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Decomposition Rate of Organic Residues and Soil Organisms' Abundance in a Subtropical *Pyrus pyrifolia* Field

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Abstract: The use of mulching, compost, and their interaction on organic residue (OR) decomposition rate (k), time of residue decay, priming effect, and soil organisms' community composition was tested in a 16-year *P. pyrifolia* field experiment conducted from January 2020 to June 2021. A 2 $\times$ 2 factorial design was used with compost and mulching as the two factors within four blocks. OR decomposition was characterized by using litter bags with different mesh, and soil organisms were identified at family level. The half-decay rate (hd), total-decay rate (td), and remaining residue mass (Rm) varied among the organic residue management and mesh-type. The highest values of k and priming effect were found in litter bags with 15 mm^2 size containing compost in the plots that received compost. For soil organisms' abundance and richness, the highest values were found on plot that received both mulching and compost. The observed results suggested that the OR management determined organic matter decomposition, soil organisms' abundance and richness in an Acrisols of the Southern Brazil. Soil organisms were the main factors contributing to the data variance (e.g., Acaridae, Blattidae, Chrysopidae, Halictophagidae, and Forficulidae).

Keywords: compost; litterbags; mulching; nutrient cycling; priming effect; soil organisms

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1. Introduction

In subtropical agroecosystems, organic residues are the major source of energy supply and habitat for nutrient cycling and soil organisms [1]. In *Pyrus pyrifolia* (Burm.f.) Nakai plantation, the transition process from conventional to organic farming system (OFS) accounts for 18% of its cultivated area in the southern Brazil and represents 22,000 t year^{-1} of *P. pyrifolia* fruits produced in an OFS [2,3]. In this condition, organic residues with C- and N-rich compounds may improve net primary production, soil food web, and organic residue decomposition [4–6]. OFS may reduce the use of mineral fertilizers and ICIDE-type products (e.g., herbicides, pesticides, fungicides) due to an increase in the soil organisms' abundance and richness that promotes organic matter fragmentation [7,8]. However, field studies considering the effects of the continuous use of organic residues as compost and mulching on organic residue decomposition modulated by the soil organisms' activity are rare [2,3,5]. In this context, the use of organic residues can be an important alternative to promote soil quality, nutrient cycling by increasing soil organisms' activity, its community structure, and soil food web [9].

Decomposition of organic residues is controlled by many factors (e.g., fractional composition of organic matter, temperature, soil moisture, soil organisms' activity), but their quantity (C-rich) and quality (N-rich) along with soil organisms' community are considered key-factors in subtropical agricultural systems [10]. The consensus is that C-and N-rich residues are generally found to stimulate habitat provision and decomposition, respectively [11,12]. Other studies have provided evidence of C-rich residues negatively influencing decomposition rates [13,14]. Organic residues as mulching may act as habitat for soil organisms, while compost may act as energy supply for nutrient cycling [15,16]. Next, these two organic residues ensure the organic matter input into soil profile, which avoids soil quality loss, and increases plant nutrient release overtime [17]. Finally, the continuous use of compost and mulching can create positive plant-soil feedback, which overtime increases plant production, and decreases costs with low C input [18]. Previous studies showed that the use of organic residues increased the soil organic matter decomposition, and soil organisms' community structure [18–20].

Soil organisms' community is amongst the most important biotic factor in tropical and subtropical ecosystems [10,21,22]. These soil organisms perform a range of ecosystem services including soil structure, soil organic matter transformation, nutrient cycling, biological control etc., [23,24]. *Pyrus pyrifolia* is one of the four most important tree species in Brazilian fruticulture, and pearl fruits have shown to have an important social-economic impact on southern Brazil [2]. However, the role of soil organisms' community in organic residues decomposition in a 16-year *P. pyrifolia* field remains unclear. Some studies have described that compost may influence soil organic matter dynamics by improving decay rate, and priming effect, which in turn influences nutrient cycling, and soil organisms' abundance [25–27]. On the other hand, other works have shown that soil organic residues management may alter soil reaction by the H^+ extrusion and the release of some C-rich compounds, thus promoting rootability improvement [17,28]. Finally, organic residues management that provide high input of C-rich compounds may positively affect soil organisms' community structure by habitat provision [10,17].

This study aimed to assess if: (a) the organic residue management (considering the plots) may influence the residues decomposition in a litterbag assay using different mesh sizes; (b) there are different decomposition rates influenced by soil organisms; and (c) the use of organic residues may improve the soil organisms' community structure. Soil sampling, litter bag assay using different mesh sizes, and soil organisms' community assemblage were used to achieve these aims [17,29,30].

2. Materials and Methods

2.1. *Pyrus Pyrifolia and Study Site*

Pyrus pyrifolia has been cultivated in Paraná, Santa Catarina, Rio Grande do Sul covering an area of 1300 ha from which just 18% is cultivated following the organic farming system [31]. This field experiment was conducted in a 16-year *P. pyrifolia* var. Hosui field cultivated in a subtropical Acrisol [32] that follows an organic farming system at the Pirapora emprise (27°12′47.01″ S and 50°39′44.52″ W), Curitibanos, SC, Brazil, from January 2020 to June 2021. It comprises an area of 123.10 ha. The enterprise count with an area of 21.4 ha planted, included principally *Pyrus pyrifolia* var. Housui. The climate is type Cfb-type following Köppen-Geiger classification, with average annual precipitation and air temperature of 1676 mm and +15.0 °C, respectively [33]. Climate data, monthly rainfall, mean temperature, and thermal amplitude (monthly temperature fluctuation from maximum and minimum temperature) from the field experiment, Curitibanos, SC, Brazil (January 2020 to June 2021), were obtained online: https://ciram.epagri.sc.gov.br (accessed on 23 August 2021) (Figure 1).

