UNIVERSIDAD DE CIENCIAS Y ARTES DE CHIAPAS
FACULTAD DE INGENIERÍA

TESIS

DINÁMICA DE LA COMUNIDAD DE INVERTEBRADOS EN UN SISTEMA AGROFORESTAL DE PITAHAYA (*HYLOCEREUS UNDATUS*)

QUE PARA OBTENER EL GRADO DE
MAESTRA EN CIENCIAS AGROFORESTALES

PRESENTA
YESICA DANIELA RODRÍGUEZ BELTRÁN

DIRECTOR
DR. MIGUEL PRADO LÓPEZ

Villa Corzo, Chiapas **Noviembre 2025**

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P r e s e n t e

Con fundamento en la **opinión favorable** emitida por escrito por la Comisión Revisora que analizó el trabajo terminal presentado por usted, denominado **Dinámica de la comunidad de invertebrados en un sistema agroforestal de pitahaya (*Hylocereus undatus*)** y como Director de tesis el Dr. Miguel Prado López (CVU: 215004) quien avala el cumplimiento de los criterios metodológicos y de contenido; esta Dirección a mi cargo **autoriza** la impresión del documento en cita, para la defensa oral del mismo, en el examen que habrá de sustentar para obtener el **Grado de Maestra en Ciencias Agroforestales.**

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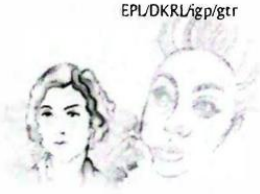

***2025,** Año de la mujer indígena*
Año de Rosario Castellanos

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Dedicatoria

Dedico esta tesis a Dios, fuente de fortaleza, paciencia y sabiduría en cada paso de este camino.

A mi familia, por ser mi raíz, mi impulso y el refugio que me sostuvo en los momentos más difíciles.

A mis amigos, con quienes compartí risas, desvelos y la alegría de cada logro.

A mi perrita Luna, compañera silenciosa de largas noches, que con su cariño llenó de calma y ternura este proceso.

Y me la dedico también a mí misma, por la constancia, la fe y la valentía de seguir adelante, incluso cuando las fuerzas parecían agotarse.

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ÍNDICE DE CONTENIDO

RESUMEN GENERAL

El cultivo de pitahaya (*Hylocereus undatus*) se expande en regiones semiáridas de México por su rentabilidad y adaptabilidad, integrándose en sistemas agroforestales con árboles nativos dispersos. Estos árboles pueden modificar las condiciones microclimáticas y edáficas, afectando la biodiversidad del suelo, un componente esencial para funciones ecológicas como la descomposición, el ciclado de nutrientes y el secuestro de carbono. Sin embargo, aún se desconocen sus efectos en sistemas agroforestales de cactáceas.

Este estudio evaluó el efecto de árboles dispersos y la estacionalidad sobre la diversidad, composición y estructura funcional (por gremios tróficos) de la comunidad de invertebrados del suelo en un sistema agroforestal de pitahaya en la Depresión Central de Chiapas. Se realizaron muestreos mensuales durante un ciclo anual (agosto 2023–julio 2024) bajo tres especies arbóreas y en áreas a pleno sol, mediante monolitos de suelo y trampas pitfall. Los invertebrados se identificaron a nivel de orden y familia, y se clasificaron en tres gremios tróficos: depredadores, fitófagos y detritívoros. En cada punto se registraron variables edáficas (temperatura, humedad, N, P, K y conductividad eléctrica). La diversidad alfa se estimó con números de Hill (q_0, q_1, q_2), y la composición se evaluó mediante los índices de Jaccard y Bray–Curtis. Las diferencias entre micrositios y estaciones se analizaron con GLM y PERMANOVA, mientras que la estructura comunitaria se visualizó mediante NMDS.

Se registraron 13 499 individuos pertenecientes a 124 familias, dominadas por Formicidae, Entomobryidae y Hodotermitidae (86 % del total). La abundancia y diversidad fueron significativamente mayores en áreas a pleno sol que bajo la copa de los árboles (Mann–Whitney y GLM, $p < 0.01$), y aumentaron durante la época lluviosa ($p < 0.001$). En los gremios tróficos, los depredadores mostraron mayor abundancia y diversidad en pleno sol; los fitófagos presentaron interacción significativa árbol × estación, con máximos en sol durante lluvias; y los detritívoros se asociaron positivamente con el nitrógeno del suelo. En la diversidad beta, se detectaron 30 familias exclusivas de sol y 31 de sombra, mientras que 48 familias fueron exclusivas de lluvias. El NMDS mostró una clara separación entre épocas secas y lluviosas, corroborada por PERMANOVA, donde la estación explicó el 9.1 % de la

variación composicional, casi el doble del efecto de los árboles (4.9 %). Las demás variables edáficas no fueron significativas.

En conjunto, los resultados indican que los árboles dispersos no actúan como “islas de fertilidad” en este sistema, sino como filtros ambientales que reducen la diversidad bajo copa. La estacionalidad fue el principal modulador de la estructura comunitaria. Se recomienda la retención selectiva de especies con rasgos funcionales favorables (hojarasca de alta calidad, copas pequeñas, fijación de nitrógeno y raíces superficiales) y estrategias que mantengan la diversidad trófica, conciliando la productividad con la conservación de la biodiversidad edáfica.

Palabras clave: Agricultura resiliente, Bioindicadores edáficos, Ecología del suelo basada en rasgos, Monitoreo de la Biodiversidad, Redes tróficas del suelo.

ABSTRACT

Dragon fruit (*Hylocereus undatus*) cultivation is expanding across Mexico's semiarid regions due to its profitability and adaptability, increasingly embedded within agroforestry systems featuring scattered native trees. These trees can modify microclimatic and edaphic conditions, thereby affecting soil biodiversity, a key driver of ecosystem functions such as decomposition, nutrient cycling, and carbon sequestration. Yet, their effects in cactus-based agroforestry remain poorly understood.

This study evaluated the effects of scattered trees and seasonality on the diversity, composition, and functional structure (by trophic guilds) of the soil invertebrate community in a dragon fruit agroforestry system in the Central Depression of Chiapas. We conducted monthly sampling over one annual cycle (August 2023–July 2024) beneath three tree species and in full-sun areas, using soil monoliths and pitfall traps. Invertebrates were identified to order and family and assigned to three trophic guilds: predators, herbivores, and detritivores. At each sampling point we recorded edaphic variables (temperature, moisture, N, P, K, and electrical conductivity). Alpha diversity was estimated with Hill numbers (q_0, q_1, q_2), and community composition with Jaccard and Bray–Curtis indices. Differences between microsites and seasons were analyzed with GLMs and PERMANOVA, and community structure was visualized using NMDS.

We recorded 13,499 individuals from 124 families, dominated by Formicidae, Entomobryidae, and Hodotermitidae (86% of total abundance). Abundance and diversity were significantly higher in full sun than under tree canopies (Mann–Whitney and GLM, $p < 0.01$) and increased during the rainy season ($p < 0.001$). By trophic guild, predators showed higher abundance and diversity in full sun; herbivores displayed a significant tree × season interaction, peaking in sunlit microsites during the rainy season; and detritivores were positively associated with soil nitrogen. For beta diversity, 30 families were exclusive to sunlit areas and 31 to shaded areas, while 48 families were exclusive to the rainy season. NMDS revealed

a clear separation between dry and rainy seasons, corroborated by PERMANOVA, where season explained 9.1% of compositional variation, nearly twice the effect of trees (4.9%). Other edaphic variables were not significant.

Collectively, these results indicate that scattered trees do not act as “fertility islands” in this system but rather as environmental filters that reduce under-canopy diversity. Seasonality was the primary modulator of community structure. We recommend selective retention of species with favorable functional traits (high-quality litter, small crowns, N fixation, and shallow roots) and strategies to maintain trophic diversity, balancing crop productivity with the conservation of belowground biodiversity.

Keywords: Belowground trophic networks, Biodiversity monitoring, Climate-resilient agriculture, Soil bioindicators, Trait-based soil ecology.

INTRODUCCIÓN GENERAL

En los agroecosistemas, los invertebrados del suelo son clave para la provisión de servicios ecosistémicos y de una serie de funciones ecológicas, como la descomposición de la materia orgánica, el almacenamiento de carbono, el ciclaje de nutrientes y la infiltración del agua (De-Souza et al. 2016; Sofo et al. 2020; Manchado-Cuellar et al. 2021; Chamorro-Martínez et al. 2022). Para entender el rol de los invertebrados del suelo, hay diferentes enfoques. De manera clásica se ha usado la diversidad taxonómica, que toma en cuenta la clasificación de los grupos de organismos de acuerdo a la función que desempeñan o por su nutrición (Paz-Ríos et al. 2022). La funcionalidad se refiere al conjunto de rasgos y actividades mediante los cuales los invertebrados transforman materia y energía en el suelo y modulan procesos ecosistémicos.

Los invertebrados del suelo realizan diversas funciones en el suelo, por lo que son conocidos como ingenieros del ecosistema, ya que por medio de sus actividades crean galerías y túneles en el suelo, las cuales mejoran la porosidad, facilitando el flujo de agua y aire y forman agregados estables en el suelo (Cabrera-Dávila and López-Iborra 2018). Según su tipo de alimentación, los detritívoros facilitan la fragmentación y descomposición de la hojarasca, mientras que los herbívoros y depredadores regulan la disponibilidad de recursos en el hábitat (Cabrera-Dávila and López-Iborra 2018; Paz-Ríos et al. 2022; Chiriac and Murariu 2024). En su conjunto, estas actividades contribuyen a mejorar las propiedades físicas y químicas del suelo que aseguran la productividad del agroecosistema (Santos et al. 2021; Chamorro-Martínez et al. 2022; Castillo-Trejo et al. 2023).

