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PROGRAMA DE PÓS-GRADUAÇÃO EM ECOSSISTEMAS AGRÍCOLAS E NATURAIS

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Resíduos orgânicos aplicados em sistema comercial de produção de pera asiática:

Sustentabilidade, organismos do solo, estrutura trófica e processos ecológicos

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O presente trabalho em nível de mestrado foi avaliado e aprovado por banca examinadora composta pelos seguintes membros:

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RESUMO GERAL

O presente estudo teve como objetivos avaliar o efeito do manejo de cobertura morta e composto orgânico sobre: i) o estado nutricional das plantas de *Pyrus pyrifolia*; ii) produção de frutos; iii) produção de biomassa da parte aérea e da raiz; iv) estoque de carbono; v) taxa de decomposição dos resíduos orgânicos; e vi) biodiversidade edáfica. Para isso delineou-se um experimento em blocos casualizados usando um esquema fatorial 2 × 2 (presença e ausência da cobertura morta e composto orgânico), em 4 blocos. Cada parcela possuiu um espaçamento de 24 × 36 m (n= 25, plantas por parcela). Realizaram-se coletas de solo (e.g., uma amostra composta por parcela) e resíduos orgânicos (cobertura morta nos pomares e composto nas pilhas de compostagem), para as análises químicas. Para analisar o estado nutricional e determinar a produção foram coletadas folhas e todos os frutos de 9 plantas na porção central de cada parcela. Para determinação da biomassa da parte aérea, da raiz, biomassa total e densidade de carbono em cada compartimento utilizaram-se modelos preditivos considerando a altura total das plantas (h) e diâmetro do caule a 30 cm do solo. Para determinação do tempo total (*td*) e tempo médio (*hd*) de decaimento dos resíduos orgânicos e massa remanescente (Rm), taxa de decomposição (*k*) e efeito *primming*, utilizaram-se *litterbags* em cada parcela com diferentes aberturas de malhas (4 mm^2 e 15 mm^2). Para a caracterização da biota edáfica, utilizaram-se armadilhas do tipo Provid. Os maiores valores para abundância das Famílias Araneidae, Termitidae, Staphylinidae e Cicadidae foram observados no tratamento controle. Enquanto os maiores valores para o estoque de carbono orgânico no solo, densidade total de carbono no ecossistema, *hd*, *td*, massa remanescente (*litterbags* com 15 mm^2 de abertura contendo cobertura morta), abundância das Famílias Acaridae, Pulmonata e Halictophagidae foram observados onde apenas cobertura morta foi aplicada. Em seguida, os maiores valores para teor de nitrogênio foliar, *hd*, *td*, massa remanescente (*litterbags* com 4 mm^2 de abertura contendo cobertura morta), taxa de decomposição, efeito *primming*, abundância das Famílias Cugygidae, Forficulidae e índice de riqueza foram observados no tratamento onde apenas o composto foi aplicado. Finalmente, os maiores valores para altura total, biomassa do caule, raiz, galhos, biomassa total, produção, densidade de carbono acima e abaixo do solo e abundância das Famílias Blattidae, Muscoidea, Gymnomorpha e Chrysopidae foram observados no tratamento onde a cobertura morta e o composto foram aplicados em conjunto. Os resultados demonstram que o manejo de resíduos orgânicos promoveu melhorias no sistema de produção de *P. pyrifolia* (estado nutricional das plantas, produção de frutos, produção de biomassa, taxa de decomposição, mineralização, abundância e riqueza da biota edáfica), principalmente onde foi aplicado composto.

Palavras-chave: *Pyrus pyrifolia* (Burm.) Nak; Estoques de carbono no solo; Produção; Fontes orgânicas; Nutrição de plantas; Comunidade da biota edáfica.

MAIN ABSTRACT

The present study aimed to evaluate the effect of mulching and compost management under: i) *P. pyrifolia* nutritional status; ii) yield; iii) shoot and root biomass production; iv) carbon sequestration; v) organic residues decomposition rate; vi) soil biota community composition. To achieve these aims, we installed a randomized block using a factorial design 2 × 2 (presence and absence of mulching and compost) within four blocks. Each plot consisted of 24 × 36-m (n= 25 plants per plot). We collected soil samples (a compost sample per plot), organic residues (mulching on orchard piles, and organic compost on composting piles), for chemical analysis. To determined *P. pyrifolia* nutritional status, and yield we collected leaves and all fruits of nine *P. pyrifolia* plants on the central portion of each plot. While, for determining shoot, root, total biomass, and carbon density in each compartment we utilized predictive models, considering height (m), and stem diameter at 30-cm of soil surface. Next, total, and half time of residues decay, remaining mass, decomposition rate, and primming effect were determined utilizing litter bags with different mesh sizes (04-mm^{-2} and 15-mm^{-2}) on each plot. To characterize the soil biota community Provid-type traps were placed. The highest values for abundance of Families Araneidae, Termitidae, Staphylinidae e Cicadidae were observed where no residue was applied. While, the highest values for soil organic carbon stock, total carbon density, *hd, td*, remaining litter mass (litterbags 15-mm^{-2} size containing mulching), abundance of Families Acaridae, Pulmonata, and Halictophagidae were observed where mulching was applied. Next, the highest values for leaf nitrogen, *hd, td*, remaining litter mass (litterbags 4-mm^{-2} size containing mulching), decomposition rate, primming effect, abundance of Families Cugygidae, Forficulidae, and richens index were observed where compost was applied. Finally, the highest values for height, stem biomass, root biomass, branches biomass, total biomass, yield, above- belowground carbon density, abundance of Families Blattidae, Muscoidea, Gymnomorpha e Chrysopidae were observed where mulching and compost were applied together. Our findings showed that organic residues management promoted improvements on *P. pyrifolia* production system (plant nutritional status, yield, biomass production, decomposition rate, mineralization, soil biota abundance and richness), principally where compost was applied.

Keywords: *Pyrus pyrifolia* (Burm.) Nak; Soil organic carbon stock; Yield; Organic sources; Plant nutrition; soil biota community.

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INTRODUÇÃO GERAL

A fruticultura de clima temperado brasileira concentra-se principalmente nos Estados da região Sul (Paraná, Rio Grande do Sul e Santa Catarina), sendo as culturas de maior importância econômica *Mallus domestica* (Borkh)*, Prunus persica* (L.)*, Pyrus pyrifolia* (Burm.) Nak.*, Prunus domestica* (L.) *e Vitis vinifera* (L.) (PIO et al., 2018). O destaque na produção nacional da-se principalmente pelas condições ofertadas nessa região (e.g., quantidade de horas de frio próxima ao ideal, inverno amenos, verões quentes, chuvosos, estações bem definidas e altitudes elevadas), como descrito por Curi et al. (2020). Entretanto, a produção de algumas culturas ainda se apresenta incipiente devido a fatores como: Fertilidade do solo, adaptabilidade de porta-enxertos, alta exigência de horas de frio por parte de algumas culturas e aspectos fitossanitários, o que eleva consideravelmente os custos associados a produção (OLDINI et al., 2019; SETE et al. 2020).

A pera asiática [*Pyrus pyrifolia* (Burm.) NAK] é uma das culturas mais importantes de clima temperado da região Sul do Brasil, além de uma das mais comercializadas em todo o mundo (QUINET e WESEL, 2019). O interesse comercial da fruta no país estimula pesquisas que visem preencher lacunas ainda existentes neste campo de estudo, principalmente no que se refere à ecologia dos agroecossistemas em pomares comerciais em transição para sistemas orgânicos, redução de custos e aumento na produtividade (WANG et al., 2020). Nesse contexto, a utilização de práticas de manejo que reduzem limitações e custos associados são necessárias, por exemplo, a utilização de fontes orgânicas (CEN et al., 2020). Estas que contribuem diretamente na promoção da fertilidade do solo, produção sustentável, estruturação da teia trófica da biota edáfica e contribuindo com o sequestro de carbono no solo (MELO et al., 2019; NASCIMENTO et al., 2021).

O manejo de resíduos orgânicos pode: 1) promover atributos biológicos do solo, como por exemplo, a riqueza e abundância da biota edáfica, pelo fornecimento de habitat e recursos energéticos como hipotetizado por Souza e Freitas (2018); 2) melhorar o status nutricional das plantas e promover seu crescimento, pela maior disponibilidade de nutrientes a partir da intensificação da ciclagem de nutrientes (DELONZEK et al., 2019; YANG et al., 2020); 3) incrementar os estoques de carbono no solo, pela introdução de nitrogênio e carbono lábeis no solo, protegendo a fração recalcitrante de carbono presente na materia orgânica do solo (LI et al., 2018).

Nesse contexto, a comunidade da biota edáfica exerce um papel determinante na taxa de decomposição da materia orgânica, controle de herbívoria e melhoria nos atributos químicos do solo (YANG et al., 2018). Esses organismos são extremamente numerosos e diversos, contribuindo com serviços ecossistêmicos, tais como a estruturação do solo, transformação da matéria orgânica do solo, sequestro de carbono, ciclagem de nutrientes, controle biológico, predação e herbívoria (TOSELLI et al., 2020; ZHANG, MALTAIS-LANDRY e LIAO, 2021). Os organismos da biota edáfica podem ser considerados bioindicadores de qualidade nos agroecossistemas, devido a rápida resposta (redução de diversidade e riqueza) frente as atividades antrópicas empregadas nestes sistemas, por exemplo, práticas de manejo convencionais (revolvimento contínuo do solo, remoção da cobertura vegetal, adubação mineral e etc...), alteram negativamente a dinâmica da materia orgânica do solo, limitam a disponibilidade de recursos alimentares e provisão de habitat (SOUZA e FREITAS, 2018).

Estudos recentes demostram que práticas de manejo voltadas à conservação do solo (adição de fontes orgânicas), em sistemas de produção podem influenciar positivamente a comunidade da biota edáfica (ROWEN, TOOKER e BLUBAUGH, 2019; TAHAT et al., 2020). Estudos conduzidos por Gómez et al. (2018), demonstraram que a utilização de diferentes fontes orgânicas aumentou a presença de predadores na ordem de 148% em dois anos de manejo em relação ao manejo convencional. Em um estudo semelhante, de Pedro et al. (2020) observaram que a adoção de práticas que promovem aumento nos teores de carbono orgânico no solo favoreceram a diversidade da biota edáfica, principalmente grupos-funcionais como: transformadores de serapilheira (Ordem Coleoptera, Familia Tenebrionidae) e predadores (Ordem Coleoptera, Familia Carabidae e Ordem Araneae, Familia Gnaphosidae), em pomares comerciais de peras. Dessa forma, o fornecimento de habitat para grupos específicos da biota edáfica (e.g., predadores), contribui diretamente com a estruturação da teia trófica do solo, reduzindo a pressão de herbívoria e a utilização de defensivos químicos (SOUZA et al., 2020).

A biota edáfica está diretamente relacionada com a ciclagem de nutrientes, de forma direta pelo forrageamento dos resíduos e excreção de *pallets* fecais facilitando a decomposição e mineralização por parte da microbiota (e.g., fungos e bactérias), ou de forma indireta, pelo controle nas taxas de forrageamento (predação), e pela microrregulação de decompositores (SOFO et al., 2020). Estudos realizados por Sommaggio, Pretti e Burgio (2018), demonstraram que a diversificação de fontes orgânicas em sistemas de produção de frutas de clima temperado, pode favorecer indivíduos responsáveis pelo forrageamento da serapilheira em até 261%, incremento a ciclagem de nutrientes e a criando um *feedback* planta-solo positivo, como descrito por Forstall-Sosa et al. (2020). Pomares comerciais que adotam práticas de manejo voltadas a utilização de fontes orgânicas, contribuem com a manutenção e fornecimento de matéria orgânica através da aplicação da compostagem e de cobertura morta podem apresentar elevada abundância de grupos-chave da biota edáfica e incrementar e ciclagem de nutrientes (de NOVAIS et al., 2020).

No entanto, ainda é pouco conhecida a influência e viabilidade da aplicação de resíduos orgânicos (composto orgânico e cobertura morta) sob: i) o estado nutricional da *P. Pyrifolia*; ii) taxa de crescimento, produção de biomassa e produtividade de frutos; iii) potenciais incrementos no sequestro de carbono no solo; iv) aspectos de qualidade biológica do solo; v) caracterização dos principais grupos da biota edáfica ligados a ciclagem de nutrientes e taxa de decomposição em pomares de *P. Pyrifolia*; e vi) na estruturação da teia trófica do solo nesses ambientes. O objetivo do presente trabalho foi avaliar os efeitos do manejo de resíduos orgânicos sob o estado nutricional, produção de biomassa, produtividade, e potencial incremento no sequestro de carbono em uma plantação de *P. pyrifolia* no Sul do Brasil. Bem como, os efeitos do uso de resíduos orgânicos sob a taxa de decomposição, taxa de decaimento dos resíduos, efeito *primming* e riqueza e abundância da biota edáfica.