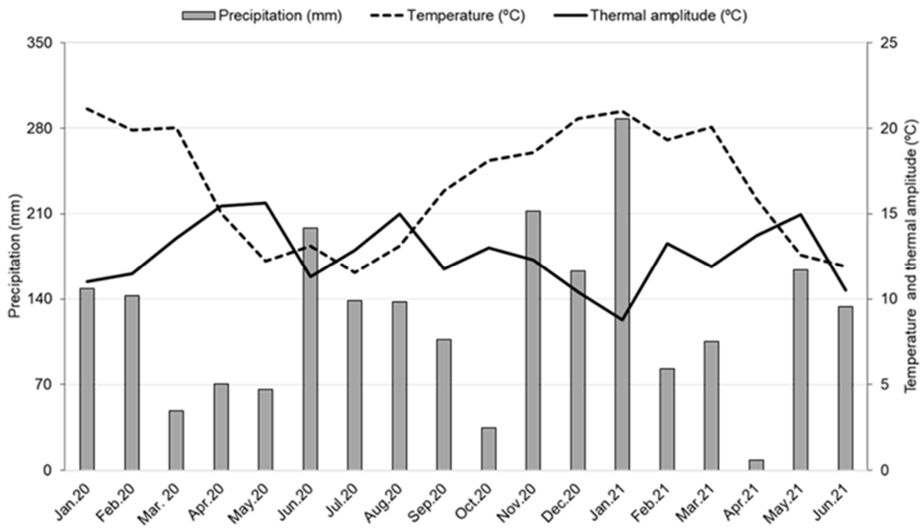

Figure 1. Monthly precipitation (mm), air temperature (°C), and thermal amplitude (°C) from the field experiment, Curitibanos, SC, Brazil (January 2020 to June 2021). Data were obtained online: https://ciram.epagri.sc.gov.br (accessed on 23 August 2021).

2.2. Experimental Design

The experiment was conducted in field conditions using a 2 × 2 factorial design with compost and mulching as the two treatment factors within four blocks. The presence and absence of mulching and compost were the studied treatments. Each treatment was tested in permanent plots (25 × 36 m), which contained 25 plants of *P. pyrifolia* (Figure 2).

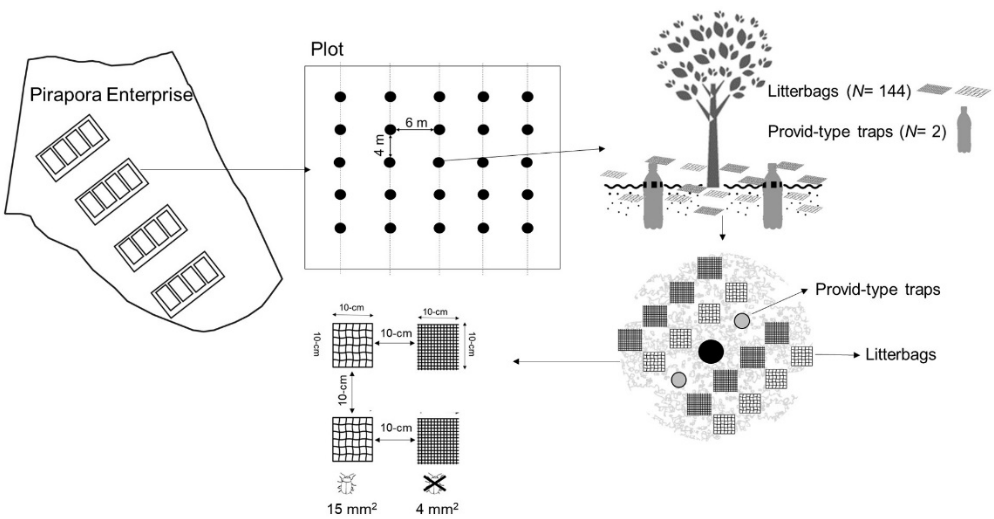

Figure 2. Experimental scheme of the field study inside a 16-year *P. pyrifolia* field using different organic residues management in a subtropical ecosystem, Curitibanos, SC, Southern Brazil.

2.3. Mulching and Compost Production

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 × 2.0 × 5.0 m; height: width: lenght) covered by black plastic during all process. Temperature changes in mulching piles was not detected. In this study, the use of 3 kg m^{-2} of this material applied around the *P. pyrifolia* plants was tested. For compost, piles (1.5 × 1.5 × 3.0 m; height: width: length) using a mixture of chicken manure, green biomass, and cow manure (1: 2: 1 ratio) were made. Daily, compost piles were watered (e.g., 80% of field capacity), and once a week they were turned by providing oxygen inside the piles, and to reduce thermal variation preventing the piles to self-burn. The effect of using 10 kg m^{-2} of compost applied on the soil surface and then incorporating at 20 cm soil depth, 60 days before the flowering stage was studied. For the organic residue characterization, both compost and mulching materials were sampled from each pile. Mulching and compost piles were produced in their own experimental areas. For both studied organic residues, twenty samples were collected per organic residue, separately. Both compost and mulching samples were air-dried and passed through a 2-mm size sieve for C, N, P, and K analysis (Table 1) following Tedesco et al. [34].

Table 1. Chemical composition (N, P, and K) of the organic residues used in the field experiment.

Organic Residues	C/N Ratio	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Mulching	45.85 ± 0.98 [1]	8.52 ± 1.12	13.87 ± 1.34	86.68 ± 4.23
Compost	21.13 ± 1.02	20.84 ± 1.18	16.18 ± 1.37	31.18 ± 4.39

[1] Vales are given as mean and standard deviation (*n* = 20).