Los factores que promueven la diversidad de invertebrados en los agroecosistemas se encuentra la heterogeneidad del paisaje (e.g tipo de cobertura vegetal, uso de suelo). Cuando el componente vegetal es diverso y poco homogéneo en el agroecosistema, tiene una influencia determinante en la estructura de las redes tróficas, como también en la abundancia, diversidad y funcionalidad de las especies. Lo que promueve un incremento en la fertilidad del suelo, la protección de los cultivos y la productividad en general. Específicamente, la inclusión de árboles en los agroecosistemas contribuye significativamente en la distribución, diversidad y

composición de la macrofauna edáfica (Kamau et al. 2017; Socarrás-Rivero 2018). Ya que provee refugio durante condiciones ambientales adversas, como los cambios estacionales, regula la humedad y la temperatura del suelo mediante la sombra generada por la copa y actúa como fuente de alimento y refugio por medio de la hojarasca producida. Estas interacciones fomentan la actividad de la fauna del suelo, mejoran la aireación y la disponibilidad de nutrientes en el suelo y contribuyen a la salud general del cultivo (Tajik et al. 2019; Haghverdi and Kooch 2019; Heydari et al. 2020). Asimismo, promueven la descomposición rápida de la materia orgánica y ayudan en el control natural de plagas, lo que conlleva a una mejora significativa en la estructura y funcionalidad del suelo en los sistemas agroforestales (Cakir 2018; Insfrán-Ortiz et al. 2023). Por ejemplo, se ha observado que en sitios de producción agroforestal se incrementa la diversidad de macrofauna edáfica con respecto a las áreas de pastoreo y campos de cultivo, que muestran una disminución en la diversidad (Bufebo et al. 2021) y que los árboles en sistemas agroforestales actúan como "islas de recursos" que incrementan los niveles de carbono y nitrógeno en el suelo, lo que favorece la abundancia de macrofauna, como lombrices, escarabajos y termitas, que varían según la especie de árbol y la duración del cultivo (Kamau et al. 2017). Además, la agroforestería no solo permite la integración de árboles y cultivos, sino que también proporciona un marco para mejorar las características físicas, químicas y biológicas del suelo, incrementando la resiliencia de las comunidades y asegurando beneficios económicos (Octavia et al. 2023). Estos hallazgos subrayan el potencial de los sistemas agroforestales para apoyar no solo la diversidad y funcionalidad de la fauna del suelo, sino también la sostenibilidad a largo plazo de los suelos agrícolas.

Ante este contexto, el cultivo de pitahaya (*Hylocereus undatus*) se ha vuelto popular debido al valor económico de los frutos en el mercado nacional e internacional y en México este cultivo es redituable debido a su capacidad de adaptarse a condiciones adversas, como climas semiáridos y condiciones de suelos pobres y pedregosos, hasta aquellos con alto contenido de materia orgánica (Morales-Ayala et al. 2020; Ortiz and Takahashi 2020). Este cultivo se realiza en diferentes tipos de manejo, que incluyen el monocultivo, con tutorado muerto o vivo y bajo el esquema de un

sistema agroforestal (Cálix de Dios et al. 2014; Vargas et al. 2022; Hasan et al. 2023). Actualmente, en Chiapas se empieza a implementar sistemas de producción de pitahaya bajo un manejo agroforestal, no obstante, se carece de información documentada sobre la influencia de los sistemas agroforestales específicamente de la presencia de árboles dispersos sobre la fauna edáfica en cultivo de pitahaya y de las interacciones ecológicas de los árboles dispersos y tutores vivos.

En este estudio se evalúa el rol funcional de los árboles sobre los distintos gremios tróficos de invertebrados edáficos y cómo estos afectan a un sistema agroforestal de pitahaya con árboles nativos dispersos y tutores vivos. Se plantearon las siguientes preguntas ¿Los árboles tienen un efecto significativo sobre la composición y diversidad de los invertebrados? ¿Las especies de árboles tienen efectos independientes e individuales sobre la composición y diversidad de los invertebrados? ¿Cuál es la magnitud del efecto de la estacionalidad (época de lluvias y de sequía) sobre la variación de invertebrados del suelo?

1.1 OBJETIVOS

1.1.1 Objetivo general

Caracterizar la dinámica estacional de la comunidad de invertebrados en un cultivo agroforestal de *Hylocereus undatus.*

1.1.2 Objetivos específicos

2. Evaluar el efecto de árboles nativos dispersos sobre la diversidad y la composición de la comunidad de invertebrados.

3. Describir las variaciones estacionales en la diversidad y composición de la comunidad de invertebrados en el sistema agroforestal de pitahaya.

CAPITULO I

Articulo 1. Seasonality, not Scattered trees, drives soil invertebrate diversity in agroforestry of dragon fruit

El siguiente artículo fue sometido a la revista Applied Soil Ecology y se encuentra en proceso de revisión

Applied Soil Ecology

Seasonality, not Scattered trees, drives soil invertebrate diversity in agroforestry of dragon fruit

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	Miguel Prado-López, Ph.D
Abstract:	Scattered trees are key structural components in agroforestry systems, often enhancing microclimatic conditions and soil biodiversity. However, their role in cactus-based agroforestry systems remains poorly understood. We evaluated their effect and seasonality on the diversity, composition, and functional structure of soil invertebrate community in a Hylocereus undatus (dragon fruit) agroforestry system in Chiapas, Mexico. Monthly sampling was conducted over 12 months using soil monoliths and pitfall traps under the canopies of three native tree species and in full-sun conditions. Soil physicochemical variables were measured, and the diversity patterns (alpha and beta diversity) were determined using Hill numbers. A total of 13,499 individuals from 124 families were recorded, with Formicidae, Entomobryidae, and Hodotermitidae accounting for 86% of total abundance. Seasonality, rather than tree presence, was the main driver of community structure, explaining nearly twice the variation in composition. Alpha diversity increased significantly during the rainy season across all trophic guilds, whereas diversity under tree canopies was consistently lower than in full-sun microsites. Soil nitrogen was positively associated with detritivore and herbivore diversity, but most soil variables showed no significant relationship with community composition. These findings suggest that scattered trees do not consistently act as “fertility islands” and may not provide microhabitats conducive to higher soil invertebrate diversity. Management strategies should focus on selective tree retention based on functional traits and the maintenance of trophic diversity, balancing crop productivity with belowground biodiversity conservation. Our results provide a framework for designing agroforestry systems in drought-tolerant crops, where ecological trade-offs operate under distinctive environmental constraints.

Felipe Bastida
Editor-in-Chief
Applied Soil Ecology

Dear Editor-in-Chief,

I am pleased to submit our manuscript entitled “Seasonality, Not Scattered Trees, Drives Soil Invertebrate Diversity in agroforestry of Dragon Fruit” for consideration as a Research Article in Applied Soil Ecology.

Our study directly addresses the central aims of your journal specifically, the role of soil organisms and their interactions in soil fertility and ecosystem processes. We present novel findings showing that, in Cactaceae-based agroforestry systems (pitahaya under native tree canopies), seasonality, not scattered tree presence, is the key determinant of soil invertebrate community structure. We challenge the traditional “fertility island” model and propose a refined understanding of ecological trade-offs in drought-tolerant agroecosystems.

This fits your journal because it explores soil invertebrate dynamics within the context of nutrient cycling and soil health under human-managed systems. It integrates interdisciplinary approaches including community ecology, agroforestry, and functional soil biology, and the findings offer practical insights, guiding management strategies that balance productivity and belowground biodiversity.

The abstract, highlights, graphical abstract, and full manuscript follow the journal’s author guidelines. All co-authors have approved the submission, and this work is not under review elsewhere.

We believe our research will stimulate interest among Applied Soil Ecology readers and contribute to the current discourse on sustainable agroecological practices.

Thank you for considering our manuscript. We look forward to your feedback.

Sincerely,

Miguel Prado Lopez, PhD.
On behalf of all co-authors
Universidad de Ciencias y Artes de Chiapas
Km 3 Carretera Villa Corzo – Ejido Monterrey, Chiapas, México

Highlights

- Seasonality, not scattered trees, was the main driver of soil invertebrate diversity
- Alpha diversity increased in the rainy season across all trophic guilds
- Tree canopies did not act as “fertility islands” in dragon fruit agroforestry systems
- Nitrogen was positively related to detritivore and herbivore diversity
- Findings guide tree retention strategies for drought-tolerant crop agroforestry

Seasonality, not Scattered trees, drives soil invertebrate diversity in agroforestry of dragon fruit

Abstract

Scattered trees are key structural components in agroforestry systems, often enhancing microclimatic conditions and soil biodiversity. However, their role in cactus-based agroforestry systems remains poorly understood. We evaluated their effect and seasonality on the diversity, composition, and functional structure of soil invertebrate community in a *Hylocereus undatus* (dragon fruit) agroforestry system in Chiapas, Mexico. Monthly sampling was conducted over 12 months using soil monoliths and pitfall traps under the canopies of three native tree species and in full-sun conditions. Soil physicochemical variables were measured, and the diversity patterns (alpha and beta diversity) were determined using Hill numbers.

A total of 13,499 individuals from 124 families were recorded, with Formicidae, Entomobryidae, and Hodotermitidae accounting for 86% of total abundance. Seasonality, rather than tree presence, was the main driver of community structure, explaining nearly twice the variation in composition. Alpha diversity increased significantly during the rainy season across all trophic guilds, whereas diversity under tree canopies was consistently lower than in full-sun microsites. Soil nitrogen was positively associated with detritivore and herbivore diversity, but most soil variables showed no significant relationship with community composition.

These findings suggest that scattered trees do not consistently act as “fertility islands” and may not provide microhabitats conducive to higher soil invertebrate diversity. Management strategies should focus on selective tree retention based on functional traits and the maintenance of trophic diversity, balancing crop productivity with belowground biodiversity conservation. Our results provide a framework for designing agroforestry systems in drought-tolerant crops, where ecological trade-offs operate under distinctive environmental constraints.

