The middle three trees from each cultivar plot within each treatment of each row were used for tree growth measurements, nutrient analysis of leaf, fruit, and wood tissue, and fruit yield. Tree growth was evaluated using the trunk cross-sectional area (TCSA) and tree height. TCSA was calculated during tree dormancy before annual pruning by measuring the tree diameter 10–15 cm above the graft union with a caliper ( $TCSA = \pi * [\text{tree diameter}/2]^2$ ). Tree height was measured from the ground using a marked pole with demarcations at 0.1 m intervals, and the highest shoot was recorded. In 2022, leaf area was calculated for six trees (two out of the middle three trees) per treatment by photographing 30 mature leaves pressed beneath a 26 × 38 cm glass and analyzing the images using ImageJ (Version 1.53s). The length of 12 new (green) shoots per tree, located 1.2 to 1.8 m above the ground, was also measured from the middle three trees. Leaf nutrient concentrations of K, Ca, and Mg were measured using atomic absorption spectrometry following a dry ash method suspended in 0.1 M HCl similar to Lawrence and Melgar (2018). Leaf P was determined using the molybdenum blue colorimetric method (Murphy and Riley 1962), while leaf N was quantified using a modified Dumas method (Jones and Case 1990). Ten fully expanded leaves from the 4th to 6th node were collected from each of the three middle trees during each sampling period (April, July, and October) annually, by cultivar. Leaves were not collected in April 2020.

Total fruit yield was determined by adding the weight of commercially ripe harvested fruit ( $\text{kg tree}^{-1}$ ) and estimating the weight of any dropped fruit beneath the measured trees. The weight of dropped fruit was calculated by multiplying the number of dropped fruit by the average fruit weight, which were determined based on a sample of 50 fruit from each treatment. Average fruit mass, size, and firmness were measured using a fruit texture analyzer (GÜSS Manufacturing (Pty) Ltd., South Africa) following a methodology and using equipment similar to Abdelghafar et al. (2018). The total soluble solids (TSS, °Brix) were measured using a digital refractometer (Atago 3810 PAL-1), and the titratable acidity (% malic acid) was calculated by conducting NaOH titration (862 Compact Titrosampler, Metrohm, Riverview, FL, USA). After the texture analysis, two 1-cm-thick slices were

taken from both sides of the fruit, dried, and analyzed for nutrient content using atomic absorption spectrophotometry, similar to the method described by Zhou and Melgar (2019).

## 2.5 Statistical Analysis

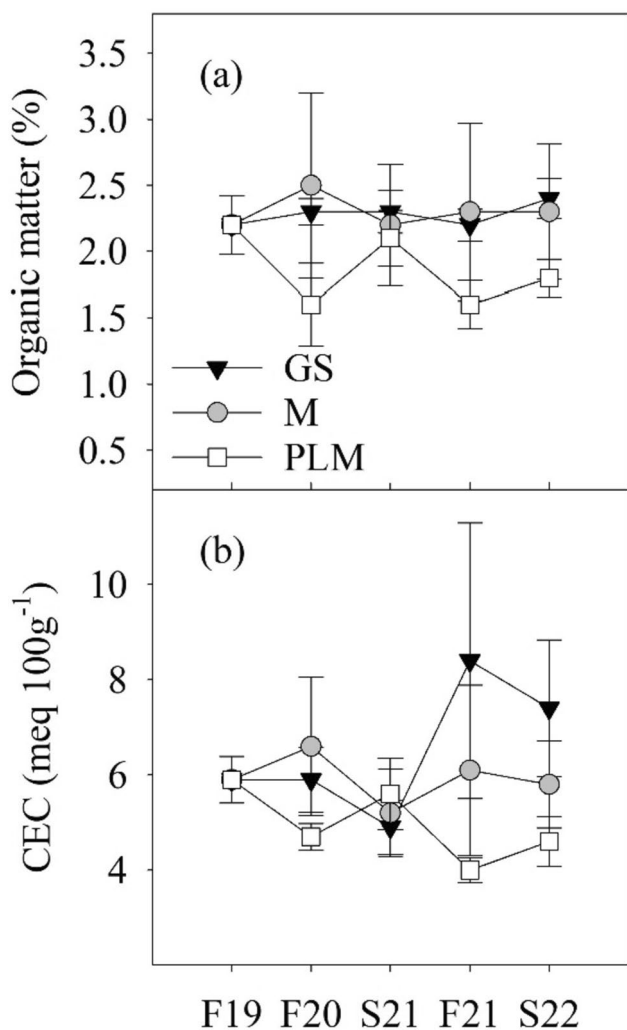
The peach orchard was initially established in 2014 with three rows of trees evenly divided between two cultivars. When the soil treatments were applied to plots across the two cultivars, the study followed a randomized split-plot design. However, since the primary focus was on the effects of soil treatment and not the cultivars, the cultivar factor was not included as a model effect. The general model was thus  $y = \text{soil treatment} + \text{tree row} + \text{interaction of soil treatment and tree row}$ . The tree row and the interaction between soil treatment and tree row were considered random effects in the analysis of horticultural data based on the date of measurement. Tree and fruit data were also analyzed across all dates using the same model. In 2020, the third tree row was excluded from fruit analysis as the flowers had been removed due to a thinning error. Soil parameters were analyzed using a similar model, considering the effect of sample date and sample depth, and were analyzed using *t*-tests using pairwise comparisons with an alpha of 0.01 to avoid type 1 error due to small sample size ( $n < 5$ ). A parametric test was still used with the small sample sizes as treatment soil effects on soil OM, CEC, and nutrients were expected to be large (De Winter 2019). All other data were checked for normality and equal variances using Shapiro–Wilk’s and Levene’s tests, respectively, before exploring the analysis of variance (ANOVA) between soil treatments using the statistical program JMP® (Version 14.1.0; SAS Institute, Cary, NC, USA). Significant effects were then additionally explored using Tukey’s honest significant difference (HSD) post hoc test with a significance level ( $\alpha$ ) of 0.05. Tree growth measurements were compared using Student’s least significant difference (LSD) post hoc test with a significance level ( $\alpha$ ) of 0.1.

## 3 Results

### 3.1 Soil Nutrient Analysis

The repeated application of the M and PLM amendments did not increase OM or CEC at 15 cm depth over the study years (Fig. 1). However, there was a significant effect on soil P, B, Cu, Mn, Na, and Zn by at least one factor of soil treatment, date of sampling, or the interaction at 15 cm and 45 cm depth (Table 1). The effect of soil treatment across the sample dates was significant for Na, as the PLM treatment had higher Na than the M and GS treatments at 15 cm depth ( $F = 38.2, P \leq 0.01$ ). Several soil nutrients showed significant





**Fig. 1** Soil (a) organic matter (OM, %) and (b) cation exchange capacity (CEC, meq 100g<sup>-1</sup>) measured in a peach orchard at 15 cm depth of the soil under treatments including the grower standard (GS, black triangles), municipal mulch (M, gray circles), and poultry litter with municipal mulch (PLM, white squares) between fall of 2019 (Baseline, F19), fall of 2020 (F20), spring of 2021 (S21), fall of 2021 (F21), and spring of 2022 (S22). Error bars represent ± standard error of the mean

changes over the sample dates across soil treatments. Soil P increased over time at both 15 cm ( $F=7.3, P\leq 0.01$ ) and 45 cm depth ( $F=16.0, P\leq 0.001$ ) in the control, M, and PLM treatments. The interaction of treatment and sample date was observed for Zn at 45 cm depth.

