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Aboveground Biomass, Carbon Sequestration, and Yield of *Pyrus pyrifolia* under the Management of Organic Residues in the Subtropical Ecosystem of Southern Brazil

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Abstract: Organic residues management (ORM) alter plant traits and soil properties by changing nutrient and carbon cycling. It is unclear how ORM (mulching, compost, and their combination) applied for 18 months creates a mechanism to promote changes in a *P. pyrifolia* field. Our aim was to evaluate the influence of ORM on *P. pyrifolia* nutritional status, plant traits, yield, and carbon sequestration in a 16-year subtropical *P. pyrifolia* field. For this purpose, we performed an experiment in a randomized block design, using a factorial scheme 2 × 2, with the use of Compost and Mulching (e.g., presence and absence). The highest values of leaves N content, plant height, stem biomass, root biomass, total biomass, yield, and above- and belowground carbon (C) density were found on plots that received compost as the ORM. For soil organic C stock, the highest values were found on plots where mulching was applied. Finally, the highest values of total C density were found on plots that received the combination of Mulching and Compost. Our findings suggest that: (i) the use of Compost is the best alternative to promote leaves N content, plant height, stem dry biomass, root dry biomass, and total dry biomass, plant yield, and above- and belowground C density into a 16-year *P. pyrifolia* field into subtropical conditions; and (ii) the soil organic C stocks were improved using just the mulching treatment. The results highlight the importance of considering just one organic residue practice based on a sustainable way to improve both plant production and carbon sequestration, no differences were found between the use of compost and the combination of compost and mulching.

Keywords: compost; field experiment; mulching; soil C pools; subtropical fruticulture

1. Introduction

The transition process from conventional to organic farming systems in *Pyrus pyrifolia* (Burm.f.) Nakai plantations in the Brazilian subtropical region has increased in the last decade (2012–2021). This process promotes soil ecosystem, plant growth, plant nutritional status, biomass production, and carbon sequestration [1,2]. In southern Brazil, the majority of *P. pyrifolia* fields are based in conventional farming systems that use high quantities of mineral fertilizers and chemical products (e.g., herbicide, fungicide, and insecticide) at high costs to sustain the plant yield with low carbon input. However, the continuous use of mineral fertilizers in fruticulture is becoming less efficient over time through soil organic carbon loss, soil food web disruption, soil contamination, and soil erosion [3]. In this context, the use of organic residues can be an important alternative to reduce related costs and to improve soil quality, soil carbon pools, plant growth, carbon sequestration, and biomass production by increasing soil fertility and nutrient cycling [4,5].

In southern Brazil, *P. pyrifolia*, is one of the fourth most important tree species (*Vitis vinifera* L., *Mallus domestica* (Borkh), *Prunus persica* (L.) Batsch. and *P. pyrifolia*) cultivated with high economic impact for the regional fruticulture. *P. pyrifolia* is a perennial tree that is native to China [6]. It has been cultivated in Paraná, Santa Catarina, São Paulo, and Rio Grande do Sul since the 1970s, covering a total of 1300 ha (into this area just 18% is cultivated following organic farming system) in southern Brazil [7]. In 2018, a total of 22,000 t year^{-1} *P. pyrifolia* fruits were produced and consumed throughout Brazil [8], however a total of 95,000 t year^{-1} *P. pyrifolia* fruits were imported from Asia to fulfil the demand in Brazil. Additionally, the Brazilian pear fruit production is considered the fourth highest production in Southern America [8]. It generates 5 million direct and indirect jobs, and the organic *P. pyrifoli* a fields are considered a fruticulture system with high C income and high capacity to C sequestration [9,10].

The consensus is that organic fertilization positively influences soil chemical characteristics by improving soil C pools, C sequestration, and plant nutrient contents (e.g., N, P, K and micronutrients), which may affect plant species traits and their behavior (e.g., plant nutritional status, growth, dry biomass production, and yield), as described by Dai et al. [11]. First, the application of organic residues acts as habitat and energy supply to soil organisms [12], which in turn starts both mineralization and nutrient cycling processes [13]. Next, these two processes ensure the gradual release of N, P and other plant nutrients, which avoids nutrient loss and increases the plant nutrient uptake efficiency [14]. It also promotes root growth, thus influencing belowground biomass production. Finally, the continuous use of organic residues can create positive plant-soil feedback, which overtime increases dry biomass production, plant yield, C sequestration (e.g., above- and belowground C density) and soil C pools [15].

Based on these statements, we hypothesized that the organic fertilization in *P. pyrifolia* plantation may promote: (i) the soil C pools through the increase in dry biomass production in the *P. pyrifolia* field, following the main results described by Montanaro et al. [16], and Baldi et al. [17]. The use of organic residues can influence both soil chemical characteristics, and the plant nutrient supply [17,18]. Other studies have showed an increase in soil organic carbon, total nitrogen, soil C:N ratio, and soil exchangeable cations through the continuous use of organic residues as a source of plant nutrients [19]; and (ii) the biomass production, plant yield, and plant nutritional status as concluded by Forstall-Sosa et al. [20]. Organic residues can play a multifunctional role by promoting soil health, ecosystem services, soil food web, C sequestration, and plant nutrient supply in tropical and subtropical ecosystems [21–23].