Keywords: Agroforestry, *Hylocereus undatus*, soil biodiversity, seasonality, Hill numbers, ecological trade-offs, fertility islands

1. **Introduction**

Agroforestry cactus systems have gained increasing attention due to their potential to improve soil health through erosion control and enhanced soil structure. However, empirical studies evaluating plant–soil ecological interactions in cacti remain scarce (Bautista-Cruz et al., 2018; Muchane et al., 2020). In dragon fruit (*Hylocereus undatus*) agroforestry systems, these plant–soil interactions are critical for regulating key soil ecosystem processes such as carbon storage, nutrient cycling, and water infiltration (Cálix de Dios et al., 2014; Santos et al., 2021). Within this network of interactions, soil invertebrates play a central role in maintaining soil structure and functionality (Jouquet et al. 2014). Their importance is particularly pronounced in agroecosystems with seasonal and limited water availability, where their activity contributes to improved soil health, system sustainability, and water-use efficiency (Chamorro-Martínez et al., 2022; De-Souza et al., 2016; Manchado-Cuellar et al., 2021; Sofo et al., 2020).

Among soil invertebrates, functional groups contribute specifically to the regulation of soil ecosystem functions and processes (Paz-Ríos et al., 2022). For instance, detritivores facilitate litter fragmentation and decomposition, herbivores influence the amount of plant material entering the soil, and predators act as biological control agents (Cabrera-Dávila and López-Iborra, 2018; Cabrera et al., 2017; Hambäck et al., 2021; Paz-Ríos et al., 2022). Invertebrates also modify soil physical and chemical properties through the creation of galleries and tunnels, which enhance porosity and facilitate water, air, nutrient flow, and root growth (Cabrera-Dávila and López-Iborra, 2018; Lavelle et al., 2006).

The effects of soil invertebrate activity on ecological processes can be regulated by abiotic factors (e.g., soil physicochemical properties, temperature, moisture) and biotic factors (e.g., plants, fungi, macrofauna) (Chávez et al., 2020; Navia et al., 2021). The complexity of agroforestry systems arising from these factors plays a key role in regulating ecological processes and may contribute to improved soil health and system sustainability (Bastida et al., 2020; Tajik et al., 2019b). Therefore, interactions among these elements still require a more detailed description, particularly regarding biological interactions and dynamics, nutrient and energy flows—fundamental to system productivity and sustainability—and the effects of diversification, considering different crop–tree combinations (Luedeling et al., 2016; Rosati et al., 2021). In addition, it is important to note

that further investigation is needed to assess the impact of soil management practices on soil structure and water retention capacity, as well as on system resilience to climate change. Such understanding is crucial for improving agroforestry management strategies and anticipating system responses to environmental stressors (Ghimire et al., 2024).

In agroforestry systems, trees influence the spatial distribution of resources and microenvironmental heterogeneity. This effect is often described as "fertility islands," where tree presence modifies soil organism activity and soil physical and chemical properties, creating more stable environmental conditions (Cakir, 2018; Fahad et al., 2022; Rodríguez-Suárez et al., 2019). The concept has been widely applied in productive systems under stressful environmental conditions, such as low water availability (Pinho et al., 2012). For example, in a study where *Ziziphus jujuba* trees were intercropped with canola and lily, soil bulk density decreased, and water availability increased in tree-associated areas compared with *Z. jujuba* monocultures (Cardinael et al., 2020). Another study reported that tree presence enhances soil invertebrate activity, increasing organic matter decomposition and supporting biological control compared with grazed areas and croplands without trees (Bufebo et al., 2021; Niether et al., 2020; Visscher et al., 2024). These findings reinforce the idea that trees act as resource islands, promoting heterogeneity in soil conditions and enhancing soil water conservation. Consequently, this may significantly affect soil invertebrate distribution, diversity, and composition, which in turn influences the regulation of agroforestry soil ecosystem processes such as increases in soil carbon and nitrogen levels (Kamau et al., 2017).

Evidence suggests that species diversification in agroforestry systems can improve soil regulatory functions. However, the role of trees in cactus-based agroforestry systems is not yet fully understood, especially in light-demanding and water-limited systems such as dragon fruit (*H. undatus*) cultivation (Fahad et al., 2022). As a cactus, dragon fruit possesses the physiological capacity to grow in environments with low water and humidity availability. Moreover, it can develop in a wide range of soils—from sandy to those with high organic matter content—and does not require substantial shade (Khatun et al., 2023; Verona-Ruiz et al., 2020). Therefore, in dragon fruit plantations, tree presence may compromise production by providing shade and altering soil properties such as temperature and moisture (Minor and

Kobe, 2019; Vargas-Tierras et al., 2021). It is thus necessary to assess the role of scattered trees on soil invertebrate communities and consequent soil properties.

We hypothesize that scattered tree presence reduces thermal stress during the dry season, thereby enhancing the abundance and diversity of soil invertebrates. Furthermore, we expect that tree effects are modulated by seasonality, particularly in the dry season when trees may act as islands of favorable environmental conditions for soil fauna. One of the main challenges in using diversity as an indicator of soil quality is the lack of standardized data (e.g., sampling methods and design), which limits the integration of soil biodiversity into land management indicators (Creamer et al., 2016; Römbke et al., 2018). Moreover, it is necessary to address the relationships between soil properties—such as nutrient content and pH—and diversity metrics to improve assessment accuracy (Gholizadeh et al., 2018).

In this context, the aim of this study was to evaluate the effect of scattered trees on the diversity and composition of soil invertebrate communities, considering their potential role as modulators of spatial heterogeneity in soil conditions and soil fauna community structure compared with fully sun-exposed areas. This approach seeks to provide evidence on potential ecological trade-offs between crop productivity and the conservation of agroforestry ecological processes (Luedeling et al., 2016; Rosati et al., 2021) thereby improving management strategies (Ghimire et al., 2024). Implementing studies that address these aspects could provide clearer direction for the sustainable use of cacti in agroforestry systems.

2. Materials and methods

2.1 Study area

The study was conducted at El Brasil ranch, located in the Central Depression of Chiapas, Mexico (Fig. 1). The area has a warm subhumid climate (Aw) with a mean annual temperature ranging from 22.8 to 25.8 °C, and average annual precipitation between 660 and 1051 mm (Rocha-Loredo et al., 2010). The soils in the study region are calcareous and include Leptosols, Regosols, Phaeozems, Vertisols, and Fluvisols (Cruz Roblero et al., 2024; Rocha-Loredo et al., 2010). The remaining and surrounding vegetation is tropical dry forest,

with patches of sub-evergreen medium-stature forest in more humid areas (Cruz Roblero et al., 2024; Rocha-Loredo et al., 2010)

The dragon fruit plantation covers 3 ha, with a total of 1,802 plants arranged in rows. Dragon fruit plants grow on living supports of *Bursera diversifolia* (Burseraceae). Within the cultivated area, 12 native tree species are present, under which dragon fruit plants with their respective living supports are also found. These native trees are randomly distributed throughout the plantation and include *Alvaradoa amorphoides, Byrsonima crassifolia, Casearia* sp., *Ceiba aesculifolia, Gliricidia sepium, Haematoxylum brasiletto, Leucaena leucocephala, Lysiloma divaricatum, Neopringlea viscosa, Pithecellobium dulce, Sideroxylon obtusifolium y Swietenia humilis.* These trees are remnants of the original forest and were deliberately retained during plantation establishment. For the purposes of this study, only the three most abundant species (*Alvaradoa amorphoides, Haematoxylum brasiletto* y *Lysiloma divaricatum*).

2. 2 Field sampling

Soil invertebrate sampling was conducted every 30 days over a 12-month production cycle, from August 2023 to July 2024. In each sampling event, four individuals of each tree species (12 trees in total) were randomly selected. For each selected tree, one dragon fruit plant growing on its living support under the tree canopy was chosen. Additionally, one dragon fruit plant growing on a living support outside the influence of the tree canopy (i.e., fully sun-exposed plants) was selected. All sampled plants were located at least 5 m from the canopy edge. Each sampling event comprised 24 sampling units: 12 under the canopy of scattered trees and 12 in fully sun-exposed conditions. Soil invertebrates were collected using two complementary methods: (i) for hypogeic invertebrates, soil monoliths (20 × 20 × 20 cm) were extracted; and (ii) for epigeic invertebrates, pitfall traps were installed in the same location where the monoliths were taken (Navarro et al., 2011). Both methods were applied 1.5 m from the base of the selected dragon fruit plant. Monolith sampling involved removing the soil layer by layer and manually extracting visible invertebrates; this process took approximately 5 minutes per monolith. Pitfall traps consisted of 200 ml containers buried flush with the soil surface, filled with 80 ml of preservative solution, and left in place for 48

h (Cole et al., 2016; da Silva et al., 2021). Collected specimens were preserved in 90% ethanol for transport to the laboratory, where they were identified to order and family (Milne y Milne, 1980; Zumbado and Azofeifa, 2018) and assigned to a trophic guild (predators, herbivores, and detritivores) following Cabrera et al. (2017), Potapov et al. (2022) y Sabatté et al. (2021).

2.3 Soil variables

At each sampling point, soil temperature (°C), moisture (%), N, P, and K (mg kg^{-1}), and electrical conductivity (µS cm^{-1}) were recorded using a three-prong Soil Electrical Conductivity (EC) and Temperature Sensor (AO-SoilECTempSensor, Chao Sensor). For each variable, three readings were taken 1.5 m from each plant, oriented to different cardinal points, at a depth of 10 cm. Measurements were performed twice daily (07:00 and 12:00 h) during all sampling months. From these monthly datasets, seasonal and location-specific averages were calculated to obtain representative values for each plant.

2.4 Statistical analyses

Alpha diversity was assessed using Hill numbers or true diversity (Hill, 1973). Three diversity orders were calculated: the effective number of families or observed family richness (q = 0, ${}^{0}D$); common families, weighted by their proportional abundances, obtained as the exponential of the Shannon index (q = 1, ${}^{1}D$); and dominant families, which assign greater weight to abundant families, calculated as the inverse of the Simpson index (q = 2, ${}^{2}D$) (Chao et al., 2014). Alpha diversity values were calculated at two analytical levels: overall and separately for each trophic guild.