There were differences ( $P < 0.01$ ) by the effect of soil treatment during individual sampling dates throughout the study for several soil nutrients, but only Cu and Na at 15 cm depth (Fig. 2) and Na at 45 cm (Fig. 3) showed a similar trend from one sample date to another. Other measured soil nutrients at 15 cm and 45 cm depths showed similar results among the different treatments (Supplementary Table 2 and 3, respectively).

### 3.2 Soil and Tree Moisture Status Measurements

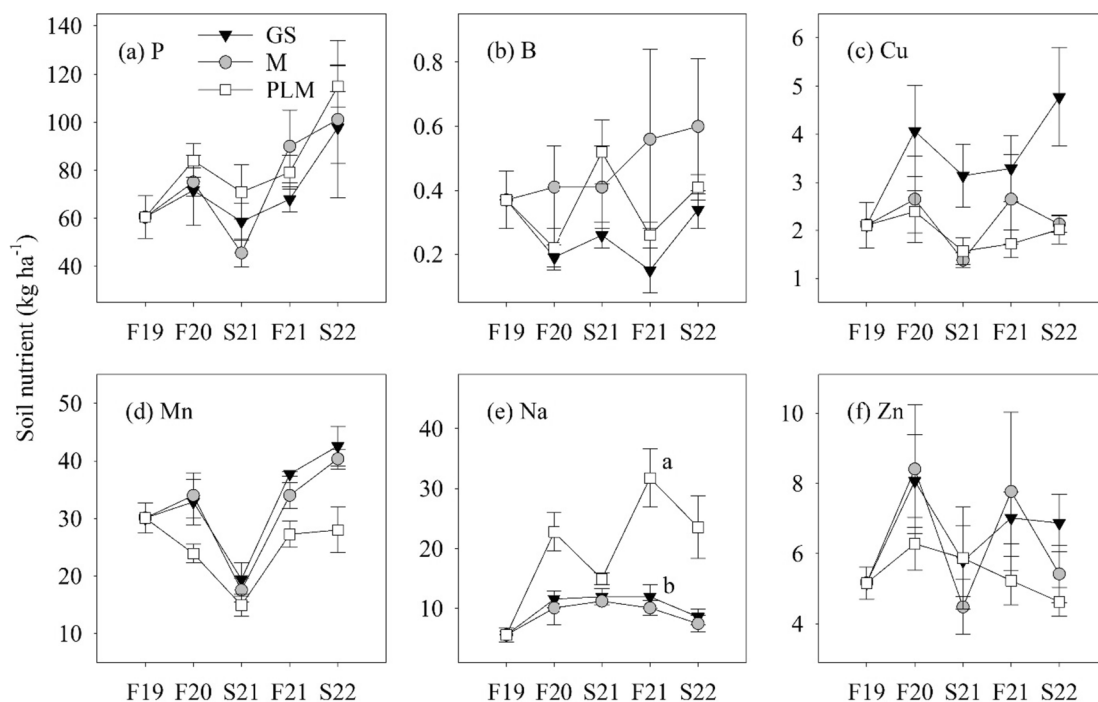
The soil moisture and SWP varied throughout the study according to seasonal rainfall and the soil treatments (Fig. 4a). Soil moisture probes exhibited lower values during the winter months when the trees were dormant, while generally showing higher  $h_m$  values during each growing season at both 15 cm and 45 cm depths (Fig. 4b, c). When averaged by month at 15 cm, the GS treatment had significantly higher  $h_m$  than M and PLM treatments from January through April in both 2021 and 2022 ( $P < 0.01$ ). The GS treatment also had higher  $h_m$  than PLM in August 2021 ( $P < 0.05$ ), but lower  $h_m$  than M and PLM in November and December 2021 ( $P < 0.01$ ). In the summer of 2022, the M treatment had higher  $h_m$  than GS and PLM in June and July ( $P < 0.01$ ). Since there was only one probe per treatment at a depth of 45 cm, statistical comparisons were not conducted. However, the two probes at 45 cm depth for the M and PLM treatments trended higher compared to the GS treatment towards the end of the growing season in the fall of 2021 and in September 2022.

SWP decreased throughout the growing seasons of 2021 and 2022 as temperature increased and soil moisture generally decreased (Fig. 4d, e). Differences in SWP by soil

**Table 1** Soil nutrients measured at 15 cm or 45 cm depth which resulted in at least one significant difference by the main effects of soil treatment, sample date, and/or the interaction

Depth	Effect	P	B	Cu	Mn	Na	Zn
15 cm	Soil treatment	NS	NS	NS	NS	*	NS
	Sample date	*	*	NS	**	NS	NS
	Treatment × sample date	NS	NS	NS	NS	NS	NS
45 cm	Soil treatment	NS	NS	NS	NS	NS	NS
	Sample date	**	**	**	**	NS	*
	Treatment × sample date	NS	NS	NS	NS	NS	*

The asterisks \* and \*\* represent  $P \leq 0.01$  and  $\leq 0.001$ , respectively. NS indicates no significant effect



**Fig. 2** Soil nutrients ( $\text{kg ha}^{-1}$ ) including (a) phosphorus (P), (b) boron (B), (c) copper (Cu), (d) manganese (Mn), (e) sodium (Na), and (f) zinc (Zn) measured in a peach orchard at 15 cm depth of the soil under treatments within the grower standard (GS, black triangles), municipal mulch (M, gray circles), and poultry litter with

municipal mulch (PLM, white squares) between fall of 2019 (Baseline, F19), fall of 2020 (F20), spring of 2021 (S21), fall of 2021 (F21), and spring of 2022 (S22). Different letters indicate significant differences between treatments, determined by the HSD post hoc test ( $\alpha=0.01$ ,  $n=3$ ). Error bars represent  $\pm$  standard error of the mean

treatment were observed on three dates after fruit harvest, during the end of the growing season. In August 2021, GS trees had less negative SWP compared to M and PLM treatments for both “Juneprince” ( $F=7.0$ ,  $P\leq 0.01$ ) and “Scarletprince” trees ( $F=7.4$ ,  $P\leq 0.01$ ). Similarly, the final measurement date in 2021 also showed less negative SWP of GS “Scarletprince” trees compared to M and PLM ( $F=5.8$ ,  $P\leq 0.05$ ).