2.4. Soil Chemical Characterization

Soil was collected before starting the field experiment on January 2020 using a soil auger and sampling at 0.2 m soil depth in each plot. Five soil samples were collected, nested per plot. All soil samples were air dried and passed through a 2-mm size sieve as described by Teixeira et al. [35]. The soil chemical characterization included soil pH, available phosphorous, soil exchangeable cations (K^+, Ca^{2+}, and Mg^{2+}), soil organic carbon, and total nitrogen (Table 2). Soil pH was measured in a suspension of soil and distilled water (1:1, *v*:*v*, soil: water suspension). Available phosphorous was measured using colorimetry of the phospho-molybdic complex at 882 nm wavelength after extraction by Mehlich-1 method M-1 (0.05 mol L^{-1} HCl + 0.025 mol L^{-1} H_2SO_4). The potassium chloride extraction method was used to determine exchangeable Ca^{2+}, K^+, and Mg^{2+} [36]. Total organic carbon was estimated according to the methodology described by Teixeira et al. [35]. The total nitrogen was estimated using sulfuric acid and potassium sulfate digestion followed to a distiller by Kjeldahl's method [35].

Table 2. Soil chemical properties of before to start the field experiment (mean, *n* = 192) in a 16-year *P. pyrifolia* plantation, Curitibanos, SC, Brazil.

Treatments	pH (H_2O)	P (mg dm^{-3})	K^+ (mg dm^{-3})	Ca^{2+} (cmol$_c$ dm^{-3})	Mg^{2+} (cmol$_c$ dm^{-3})	SOC [1] (g kg^{-1})	TN [2] (g kg^{-1})
Control	6.28 ± 0.03	30.22 ± 1.04	408.23 ± 2.32	10.28 ± 0.08	3.08 ± 0.02	30.59 ± 2.34	1.62 ± 0.08
Mulching (M)	6.35 ± 0.03	48.98 ± 1.29	461.30 ± 2.09	11.88 ± 0.08	3.06 ± 0.03	30.59 ± 1.99	1.81 ± 0.05
Compost (C)	6.15 ± 0.02	35.07 ± 1.27	326.31 ± 1.99	10.96 ± 0.05	3.26 ± 0.02	27.98 ± 2.11	1.80 ± 0.06
M + C	6.23 ± 0.04	43.12 ± 1.39	576.92 ± 2.05	10.36 ± 0.09	2.92 ± 0.03	30.16 ± 2.10	1.78 ± 0.02

[1] SOC = Soil organic carbon. [2] TN = Total nitrogen.

2.5. Organic Residues Decomposition Assay

Litterbags (10 × 10 cm) with different mesh (e.g., 4-mm^2 and 15-mm^2) were used to determine the organic residue decomposition rate (k, years^{-1}). The use of litterbags with different mesh enabled us to assess: (i) macrofauna action on litter fragmentation (e.g., by the action of litter transformers on the coarse mesh); and microbiota action on litter decomposition (e.g., by the action of decomposer on the fine mesh). Each litterbag received 10 g of organic residues (e.g., mulching and compost). Hundred forty-four litterbags were placed per plot that were distributed in the central portion of each plot (e.g., sixteen litterbags around each plant). Following a 30 day-schedule, eight litterbags (e.g., two fine mesh and two coarse mesh) were collected. The last litterbags remained in field conditions for eighteen months. Litterbags were harvested and placed in individual paper bags. In the lab, the organic residues sampled in each litterbag were oven-dried at 60 °C until reaching a constant weight for 72 h, and then organic residues samples were weighed.

The change in mass was used to determine the organic residues decomposition rate (k, years^{-1}) as described by Olson [37]: $X/X_0 = e^{(-kt)}$. Where, X is the remaining mass (g) after t years, X_0 is the initial organic residues mass (g). Half-decay time (hd) and total-decay time (td) were estimated by using two nonlinear regression models that were tested for robustness. Finally, the remaining residue mass was estimated by using the following equation: Rm (%) = $X/X_0 \times 100$. Where, Rm is the remaining litter mass (%), X_0 represents the initial dry mass of litter (g); X is the dry mass of the litter remaining after retrieval (g) at time t [38], and priming effect: pf = $\ln(X_0/X)$. Where, pf is the priming effect, X_0 is (g) is the initial organic residues mass, and X is the mass remaining.

2.6. Soil Organisms' Collection

The Tropical Soil Biology and Fertility protocol [17,39] was used to sample soil organisms. Two Provid-type traps were placed per plot following a 2-days schedule without any interruption to collect soil organisms (e.g., Annelida, Arachnida, Insecta, Mollusca, and Myriapoda). Each trap received a solution of 100 mL of distilled water, 40 mL of neutral liquid detergent, and 15 mL of 70% alcohol. All Provid-type traps were placed six times during the whole study, but we present the mean of each studied treatment in our Section 3. The soil organisms within each trap were inserted in plastic pots containing 30 mL of 70% alcohol. All collected organisms were considered for our analysis, and they were sorted, counted, and classified at family level. The soil organism community structure was characterized by the mean abundance (individual trap^{-1}), richness, Shannon diversity index [40], Simpson dominance index [41], and functional groups [23].

2.7. Statistical Analysis

Prior to the statistical analysis all dataset was tested for normality by Shapiro–Wilk test ("shapiro.test" function), and log transformation ("decostand" function) was applied when necessary. The entire dataset was analyzed to detect spatial autocorrelation ("Moran.I" function). All variables were analyzed with a two-way ANOVA with the main factor organic residue management, the secondary factor litter bag residue/mesh, and plot number as a random factor. Bonferroni's test was used as the post-hoc test. To analyze differences among the organic residue management in terms of soil organism community structure we used a NMDS procedure with Jaccard dissimilarities ("metaMDS" function). The decomposition rates, half-decay time, total decay time, remaining litter mass, and ecological indices were summarized using PCA ("vegan" package) to identify possible organic residue management dissimilarities, and to reduce the n-dimensional nature of variables to two linear axes explaining all the data variance. All functions and statistical analyses were performed in R 3.4.0 [42].