To assess the effects of tree influence (under canopy vs. full sun), seasonality (dry vs. rainy season), and soil variables (temperature, moisture, N, P, K, and electrical conductivity) on abundance and Hill numbers, generalized linear models (GLMs) were fitted. Analyses were performed for both overall diversity and for each trophic guild. Prior to model fitting, Pearson correlation tests were applied to evaluate collinearity among soil variables. Different GLM families were used according to the error distribution of the response variable: Poisson

for abundance and family richness (^0D), and Gaussian or Gamma for other alpha diversity components (^1D and ^2D). Models were simplified according to the principle of parsimony, retaining only variables with significant effects (Crawley, 2007). Model validation included assessing residual normality using Q–Q plots and the Shapiro–Wilk test; if normality assumptions were violated, the Wilcoxon–Mann–Whitney test was applied. GLMs in the R Software (R Core Team, 2023).

Variation in community composition was evaluated using Jaccard (presence/absence) and Bray–Curtis (abundance) indices to compare invertebrate family composition across sampling conditions (tree effect and seasonality). These indices quantify the proportion of families shared between two sites relative to the total number of families in the study, providing insight into community variability as a function of tree presence and season. Indices were calculated using the *vegan* package (Oksanen et al., 2024). Patterns of community composition were visualized using non-metric multidimensional scaling (NMDS) based on both Bray–Curtis and Jaccard dissimilarity matrices, implemented with *vegan* package (Oksanen et al., 2024). The effects of soil variables on compositional variation were analyzed using permutational multivariate analysis of variance (PERMANOVA) with distance matrices, implemented via the *adonis2* function in *vegan* (Oksanen et al., 2024). Both Bray–Curtis and Jaccard indices were used, incorporating predictor variables to partition dissimilarities among potential sources of variation, with significance tested via 999 permutations. All analyses were conducted in R (R Core Team, 2023). Sixty-two specimens identified only to order were excluded from the analyses. For all statistical tests, the significance threshold was set at $\alpha = 0.05$ ($p < 0.05$).

3. Results

A total of 13,499 individuals belonging to 124 families were recorded. The most abundant families were Formicidae (9,913 individuals), Entomobryidae (1,414), and Hodotermitidae (271), which together accounted for 86% of the total abundance (Table 1). At the trophic guild level, detritivores were the most abundant group (14.9 ± 36.1, mean ± SD), followed by predators (1.57 ± 1.41) and herbivores (1.35 ± 0.887). In terms of family richness within each guild, predators had the highest richness (60 families), followed by detritivores (45) and herbivores (17). The most representative families within each guild were

Salticidae among predators, Formicidae among detritivores, and Cicadellidae among herbivores (Table 1).

Table 1. Top five most abundant soil invertebrate families within each trophic guild in a dragon fruit agroforestry system.

Trophic guild	Families	Abundance
Detritivore	Formicidae	9913
	Entomobrydae	1414
	Hodotermitidae	271
	Termopsidae	150
	Culicidae	126
	Others (40)	635
Phytophagous	Cicadellidae	46
	Tetranychidae	32
	Thripidae	23
	Acrididae	19
	Gryllidae	18
	Others (12)	34
Predator	Salticidae	147
	Vespidae	127
	Asilidae	80
	Muscidae	57
	Anyphaenidae	51
	Others (55)	292

3.1 Effect of scattered trees and seasonality on abundance and true diversity

Overall, soil invertebrate abundance was significantly higher in full sun areas compared with under tree canopies ($p < 0.003$, Mann–Whitney test; Table 2). Seasonal patterns showed a gradual increase in abundance towards the rainy season; however, GLM analysis did not detect a statistically significant seasonal effect (Fig. 2, Table 2). Regarding alpha diversity models, for ${}^{0}D$, diversity was significantly lower under tree canopies ($\chi^2 = 57.545$, $p < 0.001$), whereas seasonality had a significant positive effect, with higher ${}^{0}D$

during the rainy season (χ^2 = 26.874, p < 0.001). For ^1D and ^2D, diversity was also significantly higher in full sun compared with under trees (^1D: χ^2 = 41.962, p < 0.001; ^2D: χ^2 = 24.804, p < 0.001). Seasonality increased diversity for both indices (^1D: χ^2 = 26.050, p < 0.001; ^2D: χ^2 = 16.494, p < 0.001) (Table 2, Fig. 3). No significant interaction between tree presence and seasonality was detected in any model.

Table 2. Summary of GLM assessing the relationship between true diversity parameters (^0D, ^1D, and ^2D) and the predictor variables (tree effect, season, and their interaction). For abundance, a non-parametric Wilcoxon Mann–Whitney test was performed; in this case, significance values are shown for tree effect and season. Non-significant (NS) variables (N and soil temperature) are not shown. D, deviance explained. NA, not applicable due to the type of test performed.

Variable	Estimate	Tree effect	Season	Tree effect x Season	*D*
Abundance		0.003**	0.148	NS	NA
^0D	18.913***	-9.841***	5.4358***	NS	56.1227
^1D	16.326***	-11.3781***	5.7487***	NS	64.8297
^2D	10.34***	-6.922***	3.6245***	NS	55.7633

Significance: ***, p < 0.001; **, p < 0.01; *, p < 0.05.

3. 2 Effect of tree presence on trophic guilds

At the trophic guild level, both tree presence and seasonality significantly affected predator abundance and alpha diversity. Full sun areas exhibited higher values than areas under tree canopies (Abundance: χ^2 = 29.675, p < 0.001; ^0D: F = 203.062, p < 0.001; ^1D: χ^2 = 87.897, p < 0.001; ^2D: χ^2 = 81.089, p < 0.001). Predator diversity also increased during the rainy season, except for ^2D, which showed no significant seasonal effect (Abundance: χ^2 = 13.886, p < 0.001; ^0D: F = 22.6875, p < 0.001; ^1D: χ^2 = 4.028, p < 0.001) (Table 3).

Table 3. Summary of GLM assessing the relationship between true diversity parameters (^0D, ^1D, and ^2D) and the predictor variables (tree effect, season, and their interaction) for the

predator trophic guild. Non-significant (NS) variables (N and soil temperature) are not shown. D, deviance explained.

Variable	Estimate	Tree effect	Season	Tree effect x Season	*D*
Abundance	23.946***	-16.0246**	7.4960**	NS	44.0226
${}^{0}D$	8.8958***	-4.7500***	1.375*	NS	0.4737
${}^{1}D$	2.7258***	-1.0481***	0.208*	NS	65.1463
${}^{2}D$	2.7150***	-1.0578***	NS	NS	63.4867

Significance: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$.

For detritivores, abundance was higher in full sun than under tree canopies ($F = 10$, $p < 0.001$). Both tree presence and seasonality significantly influenced alpha diversity indices, with consistently higher values in open microsites (${}^{0}D$: $\chi^2 = 11.329$, $p < 0.001$; ${}^{1}D$: $\chi^2 = 63.45$, $p < 0.001$; ${}^{2}D$: $F = 2.184$, $p < 0.001$) and during the rainy season (${}^{0}D$: $\chi^2 = 25.01$, $p < 0.001$; ${}^{1}D$: $\chi^2 = 40.742$, $p < 0.001$; ${}^{2}D$: $F = 5.236$, $p < 0.001$). In addition, soil nitrogen had a significant effect on ${}^{2}D$ ($F = 0.90$, $p < 0.001$), indicating that higher nitrogen concentrations reduced dominance of certain detritivore families (Table 4). No significant interaction between tree presence and seasonality was observed for either predators or detritivores (Tables 3 and 4).

Table 4. Summary of GLM assessing the relationship between true diversity parameters (${}^{0}D$, ${}^{1}D$, and ${}^{2}D$) and the predictor variables (tree effect, season, and their interaction) for the detritivore trophic guild. The non-significant (NS) variable (soil temperature) is not shown. D, deviance explained.

Variable	Estimate	Tree effect	Season	N	Tree effect x Season	*D*
Abundance	5.6118***	-1.0541**	NS	NS	NS	0.1726
${}^{0}D$	6.8050***	-2.9687**	3.7630***	NS	NS	37.7205
${}^{1}D$	2.2172***	-1.0257***	0.7717***	NS	NS	70.2274
${}^{2}D$	1.1587***	-0.6186**	0.6755***	0.0114*	NS	0.5832

Significance: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$.

For herbivores, there was a significant interaction between tree presence and seasonality for ^1D ($\chi^2 = 5.228$, $p < 0.001$) and ^2D ($\chi^2 = 4.604$, $p < 0.001$) (Table 5). Post hoc comparisons revealed that the highest diversity occurred in sun-exposed plants during the rainy season, with significantly higher values than in shaded conditions in the same season or during the dry season (^1D: $p = 0.0139$ and 0.0279; ^2D: $p = 0.0001$ and 0.0024, respectively) (Fig. 4). Soil nitrogen also significantly affected herbivore abundance ($\chi^2 = 19.094$, $p < 0.001$), indicating that abundance increased with higher nitrogen concentrations (Table 5). However, neither tree presence nor seasonality had significant effects on herbivore abundance or richness, suggesting that their dynamics may be influenced by other environmental factors or specific resource availability not assessed in this study.

Table 5. Summary of GLM assessing the relationship between true diversity parameters (^0D, ^1D, and ^2D) and the predictor variables (tree effect, season, and their interaction) for the phytophagous trophic guild. The non-significant (NS) variable (soil temperature) is not shown. D, deviance explained.

Variable	**Estimate**	**Tree effect**	**Season**	**N**	**Tree effect x Season**	***D***
Abundance	0.6926	-0.6232*	NS	0.0262***	NS	68.2142
^0D	-5.5084	NS	NS	NS	NS	0.31
^1D	3.8140***	NS	NS	NS	-4.5520*	52.8479
^2D	1.2891***	NS	NS	NS	-0.8876*	49.3739

Significance: ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$.

3.3 Community composition variation and determining effects

Of the 124 recorded families, 30 were exclusive to full sun sites and 31 to under-tree sites. In terms of seasonality, 29 families were exclusive to the dry season, whereas 48 were exclusive to the rainy season. The Jaccard index indicated greater similarity in family composition between microsites under trees and in full sun (0.50) than between the two

seasons (0.37). In contrast, the Bray–Curtis index showed that the magnitude of compositional change was similar between tree presence and seasonality (0.63 in both cases), with both values higher than those obtained using Jaccard.