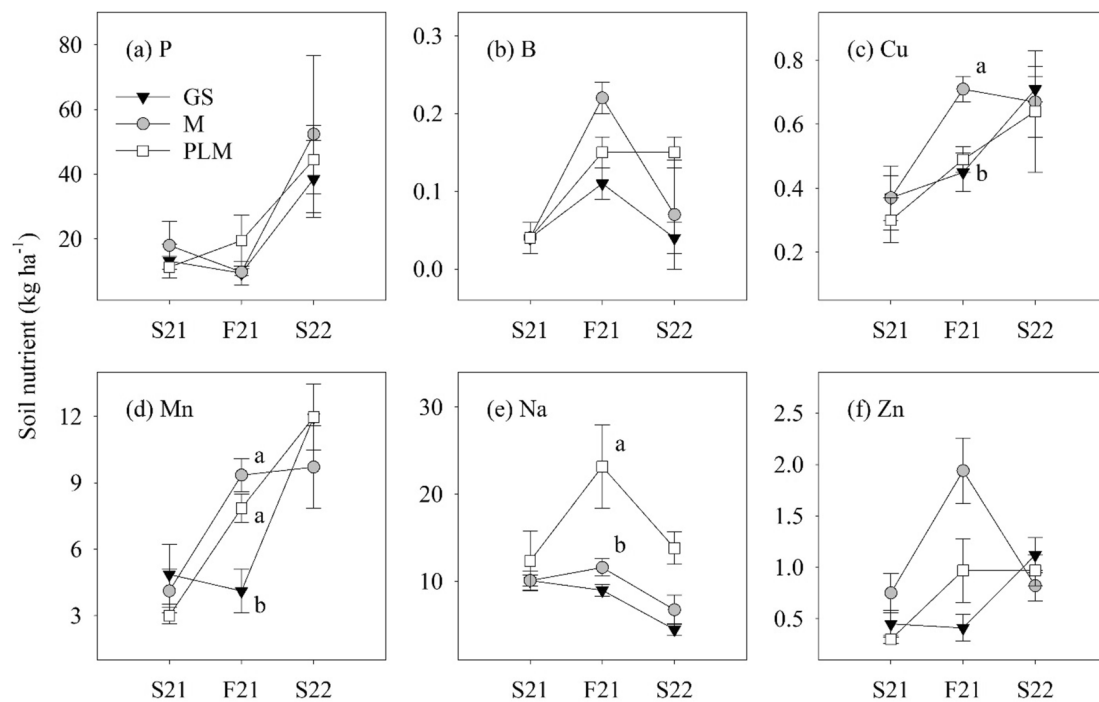
### 3.3 Tree Growth

The PLM treatment tended to increase vegetative growth compared to the GS and M treatments during the study (Table 2). There were no differences in tree height between the soil treatments in 2020. However, in 2021 and 2022, “Juneprince” PLM trees were taller, although not statistically taller than GS trees in 2021 ( $P=0.07$ ), but taller in 2022 ( $F=8.1$ ,  $P\leq 0.05$ ), while “Scarletprince” PLM trees were taller, although not statistically taller than M trees ( $P=0.07$ ) in 2021. Each year of the study, TCSA was not different between the soil treatments, but the rate of trunk size increase ( $\text{cm}^2 \text{year}^{-1}$ ) over the study was higher ( $P\leq 0.05$ ) for PLM ( $y=12.9x+107$ ) and M ( $y=13.0x+91$ ) than GS ( $y=9.8x+94$ ) in “Juneprince” trees, and similarly for “Scarletprince” trees [PLM ( $y=16.0x+92$ ), M ( $y=17.9x+81$ ),

and GS ( $y=10.7x+93$ )]. Visually, the PLM treatment appeared to have denser foliage than the M and GS treatments, but the average shoot length measurements taken in 2022 were similar between the soil treatments for both cultivars. Nevertheless, the leaf area of PLM trees was larger than GS and M in “Juneprince” trees ( $F=7.7$ ,  $P\leq 0.05$ ) and larger across both cultivars ( $F=58.0$ ,  $P\leq 0.001$ ) compared to GS and M in 2022.

### 3.4 Leaf Nutrient Status

The soil treatments resulted in differences for each leaf nutrient concentration measured at least once during the study (Fig. 5), but only K showed a consistent pattern between seasonal sampling dates in “Scarletprince” trees (Fig. 5h). Leaf N was similar ( $P\leq 0.05$ ) between the soil treatments during the summer sampling time for both cultivars. The PLM treatment increased leaf N during spring 2021 in “Juneprince” ( $F=17.2$ ,  $P\leq 0.01$ ) and “Scarletprince” ( $F=172.7$ ,  $P\leq 0.0001$ ) trees compared to M and GS. During spring 2022, trees in the PLM treatment had higher N within “Juneprince” ( $F=30.1$ ,  $P\leq 0.01$ ) and trended higher in “Scarletprince” ( $P=0.06$ ) compared to M and GS leaves (Fig. 5a, f). Leaf P concentrations trended higher during the study for the M and PLM treatments compared to GS throughout



**Fig. 3** Soil nutrient levels ( $\text{kg ha}^{-1}$ ), including (a) phosphorus (P), (b) boron (B), (c) copper, (d) manganese (Mn), (e) sodium (Na), and (f) zinc (Zn) measured in a peach orchard at 45 cm depth between the grower standard (GS, black triangles), municipal mulch (M, gray circles), and poultry litter with municipal mulch (PLM, white squares)

during the spring of 2021 (S21), fall of 2021 (F21), and spring of 2022 (S22). Different letters between treatments denote significant differences using HSD post hoc test ( $\alpha=0.01$ ,  $n=3$ ) while error bars represent  $\pm$  standard error of the mean

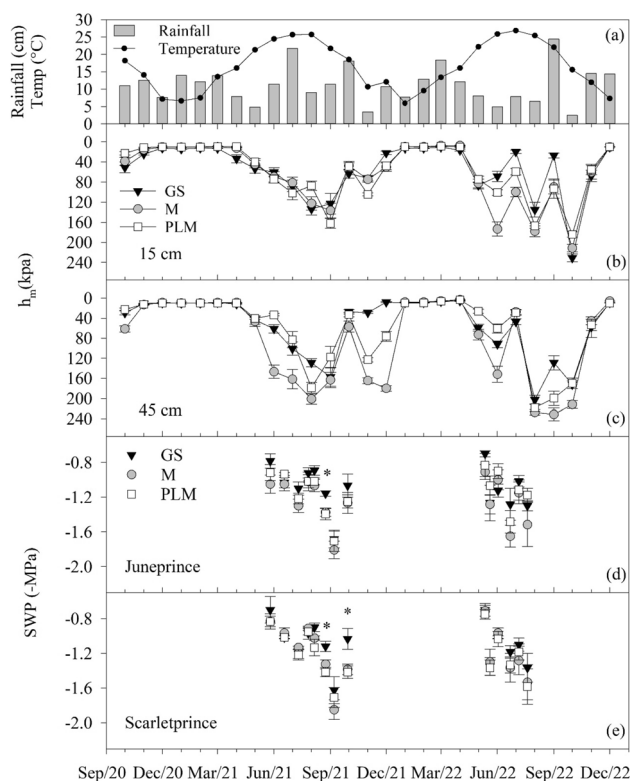
the study for both cultivars but were similar during the summer sampling dates each year (Fig. 5b, g). The “Juneprince” trees had higher P in the PLM treatment compared to the GS during the fall of 2020 ( $F=8.9$ ,  $P\leq 0.05$ ) and the following spring of 2021 ( $F=8.3$ ,  $P\leq 0.05$ ), while “Scarletprince” trees had higher P in the PLM treatment during the spring of 2022 ( $F=63.5$ ,  $P\leq 0.001$ ). For leaf K, the “Juneprince” trees appeared to have higher leaf K in the PLM and M treatments compared to GS leaves over the study, but only once was PLM statistically higher ( $F=7.0$ ,  $P\leq 0.05$ ) than GS during summer 2021 (Fig. 5c). In contrast, the “Scarletprince” PLM treatment had higher K than the GS treatment during spring ( $F=11.9$ ,  $P\leq 0.05$ ) and summer ( $F=12.5$ ,  $P\leq 0.019$ ) of 2020; during spring ( $F=23.0$ ,  $P\leq 0.01$ ), summer ( $F=9.4$ ,  $P\leq 0.05$ ), and fall ( $F=10.2$ ,  $P\leq 0.05$ ) of 2021; and during summer of 2022 ( $F=7.8$ ,  $P\leq 0.05$ ; Fig. 5h).