In this context, our study addressed the following goals: (a) the management of organic residues may enhance the *P. pyrifolia* nutritional status, growth, yield, and dry biomass production; (b) the use of compost and mulching could contribute with the increase in both above- and belowground C density; and (c) the soil organic carbon stocks could be influenced by the management of organic residues. To achieve these goals, we collected in a 16-year *P. pyrifolia* field study: leaves (e.g., for plant nutritional status characterization), plant material (stems, branches, and roots to determine plant dry biomass production), soil samples (for soil organic carbon stock characterization), commercial fruits (to estimate plant yield), and C compartments (to estimate above- and belowground C density), as described in the studies conducted by Li et al. [24], Tesfaye et al. [25], Sahoo et al. [26] and Zahoor et al. [27].

2. Materials and Methods

The field experiment was carried out in a 16-year field experiment from January 2020 to June 2021 comprising an area of 123.10 ha with *Pyrus pyrifolia* fields at the "Pirapora Agropecuária" enterprise, located in Curitibanos, Santa Catarina, Brazil (27°12′47.01″ S and 50°39′44.52″ W). The climate is Cfb-type following Köppen–Geiger climate classification (e.g., temperate oceanic climate, with a warm summer and without a dry season), with average annual precipitation and air temperature of 1676 mm and +15 °C, respectively [28]. Climate data, monthly rainfall, mean temperature, and thermal amplitude from the experimental area, Curitibanos, Santa Catarina, Brazil (January 2020 to June 2021), were obtained online: https://ciram.epagri.sc.gov.br (accessed on 23 August 2021) (Figure 1). The soil type of the experimental area was classified as Acrisol [29].

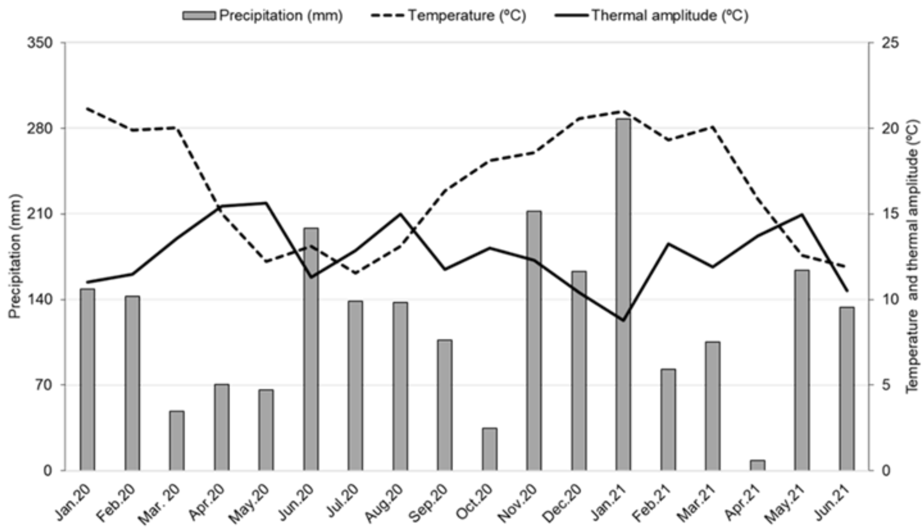

Figure 1. Monthly precipitation (mm), air temperature (°C), and thermal amplitude (°C) from the field experiment, Curitibanos, Santa Catarina, Brazil (January 2020 to June 2021). Data were obtained online: https://ciram.epagri.sc.gov.br (accessed on 23 August 2021).

2.1. Experimental Design

We analyzed the effects of mulching, compost, and their interaction in a 16-year *P. pyrifolia* field. The plant material used as mulching was obtained by *P. pyrifolia* pruning. All mulching material were air dried for 7 days in mulching piles (1.5 m × 2.0 m × 5.0 m; height: width: lenght) covered by black plastic during all process. We did not identify temperature changes into mulching piles. In our study, we tested the use of 3 kg m^{-2} of this material applied around the *P. pyrifolia* plants in the beginning of the field experiment. For compost, we made compost piles (1.5 m × 1.5 m × 3.0 m; height: width: length) using a mixture of chicken manure, green biomass, and cow manure (1:2:1 ratio). The compost piles were watered daily (e.g., 80% of field capacity), and once a week we turned them to provide oxygen inside the piles, and to reduce thermal variation, preventing the piles from self-burning. We studied the effect of using 10 kg m^{-2} of compost applied on soil surface and then incorporated it at 20 cm soil depth, 60 days before the flowering stage. The control treatment did not receive chemical fertilization. The field experiment was carried out in a randomized block design using a factorial scheme 2 × 2, with the use of compost and mulching (e.g., presence and absence) within four blocks. The use of all treatments was evaluated for 18 months. Each plot (24 m × 36 m) contained five lines spaced 4.8 m apart, and each line contained five plants spaced 7.2 m apart (25 trees per plot) (Figure 2). In total, we established sixteen plots. The horizontal distance between the plots within each block was 150 m.