Non-metric multidimensional scaling (NMDS) revealed a clear segregation of community composition by seasonality, forming two distinct groups corresponding to the dry and rainy seasons (Fig. 5). These patterns were corroborated by PERMANOVA, which indicated that seasonality explained 9.1% of the compositional variation, almost twice the influence of scattered trees (4.9%). None of the measured soil variables had significant effects on community composition ($p > 0.5$ in all cases) (Table 6).

Table 8. PERMANOVA results assessing the influence of seasonality, tree effect, and edaphic variables on the soil invertebrate community.

Variable	R^2	F	p
Tree effect	0.049	2.5551	0.0020**
Season	0.091	4.7371	0.0001***
Soil temperature	0.019	0.9999	0.4081
Nitrogen	0.017	0.9108	0.5461
Tree effect x Season	0.019	0.9828	0.4809
Total	1.00		

4. Discussion

4.1 Challenging the fertility island paradigm

Our results provide evidence of a counterintuitive pattern in dragon fruit agroforestry systems, where scattered trees do not act as facilitators of belowground diversity but rather as environmental filters that significantly reduced soil invertebrate diversity. This finding challenges the classical "fertility island" paradigm in agroforestry systems (Cakir, 2018; Fahad et al., 2022), suggesting that ecological trade-offs in cacti cultivated under scattered tree canopies may involve particular mechanisms that should be considered in the management of these agroecosystems. Discussion of these results is organized into four focal points: (1) the effects of seasonality and tree canopy on soil invertebrate alpha diversity; (2) seasonality as the primary driver of soil invertebrate community composition; (3) the functional dominance of key families; and (4) the decoupling between soil variables and community structure.

4.2 Seasonality vs. tree canopy effects

Seasonality emerged as the main determinant of soil invertebrate diversity, explaining nearly twice the variation in community composition compared with tree presence. This pattern was consistent across all trophic guilds, with significant increases in alpha diversity during the rainy season, even in fully sun-exposed areas. These findings suggest that during the dry season, water stress homogenizes soil invertebrate communities and tree presence has no significant effect, possibly due to the adaptation of these communities to markedly seasonal environments (Chown et al., 2011; Takola and Schielzeth, 2022).

Rainfall appears to act as an ecological trigger by increasing resource availability both aboveground (e.g., plant biomass) and in the soil, thereby reducing competition for moisture and diluting canopy effects (Sofo et al., 2020). In particular, increased soil moisture enhances microbial and enzymatic activity, accelerating organic matter decomposition and releasing key nutrients such as ammonium and nitrate, which become more accessible to plants and other soil organisms (Gao et al., 2020; Mellado-Vázquez et al., 2019).

In contrast to our hypothesis, trees did not function as fertility islands providing microclimatic refugia for soil invertebrates during the dry season. Possible mechanisms underlying this pattern include water and nutrient uptake by some scattered tree species that may exacerbate soil stress beneath the canopy (Cardinael et al., 2020). and the release of tannins and polyphenols by species such as *Haematoxylum brasiletto* and *Lysiloma divaricatum*, which may inhibit microbial and invertebrate activity (Pedraza-Bucio and Rutiaga-Quiñones, 2011). Moreover, the microclimatic conditions generated by scattered trees could negatively affect invertebrates adapted to more open and warmer conditions (Decaëns, 2010; Tajik et al., 2019a). However, this explanation should be interpreted with caution, as many soil invertebrate species exhibit considerable plasticity to environmental conditions (Rodríguez-Suárez et al., 2019). The reduced abundance under canopies may also be a transient phenomenon or be influenced by factors other than microclimatic effects *per se*.

4.3 Functional dominance in soil invertebrates: ecosystem efficiency and structural vulnerability

The co-dominance of Formicidae (ants), Entomobryidae (springtails), and Hodotermitidae (termites) supports previous research indicating that ants are often dominant in tropical systems due to their tolerance to extreme environmental variation (Amazonas et al., 2017; Kreider et al., 2021) and their trophic plasticity, which allows them to act both as predators and detritivores. This dual role enables resource optimization in environments where food and organic matter availability vary spatially and temporally (Cabrera et al., 2017).

The observed community composition reflects specialization in the rapid decomposition of labile organic matter, a characteristic of organically managed systems with high residue inputs (Lavelle et al., 2022), as in El Brasil ranch where agroecological practices such as organic fertilization and cover cropping are implemented. However, ant dominance could reduce functional redundancy, as ants may exert predation pressure on other families, such as dung beetles (absent in our samples) which are key nutrient cyclers in tropical environments (Niether et al., 2020). For termites, while accelerating woody residue decomposition, could also increase the risk of root damage in young plants, a phenomenon

documented in cactus agroforestry (Davies, 2011), potentially exacerbating susceptibility to other stressors such as interspecific competition for water and nutrients.

Low functional redundancy may make the system more vulnerable to disturbances due to dependence on a few dominant groups for key ecosystem functions (Pollierer et al., 2021; Wolters, 2001). While these dominant taxa are efficient nutrient cyclers in the short term, the absence of complementary taxa could increase vulnerability to disturbances that directly affect them, such as prolonged drought or changes in soil management.

4.4 Decoupling between soil physicochemical variables and community structure

The lack of significant relationships between most soil variables (P, K, moisture) and soil invertebrate community composition, except for nitrogen, contrasts with previous studies suggesting that nutrient availability and soil moisture directly influence soil community structure and diversity (Castillo-Trejo et al., 2023; Rodríguez-Suárez et al., 2019). This expectation is grounded in the idea that soil invertebrates respond to edaphic properties due to their functional roles in processes such as organic matter fragmentation, bioturbation, and interactions with microorganisms—processes that depend on nutrient and moisture availability (Anderson, 1988; Chakravarthy and Sridhara, 2016; McCary and Schmitz, 2021).

Nevertheless, other research in production systems and natural forests has shown that canopy cover can significantly modify soil properties, including nutrient availability, organic matter content, litter quality, and microclimate, thereby influencing soil invertebrate abundance and diversity (Inkotte et al., 2022; Wu et al., 2023) The absence of a clear pattern in our study may be due to unmeasured factors, such as litter chemical composition or volatile organic compound emissions by tree species, which have been identified as important modulators of soil invertebrate activity in other contexts (Fahad et al., 2022; Mujeeb Rahman et al., 2012).

Nitrogen was the only nutrient positively related to detritivore and herbivore guilds. In detritivores, localized nitrogen enrichment may result from organic matter accumulation within nests (Farji-Brener and Werenkraut, 2017; Zuo et al., 2021), potentially generating cascading effects on leaf quality that also benefit herbivores (Joern et al., 2012; Prather et al., 2021).

4.5 Implications for sustainable management of dragon fruit agroforestry systems

From a management perspective, incorporating trees into agroforestry systems is widely recognized for providing multiple ecosystem services, including microclimate regulation, biodiversity conservation, and nutrient cycling. However, our findings highlight a practical dilemma: in dragon fruit cultivation, scattered trees are associated with increased disease incidence and reduced fruit yield compared with full-sun areas (Prado-López et al., in prep.), while also failing to enhance soil invertebrate diversity. Tree removal, however, could compromise other services such as carbon sequestration and erosion control.

Selective tree retention is therefore recommended, focusing on species with favorable traits such as high-quality litter, smaller canopies, small leaves, nitrogen-fixing capacity, and shallow root architecture (e.g., *Gliricidia sepium*) to minimize water competition (Fahad et al., 2022; Rubio-Ríos et al., 2021). Additionally, conserving patches of surrounding native vegetation or live fences could help sustain generalist predators (e.g., Salticidae spiders) that regulate herbivore populations.

4.6 Scope and future perspectives

Although our spatiotemporal design (monthly sampling × 12 months) captured seasonal variability, important limitations remain. Expanding the number of tree species evaluated would help determine whether observed patterns are driven by phylogenetic or functional traits. Future studies should also incorporate trophic flow mapping using $\delta^{13}C$ and $\delta^{15}N$ isotope profiles to validate inferred functional groups, as well as microbiome metabarcoding to explore bacteria–invertebrate interactions as regulators of decomposition.

5. Conclusions

In conclusion, our study demonstrates that in dragon fruit agroforestry systems, seasonality—rather than the presence of scattered trees—is the primary factor shaping soil community structure. The inclusion of scattered trees in such systems does not necessarily create differentiated microenvironments that promote greater diversity of soil invertebrates. These findings redefine the concept of “fertility islands” in cactus-based agroforestry

production systems, emphasizing the need for context-specific approaches in agroforestry design.

These results do not contradict the well-recognized ecological benefits of trees in agroecosystems; rather, they highlight the importance of better understanding the temporal dynamics of soil community responses, as well as identifying the critical thresholds of canopy cover and functional traits required to achieve a balance between crop productivity and the maintenance of soil biodiversity.