Esta dissertação está dividida em dois capítulos que foram publicados na revista *Agronomy* MDPI (https://www.mdpi.com/journal/agronomyite). Abaixo seguem os títulos originais dos capítulos publicados em língua inglesa.

I. Aboveground Biomass, Carbon Sequestration, and Yield of *Pyrus pyrifolia* under the Management of Organic Residues in the Subtropical Ecosystem of Southern Brazil (https://doi.org/10.3390/agronomy12020231)

II. Decomposition Rate of Organic Residues and Soil Organisms' Abundance in a Subtropical *Pyrus pyrifolia* Field (https://doi.org/10.3390/agronomy12020263)

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REFERENCIAL TEÓRICO

Fruticultura de clima temperado

As espécies frutíferas de clima temperado são originarias da Ásia e da Europa, atualmente são cultivadas em diversas regiões do mundo que apresentam condições semelhantes às do centro de origem das espécies, principalmente com estações do ano bem definidas e invernos com baixas temperaturas (PIO et al., 2018). As principais culturas de clima temperado produzidas no Brasil são: *Malus domestica*, *Pyrus* sp., *Prunus persica*, e *Vitis* sp. A produção de frutas de clima temperado é uma das atividades agrícolas mais expressivas do Sul do Brasil (STUPP et al., 2021). O mercado interno é responsável por absorver grande parte da produção anual, destaca-se a participação (e.g., devido os melhores preços na comercialização dos frutos) no mercado externo, tendo exportado no ano de 2020 62,5 mil toneladas de *M. domestica*, 49,2 mil toneladas de *V. vinífera*, 93 toneladas de *P. persica* e 90 toneladas de *Pyrus* sp. (PEREIRA et al., 2019; FAO, 2021).

Na América Latina, o Brasil é o segundo maior produtor de maçãs (1.222.979 ton.), o terceiro maior produtor de uvas (1.485.292 ton.) e pêssegos (183.132 ton.) e o quarto maior produtor de espécies do gênero *Pyrus* (16.722 ton.). Em 2019, o país apresentou uma área plantada de 126.390 hectares com espécies de frutíferas de clima temperado divididas em 19 Estados brasileiros (IBGE, 2021).

Apesar de muitos anos desde a domesticação dessas culturas, as alterações nas condições climáticas em regiões historicamente reconhecidas como centro de produção, têm atualmente limitado a produção em algumas partes do mundo e em algumas mesorregiões dos Estados do Sul do Brasil (ANDRESEN e BAULE, 2018).

No Brasil, as espécies frutíferas têm como característica principal a perda da folhagem e a diminuição das atividades metabólicas nos períodos de outono e inverno para superar as baixas temperaturas, tendo seu crescimento e desenvolvimento impulsionados entre a primavera e o verão (SALAMA et al., 2021). A produção brasileira concentra-se principalmente no Paraná, Santa Catarina e Rio Grande do Sul (WREGE et al., 2018). No entanto, também podemos encontrar essas espécies sendo cultivadas em alguns Estados do Sudeste brasileiro e no vale do São Francisco (e.g., produção de uvas de mesa), graças ao melhoramento genético, a técnicas avançadas de quebra de dormência e uso de porta-enxertos adaptados a diferentes condições climáticas (PETRI et al., 2019).

Espécies de plantas do gênero *Pyrus*

As espécies do gênero *Pyrus*[1] são originarias das regiões montanhosas da China e acredita-se que tenham surgido no período terciário a 65 milhões de anos atrás (WAHOCHO et al., 2020). Dentre as espécies de maior destaque a *Pyrus pyrifolia* está entre as mais consumidas e comercializadas em todo o mundo, devido ao seu sabor adocicado, suculência, aspectos nutricionais, como altos teores de vitamina C, ácido fólico, potássio, magnésio e outros minerais, além de benefícios a saúde humana, como propriedades antioxidantes, aceleração na recuperação de doenças urinárias e gastrointestinais (MICHAILIDIS et al., 2021).

As espécies do gênero *Pyrus* possuem grande importância na fruticultura temperado e na economia mundial, com uma produção anual próxima de 24 mil toneladas, ocupando uma área de 1,4 mil hectares, onde, os maiores produtores mundiais são a China (17.000.000 ton.), Estados Unidos (661.340 ton.) e Argentina (595.427 ton.) (FAO, 2021). No Brasil a produção de plantas do gênero *Pyrus* é de 16.722 toneladas em uma área de 1.156 ha, sendo Santa Catarina o segundo maior produtor brasileiro, com uma produção de 5090 toneladas (IBGE, 2021). A produção nacional ainda não consegue abastecer o mercado interno, sendo que 91% das frutas consumidas no país vem da importação (cerca de 190 mil toneladas) anualmente, tornando a importação da fruta relativamente cara (ARAUJO et al., 2021).

Dentre os principais fatores que limitam a produção brasileira, pode-se destacar a adaptabilidade de porta-enxertos, que devem exercer menor vigor para que a planta não concentre seu desenvolvimento apenas nas partes vegetativas (OU et al., 2019). Atualmente, os porta-enxertos mais utilizados no país são variedades de marmelo (*Cydonia oblonga* Mill.) e variedades selvagens de pera asiática (*Pyrus calleryana* Decne.) (PASA et al., 2020). Diversos estudos têm sido realizados na busca de porta-enxertos com adaptação ideal para plantas do gênero *Pyrus*, por exemplo, maior produtividade e menor vigor (ALMEIDA, FIORAVANÇO e MARODIN, 2020; PASA et al., 2020).

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[1] O gênero *Pyrus* possui cerca de 22 espécies, sendo as mais comercializadas a [(*Pyrus communis*) L.] pera europeia e a [(*Pyrus pyrifolia* Burm.) Nak] pera asiática, tendo seu cultivo datado de aproximadamente 3300 anos atrás (WAHOCHO et al., 2020).

Como fator limitante, destaca-se também a ação de patógenos, como: A mosca-da-fruta (*Anastrepha fraterculus*), que age depositando seus ovos nos frutos ocasionando apodrecimento interno e consequentemente perdas econômicas (MONTEIRO et al., 2019). A mariposa oriental (*Grapholita molesta*), que age depositando seus ovos nos frutos ocasionando lesões e perda de qualidade (PADILHA et al., 2018). A cochonilha piolho-de-são-josé (*Quadraspidiotus perniciosus*), que age sugando a seiva e enfraquecendo a planta (ANSARI, BASRI e SHEKHAWAT, 2019). Além dos fungos causadores da entomosporiose (*Entomosporium mespili*), doença que ocasiona a desfolha precoce enfraquecendo a planta e diminuindo a produtividade e o fungo causador do cancro (*Botryosphaeria* sp.) que ocasiona infecções no tecido vegetal e lesões necróticas na planta (BOGO et al., 2018; ARAUJO et al., 2021).

Sistemas Orgânicos de Produção de Fruticultura de Clima Temperado

O consumo de alimentos de origem orgânica tem crescido rapidamente nos últimos anos, isso se deve a maior percepção da população sobre sustentabilidade, preocupação com a segurança alimentar e saúde humana (ŚREDNCIKA-TOBER et al., 2020). A produção de alimentos orgânicos ocupa hoje uma área de aproximadamente 69,8 milhões de hectares, o mercado atingiu cerca de 97 bilhões de dólares, tendo como países que mais comercializam: Estados Unidos, Alemanha e França (LIMA et al., 2019). A fruticultura orgânica de clima temperado ocupa uma área de 308,2 mil hectares no mundo, o que equivale a cerca de 2% da área total plantada com fruticultura de clima temperado (WILLER et al., 2020). Os países que mais produzem orgânicos nesse setor são: China (116 mil ha), Itália (26,5 mil ha), França (23,5 mil ha), Turquia (20,2 mil ha), EUA (18,0 mil ha) e Polônia (13.3 mil ha) (FiBL STATISTICS, 2021).

A área plantada com espécies do gênero *Pyrus* ocupou, em 2019, o equivalente a aproximadamente 5,6% da área ocupada com fruticultura orgânica de clima temperado. Os países que apresentaram as maiores áreas plantadas em ordem decrescente foram: China (5 mil ha), Itália (2,78 mil ha), Argentina (2,09 mil ha) e França (1,48 mil ha) (FiBL STATISTICS, 2021). Entre os anos de 2005 e 2018, a área plantada com espécies do gênero *Pyrus* no mundo cresceu na ordem de 2775%, sendo o ano de 2018, o que apresentou o maior crescimento. As principais espécies do gênero produzidas no mundo são: a pera japonesa (*P. pyrifolia* Nakai), pera europeia (*P. communis* L.) e as espécies chinesas (*P. bretschneideri* Rehd e *P. ussuriensis* Maxim). No Brasil as principais espécies mais cultivadas são a *Pyrus pyrifolia* e a *Pyrus communis*, no entanto o cultivo é realizado em pequenas áreas, que se concentram nos Estados de Santa Catarina, Paraná, Rio Grande do Sul, São Paulo e Minas Gerais (da SILVA et al., 2018). São escassas informações que descrevam em detalhes a produção orgânica de *P. pyrifolia* por Estado no Brasil (WILLER et al., 2020).

Em sistemas orgânicos de produção independentemente se o sistema é agrícola, florestal ou considerando espécies frutíferas, o preço do produto colhido é superior ao preço de produtos oriundos de sistemas convencionais (FERREIRA, MOTA e GARCIA, 2019). Na década de 90 esses altos preços eram justificados pela baixa produtividade obtida em sistemas de transição para o orgânico (ESTEVES, VENDRAMINI e ACCIOLY, 2021). No entanto, nos dias atuais, os altos preços são justificados pelas seguintes características: ausência de substâncias potencialmente tóxicas ao produtor e ao consumidor, aspectos organolépticos superiores e a sustentabilidade associada ao sistema produtivo (EBERLE et al., 2019). Nos últimos dez anos, ocorreu um aumento tanto no interesse de produzir quanto na demanda de consumir produtos oriundos de sistemas orgânicos de produção. É importante salientar que este sistema se baseia em um tripé (REN et al., 2019), que considera os seguintes aspectos:

i) sistema economicamente viável;
ii) socialmente justo;
iii) ecologicamente correto.

No segmento da fruticultura de clima temperado, espécies do gênero *Pyrus* tem demonstrado notável expansão na transição de sistemas convencionais para sistemas orgânicos (GRANATSTEIN et al., 2016). A produção orgânica pode se beneficiar com a percepção de consumir produtos de boa qualidade por parte da população em comparação com a produção convencional (uso de adubos minerais, uso de agroquímicos e impactos ambientais).

Nos sistemas orgânicos de produção, as técnicas de manejo são voltadas para favorecer a ciclagem de nutrientes, promover melhorias na qualidade física, química e biológica do solo, além de diminuir a pressão de herbívoria e a competição com plantas espontâneas, sem a necessidade da adição fertilizantes minerais e defensivos químicos (ALDEBRON et al., 2020).

Esses sistemas adotam um manejo voltado para a adição de fontes orgânicas (e.g., esterco de animais, compostagem, cobertura e subprodutos da indústria) e plantio de culturas de coberturas com aptidão para adubação verde (MDITSHWA et al., 2017).

Dessa forma, o manejo desses resíduos orgânicos pode ser considerado um fator chave para a produção, aumentando os teores de materia orgânica do solo, a atividade da biota edáfica, mediando as interações solo-planta e contribuindo com o sequestro de carbono nos pomares (FRENCH et al., 2021)

Manejo de resíduos orgânicos na fruticultura de clima temperado

A utilização de fertilizantes minerais pode ser substituída por fontes alternativas de nutrientes, como por exemplo compostos orgânicos, diminuindo os custos de produção, aumentando a biodiversidade da biota edáfica, promovendo processos ecológicos importantes para esses sistemas como a ciclagem de nutrientes (ONWOSI et al., 2017). A compostagem é um processo dinâmico no qual os microrganismos transformam resíduos orgânicos vegetais e/ou animais em compostos estáveis (WEI et al., 2018), sob temperatura e umidade controladas, podendo ser realizada em sistemas abertos (a partir de pilhas que são revolvidas constantemente para auxiliar na aeração) ou sistemas fechados (com o uso de reatores controlando a temperatura, umidade e oxigênio) (TRATSCH et al., 2019).

O manejo de resíduos orgânicos é uma prática promissora, na melhoria da fertilidade do solo, diminuição de doenças nas plantas e promoção de sustentabilidade, devido a reciclagem de resíduos produzidos nos próprios módulos, conferindo destinação ambientalmente correta dos resíduos gerados no processo produtivo (CESARO et al., 2019; AYILARA et al., 2020). No entanto, os resíduos aplicados devem estar completamente estabilizados, devido as altas concentrações de sais solúveis, amônia, ácidos graxos voláteis, sendo prejudiciais no desenvolvimento das plantas (TOSELLI et al., 2020). A melhoria na qualidade final do processo depende de fatores importantes como a umidade, pH, temperatura e ação de microrganismos.