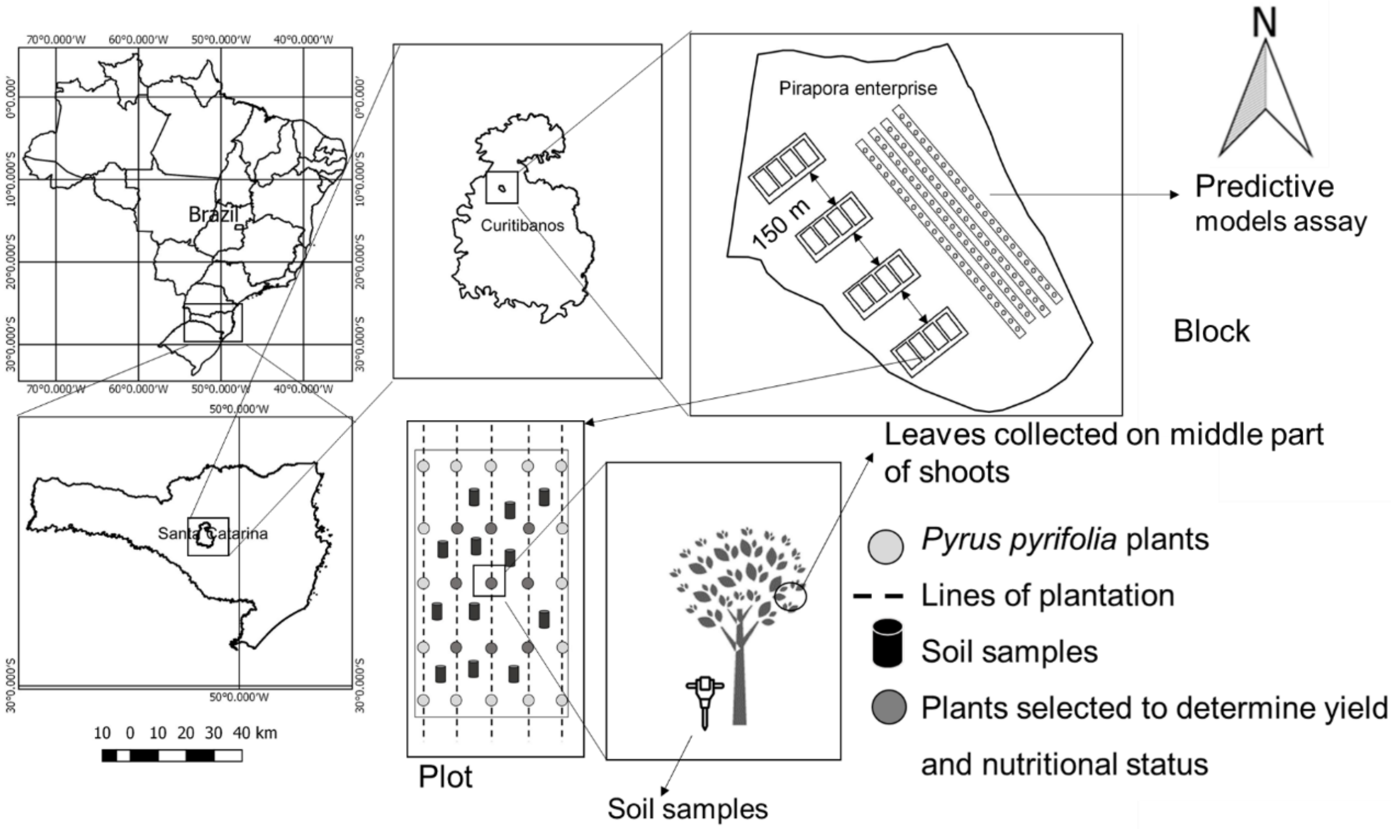

Figure 2. Experimental scheme of our field study inside a 16-year *P. pyrifolia* field using different organic residues management in a subtropical ecosystem, Curitibanos, Santa Catarina, Southern Brazil.

2.2. Laboratory Analyses

Soil samples were taken with a soil auger from 0.0–0.2 m soil depth in each plot during two phases: (i) before the start of the experiment; and (ii) in May 2021. To characterize the soil chemical properties from each plot, we collected 12 soil samples nested per plot. The soil samples were air-dried and passed through a 2 mm sieve [30]. For the organic residues, we sampled both compost and mulching material. Mulching and compost piles were placed in their own experimental area. For both studied organic residues, we collected 20 samples per pile. Both compost and mulching samples were air-dried and passed through a 2 mm size sieve for C, N, P, and K analysis [31].

The chemical characterization of the soil obtained from each plot included analysis of soil pH, available phosphorous, soil exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, Al^{3+}), sum of bases, cation exchange capacity, soil organic carbon, total nitrogen, and base saturation (Table 1). Soil pH was measured in a suspension of soil and distilled water (1:1 *v:v*, soil: water suspension). Available phosphorous was extracted by Mehlich-1 and determined using colorimetry. The potassium chloride extraction method was used to determine exchangeable Al^{3+}, Ca^{2+}, K^+ and Mg^{2+} [32]. The sum of bases was measured using the following equation: SB (cmolc kg^{-1}) = $Na^+ + K^+ + Ca^{2+} + Mg^{2+}$, while cation exchange capacity was measured using the following equation: C.E.C. (cmolc kg^{-1}) = Sum of bases + $H^+ + Al^{3+}$. Soil organic carbon was estimated according to the methodology described by Teixeira et al. [30], while total nitrogen was estimated using sulfuric acid and potassium sulphate digestion, following the Kjeldahl protocol [30].

Table 1. Soil chemical properties of before to start the field experiment (mean, n = 192) in a 16-year *P. pyrifolia* plantation, Curitibanos, Santa Catarina, Brazil.

Studied Treatment	pH (H_2O)	P (mg dm^{-3})	K^+ (mg dm^{-3})	Ca^{2+} (cmolc kg^{-1})	Mg^{2+} (cmolc kg^{-1})	Al^{3+} (cmolc kg^{-1})	SOC (g kg^{-1})	TN (kg kg^{-1})	SB (cmolc kg^{-1})	CEC (cmolc kg^{-1})
Control	6.28	30.22	408.23	10.28	3.08	0.00	30.59	1.62	14.41	14.40
Mulching (M)	6.35	48.98	461.30	11.88	3.06	0.00	30.59	1.81	16.13	16.13
Compost (C)	6.15	35.07	326.31	10.96	3.26	0.00	27.98	1.80	15.06	15.06
M + C	6.23	43.12	576.92	10.36	2.92	0.00	30.16	1.78	14.76	14.77

SOC: Soil organic carbon; TN: Total nitrogen; SB: Sum of bases; CEC: Cation exchange capacity.