3. Results

3.1. Influence of the Organic Residue Management and Soil Organisms' Activity on Organic Residues Decomposition

The half-decay rate (hd), total-decay rate (td), and remaining residue mass (Rm) varied among the organic residue management and mesh-type in a 16-year *P. pyrifolia* field. The highest values of hd, td, and Rm were found in the mulching treatment with litter bags (15 mm^2 size) containing mulching, and in the compost treatment with litter bags (4 mm^2 size) containing mulching (Table 3).

Decomposition rate (k), and primming effect varied among the organic residue management and mesh-type in the 16-year *P. pyrifolia* field. The highest values of k and primming effect were found in the compost treatment with litter bags (15 mm^2 size) containing compost (Figure 3).

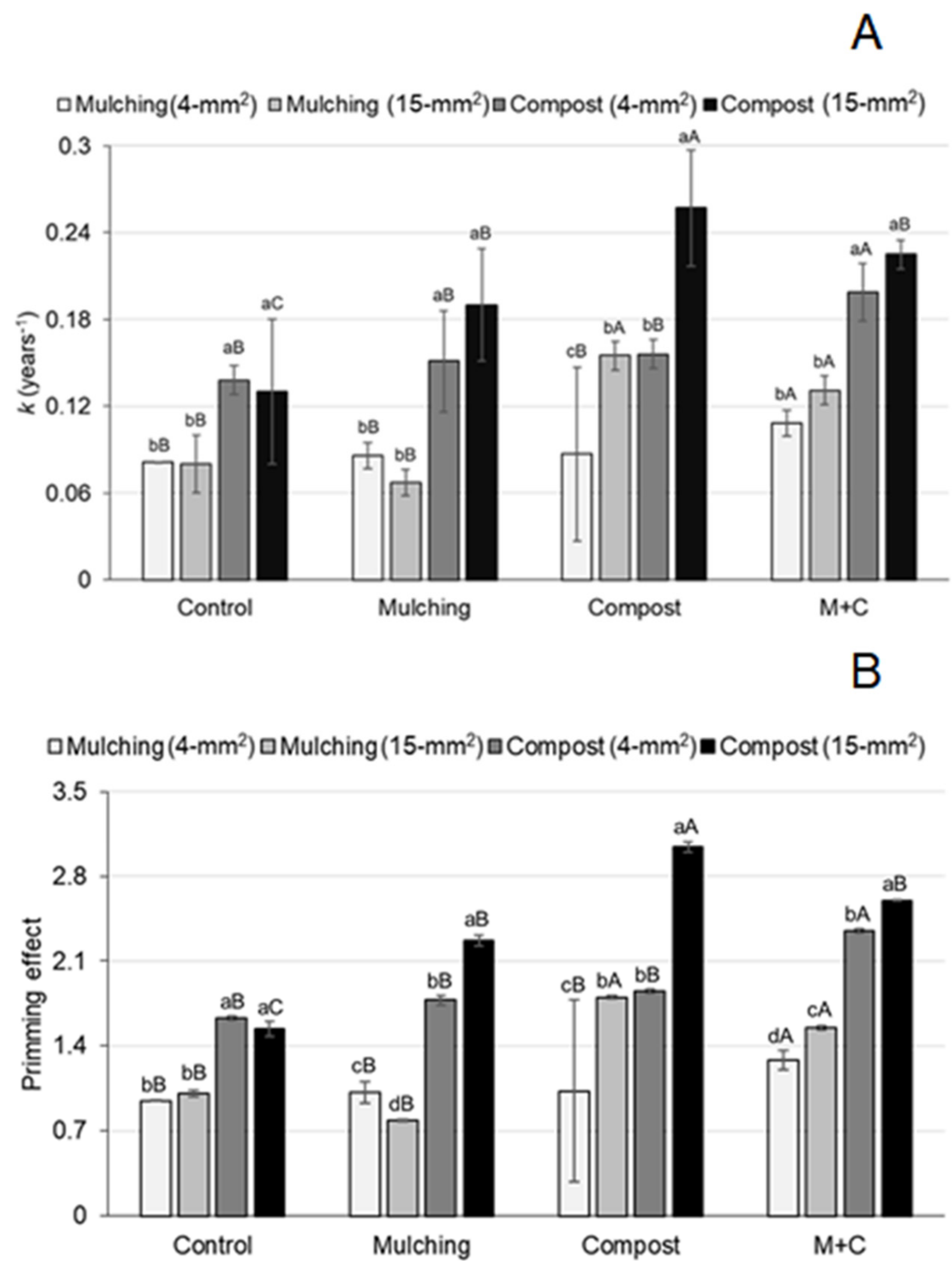

Figure 3. Decomposition rate (k, years^{-1}, **A**), and primming effect (**B**) as affected by different organic residues management and litterbag mesh-type in a subtropical ecosystem, Curitibanos, SC, Southern Brazil. Different small letters in each organic residue management differ by Bonferroni's test ($p < 0.05$), while different capital letters in each litterbag mesh-type differ by Bonferroni's test ($p < 0.05$). The decomposition rate was adjusted by multiplication by 10.

Table 3. Half-decay time (hd, days), total-decay time (td, days), and remaining litter mass (Rm, %) among the organic residues influence and litterbag mesh-type in a subtropical ecosystem, Curitibanos, SC, Southern Brazil.