No processo de compostagem pode-se identificar com base nas variações de temperatura três fases distintas: mesofílica, termofílica e maturação (AZIM et al., 2018). Na fase mesofílica ocorre a metabolização de moléculas simples, que são transformadas em ácidos orgânicos, sendo realizada principalmente por bactérias, em temperaturas que podem chegar a 40–45 ºC (MARGARITIS et al., 2018). A fase termofílica é marcada principalmente pela degradação de compostos complexos por fungos e bactérias, nesta fase a temperatura pode variar de 40–65ºC. O aumento da temperatura é extremamente importante para eliminação de patógenos (RAVIDRAN et al., 2019). Na fase de maturação ocorre a condensação dos compostos carbonosos e a polimerização, contribuindo diretamente na formulação dos ácidos fúlvicos e húmicos (FUENTES, BAIGORRI e GARCIA-MINA, 2020).

A aplicação de fontes orgânicas pode contribuir para manutenção da qualidade do solo, através de mudanças promovidas em atributos edáficos, tais como aumento da porosidade do solo e aumento na diversidade de microrganismos edáficos (JAIN e KALAMDHAD, 2020). Bem como mudanças na dinâmica da materia orgânica e potenciazaliação do efeito *primming* positivo no solo, que pode ser definido como as alterações na cinética de decomposição e mineralização da materia orgânica a partir da entrada de fontes lábeis (e.g., glicose, aminoácidos, exsudatos radiculares e raízes finas mortas no solo), estando ligado aos mecanismos de co-metabolismo, estequiometria, mineração do nitrogênio e síntese enzimática (FENG, SUN e ZHANG, 2021). Estudos recentes têm demonstrado que o manejo de resíduos orgânicos (cobertura morta) pode contribuir:

i) No controle de danos ocasionados em culturas de clima temperado, reduzindo a pressão de herbívoria, aumentando a presença de inimigos naturais em até 38% quando comparado ao controle integrado de pragas (MIP) (SÅMNEGARD et al.,2018);

ii) Melhoria dos atributos químicos do solo (carbono, nitrogênio, fosforo e potássio na ordem de 25%; 6%; 221%; e 31%, respectivamente) (ZHU et al., 2020);

iii) melhorias no estado nutricional das plantas (nitrogênio, cálcio, ferro, cobre e boro na ordem de 2%; 4%; 18%; 3% e 4%, respectivamente) nas folhas maduras, além de aumento de 28% no rendimento dos frutos (PERAZZOLI et al., 2020). Manejo de resíduos orgânicos: Aspectos legais

A procura por alimentos de origem orgânica tem crescido rapidamente no Brasil, o mercado nacional de orgânicos tem movimentado cerca de 800 milhões de dólares, o que corresponde a 0,71% em termos de participação no mercado mundial (FROEHLUCH, MELO e SAMPAIO, 2018). A transição de sistemas de produção convencional para orgânico tem se intensificado na expectativa de atender o mercado e uma das maiores dificuldades durante esse processo é a utilização de fertilizantes que se enquadrem na categoria de compostos orgânicos (MEDAETS, FORNAZIER e THOMÉ, 2020). A certificação e obtenção de selo de produção orgânica ocorre mediante o registro de, no mínimo, cinco anos de todos os procedimentos e operações de manejo no sistema de produção, bem como um plano de manejo orgânico (MUÑOZ et al., 2016).

Em sistemas orgânicos de acordo com a legislação vigente (BRASIL, 2011), é permitida a utilização de:

a) Adubos verdes;
b) Argila (vermiculita);
c) Biofertilizantes (com componentes animal e vegetal);
d) Composto orgânicos;
e) Derivados de aquicultura e pesca;
f) Excrementos (estercos) de animais;
g) Gesso agrícola;
h) Inoculantes minerais (fosfato de rocha, hiperfosfato, sulfato de potássio, sulfato duplo de potássio e magnésio, micronutrientes, sulfato de cálcio e enxofre elementar);
i) Inoculantes orgânicos (microrganismos e enzimas);
j) Preparos homeopáticos e biodinâmicos;
k) Resíduos sólidos orgânicos domiciliares;
l) Vermicompostos;
m) Resíduos industriais;
n) Turfas.

Atualmente, a legislação brasileira que trata da produção orgânica é regida pela lei nº 10.831 de dezembro de 2003, que dispõe sobre a certificação, fiscalização e certificação de produtos orgânicos. Esta lei é regulamentada pelo decreto nº 6.232 de dezembro de 2007, que estabelece medidas relacionadas com a qualidade dos produtos e processos. Bem como, pelas instruções normativas nº 17 de maio de 2009; nº 38 de agosto de 2011 e nº 46 de outubro de 2011, que tratam da aprovação de normas técnicas para obtenção de produtos de origem orgânica e extrativismo sustentável; regulamente técnico para produção de sementes e mudas em sistemas orgânicos; e substancias e práticas permitidas nos sistemas orgânicos de produção (BRASIL, 2003; 2007; 2009; e 2011 a,b).

Biota edáfica, processos ecológicos e serviços ecossistêmicos

Entende-se por biota edáfica, indivíduos que passam seu ciclo de vida ou parte dele no ecossistema solo. Esses organismos são extremamente numerosos, diversos e atuam modificando as características químicas, físicas e biológicas do solo (SOUZA e

FREITAS, 2018). A biota edáfica compõe uma extensa e complexa teia alimentar, formando interações positivas (retroalimentação solo-biota-planta), viabilizando a produção primaria líquida e garantindo o equilíbrio dos ecossistemas (ZHANG et al. 2018). Podem-se classificar esses organismos em três grupos principais (USMAN, MUHAMMADAD e CHIROMAN, 2016), levando em consideração o seu tamanho corporal (micro, meso e macrofauna). A microfauna (organismos com tamanho corporal menor que 100µm – compreende os Rotíferos, Tardígrados e Nematoides), a mesofauna (organismos de tamanho corporal entre 100 µm e 2 mm – compreende os Ácaros, Colêmbolos, Pseudoescorpiões, Dipluras, Proturas e Enchytraeidae) e a macrofauna (e.g., organismos de tamanho corporal entre 2 e 20 cm – compreende as Formigas, Térmitas, Miriápodes, Minhocas, Besouros, Aranhas e Cupins) (CASARIL et al., 2019). Destacam-se também a ocorrência de grupos diretamente envolvidos em processos ecossistêmicos (e.g., dinâmica da materia orgânica, produção primária liquida, ciclo do carbono nos ecossistemas) como por exemplo, archeaes, protistas, fungos e bactérias (ZHANG et al., 2021). Bem como, de indivíduos com tamanho corporal superior aos artrópodes (e.g., mamíferos escavadores, anfíbios e répteis), que possuem funções importantes nos ecossistemas (e.g., predação, criação de tuneis, nidificação e estimulo da produção primária por meio da herbívoria), sendo estes classificados como megafauna.

Esses indivíduos podem ser ainda classificados de acordo com as funções que desempenham no ecossistema solo (alimentação, escavação, criação de tuneis e galerias). Pode-se classificar a biota edáfica em 09 grupos-funcionais de acordo com Souza e Freitas (2018):

Produtores primários: Organismos que possuem metabolismo foto-autotrófico e são responsáveis pelo sequestro de CO_2 (e.g., plantas superiores);

Transformadores procariontes: Organismos que realizam alterações específicas nos ciclos do carbono, nitrogênio e enxofre (e.g., Indivíduos do gênero Rhizobiales e Thiobacillus);

Transformadores de serapilheira: Organismos que fragmentam a serapilheira (e.g., ação física através do aparelho bucal do tipo mastigador) em frações menores, facilitando a decomposição pela microbiota (e.g., Coleoptera-Scarabidae; Blatodea-Blattidae e Spirobolida – Scolopendromorpha);

Engenheiros ecossistêmicos: Organismos que escavam túneis e galerias para locomoção e criação de ninhos alterando os atributos físicos do solo e contribuindo com a incorporação da matéria orgânica nos horizontes mais profundos do solo além de promover hábitat para grupos menores (e.g., Hymenoptera- Formicidae; Blatodea-Terminidae; Haplotaxida-Lumbricidae);

Predadores: Organismos que regulam as populações da biota edáfica na camada da serapilheira e acima dela (e.g., Araneae-Araneidae; Dermaptera-Forficulidae; Opiliones e Coleoptera-Carabidae);

Herbívoros: Organismos que se alimentam de partes vivas das plantas (Hemiptera-Pentatomidae; Coleoptera- Chrysomelidae e Hemiptera- Cicadellidae);

Microreguladores: Organismos responsáveis pelo controle populacional de fungos e bactérias no solo (Acari- Acaridae; Colembolla- Isotomidae e Pseudoscorpiones);

Decompositores: Organismos responsáveis pela degradação de substratos complexos em formas mais simples, através da produção de enzimas específicas (e.g., indivíduos das ordens Actynomicetales, Acidobacteriales e os filos Ascomycota e Basidiomycota);

Simbiontes: Organismos que estabelecem relações mutualísticas com espécies vegetais, fornecendo nutrientes (e.g., fósforo e nitrogênio) e recebendo energia em troca (Famílias das ordens Diversisporales, Archaeosporales, Paraglomerales e Glomerales; indivíduos da ordem Rhizobiales).

Esses organismos apresentam-se como indicadores de qualidade nos agroecossistemas, devido a sensibilidade ao manejo do solo (LAURINDO et al., 2021). Estudos realizados por Gagnarli et al. (2021); Vanolli et al. (2021), demonstram que a biota edáfica apresentou maior sensibilidade a práticas intensivas de manejo, principalmente ligadas ao manejo intensivo (uso de insumos químicos), remoção da cobertura vegetal e diminuição dos teores de materia orgânica do solo; por outro lado, práticas de manejo conservacionistas como uso de cobertura morta, aumentou a abundância da biota edáfica, devido a maior disponibilidade de recursos (carbono e nitrogênio). A adoção de práticas conservacionistas em agroecossistemas promove a estruturação da teia trófica do solo, assim, melhorando a provisão de funções ecossistêmicas desempenhadas por estes indivíduos (MASCIANDARO et al., 2018).

Entende-se por funções ecossistêmicas as interações físicas, químicas, biológicas entre os indivíduos que compõem a biota edáfica com ecossistema onde estão inseridos (HE et al., 2021), ocasionando impactos diretos no funcionamento dos ecossistemas e apoiando os serviços ecossistêmicos. Estas funções determinam ainda, o balanço de carbono no solo, as concentrações de dióxido de carbono na atmosfera, a infiltração, acúmulo de água no lençol freático e a produção primária líquida (FÁUCON et al., 2016).

Dentre as principais funções ecológicas desempenhadas pelos biota edáfica, pode-se destacar principalmente:

i) **Transformação da matéria orgânica do solo, decomposição e ciclo do carbono:** Realizada pelos grupos-funcionais dos transformadores de serapilheira e decompositores, que apoiam diretamente o serviço ecossistêmico de aprovisionamento;

ii) **Armazenamento de água:** Realizado principalmente pelos engenheiros de ecossistemas, ao criarem bioporos no solo e o crescimento radicular do produtor primário, melhorando a macroporosidade do solo e contribuindo para a infiltração da água até os lençóis freáticos;

iii) **Estruturação do solo:** Desempenhado principalmente pelos engenheiros de ecossistemas, através da criação de bioporos e pelos simbiontes (fungos micorrízicos arbusculares) através da produção de um material glicoproteico (glomalina), contribuindo diretamente na formação e estabilização dos agregados do solo, apoiando o serviço ecossistêmico de suporte;

iv) **Controle biológico:** Desempenhado por predadores e microreguladores, que controlam pressões de herbívoria e reduzem a ocorrência de patógenos e doenças, apoiando o serviço ecossistêmico de regulação;

v) **Capacidade de tamponamento do solo:** A formação de um horizonte orgânico funciona como um “filtro”, composto por microrganismos que transformam as moléculas sintetizadas presentes nos agroquímicos em compostos simples, por meio da mineralização, reduzindo os riscos de percolação para o lençol freático.

Os serviços ecossistêmicos referem-se todos serviços ofertados por um ecossistema que beneficia direta- ou indiretamente os seres humanos, fornecendo-os energia e bem-estar (serviços ecossistêmicos de provisão, regulação e culturais), podendo ser mensurados de forma quantitativa (NORIEGA et al., 2018). De acordo com Plaas et al. (2019), os serviços ecossistêmicos desempenhados pela biota edáfica contribuem diretamente para a produção primária liquida (e.g., entre 17–49%) e o controle de doenças agrícolas (em até 72%).