Leaf Ca and Mg concentrations often had the opposite trend of K, as higher leaf Ca was present in “Juneprince” GS trees compared to PLM trees in spring ( $F=10.6$ ,  $P\leq 0.01$ ) of 2021 and trended higher in M trees compared to PLM and GS during the summer of 2020 ( $P=0.07$ ) and summer of 2022 ( $P=0.06$ ). The “Scarletprince” trees had higher leaf Ca in GS compared to PLM leaves during the fall ( $F=10.7$ ,  $P\leq 0.05$ ). During the fall of 2022, the “Scarletprince” M treatment had higher leaf Ca ( $F=9.6$ ,  $P\leq 0.01$ ) than in

GS or PLM (Fig. 5d, i). Regarding Mg, the “Juneprince” trees had higher Mg in GS trees compared to PLM trees in October of 2020 ( $F=6.6$ ,  $P\leq 0.05$ ) and Mg also trended higher in both GS and M compared to PLM in summer 2021 ( $P=0.06$ ), although it was not statistically different (Fig. 5e). During the fall of 2022, the M treatment had higher Mg ( $F=107.0$ ,  $P\leq 0.001$ ) than GS and PLM in “Scarletprince” trees (Fig. 5j).

### 3.5 Fruit Nutrient Status, Attributes, and Yield

The soil treatments did not consistently increase or decrease the measured fruit nutrient concentrations over the three study years (Table 3). The “Juneprince” PLM fruit had higher N than the GS fruit in 2022 ( $F=8.3$ ,  $P\leq 0.05$ ), and the “Scarletprince” PLM fruit also had higher N than the M and GS fruit in 2021 ( $F=6.0$ ,  $P\leq 0.05$ ). The “Juneprince” had higher P within GS fruit compared to M and PLM fruit in 2020 ( $F=16.3$ ,  $P\leq 0.001$ ), but P was similar between soil treatments in other years. No significant differences were found regarding fruit K or Mg concentrations between the soil treatments. Higher Ca was in “Juneprince” GS and M fruit than PLM fruit ( $F=8.6$ ,  $P\leq 0.01$ ) and more Ca in “Scarletprince” M fruit than PLM fruit ( $F=5.7$ ,  $P\leq 0.05$ ) in



**Fig. 4** Monthly (a) rainfall totals (gray bars, cm) and temperature (black circle line, °C); (b) soil water tension ( $h_m$ , kPa) measurements at 15 cm ( $n=28-31$ ) and (c) 45 cm soil depth ( $n=28-31$ ); and stem water potential (SWP, -MPa) measurements of (d) “Scarletprince” and (e) “Juneprince” peach trees under different soil treatments: grower standard (GS, black triangles), municipal mulch (M, gray circles), and poultry litter with municipal mulch (PLM, white squares) during the years 2021 and 2022 ( $n=6$ ). Asterisks above SWP dates indicate significant differences between the GS treatment to both M and PLM treatments. Error bars represent  $\pm$  standard error of the mean

**Table 2** Seasonal tree growth measurements, including highest vertical 1-year shoot growth (tree height, m,  $n=9$ ), trunk cross-sectional area (TCSA,  $cm^2$ ,  $n=9$ ), shoot length (cm,  $n=36$ ), and leaf area ( $cm^2$  leaf $^{-1}$ ,  $n=6$ ) of “Juneprince” and “Scarletprince” peach trees grown

Year	Measurement	“Juneprince”			“Scarletprince”		
		GS	M	PLM	GS	M	PLM
2020	Tree height	3.8 ± 0.2	3.9 ± 0.1	3.9 ± 0.1	4.3 ± 0.1	4.0 ± 0.1	4.2 ± 0.3
	TCSA	103.2 ± 7.0	120.5 ± 5.3	103.5 ± 4.9	105.6 ± 5.6	99.0 ± 9.0	104.5 ± 7.8
2021	Tree height	3.8 ± 0.2 b	3.9 ± 0.1 ab	4.3 ± 0.1 a	4.3 ± 0.1 ab	4.1 ± 0.1 b	4.4 ± 0.1 a
	TCSA	114.9 ± 5.0	132.5 ± 5.6	122.4 ± 8.8	110.1 ± 7.5	116.0 ± 10.0	130.9 ± 8.9
2022	Tree height	3.6 ± 0.2 b	3.8 ± 0.1 ab	4.1 ± 0.1 a	4.0 ± 0.2	3.9 ± 0.1	4.1 ± 0.2
	TCSA	123.2 ± 7.0	146.3 ± 7.7	130.8 ± 10.8	127.0 ± 7.4	134.9 ± 10.6	136.7 ± 12.4
	Shoot length	31.2 ± 1.5	32.2 ± 1.3	32.7 ± 1.6	37.7 ± 1.7	36.1 ± 1.8	38.3 ± 1.8
	Leaf area	38.8 ± 2.0 b	38.2 ± 2.3 b	46.2 ± 1.5 a	34.1 ± 1.0	34.0 ± 1.9	38.4 ± 1.4

Different letters between treatments denote significant differences by cultivar using LSD post hoc test ( $\alpha=0.1$ ). Values without letters are not statistically different

2021. Examination of fruit nutrients across the study years showed the “Juneprince” had higher Ca ( $F=6.4, P \leq 0.05$ ) in GS and M fruit than PLM fruit. For “Scarletprince” trees, PLM fruit consistently had significantly higher K levels ( $F=11.9, P \leq 0.05$ ) than GS and M fruit across the study years.