The dominance of three functionally versatile soil invertebrate families suggests a precarious balance between efficiency and resilience in the agroecosystem, where plantation management must carefully balance the provision of organic resources with the conservation of trophic diversity. This study contributes a critical framework for designing agroforestry systems in drought-tolerant crops, where ecological trade-offs operate under distinct functional and environmental rules.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Fig. 1 Location of the study area at El Brasil ranch in the Central Depression of Chiapas, Mexico. The schematic map shows rows of dragon fruit plants supported by

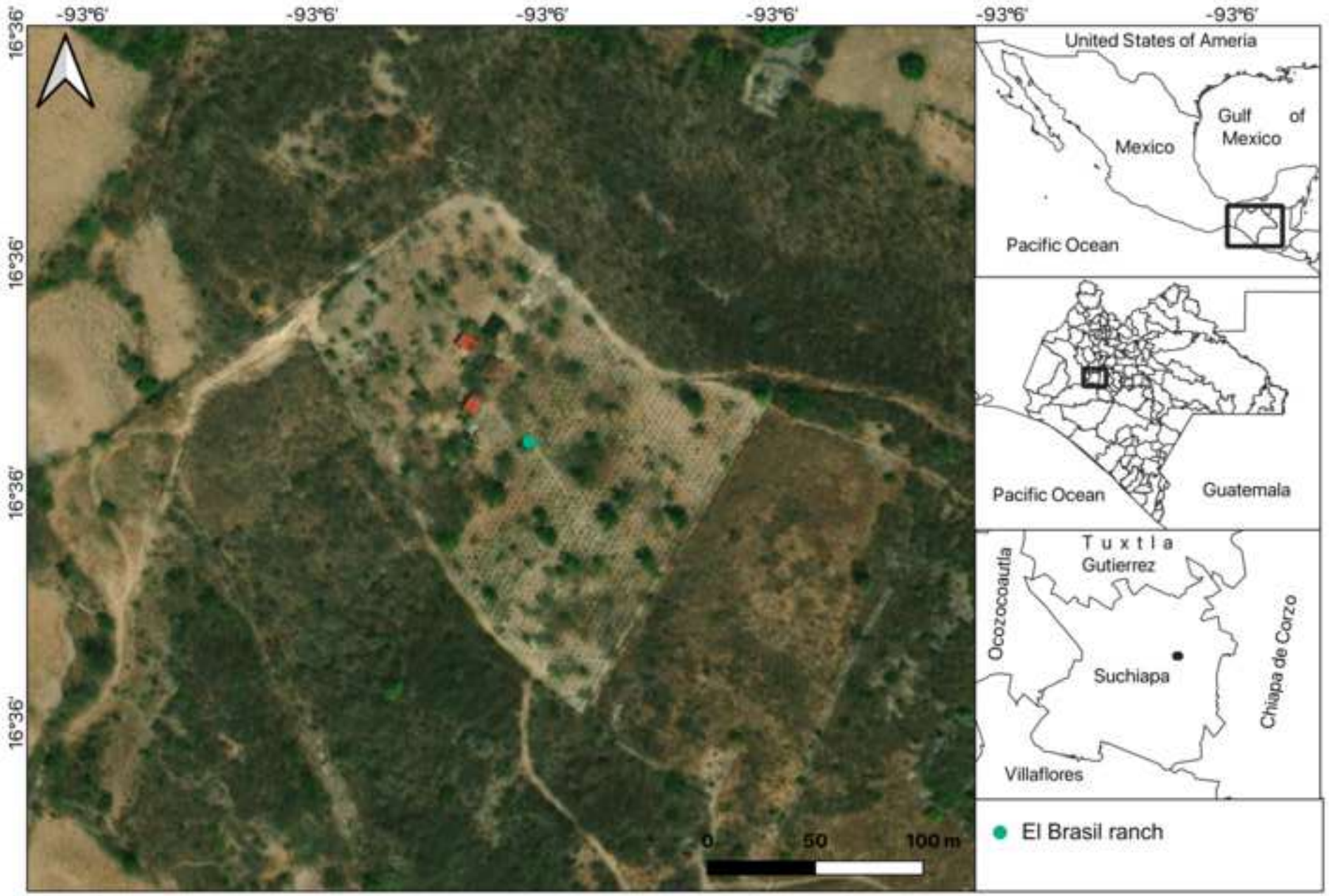


Fig. 2 Mean (±SD) monthly abundance of soil invertebrates during the 2023–2024 production cycle in a dragon fruit agroforestry system.

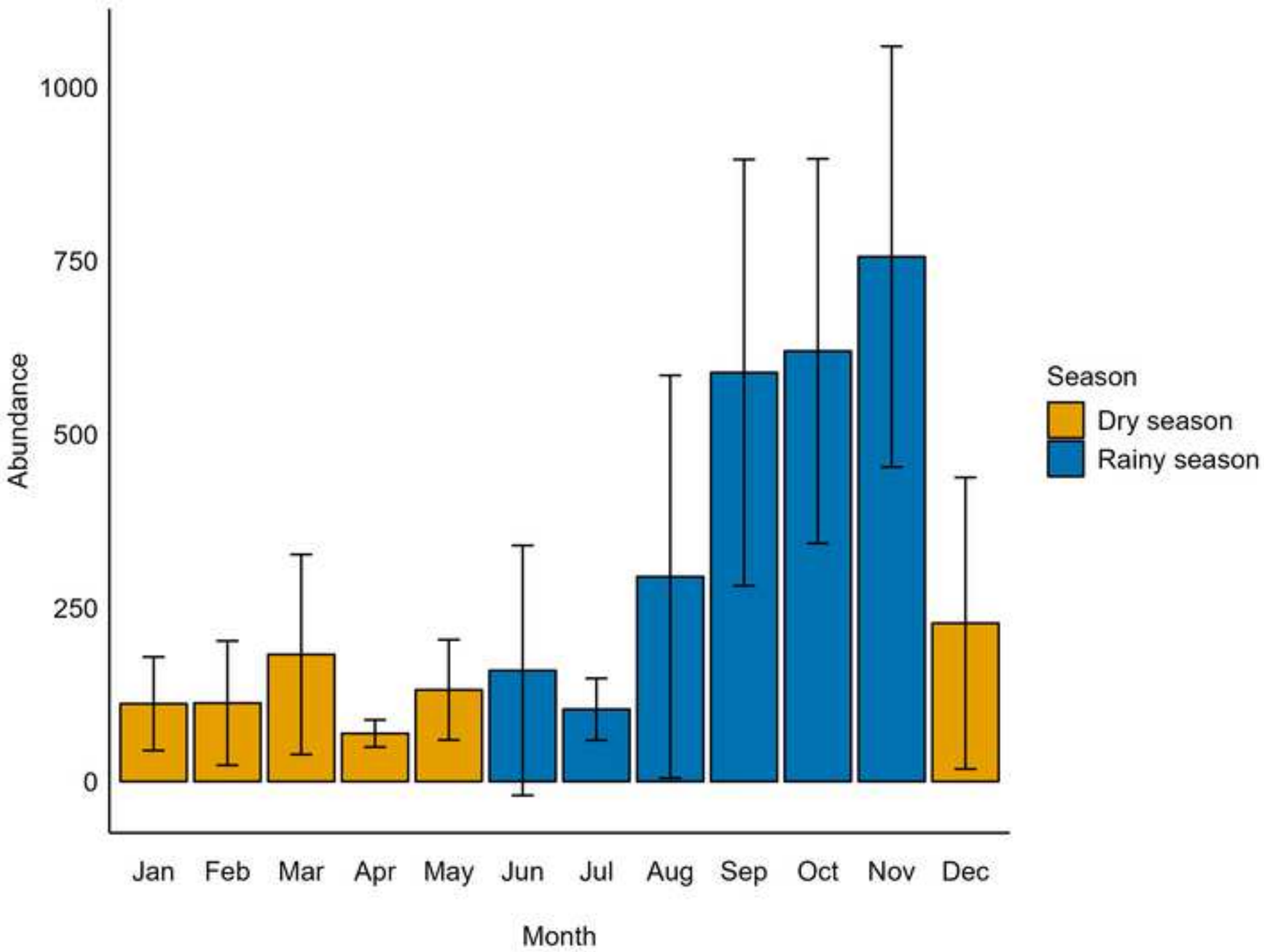


Fig. 3 Effect of trees on the abundance (a) and true diversity (b, c, and d) of soil invertebrates.

Click here to access/download;Figure;Figure 3.tiff

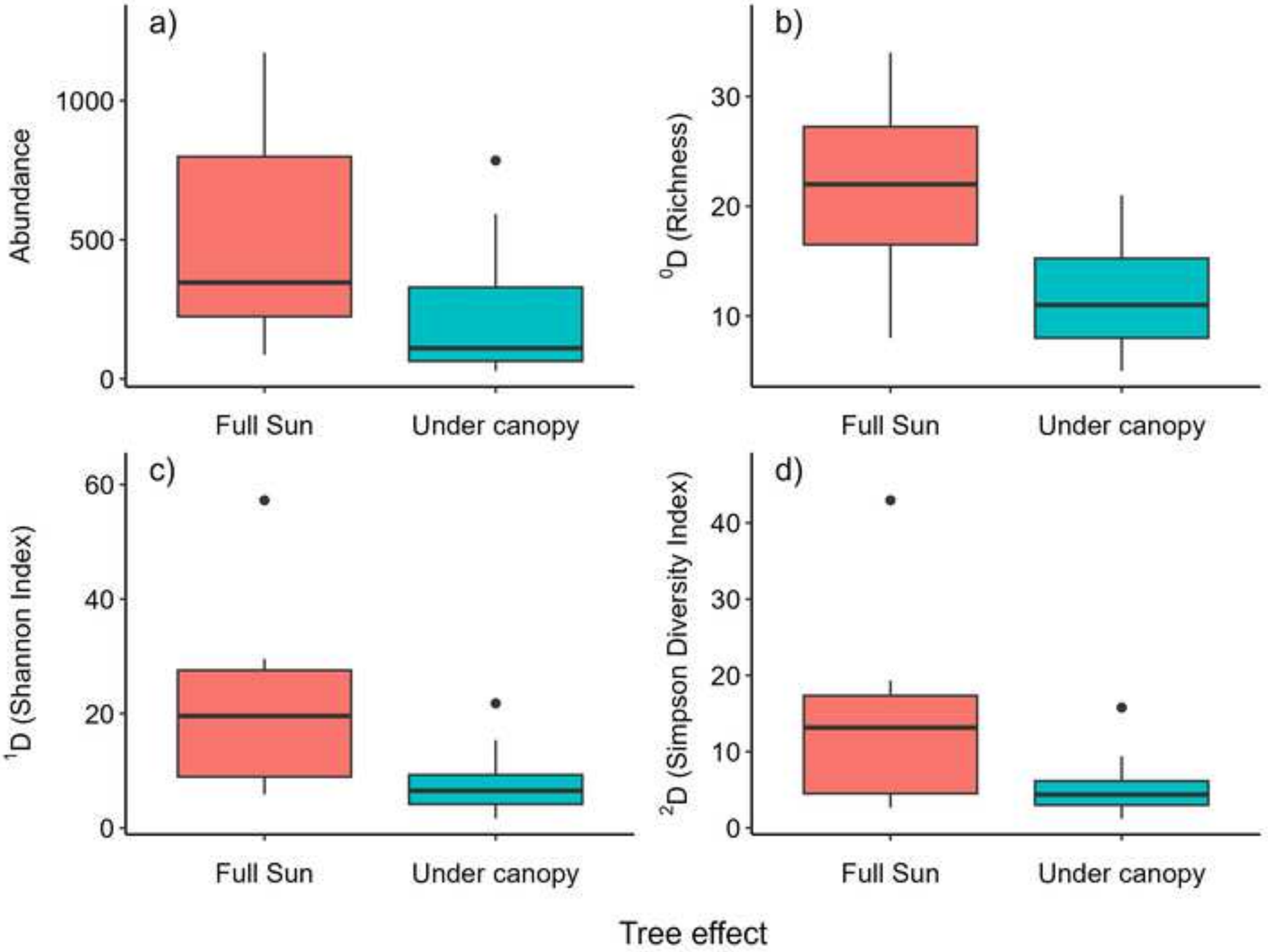


Fig. 4 Interaction effect of tree presence and season on true diversity indices 1D (a) and 2D (b) for the phytophagous trophic guild.