Comunidade da biota edáfica na fruticultura de clima temperado

A diversidade e abundância da fauna edáfica são indicadores muito importantes de equilíbrio nos ecossistemas, uma vez que todos os indivíduos possuem funções especificas em benefício do mesmo (MARSDEN et al., 2019). Do ponto de vista agronômico alguns indivíduos são vistos como potenciais ameaças a produção (herbívoros), no entanto, em ambientes equilibrados esses indivíduos estimulam a produção primária liquida e tem suas populações controladas por indivíduos superiores na teia trófica (predadores) (HEINZE, 2020). Em sistemas de produção de frutíferas de clima temperado, as práticas que promovem a diversidade da biota edáfica devem visar a manutenção dos estoques de carbono e nitrogênio do solo (SOUZA e FREITAS, 2018), sendo esses fatores observados como principais impulsionadores da maior diversidade, abundância, criação de nichos ecológicos e promoção de serviços ecossistêmicos fundamentais para a produtividade (SOFO et al., 2020).

A diversidade da biota edáfica em pomares de frutas de clima temperado é reflexo das práticas de manejo empregadas e do grau de perturbação das áreas (TURRINI et al., 2017). Os grupos da fauna edáfica desempenham diversas funções que contribuem diretamente na produção primária líquida, i.e., ciclagem de nutrientes, estimulo na produção de biomassa, predação e bioturbação (WURST, SONNEMANN e ZALLER, 2018). Neste sentido, manter a alta diversidade da biota edáfica nesses ambientes é extremamente viável e necessário para sustentar situações de alta ou moderada produção primária líquida (BOMMARCO, VICO e HALLIN, 2018).

As práticas de manejo empregadas na fruticultura de clima temperado em sistemas orgânicos ou convencionais exercem grande pressão sobre a biota edáfica, podendo aumentar ou reduzir sua diversidade e abundância (KATAYAMA et al., 2019). Em ecossistemas agrícolas e naturais os índices ecológicos mais utilizados para caracterizar a fauna do solo são:

i) Índice de riqueza (*S*): Leva em consideração o número de espécies amostradas;

ii) Índice de diversidade de Shannon-Weaver (*H'*): Pode variar entre 0 e 5. Uma vez que os valores próximos a zero indicam maior probabilidade de uma mesma espécie ser amostrada em uma população, enquanto os valores mais altos indicam maior probabilidade de todas as espécies dentro de uma população serem amostradas.

iii) Índice de dominância de Simpson (*C*): Indica a presença de grupos dominantes dentro de uma amostra. Pode variar de 0 a 1. Quanto mais

> próximo de 1 maior a probabilidade de um grupo ser dominante sobre os demais (SINA e ZULKARNAEN, 2019).

Portanto, são de grande importância estudos que demonstrem os efeitos das práticas de manejo no solo em função da diversidade da comunidade edáfica em pomares de frutas de clima temperado (de PEDRO et al. 2020).

Inventários da biota edáfica em pomares de pera, revelaram que o manejo de resíduos orgânicos aumentou a riqueza das ordens Hymenoptera, Araneae e Coleoptera em 29%; 46%; 63%, respectivamente, bem como, a diversidade em 70%, demonstrando que estas práticas influenciam a teia trófica do solo em pomares de frutas de clima temperado, contribuindo com sua diversidade, riqueza e conferindo maior complexidade ao ecossistema (de PEDRO et al. 2020). Em condições semelhantes, Aldebron et al. (2020), demonstraram que práticas que aumentem os teores de materia orgânica do solo, tem grande impacto sobre a comunidade da biota edáfica, ocasionando um aumento de 269% e 115% na abundância e riqueza de predadores em relação ao sistema convencional.

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

Abstract

Background we aimed to evaluate the influence of organic residues management on *P. pyrifolia* nutritional status (leaves N, P, and K content), plant traits (height, stem diameter, and dry biomass production), yield, and C sequestration (above- and belowground C density, soil organic carbon stock, and the total carbon density) in a 16-year subtropical *P. pyrifolia* field.

Methods We collected leaf samples to determine plant nutritional status. We measured plant traits (height, stem diameter, and dry biomass) and estimated the yield (by collecting commercial fruits) of *P. pyrifolia* plants. We collected soil samples to estimate soil organic carbon stocks. We measured leaves, shoots, and roots dry biomass production, and through allometric equations, we estimated above- and belowground C density.

Results Our plant traits assay enabled us to build four predictive models to estimate *P. pyrifolia* dry biomass production (e.g., leaves, stems, branches, and roots). The highest values of leaves N content, plant height, stem biomass, root biomass, total biomass, yield, and above- and belowground C density were found on plots that received compost as the organic residue management. 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.

Conclusion 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 to consider just one organic residues practice based on a sustainable way 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.

Keywords: Compost, Field Experiment, Mulching, Soil C Pools, Subtropical Fruticulture

Introduction

The transition process from conventional to organic farming system in *Pyrus pyrifolia* (Burm.f.) Nakai plantations in the Brazilian subtropical region has increased in the last decade (2012-2021). This process promotes the soil ecosystem, plant growth, plant nutritional status, biomass production, and C sequestration (Jiang et al. 2020, Colpaert et al. 2021). In Southern Brazil, the majority of *P. pyrifolia* fields are based in conventional farming systems that use high quantities of mineral fertilizers and "*-icide*" type products (e.g., herbicide, fungicide, and insecticide) at high costs to sustain the plant yield with low C 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 (Chen et al. 2021). In this context, the use of organic residues can be an important alternative to reduce related costs and to improve soil quality, soil C pools, plant growth, C sequestration, and biomass production by increasing soil fertility and nutrient cycling (Akhtar et al. 2019, de Corato 2020).

In Southern Brazil, *P. pyrifolia*, is one of the fourth most important tree species (*Vitis vinifera*, *Mallus domestica*, *Prunus persica*, and *P. pyrifolia*) cultivated with a high economic impact on the regional fruticulture. *P. pyrifolia* is a perennial tree that is native to China (Pio et al. 2018). It has been cultivated in Paraná, Santa Catarina, São Paulo, and Rio Grande do Sul since the 1970s' covering a total of 1,300 ha (into this area just 18% is cultivated following the organic farming system) into the Southern Brazil (FiBL Statisctics 2020). In 2018, a total of 22,000 t year^{-1} of *P. pyrifolia* fruits were produced and consumed in Brazilian (FAO 2021), however, a total of 95,000 t year^{-1} of *P. pyrifolia* fruits were imported from Asia to fulfil domestic demand. Also, the Brazilian pear fruits production is considered the fourth highest production in Southern America (FAOstat 2021). 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 (Granatstein et al. 2016; Eberle et al. 2019).

The consensus is that organic fertilization positively influences the 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. (2021). First, the application of organic residues acts as a habitat and energy supply to soil organisms (Souza and Freitas 2018), which in turn starts both mineralization and nutrient cycling processes (Menšík et al. 2018). 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 (Sharma and Bali 2018). It also promotes root growth, thus influencing belowground biomass production. Finally, the continuous use of organic residues can create positive plant-soil feedback, which over time increases dry biomass production, plant yield, C sequestration (e.g., above- and belowground C density) and soil C pools (Kang et al. 2020).

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. (2017), and Baldi et al. (2018). The use of organic residues can influence both the soil chemical characteristics and the plant nutrient supply (Baldi et al. 2018, Hunter et al. 2021). Other studies have shown an increase in the 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 (Wulanningtyas et al. 2021); and (ii) the biomass production, plant yield, and plant nutritional status as concluded by Forstall-Sosa et al. (2020). 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 (Marcillo and Miguez 2017, Daryanto et al. 2018, Giri et al. 2020).

In this context, our study addressed the following goals: a) the management of the organic residues may enhance the *P. pyrifolia* nutritional status, growth, yield, and dry biomass production; b) the use of compost and mulching could contribute to the increase in both above- and belowground C density; and c) the soil organic carbon stocks could be influenced by the management of the organic residues. To achieve these goals, we collected in a 16-year *P. pyrifolia* field study: leaves (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 done by Li et al. (2019), Tesfaye et al. (2020), Sahoo et al. (2021), and Zahoor et al. (2021).

Material 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 ha with *Pyrus pyrifolia* 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 (Temperate Oceanic climate, with warm summer and without dry season), with average annual precipitation and air temperature of 1676 mm and +15 ºC, respectively (Laurindo et al. 2021). 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 (Fig. 1). The soil type of the experimental area was classified as Acrisol (WRB 2006).

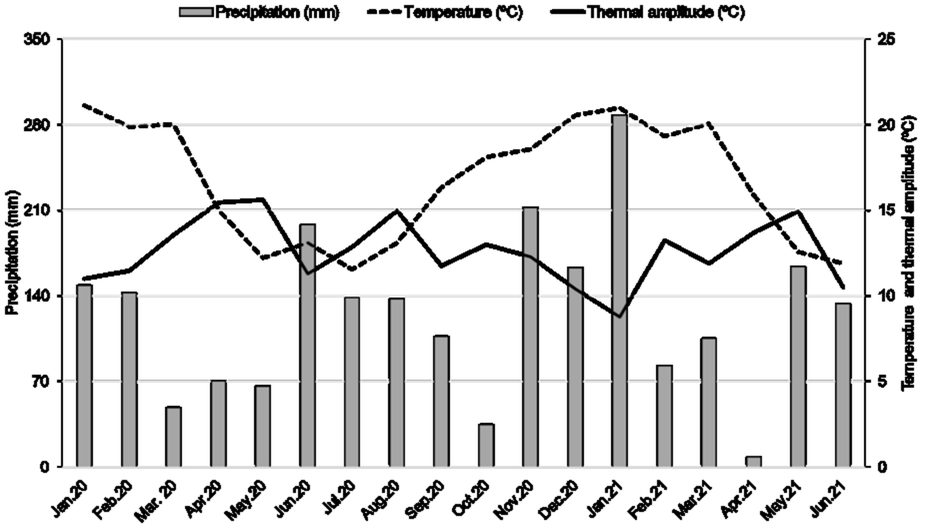

Fig. 1.1. Monthly precipitation (mm), air temperature (ºC), and thermal amplitude (ºC) from the field experiment, Curitibanos, Santa Catarina, Brazil (January 2020 to June 2021). Data were obtained online: https://ciram.epagri.sc.gov.br

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 materials were air-dried for 7 days in mulching piles (1.5 × 2.0 × 5.0 m; height: width: length) covered by black plastic during all process. We did not identify temperature changes in mulching piles. In our study, we tested the use of 3 kg m^{-2} of this material applied around the *P. pyrifolia* plants at the beginning of the field experiment. For compost, we made compost piles (1.5 × 1.5 x 3.0 m; height: width: length) using a mixture of chicken manure, green biomass, and cow manure (1: 2: 1 ratio). Daily, we watered over the compost piles (80% of field capacity), and once a week we turned it by providing oxygen inside the piles, and reducing thermal variation preventing the piles from self-burn. We have studied the effect of using 10 kg m^{-2} of compost applied on the soil surface and then incorporate at 20-cm soil depth, 60 days before the flowering stage. The field experiment was carried out in a randomized block design using a factorial scheme 2 × 2, with the use of compost and mulching. Thus, four organic residues management were compared: control (without organic residues); mulching (M); Compost (C); and mulching + compost (CM). Each plot (24 × 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) (Fig. 2). In total, we have established sixteen plots. The horizontal distance between the plots within each block was 150 m.

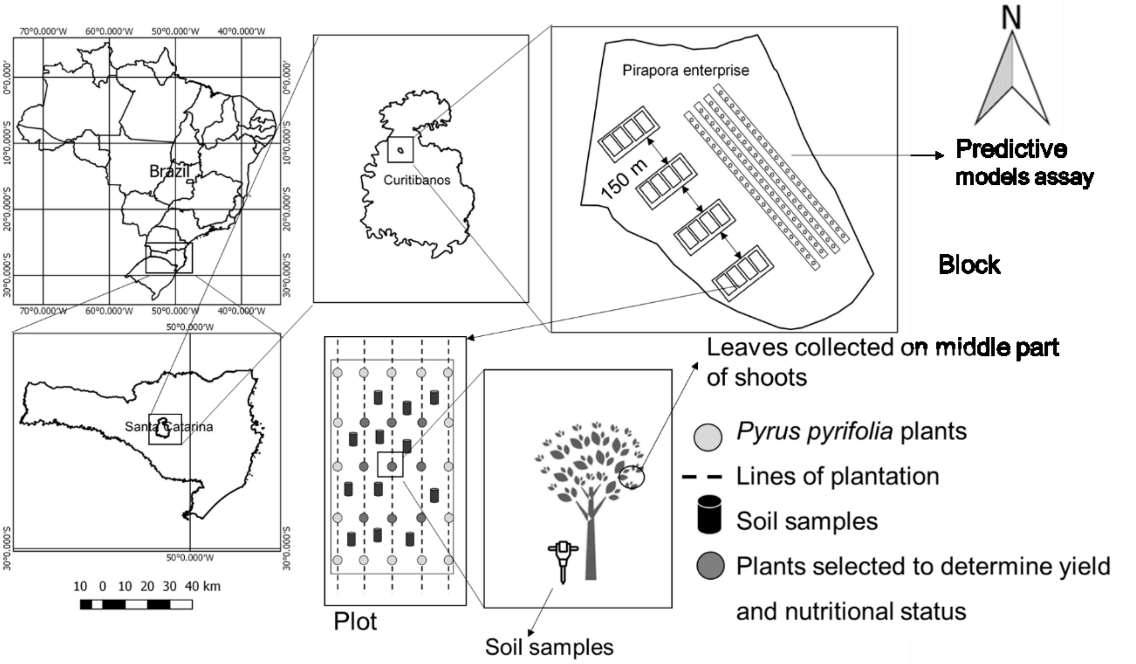

Fig. 1.2. Experimental scheme of our field study inside a 16-year *P. pyrifolia* field using different organic residues management in a subtropical ecosystem, Curitibanos, Santa Catarina, Southern Brazil.