2.3. Organic Residues Analyses

Both studied organic residues (mulching and compost) were chemically analysed before starting the field experiment to determine C/N ratio, nitrogen, phosphorus, and potassium contents (Table 2). The N, P, and K contents were measured by H_2O_2 and H_2SO_4 digestion according to Tedesco et al. [31].

Table 2. Chemical composition (N, P and K) of the organic residues used in the field experiment. Values are given as mean (n = 20).

Organic Residues	C/N Ratio	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Mulching	45.85	8.52	13.87	86.68
Compost	21.13	20.84	16.18	31.18

2.4. Leaf Analyses Tissues

Leaf samples were collected from each of the nine plants placed in the central portion of each studied plot. We selected just nine plants per plot due to: (i) their homogeneity regarding nutritional status; (ii) reduced experimental error by avoiding plants located at the plots' edge; and (iii) lack of diseases and pest damages in the leaf tissue. Some plants located at the plots' edge showed leaf damage caused by beetles (e.g., *Diabrotica speciosa* (Germar)) and caterpillars, thus we avoided selecting these individuals for plant nutritional status assay. We collected 100 leaves per plot in January 2020 and 2021 as recommended by CQFS [33]. All leaves were collected from the middle part of the shoots. They were packaged in paper bags, rinsed with distilled water, dried at 60 °C for 72 h, and preserved until chemical analyses in plastic pots. To chemically characterize the leaves of *P. pyrifolia* from each studied plot, we analysed nitrogen, phosphorous and potassium contents. The N, P and K contents were measured by H_2O_2 and H_2SO_4 digestion according to Tedesco et al. [31].

2.5. Predictive Models

For our predictive model assay, we considered four extra areas following our experimental treatments. Each area consisted of 90 *P. pyrifolia* plants and included an analysis of plant height, number of branches, and stem diameter at 30 cm from soil surface before starting the field experiment in the 16-year-old *P. pyrifolia* plantation. All the plants used to determine plant traits were marked and harvested. Leaves, stems, branches, and roots of each plant were harvested to determine leaves, stems, branches, and root dry biomass. The dataset about plant traits enabled us to build predictive models to estimate *P. pyrifolia* dry biomass through the "stepwise" function. Based in our traits' dataset, we estimated four significant predictive models: (i) leaves biomass (kg $plant^{-1}$) = 1.13 + (0.24 × number of branches) + (1.21 × plant height), R^2 = 0.93, $p < 0.001$; (ii) Stem biomass (kg $plant^{-1}$) = −3.97 + (3.29 × stem diameter), R^2 = 0.99, $p < 0.001$; (iii) branches biomass (kg $plant^{-1}$) = −56.29 + (8.64 × plant height) + (3.46 × stem diameter), R^2 = 0.95, $p < 0.001$; and (iv) root biomass (kg plant^{-1}) = −55.86 + (14.35 × plant height) + (1.38 × stem diameter), R^2 = 0.99, $p < 0.001$.

To estimate the *P. pyrifolia* yield, we collected fruits from the nine plants located in the central portion of each studied plot. We have excluded all non-commercial fruits (e.g., injured by pests and diseases) from our analysis. The plant yield was determined in kg plant^{-1}. Then, we estimated plant yield using the following equation:

$$\text{Yield (t ha}^{-1}) = (\text{Y0} \times 416)/(25 \times 1000) \quad (1)$$

where, Y0 is the plant yield (kg plant^{-1}); 416 is the number of plants per hectare; 25 is the number of plants per plot; and 1000 is the correction factor to convert kg ha^{-1} in t ha^{-1}.

The aboveground carbon density (ACD) and belowground carbon density (BCD) were estimated by the following equations, as described by IPCC [34]:

$$\text{ACD} = \text{ABG} \times 0.47 \quad (2)$$

$$\text{BCD} = \text{ACD} \times 0.24 \quad (3)$$

where ACD and BCD are the above- and belowground carbon density (t C ha^{-1}), respectively. ABG is the aboveground biomass (kg plant^{-1}), 0.47 is carbon content in the aboveground biomass, and 0.24 is the carbon content in the root biomass. The SOC stock in mineral soil was calculated based on the fixed depth method using soil organic carbon content, a layer of 0.20 m of soil depth, soil bulk density, and coarse fragmented matter at 0.20 m depth according to the procedure described by Ruiz-Peinado et al. [35]. The SOC stock was estimated by the following equation:

$$\text{SOC stock} = \text{SOC} \times \text{BD} \times 0.20 \times (1 - \text{CFM}) \quad (4)$$

where SOC stock is the soil organic carbon stock (t C ha^{-1}), SOC is the soil organic carbon content (kg C t^{-1} soil), BD is the bulk density (t soil m^{-3}), 0.20 is the depth of the sampled soil layer (m), CFM is the percent mass coarse fragmented matter >2-mm, and 10 is the correction factor required to express the result in t C ha^{-1}. The total carbon stock (carbon density) in the *P. pyrifolia* field on different organic residues application was calculated by summing up the aboveground C density, belowground C density, and soil organic carbon stocks of each plot, as described by Pearson et al. [36]:

$$\text{TPCD} = \text{ACD} + \text{BCD} + \text{SOC stock} \quad (5)$$

where TPCD: Total *P. pyrifolia* carbon density (t C ha^{-1}), SOC stock: Soil organic carbon stock, ACD: aboveground carbon density (t C ha^{-1}), and belowground carbon stock (t C ha^{-1}). The aboveground carbon density, belowground carbon density, and soil organic carbon stock were calculated for each plot, then, the different carbon pools were summarised to obtain the total ecosystem carbon density.