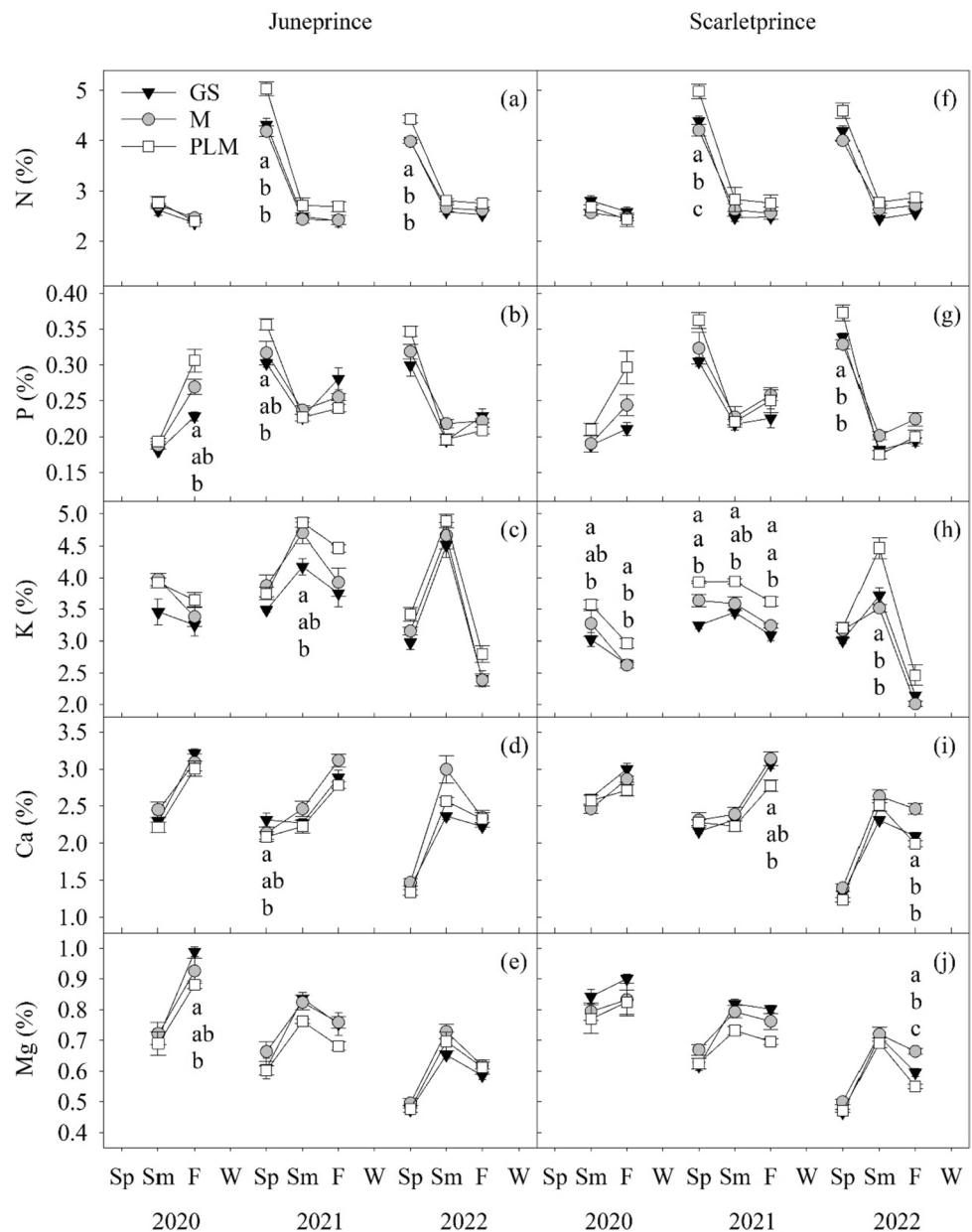
Regarding fruit yield, mass, and size, no statistically significant differences were found for either cultivar during any year of the study (Table 4). When analyzed over all 3 years, a larger cumulative yield was harvested from “Juneprince” GS trees compared to PLM trees ( $F=3.9, P \leq 0.05$ ) but was similar for “Scarletprince.” The “Juneprince” fruit mass and size were similar across treatments ( $P > 0.05$ ), but the average mass ( $F=4.2, P < 0.05$ ) and size ( $F=7.9, P \leq 0.01$ ) of “Scarletprince” PLM fruit were larger than M and GS fruit over 3 years. Regarding other annual fruit qualities, “Scarletprince” PLM fruit were firmer than M fruit ( $F=10.1, P \leq 0.05$ ) but similar to GS fruit in 2022. Both soluble solids and acidity were similar between the treatments for both cultivars throughout the study.

The fruit harvest dates of each cultivar varied slightly each year during the study due to natural variations in bloom dates and weather conditions, but the PLM treatment appeared to delay fruit maturation for both cultivars in 2021 and 2022, while the M treatment delayed “Juneprince” fruit in 2022 (Fig. 6). The first year after the treatments was applied in 2020, both cultivars were completely harvested on two picking dates (data not shown), and no noticeable differences in fruit maturation were observed based on soil treatment. In 2021, the “Juneprince” M and PLM treatments showed a delay ( $F=10.3, P \leq 0.001$ ) in fruit maturation during the first harvest compared to GS (Fig. 6a). During the second harvest date, the PLM treatment yielded significantly less fruit

between soil treatments of grower standard (GS), municipal mulch (M), and poultry litter with municipal mulch (PLM). Shoot length and leaf area measurements were only calculated during 2022



**Fig. 5** Concentration (%) of leaf nitrogen (N, **a**), phosphorus (P, **b**), potassium (K, **c**), calcium (Ca, **d**) and magnesium (Mg, **e**) of “Juneprince” and leaf N (**f**), P (**g**), K (**h**), Ca (**i**), and Mg (**j**) of “Scarletprince” peach trees between the soil treatments of grower standard (GS, black triangles), municipal mulch (M, gray circles), and poultry litter with municipal mulch (PLM, white squares) during the seasons of spring (Sp), summer (Sm), fall (F), and winter (W) of 2020–2022. Letters denote significant differences between soil treatments within a particular sampling date using the HSD post hoc test ( $\alpha=0.05$ ), while error bars represent  $\pm$  standard error of the mean ( $n=6$ )



( $F=9.5$ ,  $P\leq 0.001$ ) compared to M and GS, while it had a higher yield during the final harvest compared to GS ( $F=4.5$ ,  $P\leq 0.05$ ). A similar trend was observed with “Scarletprince” fruit in 2021 (Fig. 6c), as GS trees had a higher yield than PLM during the first harvest date ( $F=8.8$ ,  $P\leq 0.01$ ), and GS and M had a higher yield compared to PLM during the second harvest date ( $F=10.1$ ,  $P\leq 0.001$ ). In 2022, “Juneprince” fruit was once again delayed by the soil treatments, with higher yield from GS compared to M and PLM ( $F=7.7$ ,  $P\leq 0.01$ ) during the first harvest date (Fig. 6b). The “Juneprince” trees were harvested six times in 2022, and the final two harvest dates showed higher yield ( $F=4.5$ ,  $P\leq 0.05$ ;  $F=5.9$ ,  $P\leq 0.01$ , respectively) in the M and PLM treatments compared to the

GS trees. The PLM treatment also delayed “Scarletprince” fruit in 2022 (Fig. 6d), as the M and GS treatments had higher yield compared to PLM during the first ( $F=5.1$ ,  $P\leq 0.05$ ) and second ( $F=8.2$ ,  $P\leq 0.01$ ) harvest dates. Notably, an additional harvest was required in 2021 and 2022 to complete the harvest of “Scarletprince” PLM trees.