Organic Residues Management	**Mesh—Type**			
	hd (Days)			
	Compost, 4 mm^2	**Compost, 15 mm^2**	**Mulching, 4 mm^2**	**Mulching, 15 mm^2**
Control	50.86 (0.59) cA [1]	61.61 (2.64) bA	86.03 (0.67) aB	86.88 (2.56) aB
Mulching (M)	47.88 (1.21) cB [2]	37.28 (0.76) dB	81.00 (0.90) bB	105.21 (1.53) aA
Compost (C)	44.72 (0.39) bB	27.54 (0.45) cC	132.25 (9.64) aA	45.77 (0.53) bC
M + C	35.12 (0.36) bC	30.97 (0.21) bC	64.43 (0.58) aC	53.84 (0.78) aC
	td (days)			
Control	308.99 (9.44) bA	374.33 (19.58) bA	522.64 (15.25) aB	527.83 (21.80) aB
Mulching (M)	290.92 (10.76) cA	226.48 (7.95) cB	492.11 (14.93) bB	637.79 (19.61) aA
Compost (C)	274.05 (9.16) bB	167.31 (5.48) cC	806.88 (6.56) aA	275.71 (7.23) bC
M + C	213.19 (6.41) bC	188.18 (5.44) cC	391.42 (11.57) aC	327.07 (10.40) aC
	Rm (%)			
Control	19.75 (0.31) cA	24.85 (1.47) bA	38.35 (0.16) aB	37.59 (0.10) aB
Mulching (M)	17.75 (0.68) cA	11.05 (0.46) cB	36.05 (0.34) bB	45.42 (0.45) aA
Compost (C)	15.87 (0.26) bA	5.15 (0.22) cB	43.42 (2.86) aA	16.47 (0.20) bC
M + C	9.60 (0.18) bB	7.00 (0.04) bB	27.80 (0.23) aC	21.55 (0.43) aC

[1] Different small letters in each line differ by Bonferroni's test ($p < 0.05$), whereas different capital letters in each row considering the organic residues management differ by the same post-hoc test. [2] Mean values ($n = 144$ per plot) followed by the standard deviation in parenthesis.

3.2. Soil Organisms' Collection in a 16-Year P. pyrifolia Field under Different Organic Residue Management

Nineteen taxonomical orders, and thirty-three families were identified of the soil organisms' community (Table 4). The mean abundance of soil organisms varied significantly among organic residue management ($p < 0.001$). The most abundant taxonomic group was Hymenoptera—Formicidae. This taxonomic group had abundances varying from 65.65 ± 5.63 (Mulching + Compost) to 100.24 ± 7.65 (Control). The one-way ANOVA results showed significant differences among organic residue management on Acari—Acaridae, Araneae—Araneidae, Blattodea—Blattidae, Blattodea—Termitidae, Coleoptera—Cugygidae, Coleoptera—Staphylinidae, Dermaptera—Forficulidae, Diptera—Muscoidea, Gastropoda—Gymnomorpha, Gastropoda—Pulmonata, Hemiptera—Cicadidae, Neuroptera—Chrysopidae, and Strepsiptera—Halictophagidae. Control promoted the occurrence of Araneae—Araneidae, Blattodea—Termitidae, Coleoptera—Staphylinidae, and Hemiptera—Cicadidae. Then, mulching promoted the occurrence of Acari—Acaridae, Gastropoda—Pulmonata, and Strepsiptera—Halictophagidae. Next, compost promoted Coleoptera—Cugygidae, and Dermaptera—Forficulidae. Finally, compost and mulching promoted the occurrence of Blattodea—Blattidae, Diptera—Muscoidea, Gastropoda—Gymnomorpha, and Neuroptera—Chrysopidae. For ecological index, significative differences were found among organic residues management on richness, and soil organisms' abundance. Non-significative differences were observed among organic residue management on Shannon's diversity index, and Simpson's dominance index (Table 4).

Table 4. Mean abundance (ind. trap^{-1}) of soil organisms' taxonomic groups, and ecological indexes among the studied organic residue management in a 16-year *P. pyrifolia* field.