2.6. Statistical Analyses

Before the statistical analyses, all datasets were checked for normality and homogeneity of data variance. A two-way ANOVA was used to compare soil chemical properties, plant nutrition, plant traits, yield, aboveground biomass, and soil C stocks among the use of compost, mulching and their interaction. To test possible site effect, we applied the Friedman's test. We used the Bonferroni's test to compare all variables at plots. The analyses were performed using R Studio [37].

3. Results

3.1. The Effects of the Use of Compost and Mulching on Leaves N, P and K Contents of P. pyrifolia Plants under Field Conditions

Significant differences among the use of compost, mulching and their interaction were found in leaves' N content. For leaves' P and K content, no significant differences among the use of compost, mulching and their interaction by the two-way ANOVA were found. The highest values of leaves' N content in *P. pyrifolia* plants were found on plots where compost was applied (Figure 3).

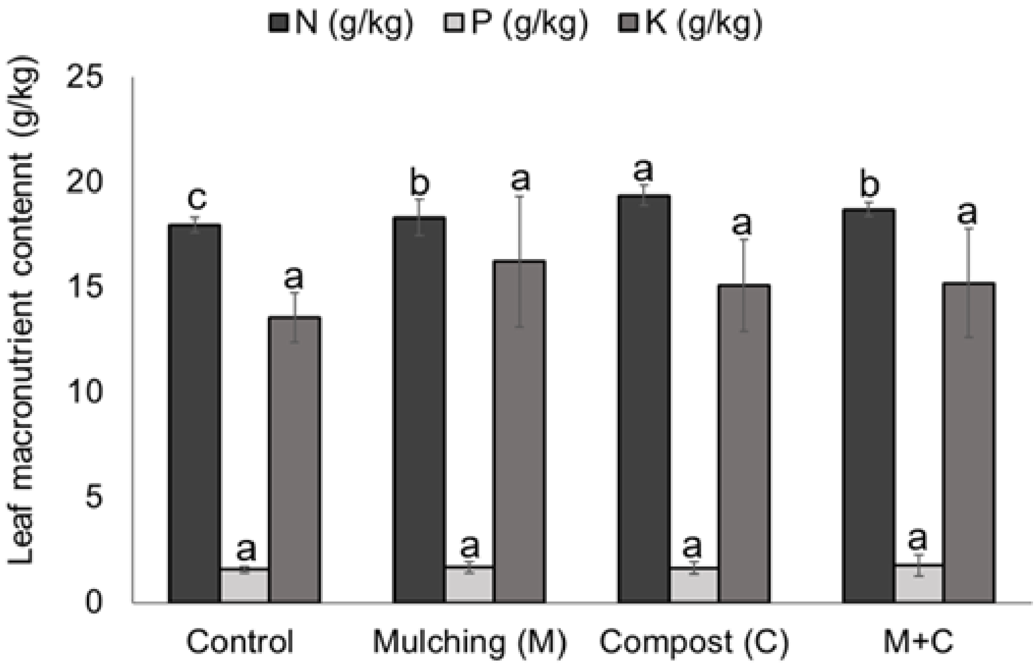

Figure 3. Leave macronutrient contents (N, P and K g kg^{-1}) among the studied treatments of organic residues management in a subtropical ecosystem, Curitibanos, Santa Catarina, Southern Brazil. Different small letters into each line differ by Bonferroni's test ($p < 0.05$). Mean values (n = 144) followed by the standard deviation in parenthesis.

3.2. Influence of the Use of Compost and Mulching on Plant Traits and Biomass Production of P. pyrifolia Plants under Field Conditions

Significant differences among the use of compost, mulching and their interaction were found for height ($p < 0.001$), stem biomass ($p < 0.01$), root biomass ($p < 0.001$), and total biomass ($p < 0.01$). For stem diameter, and branch biomass, we did not find any significant differences among the use of compost, mulching and their interaction by the two-way ANOVA. The highest values of plant height, stem biomass, root biomass, and total biomass were found on plots where compost and mulching were applied (Figure 4). For stem biomass and total biomass, we did not find significant differences between plots where we used only the compost and plots that received the combination of compost and mulching (Figure 4).

3.3. Influence of the Use of Compost and Mulching on P. pyrifolia Yield under Field Conditions

There is a significant difference in *P. pyrifolia* yield when comparing the use of compost, mulching, and their interaction. The highest values of *P. pyrifolia* yield were found on plots that received the combination of compost and mulching. We did not find significant differences for *P. pyrifolia* yield between the plots that received just the compost, and the combination with compost and mulching (Figure 5).