### 4 Discussion

The present work demonstrates the complex reality of transitioning from conventional to alternative orchard floor management practices in mature orchards, with the

**Table 3** Fruit nitrogen (N, %), phosphorus (P, %), potassium (K, %), calcium (Ca, ppm), and magnesium (Mg, %) concentrations of “Juneprince” and “Scarletprince” cultivars between the soil treatments including grower standard (GS) municipal mulch (M), and poultry litter with municipal mulch (PLM) in 2020, 2021, and 2022 ( $n=5-6$ ). Nutrient data for “Scarletprince” fruit was not available in the 2020 season

Cultivar	Year	Treatment	Nutrient				
			N	P	K	Ca	Mg
Juneprince	2020	GS	1.65±0.13	0.22±0.02 a	2.24±0.06	57.06±2.88	0.16±0.02
		M	1.57±0.10	0.15±0.01 b	2.38±0.04	55.01±1.27	0.16±0.01
		PLM	1.74±0.08	0.16±0.02 b	2.49±0.06	50.98±2.95	0.18±0.01
	2021	GS	1.02±0.09	0.18±0.02	1.09±0.02	63.41±2.13	0.12±0.02
		M	1.51±0.15	0.21±0.02	1.24±0.05	60.28±3.12	0.13±0.01
		PLM	1.18±0.16	0.21±0.01	1.61±0.20	52.27±3.20	0.13±0.01
	2022	GS	0.82±0.04 b	0.18±0.01	2.48±0.06	37.41±0.81 a	0.15±0.01
		M	0.85±0.05 ab	0.19±0.02	2.70±0.04	37.51±1.09 a	0.13±0.01
		PLM	1.10±0.07 a	0.19±0.01	2.71±0.11	30.59±1.17 b	0.15±0.02
Scarletprince	2021	GS	1.23±0.09 b	0.22±0.01	2.25±0.06	48.18±2.12 ab	0.13±0.01
		M	1.19±0.13 b	0.23±0.02	2.26±0.09	54.38±1.85 a	0.12±0.02
		PLM	1.75±0.14 a	0.19±0.01	2.59±0.13	46.72±2.20 b	0.13±0.03
	2022	GS	0.70±0.03	0.17±0.02	2.21±0.11	37.80±1.93	0.17±0.03
		M	0.62±0.02	0.18±0.02	2.23±0.07	38.66±2.29	0.17±0.02
		PLM	0.84±0.07	0.17±0.03	2.25±0.04	39.83±1.79	0.15±0.01

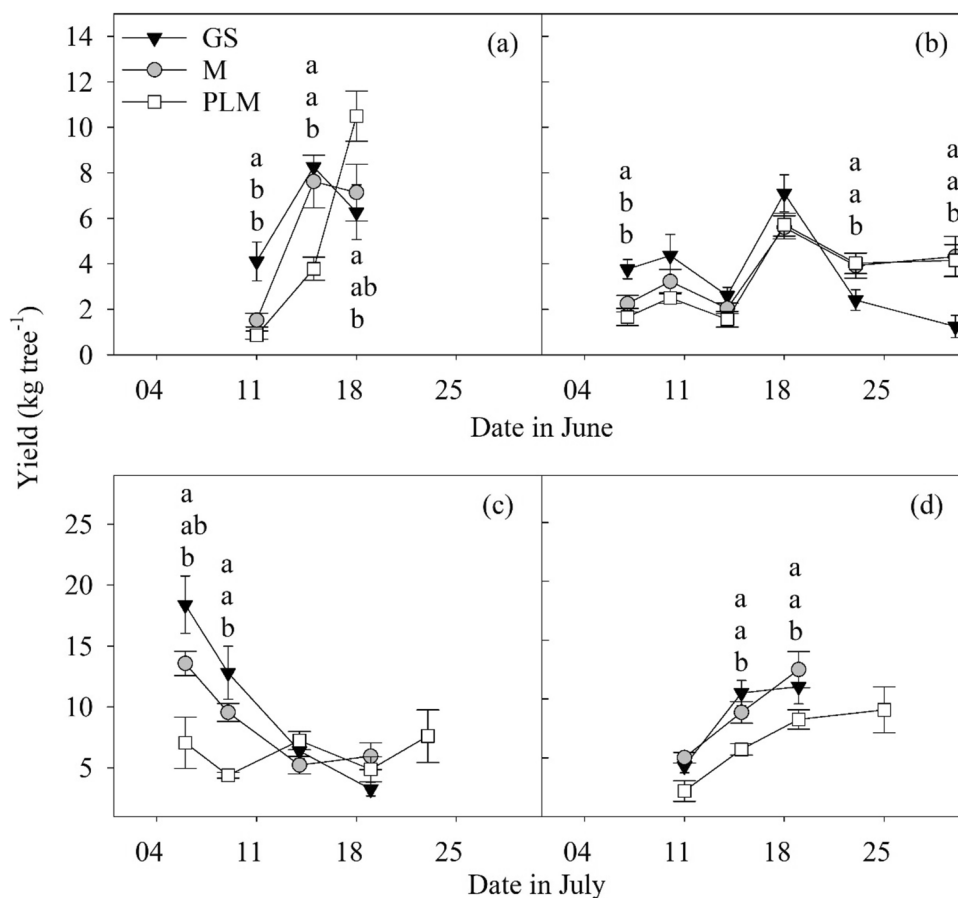
Different letters between treatments within each cultivar and year show significant differences using HSD post hoc test ( $\alpha=0.05$ ). Values without letters are not statistically different

**Table 4** Measurements of total fruit yield (kg tree<sup>-1</sup>), mass (g), size (diameter, cm), firmness (kg cm<sup>-2</sup>), total soluble solids (TSS, °Brix), and acidity (malic acid, %) of “Juneprince” and “Scarletprince” peach trees between three soil treatments including grower standard (GS), mulch (M), and poultry litter with mulch (PLM) in 2020, 2021, and 2022 ( $n=9-15$ ). Cumulative yield (kg tree<sup>-1</sup>), average mass (g), and average size (cm) from 2020 through 2022 are also shown

Year	Measurement	<i>Juneprince</i>			<i>Scarletprince</i>		
		GS	M	PLM	GS	M	PLM
2020	Total yield	17.3±1.3	14.5±1.1	14.0±1.2	29.5±3.3	27.3±3.2	32.5±3.7
	Mass	160.7±4.8	164.4±3.9	187.7±6.2	193.4±3.8	198.4±7.3	206.5±7.7
	Size	6.9±0.7	7.0±0.5	7.3±0.7	7.3±0.5	7.4±0.9	7.5±0.9
	Firmness	1.8±0.1	2.1±0.1	1.7±0.1	2.4±0.3	2.6±0.3	2.6±0.2
	TSS	-	-	-	-	-	-
	Acidity	0.7±0.03	0.7±0.02	0.7±0.03	0.5±0.02	0.4±0.02	0.5±0.04
2021	Total yield	25.5±0.9	23.4±1.1	22.6±1.4	44.2±1.9	37.5±2.3	36.9±2.0
	Mass	189.0±5.3	170.0±4.9	179.2±4.5	194.1±3.8	199.9±3.8	202.0±3.6
	Size	72.0±0.8	69.0±0.7	70.8±0.7	73.1±0.5	74.1±0.5	74.0±0.5
	Firmness	3.8±0.2	3.2±0.2	4.3±0.2	4.4±0.2	3.8±0.2	5.1±0.2
	TSS	8.1±0.3	8.7±0.2	8.0±0.2	10.7±0.2	11.2±0.3	11.6±0.5
	Acidity	0.6±0.02	0.6±0.02	0.7±0.03	0.8±0.03	0.8±0.02	0.8±0.04
2022	Total yield	21.1±1.5	17.9±1.4	16.3±0.6	28.1±1.6	28.6±1.3	28.0±2.5
	Mass	154.4±3.0	153.5±3.8	149.4±3.4	201.7±4.1	202.5±3.9	223.4±3.6
	Size	67.9±0.5	67.6±0.5	67.7±0.5	73.5±0.4	73.7±0.5	76.9±0.4
	Firmness	4.5±0.1	4.2±0.2	4.9±0.1	4.8±0.2 ab	4.5±0.2 b	5.6±0.2 a
	TSS	12.3±0.2	11.9±0.3	11.1±0.4	11.7±0.2	11.8±0.2	11.5±0.01
	Acidity	0.9±0.02	0.9±0.05	0.9±0.02	0.7±0.03	0.7±0.03	0.8±0.03
2020–2022	Cumulative yield	58.9±3.8 a	50.7±3.7 ab	47.8±3.3 b	101.8±5.0	93.4±4.1	97.4±3.7
	Average mass	168.0±2.9	162.6±2.5	172.1±3.0	196.4±2.7 b	200.3±2.8 b	210.6±3.8 a
	Average size	7.0±0.04	6.9±0.03	7.1±0.04	7.3±0.03 b	7.4±0.04 b	7.5±0.04 a