Order—Family	Control	Mulching (M)	Compost (C)	M + C	*F-Value*
Acari—Acaridae	0.62 (0.11) b [1]	1.75 (0.21) a	0.12 (0.03) c	0.50 (0.07) b	10.62 *** [2]
Araneae—Araneidae	2.25 (0.15) a	1.50 (0.13) b	0.87 (0.10) d	1.12 (0.10) c	8.25 ** [3]
Araneae—Filistatidae	4.62 (0.26) a	5.25 (0.38) a	4.37 (0.19) a	5.75 (0.22) a	3.07 ns [4]
Blattodea—Blattidae	-	0.50 (0.05) b	0.37 (0.05) c	0.62 (0.07) a	11.83 ***
Blattodea—Termitidae	0.37 (0.05) a	0.12 (0.03) b	-	-	13.50 ***
Coleoptera—Carabidae	15.75 (1.49) a	12.37 (0.98) a	15.00 (0.99) a	13.87 (1.76) a	2.00 ns
Coleoptera—Cerambycidae	0.12 (0.03) a	0.12 (0.03) a	-	0.12 (0.03) a	2.17 ns
Coleoptera—Cuccilinidae	-	0.12 (0.03) a	-	-	6.09 ns
Coleoptera—Cugygidae	-	0.12 (0.03) b	0.25 (0.04) a	-	7.96 **
Coleoptera—Gyrinidae	-	0.12 (0.03) a	0.37 (0.07) a	0.12 (0.03) a	4.77 ns
Coleoptera—Nitidulidae	34.37 (1.22) a	32.50 (1.15) a	33.75 (1.04) a	44.87 (2.13) a	4.41 ns
Coleoptera—Passalidae	0.12 (0.03) a	-	-	-	6.09 ns
Coleoptera—Scarabaeidae	7.37 (0.58) a	8.62 (0.92) a	9.37 (0.93) a	3.75 (0.25) a	4.42 ns
Coleoptera—Staphylinidae	2.12 (0.33) a	1.12 (0.16) c	0.25 (0.04) d	1.87 (0.22) b	10.07 ***
Dermaptera—Forficulidae	1.87 (0.15) d	3.50 (0.22) b	7.50 (0.70) a	2.50 (0.12) c	9.96 ***
Diptera—Muscoidea	1.12 (0.27) d	2.37 (0.23) c	3.00 (0.23) b	3.37 (0.27) a	10.51 ***
Gastropoda—Gymnomorpha	0.62 (0.07) c	1.50 (0.13) b	1.62 (0.16) a	1.75 (0.11) a	8.75 **
Gastropoda—Pulmonata	1.37 (0.14) b	2.37 (0.47) a	0.12 (0.03) d	1.87 (0.22) c	10.87 ***
Haplotaxida—Lumbricidae	0.62 (0.08) a	1.12 (0.08) a	1.00 (0.14) a	0.37 (0.05) a	7.11 ns
Hemiptera—Cicadidae	0.37 (0.05) a	-	-	0.12 (0.03) b	13.50 ***
Hemiptera—Pentatomidae	0.12 (0.03) a	-	-	-	6.09 ns
Hymenoptera—Formicidae	100.24 (7.65) a	68.25 (3.35) a	67.27 (4.57) a	65.65 (5.63) a	3.32 ns
Hymenoptera—Vespidae	0.12 (0.03) a	0.12 (0.03) a	-	0.12 (0.03) a	2.17 ns
Larvae of Lepidoptera	5.87 (0.45) a	3.12 (0.28) a	8.00 (0.59) a	8.25 (0.79) a	6.94 ns
Lepidoptera	0.12 (0.03) a	0.12 (0.03) a	0.12 (0.03) a	0.25 (0.04) a	1.40 ns
Mollusca—Pulmonata	0.50 (0.05) a	0.62 (0.07) a	0.25 (0.04) a	0.62 (0.07) a	3.50 ns
Neuroptera—Chrysopidae	-	0.25 (0.06) b	-	0.37 (0.07) a	7.77 **
Orthoptera—Grylloidea	0.12 (0.03) a	0.12 (0.03) a	-	-	4.20 ns
Opiliones	0.12 (0.03) a	0.12 (0.03) a	0.25 (0.04) a	0.12 (0.03) a	1.40 ns
Scutigeromorpha—Scutigeridae	-	0.12 (0.03) a	0.12 (0.03) a	-	4.20 ns
Spirobolida—Scolopendromorpha	0.12 (0.03) a	-	-	-	6.09 ns
Strepsiptera—Halictophagidae	-	1.87 (0.20) a	1.62 (0.25) b	1.25 (0.17) c	12.51 ***
Thysanoptera—Thripidae	3.00 (0.92) a	3.75 (0.38) a	6.62 (0.67) a	(4.75 ± 0.46) a	4.88 ns
Ecological indices	Control	Mulching (M)	Compost (C)	M + C	*F-value*
Richness—S	17.75 (0.26) b	19.87 (0.15) a	17.50 (0.19) c	19.37 (0.23) a	11.28 ***
Shannon's diversity index—H	2.00 (0.05) a	2.14 (0.03) a	2.15 (0.04) a	2.08 (0.04) a	5.06 ns
Simpson's dominance index—C	0.81 (0.05) a	0.83 (0.03) a	0.84 (0.04) a	0.82 (0.05) a	5.58 ns

[1] Within organic residue management, same letters represent no significant differences by Bonferroni's test ($p < 0.05$); [2] *** $p < 0.001$; [3] ** $p < 0.01$; [4] ns not significant.

3.3. Multivariate Analysis

The NMDS revealed that the soil organisms' composition varied significantly among the organic residue management. The ordination had a good fit (stress value = 0.17). Soil organisms' composition were highly correlated with organic residue management. Acari—Acaridae, Blattodea—Blattidae, Diptera—Muscoidea, Mollusca—Pulmonata, Opiliones, and Strepsiptera—Halictophagidae explained 33, 52, 59, 37, 49, and 28 % of the variation in the soil organisms' composition in each studied orginic residue management (Figure 4).

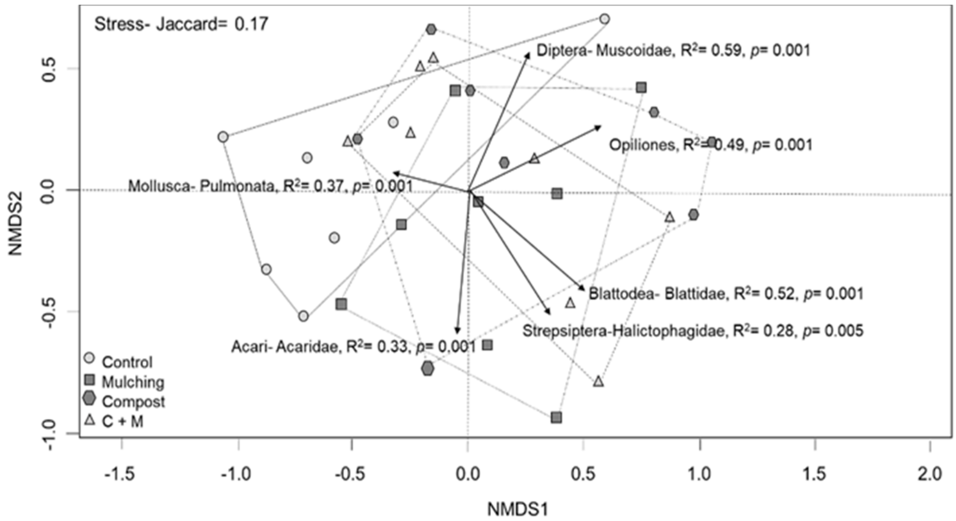

Figure 4. Non-metric multidimensional scaling (NMDS) based on soil organisms' composition among the studied organic residue management in a 16-year *P. pyrifolia* field. Organic residue management are represented as follows: Control = circles; mulching = squares; compost = hexagon; and compost plus mulching = triangles.

According to the PCA analysis, all organic residue management treatments were dissimilar. The first two axes of the overall PCA explained 80.16% of the variation in the litter decomposition data (Figure 5). The first axis explained 62.92% of variance and was positively correlated with Rm (R = 0.83, $p < 0.001$), and was negatively correlated with priming effect (R = −0.93, $p < 0.01$). The second axis explained 17.24% of the variation in litter decomposition data and was positively correlated with k (R = 0.87, $p < 0.01$) and was negatively correlated with td and hd (R = −0.80, $p < 0.01$) (Figure 5).