Click here to access/download;Figure;Figure 4.tiff

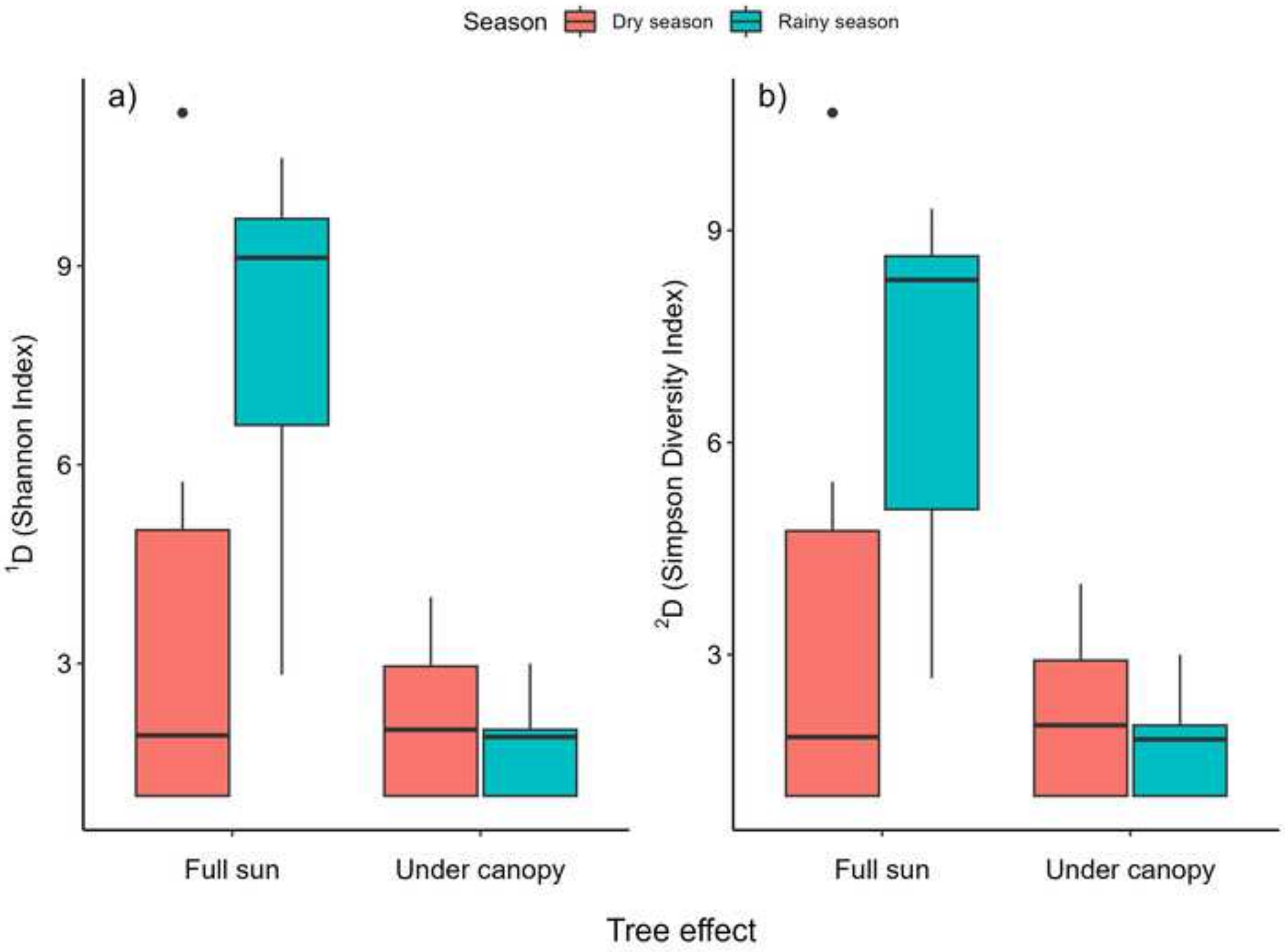
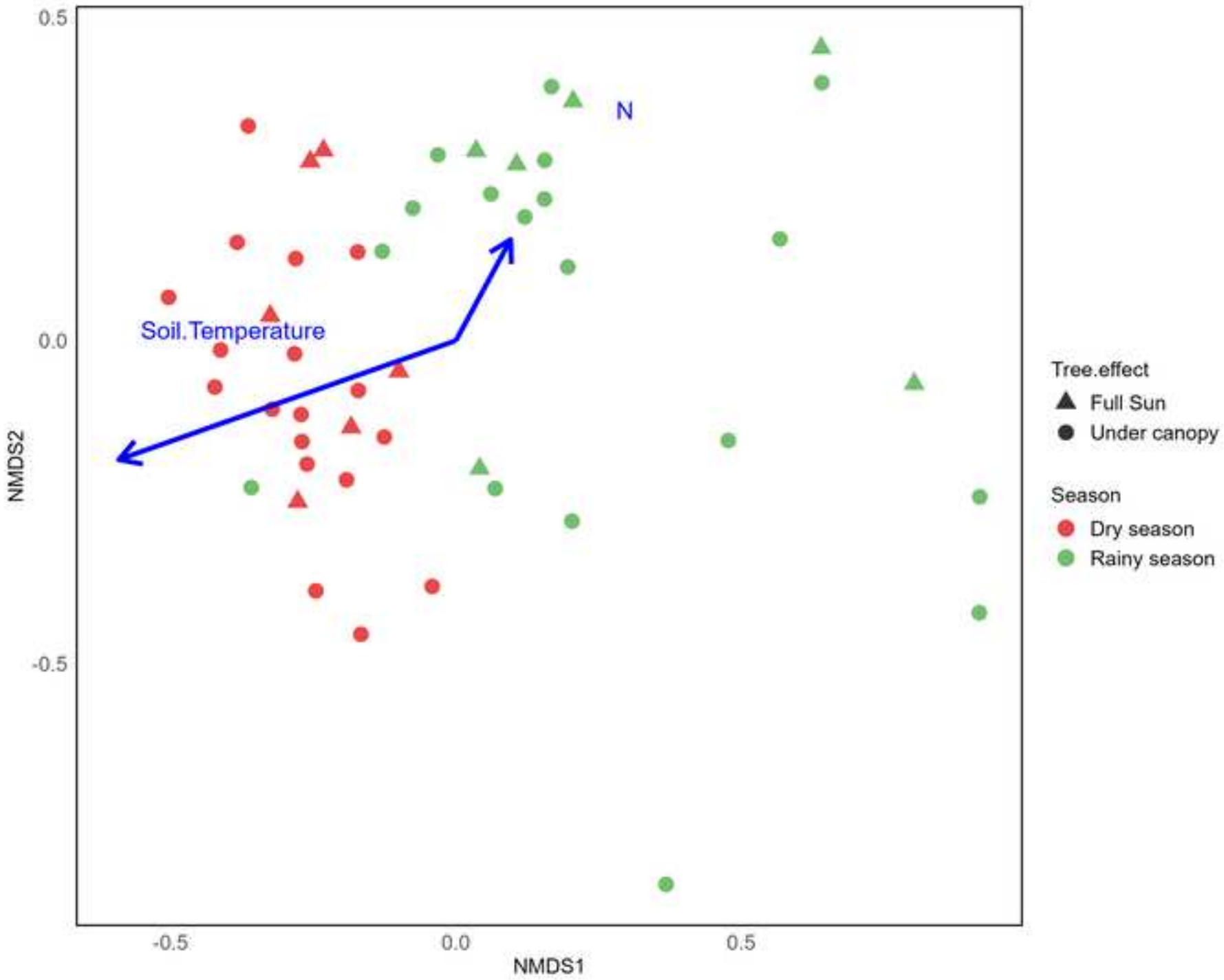


Fig. 5 NMDS showing changes in soil invertebrate community composition driven by tree effect and seasonality in a dragon fruit crop.

Click here to access/download;Figure;Figure 5.tiff



Declaration of interests

☒The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

DISCUSIÓN GENERAL

Este estudio abordó tres preguntas centrales: (i) si los árboles dispersos modifican la diversidad y la composición de los invertebrados del suelo; (ii) si hay efectos específicos de cada especie arbórea; y (iii) si tales efectos están modulados por la estacionalidad. En conjunto, los resultados muestran que la presencia de árbol sí introduce diferencias detectables (menor abundancia y diversidad bajo copa), pero su magnitud es subordinada a la estación del año. La separación composicional de invertebrados entre la época de seca y lluviosa fue más marcada que la separación bajo copa vs. pleno sol, y la diversidad alfa aumentó sistemáticamente en lluvias; ello es consistente con el papel de la precipitación como disparador ecológico que incrementa recursos y activa la descomposición microbiana (Mellado-Vázquez et al. 2019; Sofo et al. 2020; Gao et al. 2020) y con la homogeneización por estrés hídrico en la estación seca (Chown et al. 2011; Takola and Schielzeth 2022).