Soil samples were taken with a soil auger from 0.0-0.2 m soil depth in each plot during two phases: i) before starting the experiment, and ii) in May 2021. To characterize the soil chemical properties from each plot, we collected twelve soil samples nested per plot. The soil samples were air-dried and passed through a 2-mm sieve (Teixeira et al. 2017). For the organic residues, we have sampled both compost and mulching material. Mulching and compost piles were produced into the own experimental area. For both studied organic residues, we collected twenty 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 (Tedesco et al. 1995).

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+}), the 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 colourimetry. The potassium chloride extraction method was used to determine exchangeable Al^{3+}, Ca^{2+}, K^{+}, and Mg^{2+} (Nascimento et al. 2021). Sum of bases was measured using the following equation: SB ($cmol_c\ kg^{-1}$) = $Na^{+} + K^{+} + Ca^{2+} + Mg^{2+}$, while cation exchange capacity was measured using the following equation: C.E.C. ($cmol_c\ kg^{-1}$) = Sum of bases + H^{+} + Al^{3+}. Soil organic carbon was estimated according to the methodology described by Teixeira et al. (2017), while total nitrogen was estimated using sulfuric acid and potassium sulphate digestion following the Kjeldahl protocol (Teixeira et al. 2017).

Table 1.1. Soil chemical properties of before starting the field experiment (mean, n = 192) in a 16-year *P. pyrifolia* plantation, Curitibanos, Santa Catarina, Brazil

Studied treatment	pH	P	K^{+}	Ca^{2+}	Mg^{2+}	Al^{3+}	SOC	TN	SB	CEC
	(H_2O)	($mg\ dm^{-3}$)		($cmol_c\ kg^{-1}$)			($g\ kg^{-1}$)		($cmol_c\ kg^{-1}$)	
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.

Both studied organic residues (mulching and compost) were chemically analyzed 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. (1995).

Table 1.2. 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

Leaf samples were collected from each of the nine plants placed in the central portion of each studied plot. We just selected nine plants per plot because 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 damages caused by beetles (e.g., *Diabrotica speciosa*) and caterpillars, thus we avoid selecting these individuals for plant nutritional status assay. We collected hundred leaves per plot in January 2020 and 2021 as recommended by CQFS (2016). All leaves were collected from the middle part of the shoots. They were packaged in paper bags, rinsed with distilled water, dried at 60 ºC for 72 h, and preserved until chemical analyses in plastic pots. To chemically characterize the leaves of *P. pyrifolia* from each studied plot, we analyzed 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. (1995).

For our predictive model assay, we considered four extra areas following our experimental treatments. Each area consisted of ninety *P. pyrifolia* plants that included 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 "Stepwise" function. Based in our traits' dataset, we have estimated four significative predictive models:

Leaves biomass (kg plant^{-1}) = 1.13 + (0.24 * number of branches) + (1.21 * plant height), $R^2 = 0.93$, $p < 0.001$;

Stem biomass (kg plant^{-1}) = -3.97 + (3.29 * stem diameter), $R^2 = 0.99$, $p < 0.001$;

Branches biomass (kg plant^{-1}) = -56.29 + (8.64 * plant height) + (3.46 * stem diameter), $R^2 = 0.95$, $p < 0.001$

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 (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:

Equation 1: $\text{Yield (t ha}^{-1}) = (Y_0 * 416) / (25 * 1000)$

Where Y_0 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 (2006):

Equation 2: $\text{ACD} = \text{ABG} * 0.47$

Equation 3: $\text{BCD} = \text{ACD} * 0.24$

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. (2013). The SOC stock was estimated by the following equation:

Equation 4: $\text{SOC}_{\text{stock}} = \text{SOC} * \text{BD} * 0.20 * (1-\text{CFM})$

Where $\text{SOC}_{\text{stock}}$ 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. (2005):

Equation 5: $\text{TPCD} = \text{ACD} + \text{BCD} + \text{SOC}_{\text{stock}}$

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 summed up to give total ecosystem carbon density.

Before the statistical analyses, all dataset was 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 the possible site effect, we have applied Friedman's test. We used Bonferroni's test to compare all variables at plots. The analyses were performed using RStudio (R Core team 2018).

Results

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 on 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 (Table 3).

Table 1.3. 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

Leave macronutrient contents (g kg^{-1})	Control	Mulching (M)	Compost (C)	M + C	F-value
N[1]	17.96 (0.37) c	18.30 (0.85) b	19.36 (0.48) a	18.69 (0.34) b	10.32***
P	1.55 (0.15) a	1.66 (0.26) a	1.63 (0.30) a	1.74 (0.51) a	0.22^{ns}

K	13.56 (1.17) a	16.21 (3.12) a	15.07 (2.19) a	15.19 (2.58) a	1.98^{ns}

***, ^{ns} Significative differences at $p < 0.001$; and not significative by the two-way ANOVA, respectively.

[1] 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

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 on 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 (Table 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 (Table 4).

Table 1.4. Plant traits and biomass production among the studied treatments of organic residues management in a subtropical ecosystem, Curitibanos, Santa Catarina, Southern Brazil

	Control	Mulching (M)	Compost (C)	M + C	F-value
Height (m)^1	3.82 (0.34) c	3.87 (0.36) c	3.92 (0.31) b	**3.99 (0.31) a**	10.86***
Stem diameter (cm)	17.32 (3.26) a	17.82 (3.64) a	17.85 (2.90) a	17.80 (2.94) a	2.63^{ns}
Stem biomass (kg plant^{-1})	36.68 (1.05) c	38.86 (1.12) b	**39.44 (0.93) a**	**39.87 (0.92) a**	7.63**
Branch biomass (kg plant^{-1})	53.01 (1.07) a	54.68 (1.19) a	54.78 (0.95) a	54.61 (0.96) a	2.63^{ns}

Root biomass (kg plant^{-1})	22.92 (0.53) c	24.32 (0.49) b	25.16 (0.47) b	26.10 (0.46) a	20.72***
Total biomass (kg plant^{-1})	112.63 (2.47) c	117.87 (2.61) b	119.39 (0.21) a	120.59 (0.21) a	8.52**

***, **, ^{ns} Significative differences at $p < 0.001$; $p < 0.01$, and not significative by the two-way ANOVA, respectively.

[1] 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

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 (Fig. 3).

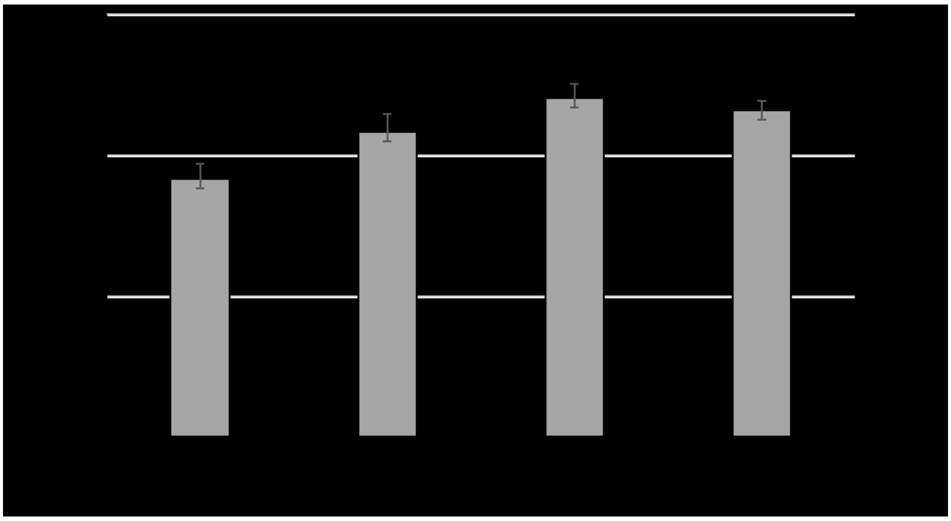

Fig 1.3. *P. pyrifolia* yield (ton. ha^{-1}) as affected by different organic residues management in a subtropical ecosystem, Curitibanos, Santa Catarina, Southern Brazil. Different small letters into each line differ by Bonferroni's test ($p < 0.05$).

The effects of the use of compost and mulching on C compartments (Aboveground, belowground, soil, and total) on *P. pyrifolia* field conditions

There are 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 on *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 applications. The highest values of above- and belowground C density were found on plots where we used the combination with 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 5).

Table 1.5. 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

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

***, ** Significative differences at $p < 0.001$; and $p < 0.01$ by the two-way ANOVA, respectively.

[1] 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

Discussion

Our results emphasized the influence of management using organic residues (mulching and compost) on plant nutrition (leaves' N content), plant traits (height, stem biomass, root biomass, and total biomass), fruit yield, and soil traits (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 (mulching, compost, and their interaction) promoted whole the studied variables. Essentially, we wanted to understand how the isolated 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 have a low cost. These results agree with a previous study by Souza et al. (2016) and Vital et al. (2020) that reported high costs with the continuous use of organic fertilization following a combined strategy to add organic residues into the 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) (Souza et al. 2015; Melo et al. 2019; Nascimento et al. 2021).

Leaves' N content was positively affected using compost on plots and incorporating it into the soil profile. Compost as an organic amendment is an interesting source of organic N and other plant essential nutrients (Botelho and Muller 2020). 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 provides a positive influence on soil that 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 the soil chemical characteristics, and the plant nutrient supply (Baldi et al. 2018, Hunter et al. 2021), and it agrees with the work done by Cesaro et al. (2019), that found organic residues promoting N cycling, thus favouring *P. pyrifolia* yield. Other studies also reported that the use of compost can alter plant nutritional status by altering plant metabolism and physiology (Mazzon et al. 2018; Kang et al. 2020; Perazzoli et al. 2020; Tesfaye et al. 2020; Zhang et al. 2021).

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 the combination with compost and mulching there were no significant differences between them on 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 residues treatments. These results agree with the studies done by Toselli et al. (2019) and Liu et al. (2020), which reported a high influence of organic fertilizers on plant traits in field experiments when compared to mineral fertilization, principally due labile sources input (here, we highlight compost), potentializing the microbial action. In fact, the soil fertility status has an important role in the vegetable development, and nitrogen sources have a significative effect on soil fertility (e.g., soil organic matter dynamic). Organic sources, such as compost and mulching, may influence the rhizoshealth, thus promoting root growth, water, and nutrient uptake. Into these conditions, it is expected to find plant species producing more biomass on their tissues, high rootability, and fast growth (Kang et al. 2020). Organic residues management can promote the rhizobiome, which positively influence microbial activity, and soil food web. Improvements into the rhizosphere may promote plant performance, plant resistance, and plant nutrition that directly affects plant morphological traits. In subtropical ecosystem, alternative farming systems which promote the use of soil and plant performance sustainably is a driver to improve organic farming and the fruticulture fields.

Organic farming systems may present a wide variety of influences on plant yield. Some studies have reported: i) short-term effects: neutral effects with fewer 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 done by Cen et al. (2020), which 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 (Carranca et al. 2018). These organic residues also provide adequate environmental conditions to stimulate root growth, which leads to a greater increase in the absorption of nutrients and production biomass (Thakur and Kumar 2021).