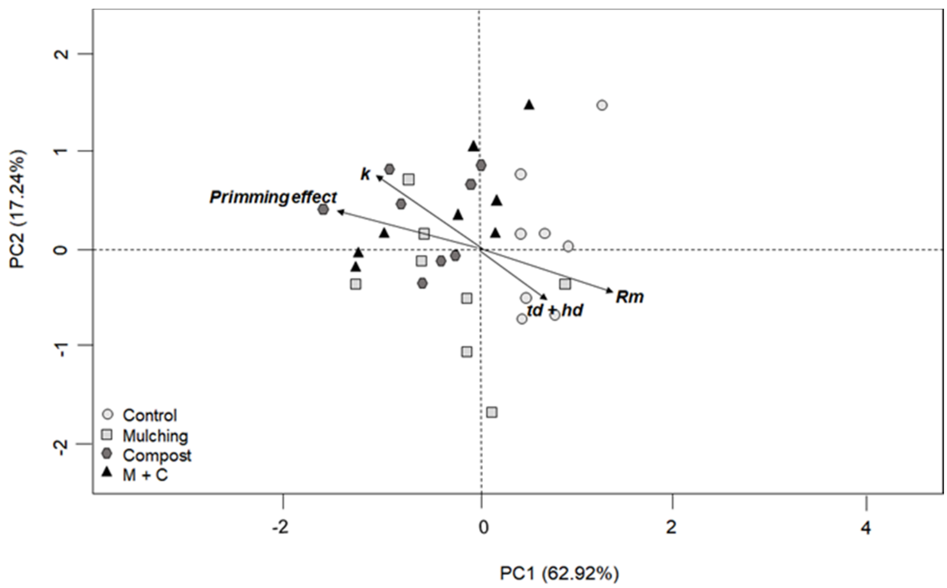

Figure 5. Principal component analysis (PCA) for the litter decomposition data (Primming effect, k, hd, td, and Rm) of different organic residue management. For analysis, priming effect, k, hd (half-decay rate), td (total decay rate), and remaining litter mass (Rm) were included. Organic residue managements are represented as follows: Control = circles; Mulching = squares; Compost = hexagon; and Compost plus mulching = triangles. Only significant vectors are shown ($p < 0.05$).

4. Discussion

The observed results in this study emphasize the influence of organic residue management (e.g., mulching and compost) on decomposition rate (k), half-decay rate (hd), total-decay rate (td), priming effect, remaining litter mass (Rm), and soil organisms' community (e.g., abundance of Acari—Acaridae, Araneae—Araneidae, Blattodea—Blattidae, Blattodea—Termitidae, Coleoptera—Cugygidae, Coleoptera—Staphylinidae, Dermaptera—Forficulidae, Diptera—Muscoidea, Gastropoda—Gymnomorpha and Pulmonata, Hemiptera—Cicadidae, Neuroptera—Chrysopidae, Strepsiptera—Halictophagidae, and richness) in the 16-year field with *P. pyrifolia* plants cultivated in subtropical Acrisols, Southern Brazil. All organic residue management improved the decomposition rate, priming effect, and soil organisms' activity (e.g., by the obtained results in the litterbag mesh assay) under subtropical conditions when we compared the results obtained in the organic residue management with the control treatment. These results also provide evidence about the organic decomposition mediated by soil organisms' community.

Essentially, this study highlighted how the isolate and combined use of compost and mulching can change organic matter dynamics, soil organisms' structure and activity, following an organic farming system schedule and preventing the use of synthetic compounds. Decomposition rate (k), half-decay time (hd), total-decay time (td), priming effect, and remaining litter mass (Rm) on plots where compost was applied were higher than their results on plots where mulching and control treatments were applied using litterbag with 4 mm^2 mesh-type. On the other hand, the observed results show strong evidence about the soil organisms' activity on mulching decomposition on plots where compost was applied using litterbag with 15 mm^2 mesh-type. These results agree with the previous studies that reported positive effects of organic residues management on soil organic matter dynamics [17,43,44]. These studies have reported soil improvements, and soil organisms' activity with the continuous use of compost and green manure practice in tropical and subtropical soils. Overtime the use of organic amendments promotes both habitat and food provision to a wide range of soil organisms that provide ecosystem services, such as organic matter decomposition, nutrient cycling, and soil food web [45–47].

In subtropical agroecosystems, the rate of organic residues decomposition is the main driver that regulates the nutrient cycling process and biomass production [48]. The decomposition rate (k) in this study was positively affected using compost on the studied plots. This variable was also influenced by soil organisms' activity, since the highest values of *k* were found on plots that received litterbags with 15 mm^2 size-mesh containing compost. The decomposition rate is directly correlated with (i) high abundance of litter transformers (e.g., Coleoptera, and Diplopoda); and (ii) organic residues quality (e.g., compost) by providing food availability to a wide range of soil organisms; and N availability [49–51]. Compost as a soil amendment is an interesting source of organic C, N, P, and other micronutrients [36,52], and these studies have shown an improved soil food web on plots where compost was applied, which in turns promoted organic matter dynamics.

The use of compost also provides positive influence on priming effect (e.g., which represent high nutrient availability). Compost treatment showed a higher priming effect when compared with the other studied organic residues management. The use of compost also provides positive influence on organic matter traits (e.g., hd, td, and remaining litter mass) that in turns promoted soil organisms' activity. Several studies have reported an improved microbial activity, N cycling, nutrient release on soil solution, and soil organic C stocks [10,53,54]. These results support the hypothesis that compost can influence soil organic matter dynamics by improving decay rate, and primming effect, which in turn influence nutrient cycling, and plant nutrient supply [25–27]. The litterbag assay using 15 mm^2 mesh-type provided evidence about the influence of soil organisms' community on decomposition rate [19].