Different letters between treatments by fruit characteristic and cultivar show significant differences using HSD post hoc test ( $\alpha=0.05$ ). Values without letters are not different statistically

**Fig. 6** Fruit yield ( $\text{kg tree}^{-1}$ ) by harvest date of the peach cultivar “Juneprince” (Jp) in June of 2021 (a) and 2022 (b) and “Scarletprince” (Sp) in July of 2021 (c) and 2022 (d) between three soil treatments including grower standard (GS, black triangles), municipal mulch (M, gray circles), and poultry litter with municipal mulch (PLM, white squares). Letters indicate significant differences between soil treatments during harvest dates using HSD post hoc test ( $\alpha=0.05$ ), while error bars represent  $\pm$  standard error of the mean ( $n=9$ )



aim of maintaining productivity and improving water and nutrient dynamics. Most concerning to growers regarding amendments would be the possibility of disrupting harvest time and reducing yield. Although previous studies have shown that repeated additions of OM can successfully replace mineral fertilizers without compromising yield or fruit quality (Baldi et al. 2010b), the current timing and rate of the PLM treatment in this study would likely have detrimental effects in future years. Visual observations of increased vegetative growth and elevated N concentrations suggest that future yield potential and fruit quality could be compromised (Minas et al. 2018; Tassinari et al. 2021). Although the current study spanned 3 years, the cumulative yield of PLM trees showed a reduction compared to the GS for “Juneprince” trees, most likely due to excessive N. Additionally, the larger average size and mass of fruit from “Scarletprince” PLM trees is probably linked to a reduction in the number of fruit per tree. Neither yield, fruit size, nor mass indicated that the M treatment was different than the GS treatment after 3 years, but the delay of fruit harvest of “Juneprince” in 2022 suggests the application rate would also need to be adjusted. Although both cultivars had high N availability from the PLM treatment, cultivar nutrient status can be

different seasonally (Zhou and Melgar 2019) and may partially explain why higher N status led to a reduction of yield of the early season “Juneprince” in comparison to the mid-season cultivar “Scarletprince.” In addition to the delay of harvest, extending the harvest period of peach fruit could be disadvantageous for growers due to labor costs and shifting harvest windows may lead to competition with other seasonal varieties in the market. Therefore, addressing the current and future season N availability, after additional nutrient mineralization from the OM (Toselli et al. 2019; Villa et al. 2021), is needed to ensure proper N management and consistent yields.

Fruit nutrient samples did not always show statistically higher N in PLM fruit compared to M or GS. However, the consistent delay of fruit maturity and higher firmness observed in “Scarletprince” PLM fruit in 2022 is probably best explained by higher N status (Toselli et al. 2019). While the PLM treatment occasionally had higher fruit N than the GS treatment, the concentrations measured were comparable to previous values of 0.6–1.2% for early or mid-season cultivars (Zhou and Melgar 2019), and all three soil treatments for “Juneprince” had fruit N concentrations greater than 1.5% in 2020. Ensuring sufficient levels of fruit Ca is important for maintaining postharvest

quality and reducing disorders, and lower Ca within the “Juneprince” fruit was most likely the result of increased K availability following amendment application, which limited Ca uptake (Kuzin and Solovchenko 2021). Further research is needed to fully understand the implications of adding different types of OM to orchards over time, including the impact on postharvest quality and potential imbalances in fruit nutrients, particularly reductions in Ca (Gomez and Kalcsits 2020).

Soil  $\text{NO}_3^-$  was only measured twice during the study at a depth of 15 cm and did not differ between the soil treatments, despite visual indications of excessive N in the PLM trees. The rate of  $\text{NO}_3^-$  leaching has been shown to decrease following the application of mulch (Cui et al. 2020), and provided the application rates of the M and PLM treatments were consistently applied above the N requirement of trees each year, accumulation of N could occur. During the study, all treatments had leaves and shoots which appeared healthy, and leaf N analysis during the summer of 2021 revealed minor deficiencies of the GS and M trees, as both were found to be below the sufficiency range of 2.75–3.5% (Blaauw et al. 2022). Despite evidence of elevated N due to fruit maturation timing, yield, and statistically larger leaves than the M and GS treatments, the PLM treatment never showed leaf N above 3.5% during the summer. Increased growth of the PLM trees may have diluted the N concentration within the plant more than M and GS, resulting in similar summer leaf N concentrations; however, a single analysis each year may not be sufficient for growers to understand N dynamics within orchards, especially when applying amendments which release N slowly over time. Moreover, current guidelines of N sufficiency might be too high and can vary depending on the guidelines used (Casamali et al. 2021). Instead, both cultivars often showed differences in N during the spring leaf sampling, which may provide growers with a better indication of excessive N status. However, considering N was only numerically higher within shoot tissue (data not shown) following the 2021 season, higher leaf N concentration within PLM trees in spring was probably a combination of both remobilization of N stored in other dormant tissues, such as roots, and a possible increase to fine root growth and nutrient uptake following the spring application of manure (Baldi and Toselli 2013). Nutrient recycling and seasonal sufficiency ranges when using OM amendments deserve further investigation, as resorption decreases with increasing soil nutrient status (Vergutz et al. 2012) or current N storage (Millard and Grelet 2010).

Increasing amounts of soil P following poultry litter additions have been reported previously in peach orchards (Preusch and Tworowski 2003), and applications that result in excessive soil P leaving orchards can be an environmental concern (Atucha et al. 2013). Decomposing OM may increase P availability (Achat et al. 2018), but except

for the PLM “Juneprince” leaves during the fall sampling period of 2020, the following spring in 2021, and “Scarletprince” leaves during the spring of 2022, the plant status of P between the soil treatments was similar and never resulted in excessive leaf P concentrations. Nonetheless, the amount of soil P throughout the study was considered “high” for all treatments, including GS by the final year (Kirk et al. 2022). Soil P possibly accumulated during the years of orchard establishment, and avoiding the accumulation of P after switching to OM sources such as M or PLM would be challenging. Furthermore, older peach trees efficiently recycle internal P between growing seasons (Zhou and Melgar 2020), requiring little soil P to sustain annual productivity.