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 the biomass production increase, which in turn promote above- and belowground C density. Other works have described the importance of considering organic farming in the carbon sequestration aspects related to soil quality and their consequences on plant performance, C uptake, and biomass production (Sorrenti et al. 2019, Iqbal et al. 2020). In fact, organic residues are high-quality materials that can promote soil improvement through nutrient cycling, thus creating a favourable condition for the development of *P. pyrifolia* plants (Sukitprapanon et al. 2020; Zeng et al. 2021). In general, plant species from *Pyrus* genus can store about 42% of organic carbon in their biomass, which contributes to the increase in above- and belowground C density into the agroecosystems (Yuan et al. 2021; Zahoor et al. 2021; Sharma et al. 2021). According to the study done by Montanaro et al. (2017), Baldi et al. (2018), Yadav et al. (2019) and Hammad et al. (2020), the above- and belowground C density are strongly influenced by key factors such as plant traits, soil fertility, and soil management, and their interactions with belowground organisms. The organic residues application may enhance belowground C density, through changes in soil properties, fine root biomass, and rhizoshealth (Khorram et al. 2019; Cao et al. 2021). Another important role of organic residues on plant performance is the high rootability and rhizodeposition into the rhizosphere as reported by Amendola et al. (2017), Forstall-Sosa et al. (2020), and Fleishman et al. (2021).

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 (de Notaris et al. 2020). Overall, the use of organic residues (mulching and compost) may promote efficient C input, mainly from improved plant biomass production, increased rhizodeposition (into rhizosphere), and increased C sequestration (by plant tissues and soil) (Forstall-Sosa et al. 2020; Cao et al. 2021). Mixture and organic residues alone (e.g., compost) can maximize the plant performance, and soil biota activity, thus promoting ecosystem functions, by reducing C loss, and increasing plant nutrient availability (e.g., soil N contents). Into this context, the management of the organic residues may exploit positive feedback between crop production, carbon sequestration, and soil sustainability (Sahoo et al. 2021; Zahoor et al. 2021). In addition, as C sequestration/storage is linked to soil quality (Cen et al. 2020), compost has the potential to increase the build-up of soil N contents, and soil organic carbon stocks over time (Baldi et al. 2018).

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 organic residues management. 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. (2020). The importance of plant-deposition of C was recently underlined by Sharma et al. (2021), who found the evergreen fruit crops influencing C sequestration 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 (2018).

Conclusion

The organic residues management influenced plant nutrition, plant traits, fruit yield, and soil traits in a *P. pyrifolia* field at subtropical Acrisols. 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 on Acrisols under field conditions. The results of our study highlight the importance of considering the use of compost has a sustainable way 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 into a *P. pyrifolia* field may exploit positive feedback between crop production, carbon sequestration, and soil sustainability in subtropical conditions. Also, long-term experiments considering the combined use of mulching and compost may exploit a deeper view inside the carbon dynamic, yield, traits and biomass production in the *P. pyrifolia* fields.

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

Abstract

Background Although the management of the organic residues into the temperate fruticulture are highly used, for an organic *Pyrus pyrifolia* field the effects of mulching and compost on soil organic carbon decomposition rate, and soil biota abundance are unknown. In a 16-year *P. pyrifolia* field experiment conducted from January 2020 to June 2021 at Pirapora enterprise, we tested the use of mulching, compost, and their interaction on organic residues decomposition rate, time of residues decay, primming effect, and soil biota community composition.

Methods We conducted a field study using a 2 × 2 factorial design with compost and mulching as the two factors within four blocks. We characterized organic residues decomposition by using litter bags with different mesh, and we identified soil biota individuals at Family level.

Results We did not find differences in half-decay rate, total-decay rate, and remaining residue mass in the litter bags with 15 and 4 mm^2 size containing mulching in the plots that received mulching and compost, respectively. The highest values of k and primming effect were found in litter bags with 15 mm^2 size containing compost in the plots that received compost. For soil biota abundance and richness, we found the highest values on plot that received both mulching and compost.

Conclusion Our results suggested that the management of the organic residues determined organic matter decomposition, soil biota abundance and richness in an Acrisol of Southern Brazil. Soil biota groups were the main factors contributing to the data variance (e.g., Acaridae, Blattidae, Chrysopidae, Halictophagidae, and Forficulidae). Our results highlight the importance of considering both residues with N- and C-rich compounds as energy source and habitat provision, respectively.

Keywords: Compost, Litterbags, Mulching, Nutrient cycling, Priming effect, Soil organisms.

Introduction

In subtropical agroecosystems, organic residues are the major source of energy supply and habitat for nutrient cycling and soil organisms (Chavarria et al. 2018). In *Pyrus pyrifolia* (Burm.f.) Nakai plantation, the transition process from conventional to organic farming system (OFS) account for 18% of its cultivated area in southern Brazil and represent 22,000 t year^{-1} of *P. pyrifolia* fruits produced into an OFS (da Silva et al. 2021; Massaccesi et al. 2020). Into this condition, organic residues with C- and N-rich compounds may improve net primary production, soil food web, and organic residues decomposition (Wan et al. 2018; Cen et al. 2020; de Leijster et al. 2020). OFS may reduce the use of mineral fertilizers, and ICIDE-type products (e.g., herbicides, pesticides, fungicides) due to increasing the soil biota abundance and richness that promotes organic matter fragmentation (Zipori et al. 2018; Barreto et al. 2020). However, field studies considering the effects of the continuous use of organic residues as compost and mulching on organic residues decomposition modulated by the soil biota activity are rare. In this context, the use of organic residues can be an important alternative to promote soil quality, nutrient cycling by increasing soil biota activity, its community structure and the soil food web (Duan et al. 2021).

Decomposition of organic residues is controlled by their quantity (C-rich) and quality (N-rich) along with soil biota community (Melo et al. 2019). The consensus is that C- and N-rich residues are generally found to stimulate habitat provision and decomposition, respectively (Sofo et al. 2020; Coulis 2021). Other studies have provided evidence of C-rich residues negatively influencing decomposition rates (Wu et al. 2020; Orpet et al. 2020). Organic residues as mulching may act as a habitat for soil organisms, while compost may act as an energy supply for nutrient cycling (Rieff et al. 2020; Libutti et al. 2021). Next, these two organic residues ensure the organic matter input into the soil profile, which avoids soil quality loss, and increases plant nutrient release over_time (Forstall-Sosa et al. 2020). Finally, the continuous use of compost and mulching can create positive plant-soil feedback, which over_time increases plant production, and decreases costs with low C input (Jacobsen et al. 2019). Previous studies showed that the use of organic residues increased the soil organic matter decomposition, and soil biota community structure (Jacobsen et al. 2019; Li et al. 2020a; Kai and Adhikari 2021).

Soil biota communities are amongst the most important biotic factor in tropical and subtropical ecosystems (Popov et al. 2018; Melo et al. 2019; Yang et al. 2021). These soil organisms perform a range of ecosystem functions including soil structure, soil organic matter transformation, nutrient cycling, biological control etc. (Souza and Freitas 2018; Zhang et al. 2021). However, it remains unclear the role of soil biota community on organic residues decomposition in a 16-year *P. pyrifolia* field. Thus, we hypothesized that: (i) compost may influence soil organic matter dynamics by improving decay rate, and primming effect, which in turn influence nutrient cycling, and soil biota abundance following the main results described by Araújo et al. (2020), Liu et al. (2020), and Anjum and Khan (2021); (ii) soil organic residues management may alter soil reaction by the H^+ extrusion and the release of some C-rich compounds, thus promoting rootability improvement as described by Tian et al. (2019), and Forstall-Sosa et al. (2020); and (iii) organic residues management that provide high input of C-rich compounds may positively affect soil biota community structure by habitat provision as described by Melo et al. (2019), and Forstall-Sosa et al. (2020).

Our study addressed the following goals: a) may the management of the organic residues (considering the plots) influence the residues decomposition into a litterbag assay using different mesh sizes? b) is it possible to find different decomposition rates influenced by soil organisms? c) how the use of organic residues may improve the soil biota community structure? To achieve these goals, we combined soil sampling, litter bag assay using different mesh sizes, and soil biota community characterization as described in the studies done by Forstall-Sosa et al. (2020), Baldi et al. (2021), and Kan et al. (2020). 2020).

Materials and methods

Pyrus pyrifolia and study site

Pyrus pyrifolia is one of the fourth most important tree species in Brazilian fruticulture in which pear fruits have an important social-economic impact in southern Brazil (da Silva et al. 2020). It has been cultivated in Paraná, Santa Catarina, Rio Grande do Sul covering an area of 1,300 ha from which just 18% is cultivated following the organic farming system (IBGE 2021). Our field experiment was conducted in a 16-year *P. pyrifolia* var. Housui field cultivated in a subtropical Acrisol (WRB 2006) that follow an organic farming system at the Pirapora emprise (27°12'47.01" S and 50°39'44.52" W), Curitibanos, Santa Catarina, Brazil, from January 2020 to June 2021. The experimental area was 1.4 ha, corresponding at 6% of total *Pyrus pyrifolia* field. The climate is type Cfb-type following Köppen-Geiger classification, with average annual precipitation and air temperature of 1,676 mm and +15.0 ºC, respectively (Laurindo et al. 2021). Climate data, monthly rainfall, mean temperature and thermal amplitude from the field experiment, Curitibanos, Santa Catarina, Brazil (January 2020 to June 2021), were obtained online: https://ciram.epagri.sc.gov.br (Fig 1).

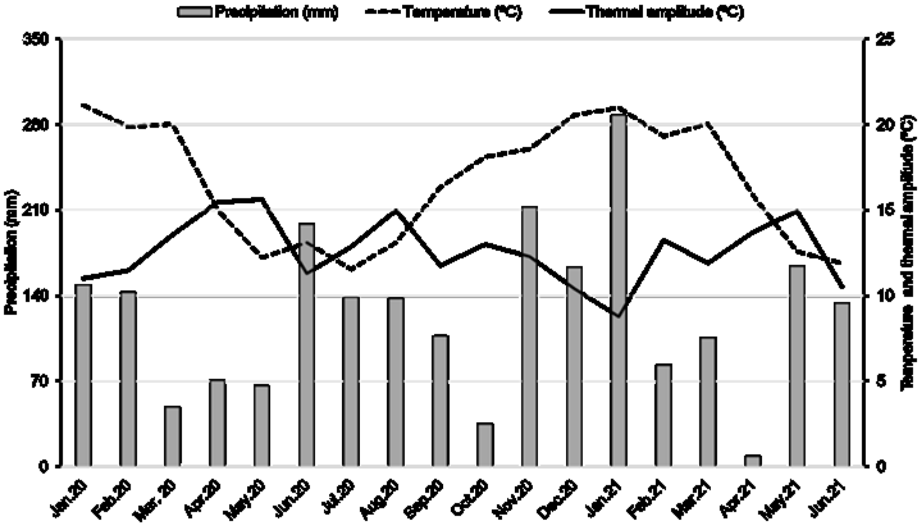

Fig. 2.1. Monthly precipitation (mm), air temperature (ºC), and thermal amplitude (ºC) from the field experiment, Curitibanos, Santa Catarina, Brazil (January 2020 to June 2021). Data were obtained online: https://ciram.epagri.sc.gov.br

Experimental design

The experiment conducted in field conditions was 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* (Fig. 2).

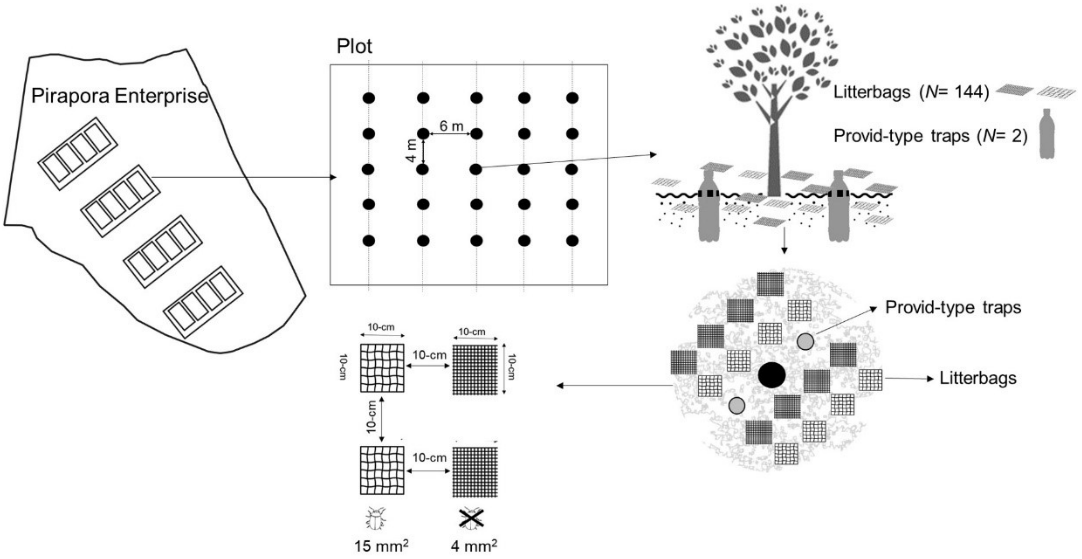

Fig. 2.2. Experimental scheme of our field study inside a 16-year *P. pyrifolia* field using different organic residues management in a subtropical ecosystem, Curitibanos, Santa Catarina, Southern Brazil.