3.4. The Effects of the Use of Compost and Mulching on C Compartments (Aboveground, Belowground, Soil, and Total) on P. pyrifolia Field Conditions

There were significant differences in aboveground carbon density ($p < 0.01$), belowground carbon density ($p < 0.01$), soil organic carbon stock ($p < 0.001$), and total C density ($p < 0.001$) among the use of compost, mulching, and their interaction in the *P. pyrifolia* field. The aboveground C density ranged from 22.12 to 23.69 t C ha^{-1}, while the belowground C density ranged from 5.31 to 5.68 t C ha^{-1} under different organic residues application. The highest values of above- and belowground C density were found on plots where we used a combination of mulching and compost. The soil organic C stock ranged from 117.53 to 128.49 t C ha^{-1}. The highest values of soil organic C stock were found on plots with mulching treatment. For soil organic C stock, we did not find significant differences between control and mulching treatments. The total *P. pyrifolia* C density ranged from 146.62 to 157.21 t C ha^{-1}. The highest values of this variable were found on plots with mulching treatment. There were no significant differences between the use of mulching and the combination with mulching and compost on total *P. pyrifolia* C density (Table 3).

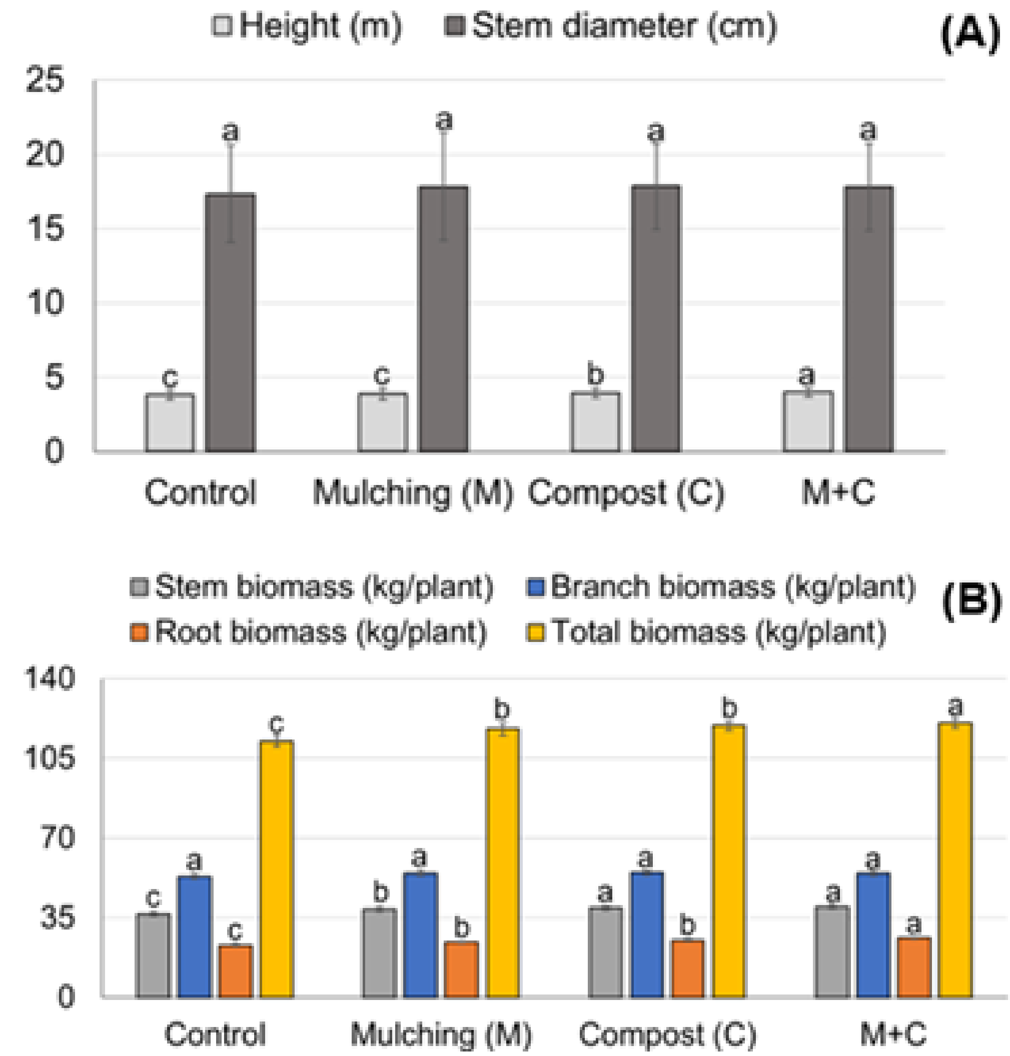

Figure 4. Plant traits (**A**) and biomass production (**B**) among the studied treatments of organic residues management in a subtropical ecosystem, Curitibanos, Santa Catarina, Southern Brazil. Different small letters into each line differ by Bonferroni's test ($p < 0.05$). Mean values (n = 360) followed by the standard deviation in parenthesis.