Only leaf K appeared to show consistent differences between the soil treatments in the “Scarletprince” trees and was the only leaf nutrient that had differences for both “Juneprince” and “Scarletprince” trees during the summer sampling, which is the traditional time for foliar nutrient analysis used by growers as a guide for fertilizer application. Without other sampling during the spring and/or fall, only leaf K would show any difference based on the soil treatments over the study years. In comparison to other elements, such as N or P, which rely more on biological processes, K is rapidly available from various OM sources and during the decomposition of previous-year growth, such as pruning wood or leaves (Baldi and Toselli 2021; Ventura et al. 2010). Although the M and PLM treatments often were higher than the GS trees, leaf K of GS trees was also occasionally above the 2–3% sufficiency range for K during summer sampling (Johnson 2008), suggesting that current guidelines may lead to the accumulation of K and that monitoring orchard nutrient status may require more than one sampling period. Discrepancies between sufficiency ranges could also lead to over-fertilization, as regional fertilizer guidelines suggest leaf K is sufficient between 1.5 and 2.5% during the summer (Blaauw et al. 2022), and K may have already been excessive within the orchard soil prior to the beginning of the study or amendment application. The other two leaf cations measured, Ca and Mg, often showed the opposite trend of leaf K, the latter of which may have been preferentially acquired by roots at the expense of Ca and Mg (Kuzin and Solovchenko 2021). However, few differences between Ca and Mg concentrations during the seasonal leaf analysis suggest that amendments provided sufficient levels of the two cations, despite a reduction of spring fertilizer and possible nutrient antagonism.

There were several soil nutrients that showed differences between the soil treatments but were not measured in plant tissue, including Cu and Na. The decrease of Cu within the soil of M and PLM treatments was expected, as Cu forms complexes with dissolved OM, and the

solubility of Cu can be partially predicted by OM (Yin et al. 2002). The bioavailability of Cu depends on aggregate size and pH in the soil (Wang et al. 2015), and the use of compost can increase Cu in plant tissue, as observed in nectarine tree (*Prunus persica* var. *nucipersica*) pruning wood and fruit mesocarp (Baldi et al. 2014). Soil Na was expected to increase following the addition of poultry litter (Thomsen et al. 2018), but whether increasing Na would have negative impacts, such as phytotoxicity or soil dispersion, would need to be monitored over time.

The M and PLM treatments both added large quantities of organic materials to the orchard. However, soil samples extracted from 15 cm depth did not show an increase in soil OM compared to the GS treatment or the initial OM content of the orchard when the trees were initially planted (2.6% OM). This suggests that there was little downward movement of OM through the sandy loam soil over the 3 years of the trial. Despite warm and humid conditions, it is possible additional time is needed for the added OM to decompose and increase the carbon content of the original soil. In other fruit-growing regions, surface-applied amendments like composted cow manure and green waste have been shown to increase soil organic carbon after a single application (Khalsa et al. 2021), but increasing soil OM is understood to be slow, often not changing after 2–5 years of alternative practices (Montanaro et al. 2017). Rapid OM decomposition occurs in warm and humid climates (Conant et al. 2011), but the rate of decomposition or the downward movement of OM through the sandy loam soil was not measured. Additionally, analyzing soil layers at smaller depth increments along with soil temperature in future studies would help understand OM retention in the orchard.

Regarding soil moisture, both the M and PLM treatments appeared to buffer soil moisture compared to the GS treatment during the spring and late growing season. However, unlike other studies that showed mulch buffering soil moisture during the dormant season and dry periods, resulting in an increased yield of young apple trees compared to bare soil (Treder et al. 2004), the M and PLM treatments in this study did not limit soil moisture loss during water deficit periods. Additionally, as the soils continued to dry during late summer and early fall, both M and PLM appeared to absorb rainfall or irrigation and prevent water movement to the lower soil profile (Gebretsadikan et al. 2023). Although the M and PLM treatments appeared to buffer the soil from drying out at a depth of 15 cm, this did not seem to influence yield, and the mature trees likely had access to moisture deeper than 45 cm depth. Previous research that applied mulch to young pecan orchards placed sensors at deeper depths and concluded that the mulch layer improved moisture status, leading to increased tree growth (Smith et al. 2000). Growers in the southeastern

USA typically only irrigate 3 weeks before fruit harvest, to ensure large fruit size for fresh market without reducing soluble solid content. Limited soil moisture during other periods of the growing season is frequently ignored by growers due to financial constraints. Furthermore, the access to deeper soil moisture despite very dry periods during the later growing season seems to be also reflected in SWP measurements, which were similar between treatments except for two dates when the GS trees had less negative SWP compared to the M and PLM trees. Similar results have been reported in other regions and with other amendments. For example, straw mulch buffered soil moisture levels compared to conventionally tilled plots in apple orchards in the northeastern USA (Merwin et al. 1994), while straw mulch repeatedly applied to peach orchards in Spain decreased simulated rainfall infiltration despite increasing soil OM (García-Moreno et al. 2013). Both scenarios seemed to be present in the current study, with a delay of moisture loss at a depth of 15 cm for M and PLM trees during winter and spring, but greater amounts of rainfall required to saturate the lower soil profile compared to GS trees. Nonetheless, the long-term impact of amendments applied to the soil on SWP during periods of critical water stress will require further study, with a need to explore the hydrophobicity of various OM amendments, and the influence of methods of amendment application, such as light tillage or initial incorporation.

The TCSA of trees in the M and PLM treatments were not different than the GS trees when measured each year, although the TCSA of young trees can be improved in comparison to bare soil after the application of wood mulch (Atucha et al. 2011). Since the study used mature trees, the annual TCSA measurements did not show a higher growth rate of the M and PLM trees, indicated by the slope of TCSA growth equations and, in the case of PLM trees, greater tree height. Increasing the biomass of trees with more vegetative growth is not preferred if additional time is required for pruning or if excessive biomass from elevated N increases shading, reducing floral bud initiation and future year fruit yield or quality (Toselli et al. 2019; Weinbaum et al. 1992). Fruit doubles and blind wood were not measured in the current study, but several “Juneprince” and “Scarletprince” PLM trees appeared to have less flowers within the interior canopy in comparison to M and GS treatments. Additionally, a larger number of fruit were harvested from the top half of the trees, indicating shading from the prior-year canopy.

## 5 Conclusions

The objective of the current study was to investigate the effects of surface-applied mulch and mulch combined with poultry litter in the orchard system, both soil and tree, in



terms of water, nutrients, and productivity. In agreement with one of our hypotheses, both amendments appeared at times to buffer soil moisture, as the amendments delayed soil from drying out during the spring but also limited water infiltration during the later growing season. Considering tree water status was nearly identical between the three treatments, additional work is needed to explore soil moisture and the potential effects of using amendments at greater depths in the soil profile. Contrary to our other hypothesis, the addition of amendments did not result in an increase in soil organic matter (OM) within the original soil over the study, but additional years of adding OM are most likely needed in order for this to occur. Furthermore, the amendments did not improve tree productivity, and trees receiving mulch (M) and mulch with poultry (PLM) maintained similar nutrient status during the summer sampling period compared to the synthetic fertilizer treatment (GS), despite reducing or eliminating synthetic fertilizer during the spring. However, further reduction of synthetic fertilizer and/or amendment rate would be required in the future to avoid increased vegetative growth and elevated leaf N concentrations; both of which likely caused a delay of fruit maturity and a cumulative reduction of fruit yield. Therefore, numerous opportunities exist for further research and optimization of OM amendments in orchard settings. Factors such as application frequency, volume, incorporation depth, and timing during the growing season as well as species and cultivar could be explored to maximize the benefits to the agroecosystem, replace synthetic fertilizers, and prevent nutrient accumulation in the soil.

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**Data Availability** The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Competing Interests** The authors declare no competing interests.

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