Mulching and compost production

The plant material used as mulching was obtained by *P. pyrifolia* pruning. All mulching materials were air-dried for 7 days in mulching piles (1.5 × 2.0 × 5.0 m; height: width: length) covered by black plastic during all processes. We did not identify temperature changes in mulching piles. In our study, we tested the use of 3 kg m^{-2} of this material applied around the *P. pyrifolia* plants at the beginning of the field experiment. For compost, we made 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). Daily, we watered over the compost piles (80% of field capacity), and once a week we turned it by providing oxygen inside the piles, and reducing thermal variation preventing the piles to self-burn. We have studied the effect of using 10 kg m^{-2} of compost applied on the soil surface and then incorporate at 20-cm soil depth, 60 days before the flowering stage. For the organic residues, we have sampled both compost and mulching materials from each pile. Mulching and compost piles were produced into the own experimental area. For both studied organic residues, we collected twenty 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 (Table 1) following Tedesco et al. (1995).

Table 2.1. 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

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. We collected five soil samples nested per plot. All soil samples were air-dried and passed through a 2-mm size sieve as described by Teixeira et al. (2017). 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 by Mehlich-1 and determined using colorimetry. The potassium chloride extraction method was used to determine exchangeable Ca^{2+}, K^+, and Mg^{2+} (Nascimento et al. 2021). Total organic carbon was estimated according to the methodology described by Teixeira et al. (2017). The total nitrogen was estimated using sulfuric acid and potassium sulfate digestion followed by a distiller by Kjeldahl's method (Teixeira et al. 2017).

Table 2.2. Soil chemical properties before starting the field experiment (mean, n = 192) in a 16-year *P. pyrifolia* plantation, Curitibanos, Santa Catarina, Brazil

Studied treatment	pH	P	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	SOC	TN	SB	CEC
	(H_2O)	(mg dm^{-3})		($cmol_c$ kg^{-1})			(g kg^{-1})		($cmol_c$ 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, and TN: Total nitrogen.

Organic residues decomposition assay

To determine the organic residues decomposition rate (k, $years^{-1}$), we used litterbags (10 × 10 cm) with different mesh ($4\text{-}mm^{-2}$ and $15\text{-}mm^{-2}$). The use of litterbags with different mesh enabled us to assess: i) macrofauna action on litter fragmentation (by the action of litter transformers on the coarse mesh); and microbiota action on litter decomposition (by the action of decomposer on the fine mesh). Each litterbag received 10 g of organic residues (mulching and compost). We placed hundred and forty-four litterbags per plot that were distributed in the central portion of each. Following a 30 day-schedule, eight litterbags (two fine mesh and two coarse mesh) were collected. The last litterbags remained in field conditions for eighteen months. In the lab, the organic residues sampled in each litterbag were oven-dried at 60 °C to constant weight~~,~~ and then weighed to determine the oven-dry weight. The change in mass was used to determine the organic residues decomposition rate (k, $years^{-1}$) as described by Olson (1963):

Equation 7: $\frac{X}{X0} = e^{-kt}$

Where, X (g) is the mass remaining after t months, X_0 (g) is the initial organic residues mass. Also, we have determined half-decay time (hd), and total-decay time by using two nonlinear regression models:

Equation 8: $hd = \left(\frac{\ln(1-0.5)}{\ln(e)}\right) \times \left(\frac{1}{-k}\right)$ for half-decay time

Equation 9: $td = \left(\frac{\ln(1-0.95)}{\ln(e)}\right) \times \left(\frac{1}{-k}\right)$ for total-decay time

We estimated the remaining residue mass (%):

Equation 10: $Rm\ (\%) = \frac{X}{X0} \times 100$

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 (Tan et al. 2021), and priming effect:

Equation 11: $pf = \ln\left(\frac{X0}{X}\right)$

Where pf is the priming effect, X_0 is (g) is the initial organic residues mass, and X is the mass remaining.

Soil biota collection

The Tropical Soil Biology and Fertility protocol (Anderson and Ingram 1993; Forstall-Sosa et al. 2020) was used to sample soil organisms. We placed two Provid-type traps 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 detergent and 15 mL of 70% alcohol. We did not find any nest in our study plots during the soil biota collection. All Provid-type traps were placed 6 times during the whole study, but we present the mean of each studied treatment in our results section. The soil organisms within each trap were inserted in plastic pots containing 30mL 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 (Shannon and Weaver 1949), Simpson dominance index (Simpson 1949), and functional groups (Souza and Freitas 2018).

Statistical analysis

Before our statistical analysis, we tested all datasets for normality by Shapiro-Wilk test ("shapiro.test" function), and log transformation ("decostand" function) was applied when necessary. We tested our dataset 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 an NMDS procedure with Jaccard dissimilarities ("metaMDS" function), and we used the environmental PCA to dataset reduce and for selecting the significative variables at 0.001%. 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 statistical analyses were performed in R 3.4.0 (R Core Team 2018).

Results

Influence of the organic residue management and soil biota activity on organic residues decomposition

In our field study, we found that 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 in size) containing mulching, and in the compost treatment with litter bags (4 mm^2 in size) containing mulching (Table 3).

Table 2.3. 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, Santa Catarina, 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	61.61 (2.64) bA	86.03 (0.67) aB	86.88 (2.56) aB
Mulching (M)	47.88 (1.21) cB	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

Different small letters into each line differ by Bonferroni's test ($p < 0.05$), whereas different capital letters into each row considering the management of the organic residues differ by the same post-hoc test.

Mean values (n = 2304) followed by the standard deviation in parenthesis

In our field study, we found that the decomposition rate (k), and primming effect varied among the organic residue management and mesh-type in a 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 (Fig. 3).

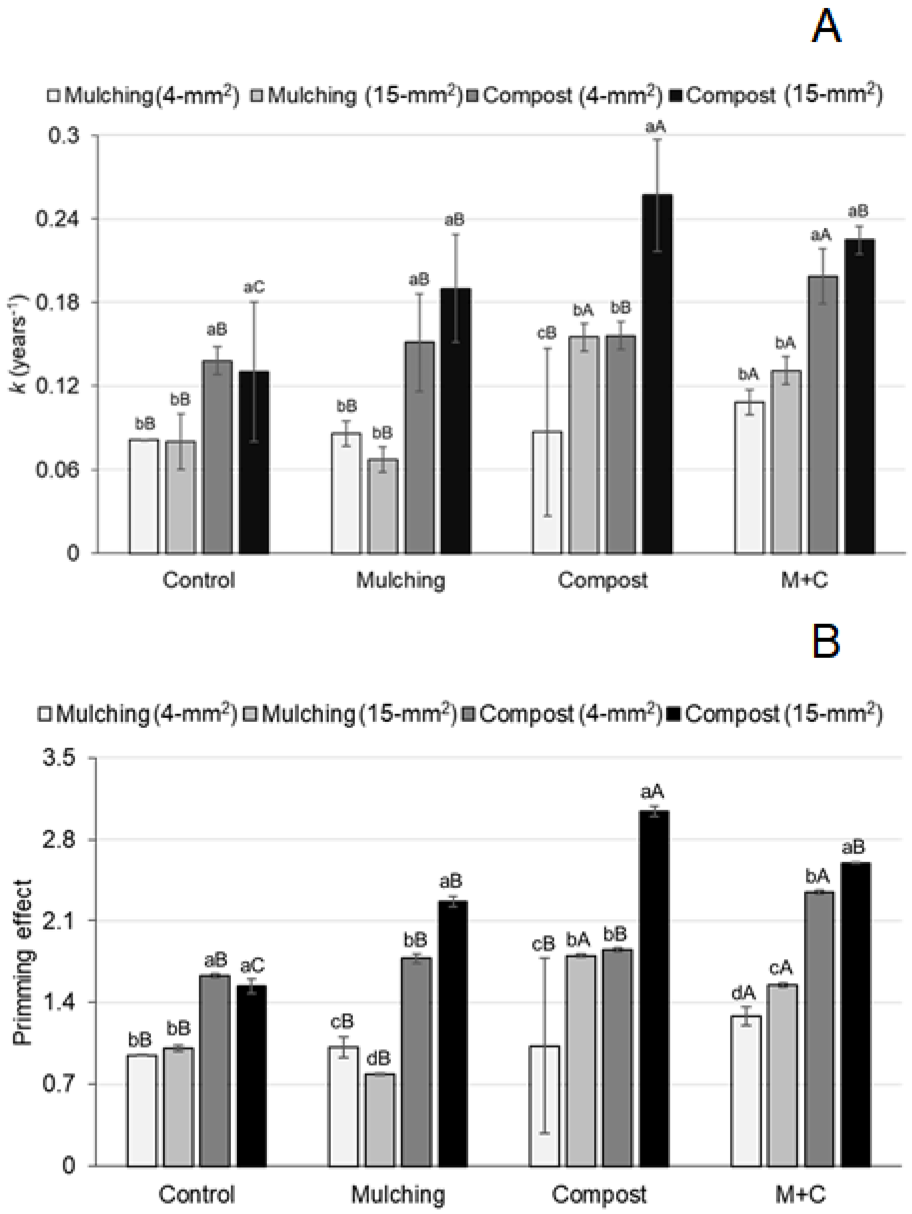

Fig. 2.3. Decomposition rate (k, years^{-1}) (Fig. A), and primming effect (Fig. B) as affected by different organic residues management and litterbag mesh-type in a subtropical ecosystem, Curitibanos, Santa Catarina, Southern Brazil. Different small letters into each organic residue management differ by Bonferroni's test ($p < 0.05$), while different capital letters into each litterbag mesh-type differ by Bonferroni's test ($p < 0.05$). The decomposition rate was adjusted by multiplication for 10.

Soil biota collection in a 16-year P. pyrifolia field under different organic residue management

Nineteen taxonomical Orders and thirty-three Families were identified in the soil biota community (Table 4). The mean abundance of soil biota 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 the ecological index, we just found significant differences among organic residues management on richness. We did not find significant differences among organic residues management on Shannon diversity index, and Simpson dominance index (Table 4).

Table 2.4. Mean abundance (ind. trap^{-1}) of soil biota 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	**1.75 (0.21) a**	0.12 (0.03) c	0.50 (0.07) b	10.62***
Araneae – Araneidae	**2.25 (0.15) a**	1.50 (0.13) b	0.87 (0.10) d	1.12 (0.10) c	8.25**
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}
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 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 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}

The standard error in parentheses

Within organic residue management, same letters represent no significant differences by Bonferroni's test ($p < 0.05$)

ns not significant

** $p < 0.01$

*** $p < 0.001$

Multivariate analysis

The Non-metric multidimensional scaling (NMDS) revealed that the soil biota composition varied significantly among the organic residue management. The ordination had a good fit (stress value = 0.17). Soil biota composition was 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 biota composition into each studied organic residue management (Fig. 4).

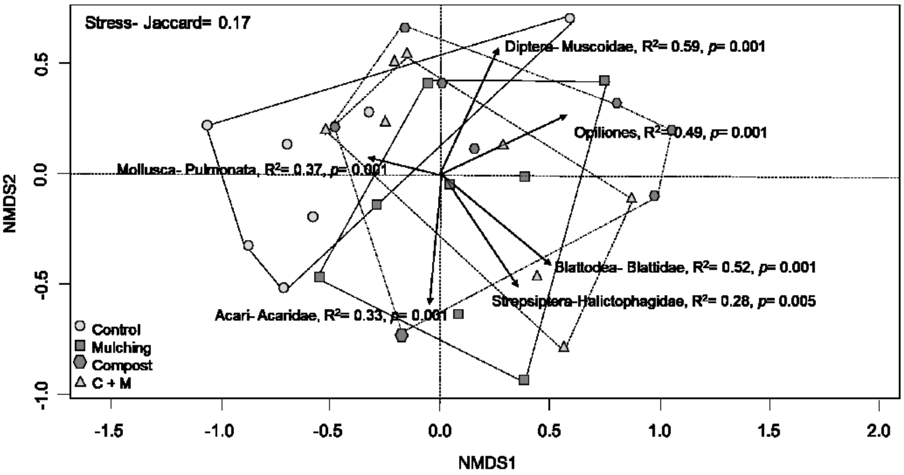

Fig. 2.4. Non-metric multidimensional scaling (NMDS) based on soil biota composition among the studied organic residue management in a 16-year *P. pyrifolia* field. Organic residue management are represented as follows: Control = circles; Mulching = squares; Compost = hexagon; and Compost plus mulching = triangles.

According to the PCA analysis, the four organic residues management were dissimilar. The first two axes of the overall PCA explained 80.16% of the variation in the litter decomposition data (Fig. 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

Primming 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, $p < 0.01$) (Fig. 5).