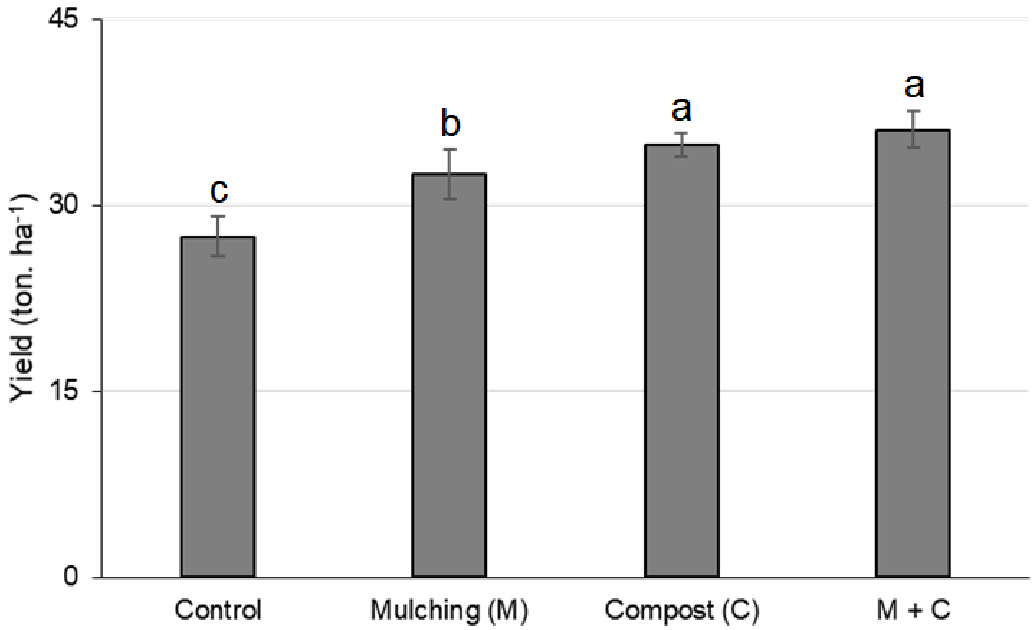

Figure 5. *P. pyrifolia* yield (ton. ha^{-1}) as affected by different organic residues management in a subtropical ecosystem, Curitibanos, Santa Catarina, Southern Brazil. Different small letters into each line differ by Bonferroni's test ($p < 0.05$).

Table 3. Above- and belowground carbon density (t C ha^{-1}), soil organic C stock (t C ha^{-1}), and total *P. pyrifolia* C density (t C ha^{-1}) among the studied treatments of organic residues management in a subtropical ecosystem, Curitibanos, Santa Catarina, Southern Brazil.

Treatments	**Aboveground C Density**	**Belowground C Density**	**Soil Organic C Stock**	**Total C Density**
	t C ha^{-1}			
Control	22.12 (4.86) b	5.31 (1.16) c	128.49 (1.51) a	155.93 (1.38) b
Mulching (M)	23.15 (5.12) b	5.55 (1.22) b	128.49 (2.18) a	157.21 (2.33) a
Compost (C)	23.45 (4.30) a	5.62 (1.03) a	117.53 (1.63) c	146.62 (1.57) c
M + C	23.69 (4.24) a	5.68 (1.01) a	126.67 (2.12) b	156.05 (2.06) a
F-value	8.52 **	8.52 **	56.04 ***	40.59 ***

***, **, Significant differences at $p < 0.001$; and $p < 0.01$ by the two-way ANOVA, respectively. Different small letters into each line differ by Bonferroni's test ($p < 0.05$). Mean values (n = 16) followed by the standard deviation in parenthesis.

4. Discussion

Our results emphasize the influence of management using organic residues (e.g., mulching and compost) applied on plant nutrition (e.g., leaves' N content), plant traits (e.g., height, stem biomass, root biomass, and total biomass), plant yield, and soil traits (e.g., above- and belowground C density, soil organic C stock, and total C density) in a 16-year field with *P. pyrifolia* plants cultivated in subtropical Acrisols. All organic residues treatments (e.g., mulching, compost, and their interaction) promoted the whole studied variables. Essentially, we wanted to understand how the isolate and combined use of compost and mulching can change plant nutrition, plant traits, yield, and soil traits (especially the soil C pools), following an organic farming system schedule and preventing the use of synthetic compounds. We found evidence that plant nutrition, plant traits, and yield on plots where compost was applied were higher than their results on plots where mulching and control treatments were applied. For some of these variables, we did not find significant differences between the use of compost alone and the combination of compost and mulching. However, considering the costs related to each management, the use of organic residue practices alone is supposed to be low cost. These results agree with previous study carried out by Souza et al. [38] and

Vital et al. [39] that reported high costs with the continuous use of organic fertilization following a combined strategy to add organic residues into a soil profile. These authors have reported plant and soil improvements (e.g., yield, and soil organic carbon content, respectively) with the continuous use of farmyard manure (10 t ha^{-1}) in a tropical Ferralsol. Overtime the use of organic amendments promotes plant nutrition (e.g., by improving nutrient cycling and plant nutrient release), plant traits (e.g., by improving plant growth and performance), plant yield, and soil traits (e.g., aboveground C density, belowground C density, and soil carbon stocks) [32,40,41].

N content in leaves was positively affected using compost on plots and incorporating it into a soil profile. Compost as an organic amendment is an interesting source of organic N and other plant essential nutrients [42]. These authors reported an improved plant nutritional status on plots where compost was applied. In our study, compost showed a higher N content when compared with mulching. The use of compost also has a positive influence on soil, which, in turn, promotes plant nutrition, such as: (i) high microbial activity that promotes N cycling; (ii) N release on soil solution; and (iii) plant transpiratory rate (data not shown). These results support our hypothesis that compost can influence both soil chemical characteristics, and the plant nutrient supply [17,18], and it agrees with the work carried out by Cesaro et al. [43], that found organic residues promoting N cycling, thus favoring *P. pyrifolia* yield. Other studies also reported that the use of compost can alter plant nutritional status by altering plant metabolism and physiology [15,25,44–46].