Inside the bags with 15 mm^2 mesh-type, soil organisms classified as litter transformers (e.g., Coleoptera and Diplopoda) were found and identified. These soil organisms influence the physical fragmentation of organic residues as described by Liu et al. [55], and Liu et al. [56]. The high-quality of the organic residues used in the studied plots created positive conditions for decomposers, as we found remaining litter mass on litterbags with 4 mm^2 mesh-type [17]. Here, in these bags a high abundance of red and gray fungi colonies combined with high abundance of microregulators (e.g., Acari) that feed on this fungi community was found. Unfortunately, strong evidence of the combined use of compost and mulching was not detected. This suggest that combined action of organic residues needed to be studied in a long-term schedule. In this case, just the eighteen studied months were not enough to go deeper in the ecological process behind the combined use of organic residues as direct sources of habitat and energy to the soil organisms [57,58].

Results of this study indicate that compost and mulching decomposed more easily by the hd and td results in the plots where compost, and the combination of compost and mulching were applied, respectively. The organic residues decomposition was significantly faster under the compost treatments than the control. Both half-, and total-decay rate were positively correlated to the soil organisms' activity. Here, the action of litter transformers on organic residue fragmentation must be considered [23]. The soil organisms promote physical fragmentation of the organic residues, thus increasing their surface area on the ground, and incorporating all fragmented residues into the soil profile. This process improves the decomposer activity that promotes chemical fragmentation of the organic residues in the soil profile [59]. Decomposition rates on areas that received N-rich organic residues have been studied, however, previous studies have concerned only compost. Other studies have shown a strong influence of N-rich organic residues than organic residues with recalcitrant-rich compounds [60,61]. Similarly, Kan et al. [30] reported that hd, and td were most strongly affected by N-rich compounds, and less significantly by C-rich compounds, stage of succession, and the stage of soil formation.

In an earlier study of agroecosystem on a subtropical region, the fast N mineralization makes it available for plant uptake, and thus retuning to soil through plant senescence and litter deposition (e.g., positive feedback). In this study, the compost treatment promoted the decomposition rate of both mulching and compost in our litterbag assay. Here, the plots where the compost was previously applied have provided an energy-rich environment with labile sources for the soil organisms' community [30]. It is commonly believed that C-rich compounds as the mulching residues are decomposed less quickly than compost, which contain more N-rich compounds and less lignin [55]. Mulching residues often contain anti-herbivory compounds such as silica, secondary compounds, and structural traits. In this condition, a trade-off among litter transformers and decomposers must be expected [11]. Thus, the hypothesis about the soil organic residues management altering the release of some C-rich compounds was supported in both cases where we have used compost and mulching. Here, strong evidence about the organic residues enhancing the soil organisms' community was found, which in turn improved decomposition rate [17,28].

For soil organisms' abundance and richness, plots that received mulching and the combination with mulching and compost showed the highest values of these variables. Thus, these results support the hypothesis that organic residues management that provide high input of C-rich compounds may positively affect soil organisms' community structure by habitat provision [10,17]. The high abundance and richness presented by plots that received high amounts of C-rich compounds may be related with the mulching layer on the soil surface. Moreover, the hypothesis provided by Melo et al. [10] that in agricultural soil the soil organisms' abundance is driven by the habitat quality, while soil organisms' diversity is driven by organic residues with N-rich compounds cannot be excluded. These results agree with previous studies which reported that soil ecosystem with constant organic residues input increase soil organic carbon, soil nutrient contents (e.g., P, N, and micronutrients), soil food web (e.g., Arachnida, Insecta, and Myriapoda), and ecological processes (e.g., nutrient cycling, herbivory control, and litter transformation) [36,62,63]. Organic residues by providing habitat and energy supply can improve both the ecological process and energy flow in the agroecosystems, thus creating a complex soil food web in positive plant-soil feedback [63].

Compost and mulching are important organic residues to soil organisms, and these kinds of residues act as food resource and refuge site, respectively [10,64]. Soil organisms, especially Orders with significative abundance (Acari—Acaridae, Blattodea—Blattidae, Diptera—Muscoidea, Mollusca—Pulmonata, Opiliones, and Strepsiptera—Halictophagidae) were determinants in our study to separate the organic residues influence. These results agree with the previous works [65,66] that reported a diverse soil food web in the soil ecosystem that received organic residues. By altering soil organic matter compartment, organic residues may alter soil reaction and some nutrient contents and thus may be responsible for the abundance and richness of soil organisms in plots where mulching, and the combination with mulching and compost were applied [67,68]. The hypothesis that compost may promote soil organisms' abundance was not supported. Overall, the soil organisms' community was strongly influenced using mulching (e.g., habitat provision), whereas the decomposer was strongly influenced using compost (e.g., energy fluxes). In fact, both organic residues may enhance the trophic structure by building links among soil organisms, plant traits, and soil factors. These links are important ecological processes such as biological control, mutualism, plant-arthropod interaction, and nutrient cycling [69,70].

5. Conclusions

The organic residues management determined organic matter decomposition (half-decay rate, total-decay rate, remaining residue mass, k, primming effect), soil organisms' abundance and richness in an Acrisol of the Southern Brazil. The use of compost showed high decomposition rate and primming effect in subtropical conditions, while the use of mulching and the combination with compost and mulching provided conditions to sustain high abundance and richness related to the soil organisms' community. The highest values of half-decay rate, total-decay rate, remaining residue mass, k, primming effect obtained using the litter bags with 15-mm^2 demonstrate the influence of soil organisms on residues decomposition. The main results observed in this manuscript suggest that organic residues have positive effects on decomposition rate of mulch and compost (e.g., improving the acceleration of organic residues decomposition), soil organisms' activity, and soil organisms' community composition. These results highlighted the importance of considering both residues with N- and C-rich compounds as energy source and habitat provision, respectively. Thus, long-term experiments considering the combined use of mulching and compost may exploit a deeper view inside the organic matter dynamics, and soil organisms' role in organic residues decomposition.

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