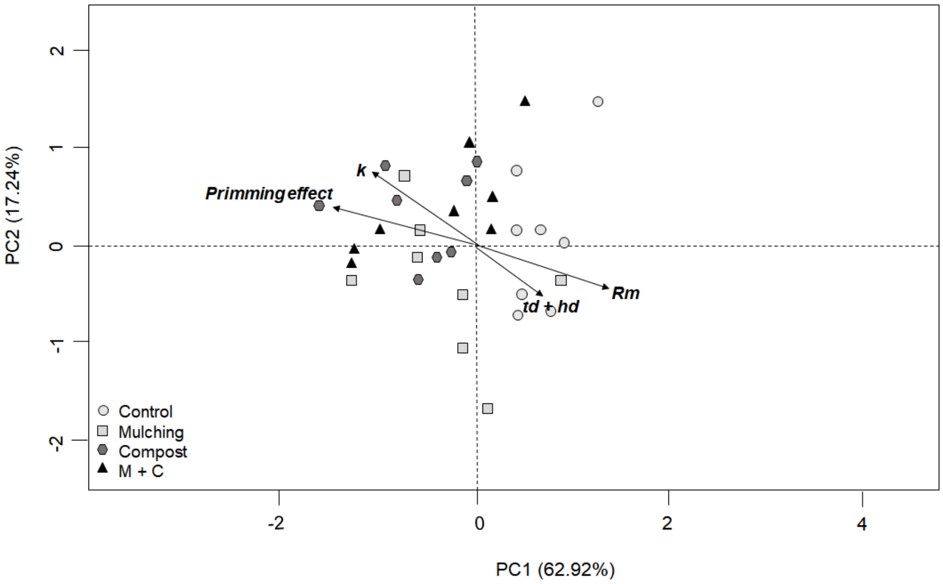

Fig. 2.5. Principal Component Analysis (PCA) for the litter decomposition data (Primming effect, k, hd, td, and Rm) of different organic residue management. For analysis, primming effect, k, hd (half-decay rate), td (total decay rate), and remaining litter mass (Rm) were included. Organic residue managements are represented as follows: Control = circles; Mulching = squares; Compost = hexagon; and Compost plus mulching = triangles. Only significant vectors are shown ($p < 0.05$).

Discussion

Our field study emphasizes the influence of organic residues management (mulching and compost) applied on organic residues decomposition rate (k), half-decay time (hd), total-decay time (td), priming effect, remaining litter mass (Rm) and soil biota 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 a 16-year field with *P. pyrifolia* plants cultivated in subtropical Acrisols, Southern Brazil. All organic residues management improved the nutrient cycling (e.g., decomposition rate, and priming effect) and soil biota activity (e.g., by the observed results in the litterbag mesh assay) under subtropical conditions. We also found evidence about the organic decomposition mediated by soil biota community.

Essentially, we wanted to understand how the isolate and combined use of compost and mulching can change organic matter compartment, nutrient cycling, and soil biota structure and activity, following an organic farming system schedule and preventing the use of synthetic compounds. We found evidence that decomposition rate (k), half-decay time (hd), total-decay time (td), priming effect, and remaining litter mass (Rm) on plots where compost was applied was 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, our results show strong evidence about the soil biota activity on mulching decomposition on plots where compost was applied using litterbag with 15 mm^2 mesh-type. These results agree with previous studies by Forstall-Sosa et al. (2020), Asigbaase et al. (2021) and Tassinari et al. (2021) that reported positive effects of organic residues management on soil organic matter dynamics. These authors reported soil improvements~~,~~ and soil biota activity with the continuous use of compost and green manure practice in tropical and subtropical soils. Over time the use of organic amendments promotes both habitat and food provision to a wide range of soil organisms that provide ecosystem functions, such as organic matter decomposition, nutrient cycling, and soil food web (Gonçalves et al. 2020; Kitamura et al. 2020; Geldenhuys et al. 2021;).

Into subtropical agroecosystems, the rate of organic residues decomposition is the main driver that regulates the nutrient cycling process and biomass production (Yang et al. 2018). The decomposition rate (k) in our study was positively affected using compost on the studied plots. This variable was also influenced by soil biota activity as we found the highest values of k 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 (Maran et al. 2020; Almagro et al. 2021; Long et al. 2021). Compost as a soil amendment is an interesting source of organic C, N, P, and other micronutrients (Sukitprapanon et al. 2020; Shang et al. 2020; Nascimento et al. 2021). These authors reported an improved soil food web on plots where compost was applied, which in turn promoted organic matter dynamics. The use of compost also provides a positive influence on priming effect (e.g., which represent high nutrient availability). In our study, compost showed a higher priming effect when compared with the other studied organic residues management. The use of compost also provides a positive influence on organic matter traits (e.g., hd, td, and remaining litter mass) that in turn promoted soil biota activity. Several studies have reported an improved microbial activity, N cycling, nutrient release on soil solution, and soil organic C stocks (Melo et al. 2019; Jones et al. 2020; Thakur and Kumar 2020). These results support our 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 (Araújo et al. 2020; Liu et al. 2020; Anjum and Khan 2021). Our litterbag assay using 15 mm^2 mesh-type provided evidence about the influence of soil biota community on decomposition rate (Liu et al. 2019). In our samples, we found inside these bags soil organisms classified as litter transformers (e.g., Coleoptera and Diplopoda). These soil organisms influence the physical fragmentation of organic residues as described by Liu et al. (2019), and Liu et al. (2021). The high quality of the organic residues used in our studied plots created positive conditions for decomposers, as we found remaining litter mass on litterbags with 4 mm^2 mesh-type (Forstall-Sosa et al. 2020). Here, into these bags we found a high abundance of red and grey fungi colonies combined with a high abundance of microregulators (e.g., Acari) that feed on this fungi community. Unfortunately, we did not find strong evidence of the combined use of compost and mulching. This suggests that the combined action of organic residues needed to be studied in a long-term schedule. In our case, just the eighteen studied months were not enough to go deeper into the ecological process behind the combined use of organic residues as direct sources of habitat and energy to the soil organisms (Plaas et al. 2019; Mockeviciene et al. 2021).

Results of this study indicate that compost and mulching decomposed more easily by the hd and td results in the plots where we applied compost, and the combination of compost and mulching, respectively. The organic residues decomposition was significantly faster under the compost treatments than the control. Both half-, and total-decay time were positively correlated to the soil biota activity. Here, we must consider the action of litter transformers as described by Souza and Freitas (2018). 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.

Accordingly, to the work done by Frouz (2018), this process improves the decomposers activity that promotes chemical fragmentation of the organic residues into the soil profile. Decomposition rates on areas that received N-rich organic residues have been studied and previous studies have concerned only compost. Sharma et al. (2021), as well as Mariotte et al. (2018) showed a strong influence of N-rich organic residues over organic residues with recalcitrant-rich compounds. Similarly, Kan et al. (2020) 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 returning to the soil through plant senescence and litter deposition (e.g., positive feedback). In our study, the compost treatment promoted the decomposition rate of both mulching and compost in our litterbag assay. Here, we consider that the plots where the compost was previously applied have provided an energy-rich environment with labile sources for the soil biota community (Fang et al. 2018; Kan et al. 2020). 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 (Lin et al. 2019). Mulching residues often contain anti-herbivory compounds like silica, secondary compounds, and structural traits. Into this condition, we must expect a trade-off among litter transformers and decomposers (Sofo et al. 2020). Our hypothesis about the rootability improvement by soil organic residues management may alter soil reaction by the H^+ extrusion and the release of some C-rich compounds was supported in both cases where we have used compost and mulching. Here, we found strong evidence about the organic residues enhancing the soil biota community, which in turn improved decomposition rate (Tian et al. 2019; Forstall-Sosa et al. 2020).

For soil biota 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 our hypothesis that organic residues management that provides high input of C-rich compounds may positively affect soil biota community structure by habitat provision as described by Melo et al. (2019), and Forstall-Sosa et al. (2020). The high abundance and richness presented by plots that received high amounts of C-rich compounds may be related to the mulching layer on the soil surface. We also cannot exclude the hypothesis provided by Melo et al. (2019) that in agricultural soil the soil biota abundance is driven by the habitat quality, while soil biota diversity is driven by organic residues with N-rich compounds. These results agree with previous studies done by Vignozzi et al. (2019), de Pedro et al. (2020), and Nascimento et al. (2021), 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). According to de Pedro et al. (2020), 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.

Compost and mulching are important organic residues to soil biota, and these kinds of residues act as a food resource and refuge site, respectively (Gómez et al. 2018; Melo et al. 2019). Soil biota groups, 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 previous works (Bufebo et al. 2021; Simoni et al. 2021) 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 biota in plots where mulching and the combination with mulching and compost were applied (Li et al. 2021; Galloway et al. 2021). Our hypothesis that compost may promote soil biota abundance was not supported. Overall, the soil biota 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 biota, plant traits, and soil factors. These links are important ecological processes such as biological control, mutualism, plant-arthropod interaction, and nutrient cycling (Mabin et al. 2021; Wang et al. 2022).

Conclusion

The organic residues management determined organic matter decomposition, soil biota abundance and richness in an Acrisol of Southern Brazil. The use of compost showed a 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 biota community. Our findings suggest that organic residues have positive effects on soil organic matter dynamics, soil biota activity, and soil biota community composition. The results of our study highlight the importance of considering both residues with N- and C-rich compounds as an 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 biota role on organic residues decomposition.

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Declarations

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Availability of data Not applicable.

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Author's contributions We declare that all the authors made substantial contributions to the conception, design, acquisition, analysis, and interpretation of the data. All the authors participate in drafting the article, revising it critically for important intellectual content; and finally, the authors gave final approval of the version to be submitted to Soil Biology and Biochemistry.

Consent to Publish We confirm that this manuscript that not been published elsewhere and is not under consideration by another journal. All Authors have approved the manuscript and agree with submission to Soil Biology and Biochemistry. We have read and have abided by the statement of ethical standards for manuscripts submitted to Soil Biology and Biochemistry.

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CONSIDERAÇÕES FINAIS

O manejo de resíduos orgânicos em sistemas comercias de produção de frutíferas de clima temperado representa um importante alternativa na melhoria do estado nutricional de frutíferas de clima temperado, produção de biomassa, incremento nos estoques de carbono no agroecossistema e estrutura da teia trófica do solo. O manejo de resíduos orgânicos na fruticultura de clima temperado demonstrou efeitos positivos em curto prazo para os teores de nitrogênio foliar, altura total das plantas, biomassa dos galhos, biomassa da raiz, densidade de carbono acima e abaixo do solo, tempo médio e total de decomposição, massa remanescente, taxa de decomposição dos resíduos orgânicos, efeito primming, abundância da biota edáfica e o índice ecológico de riqueza. Os maiores valores de incremento foram observados onde apenas o composto orgânico e onde as fontes orgânicas foram aplicadas de forma conjunta. Onde apenas o composto foi aplicado observou-se incrementos para os teores de N foliar (+7%), taxa de decomposição (litterbags com abertura 15 mm^2 contendo composto) (+92%), efeito primming (+97%), redução no tempo médio, total de decomposição e massa remanescente (litterbags com abertura de 15 mm^2 contendo cobertura morta) na ordem de - 47%, - 47% e 56%. Incremento na abundância das famílias Cugygidae (+108%) e Forficulidae (+40%). Onde as fontes orgânicas foram aplicadas em conjunto, observaram-se os maiores valores para as variáveis de altura total (+4%), biomassa dos galhos (+8%), produção (+31%), densidade de carbono acima do solo (+7%), biomassa da raiz (+17%), densidade de carbono abaixo do solo (+7%). Incremento na taxa de decomposição (litterbags com abertura de 4 mm^2 contendo composto) (+46%), efeito primming (+44%). Tempo total de decomposição (litterbags com abertura de 4 mm^2 contendo cobertura morta) (-25%) e massa remanescente (-28%). Tempo médio e total de decomposição (litterbags com abertura de 4 mm^2 contendo cobertura morta) (-25%) e massa remanescente (-28%), bem como a abundância das famílias Blattidae, Muscoidae, Gymnosmorpha Chrysipidae e o índice ecológico de riqueza (+62%; 201%; +191%; +37% e +9%, respectivamente). Fundamentando do ponto de vista teórico a importância de considerar estas práticas de manejo alternativa em sistemas orgânicos ou em transição. De forma mais específica, a aplicação de resíduos orgânicos pode incrementar a produtividade primária líquida nos agroecossistemas (produção de biomassa e produção de frutos), sequestro de carbono atmosférico e na estruturação da teia trófica no ecossistema solo, potencializando os processos ecológicos que envolvem esses organismos (trituração da serapilheira, decomposição da materia orgânica e controle biológico). Torna-se imperativo avaliar o uso de fontes orgânicas em módulos comerciais de produção como um promotor de sustentabilidade.