We found strong evidence for compost and the interaction with compost and mulching to influence plant traits (e.g., height, stem biomass, root biomass, and total biomass) in a subtropical *P. pyrifolia* field. Our results showed that on plots that received compost, or a combination of compost and mulching, there were no significant differences between them regarding stem biomass, and total biomass. For plant height and root biomass, the highest values were found on plots that received both compost and mulching. Overall, plant traits were positively correlated with both organic residue treatments. These results agree with other studies [47,48] reported in field experiments, comparing mineral and organic fertilization and the high influence of organic fertilizers on plant traits. Organic sources, such as compost and mulching, may influence rhizo health, thus promoting root growth, water, and nutrient uptake. In these conditions, plant species producing more biomass on their tissues, high rootability, and fast growth are expected to be found [15]. Organic residues management can promote the rhizobiome, which positively influences microbial activity and the soil food web. Improvements to the rhizosphere may promote plant performance, plant resistance, and plant nutrition, directly affecting plant morphological traits. In a subtropical ecosystem, alternative farming systems that promote the use of soil and plant performance following a sustainable method is a driving force behind the improvement of organic farming and fruticulture fields.

Organic farming systems may present a wide variety of influence on plant yield. Some studies have reported: (i) short-term effects: neutral effects with less yield values when compared to the mineral fertilization; and (ii) long-term effects: positive and strong effects on plant yield. Overtime, the use of compost and mulching may improve soil fertility. These beneficial effects on soil fertility may positively influence root growth by reducing exchangeable Al content, and modulating soil pH (e.g., here influencing micronutrient contents into soil solution). These results agree with the work carried out by Cen et al. [49], that reported the long-term effects of compost by improving soil nutrient contents, root density, and pear yield. In addition, the use of compost may improve soil nitrogen pools [50]. These organic residues also provide adequate environmental conditions to stimulate root growth, which leads to a greater increase in the absorption of nutrients and the production of biomass [51].

For the soil traits, we found the highest values of aboveground C density, belowground C density, and total C density on plots where compost and mulching were applied. These results support our hypothesis that the organic fertilization in *P. pyrifolia* plantation may promote the soil C pools through biomass production increase, which in turn promotes above- and belowground C density. Other works have described the importance of considering organic farming in regard to the carbon sequestration aspects related to the soil quality and their consequences on plant performance, C uptake, and biomass production [52,53]. In fact, organic residues are high quality materials that can promote soil improvement through nutrient cycling, thus creating a favorable condition for the development of *P. pyrifolia* plants [54,55]. In general, plant species from the *Pyrus* genus can store about 42% of organic carbon in their biomass, which contributes to an increase in above- and belowground C density into agroecosystems [27,56,57]. According to the study conducted by Montanaro et al. [16], Baldi et al. [17], Yadav et al. [58], and Hammad et al. [59], above- and belowground C density is strongly influenced by key-factors such as: plant traits, soil fertility, and soil management, and their interactions with belowground organisms. The application of organic residues may enhance belowground C density through changes in soil properties, fine root biomass, and rhizo health [60,61]. Another important role of organic residues on plant performance is the high rootability and rhizodeposition into the rhizosphere, as reported by Amendola et al. [62], Forstall-Sosa et al. [20], and Fleishman et al. [63].

Organic residues management is widely recognized as an important strategy to increase C pools (e.g., aboveground C density, belowground C density, and soil organic C stock), and to prevent soil erosion through soil C loss [64]. Overall, the use of organic residues (e.g., mulching and compost) may promote efficient C input, mainly from improved plant biomass production, increased rhizodeposition (e.g., into rhizosphere), and increased C sequestration (e.g., by plant tissues and soil) [20,61]. Mixture and organic residues alone (e.g., compost) can maximize plant performance soil biota activity, thus promoting ecosystem services by reducing C loss and increasing plant nutrient availability (e.g., soil N contents). In this context, the management of organic residues may exploit positive feedback between crop production, carbon sequestration, and soil sustainability [26,27]. In addition, as C sequestration/storage is linked to soil quality [49], compost has the potential to increase the build-up of soil N contents, and soil organic carbon stocks over time [17].

Carbon dynamics and plant production in subtropical ecosystems are strongly interlinked, and it is important to understand above- and belowground C density, and soil organic C stocks in *P. pyrifolia* plantation under the management of organic residues. Here, we provide an estimation of the C sequestration amount on aboveground and belowground biomass, and soil organic C stocks. The amount of C that is accumulated by the plant biomass (e.g., here including roots, stems, branches, leaves, and fruits) and in the soil (e.g., here including phyllodeposition, and soil organic matter), which is incorporated into the ecosystem overtime. Our C pools should represent the "various pathways involved in plant-deposition of C" as described by de Notaris et al. [64]. The importance of plant-deposition of C was recently underlined by Sharma et al. [57], who found that evergreen fruit crops influence C sequestration more than deciduous fruit crops. This suggests that contributions from *P. pyrifolia* above- and belowground parts to plant-deposition of C should be considered, especially when considering long-term field experiments, as also discussed by Souza and Freitas [12].

5. Conclusions

The management of organic residues influences plant nutrition, plant traits, plant yield, and soil traits in subtropical Acrisols in a *P. pyrifolia* field. Our findings suggested that the application of compost may promote leaves' N content, height, stem biomass, root biomass, plant yield, above- and belowground C density, soil C stocks, and total C density in Acrisols under field conditions. The results of our study highlight the importance of considering the use of compost based on a sustainable method to improve both plant production and carbon sequestration, since we did not find differences between the use of compost and the combination of compost and mulching. Thus, an organic farming system in a *P. pyrifolia* field may exploit positive feedback between crop production, carbon sequestration and soil sustainability in subtropical conditions.

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