En cuanto al efecto del arbolado, el patrón de menor diversidad bajo copa sugiere mecanismos simples y plausibles: (a) competencia por agua y nutrientes en el volumen radicular compartido, especialmente en periodos secos (Cardinael et al. 2020); (b) sombra prolongada que modifica el microambiente para especies adaptadas a condiciones abiertas y cálidas (Decaëns, 2010; Tajik et al., 2019a); y (c) calidad y química de la hojarasca (p. ej., taninos, polifenoles) que puede afectar la actividad microbiana y de invertebrados (Pedraza-Bucio and Rutiaga-Quiñones 2011; Mujeeb Rahman et al. 2012). Estos procesos explican que el contraste bajo copa vs. sol sea visible pero menor que el impuesto por la temporada.

Respecto a efectos por especie, las señales fueron débiles frente al contraste microambiental general. Esto apunta a que la identidad importa cuando se conoce el conjunto de rasgos (arquitectura de copa, tamaño de hoja, profundidad de raíces, C/N y compuestos de la hojarasca). Sin esa caracterización, el efecto se diluye en el ruido ambiental y estacional. Funcionalmente, la comunidad estuvo dominada por pocos grupos versátiles (hormigas, colémbolos, termitas), lo que favorece el reciclaje rápido de residuos, pero reduce la redundancia y puede aumentar la sensibilidad del sistema a disturbios que afecten a esos grupos dominantes (Wolters 2001; Amazonas et al. 2017; Pollierer et al. 2021; Kreider et al. 2021).

En las propiedades edáficas, el nitrógeno fue el predictor más consistente a favor de detritívoros y herbívoros; otras variables medidas no mostraron relaciones estables a la escala de muestreo. Esto puede deberse a desajustes de escala temporal y espacial (pulsos de lluvia, y variaciones locales y temporales en temperatura y humedad del suelo) y a factores no medidos como la calidad de la hojarasca copa (Rodríguez-Suárez et al. 2019; Inkotte et al. 2022; Castillo-Trejo et al. 2023; Wu et al. 2023). Implicaciones prácticas. El manejo debe ser selectivo y basado en rasgos: preferir copas moderadas/discontinuas, hojarasca de buena calidad y, de ser posible, especies fijadoras de N o con raíces menos competitivas en la zona de tutores vivos (Rubio-Ríos et al. 2021; Fahad et al. 2022). Conviene sincronizar aportes orgánicos con el inicio de lluvias y fraccionar el N para acompañar el pulso biológico. La conservación de cercos vivos y parches de vegetación mantiene depredadores generalistas y la conectividad del paisaje.

Líneas futuras. (i) Medir rasgos de las especies arbóreas presentes (copa, raíces, química de hojarasca); (ii) registrar microclima fino (temperatura, humedad, humedad relativa) bajo copa y a sol; (iii) incorporar isótopos estables y metabarcoding para trazar flujos tróficos; y (iv) evaluar funciones del suelo (bioturbación, infiltración, estabilidad de agregados) en paralelo con el rendimiento y la sanidad del cultivo (Joern et al. 2012; Farji-Brener and Werenkraut 2017; Prather et al. 2021; Zuo et al. 2021). Con ello, la toma de decisiones podrá afinarse desde comparaciones generales “bajo copa vs. sol” hacia umbrales de manejo concretos por especie y temporada.

CONCLUSIÓN GENERAL

La presente tesis evidencia que en el sistema agroforestal de pitahaya (*Hylocereus undatus*) estudiado, la estacionalidad constituye el eje organizador de la comunidad de invertebrados del suelo, por encima del efecto de árboles nativos dispersos y que bajo el concepto de “islas de fertilidad”, los árboles dispersos no operaron como facilitadores generalizados de la diversidad edáfica; más bien funcionaron como filtros ambientales. Por lo cual la selección de especies arbóreas dentro del sistema agroforestal debe ser guiada por rasgos tales como: copas moderadas o discontinuas que minimicen la sombra persistente del cultivo; hojarasca de buena calidad y, preferentemente, capacidad de fijación biológica de nitrógeno; arquitecturas radiculares menos competitivas por agua en la zona de influencia de los tutores vivos. Además, conviene sincronizar los aportes orgánicos con el inicio de la temporada de lluvias para capitalizar el disparo biológico de invertebrados y microorganismos, y gestionar el nitrógeno de manera fraccionada y estratégica para favorecer la diversidad de detritívoros y herbívoros sin promover la dominancia de pocas familias. La conservación de cercos vivos y parches de vegetación circundante se perfila como medida eficaz para sostener depredadores generalistas y la conectividad funcional del paisaje. Para el seguimiento adaptativo, resulta suficiente un monitoreo bianual (lluvias y secas) comparando “bajo copa vs. pleno sol”, con cálculo de índices de diversidad verdadera, una métrica de disimilitud y el registro de apertura de copa y N del suelo como covariables.

Se reconocen alcances y limitaciones ya que el estudio se centró en un subconjunto de especies arbóreas y no incorporó mediciones directas de microclima ni de química de la hojarasca, por lo que la inferencia sobre mecanismos debería reforzarse con dichos componentes. Asimismo, las funciones edáficas (bioturbación, infiltración, estabilidad de agregados) fueron inferidas a partir de la estructura comunitaria y requieren validación mediante mediciones directas acopladas a indicadores productivos (rendimiento y sanidad del fruto). Estas restricciones no invalidan las conclusiones; más bien delinean prioridades claras para robustecer la base de evidencia.

De esta manera, la tesis aporta a los sistemas agroforestales un marco de interpretación y acción: recentra la estacionalidad como regulador primario de la biota edáfica en cultivos de pitahaya, propone un enfoque de diseño orientado por rasgos y por ventanas climáticas, y ofrece criterios prácticos para conciliar la productividad del cultivo con la conservación de la biodiversidad del suelo. Como proyección, se recomienda ampliar la población de especies arbóreas por rasgos funcionales, establecer gradientes controlados de cobertura de copa para identificar umbrales de manejo, incorporar trazadores isotópicos ($\delta^{13}C$, $\delta^{15}N$) y metabarcoding para mapear flujos tróficos y redes microbio–invertebrados, y medir en campo funciones edáficas clave de forma simultánea al desempeño agroforestal. Integrar estos elementos permitirá afinar decisiones de retención y manejo arbóreo, y consolidar diseños agroforestales más resilientes y contextualmente pertinentes en paisajes agrícolas estacionales.

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CONGRESOS Y EVENTOS

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Facultad de Ingeniería

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RECONOCIMIENTO

A

Yesica Daniela Rodríguez Beltrán, Dr. Miguel Prado López

Dr. Rubén Martínez Camilo

Por su participación en el concurso de Carteles con el tema "Potenciando la diversidad de artrópodos en un sistema agroforestal de hylocereus undatus" en el marco de la XLII Semana de Ingeniería "Medio Ambiente y Seguridad Industrial", celebrado los días 16, 17 y 18 de octubre de 2024.

Tuxtla Gutiérrez, Chiapas a 18 de octubre del 2024.

ATENTAMENTE
"Por la cultura de mi raza"

Ing. Mónica Catalina Cisneros Ramos
Directora

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a

Yesica Daniela Rodríguez Beltrán, Miguel Prado López

Por su contribución en la modalidad ***Ponencia oral***, titulada

INFLUENCIA DE LOS ÁRBOLES DISPERSOS EN SISTEMAS AGROFORESTALES DE PITAHAYA SOBRE LA COMUNIDAD DE ARTRÓPODOS

en el **IX CONGRESO MEXICANO DE ECOLOGÍA**
celebrado del 6 al 11 de octubre de 2024

San Cristóbal de Las Casas, Chiapas, México.

Dr. Antonio Saldívar Moreno
Director General de ECOSUR

Dr. Arturo Flores Hernández
Presidente de SCME

Dr. Jorge Leonel León Cortés
Presidente del Comité Organizador

La Universidad Nacional Autónoma de México y diversas instituciones organizadoras, así como la Sociedad Mexicana de la Ciencia del Suelo, A.C. otorgan la presente

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A

Yesica Daniela Rodríguez, Wilber de Jesús Náfate y Miguel Prado

Por su ponencia INFLUENCIA DEL MANEJO AGROFORESTAL SOBRE LA COMUNIDAD DE LA FAUNA DEL SUELO EN CULTIVOS DE PITAHAYA

47 CONGRESO MEXICANO DE LA CIENCIA DEL SUELO

Durante el 47 Congreso Mexicano de las Ciencias del Suelo, del 16 al 20 de octubre del 2023.

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UNICACH

Maestría en Ciencias Agroforestales

Constancia de actividades de retribución social

Ciudad de México, a **05 de febrero del 2025**

A QUIEN CORRESPONDA
P r e s e n t e.-

En cumplimiento a lo establecido en el **Artículo 19, Capítulo VIII. De la Conclusión de la Beca o Apoyo**, del **Reglamento de Becas del Consejo Nacional de Humanidades, Ciencias y Tecnologías** y en el marco de la Convocatoria **BECAS CONAHCYT NACIONALES 2023,** hago constar que **la ING. YESICA DANIELA RODRÍGUEZ BELTRÁN** con número de **CVU 1272556 beneficiada** con una beca para obtener el grado de **MAESTRO** en el programa **MAESTRÍA EN CIENCIAS AGROFORESTALES**, que se imparte en **UNIVERSIDAD DE CIENCIAS Y ARTES DE CHIAPAS, SEDE VILLA CORZO,** realizó las actividades de retribución social durante el periodo de vigencia de la beca, tiempo en el que fue **alumna** regular de esta Institución.

Asimismo, hago constar que, conforme a lo establecido en la Ley General de Archivos, la coordinación del posgrado organiza y conserva la evidencia documental de dichas actividades en caso de que el CONAHCYT o cualquier otra instancia la requiera.

Sin más por el momento, le envío un cordial saludo.

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Maestría en Ciencias Agroforestales

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SEDE VILLAFLORES

Miguel Prado López
Nombre y firma de la persona responsable de supervisar la actividad de retribución social en el programa de posgrado
(Director)

Dr. Miguel Ángel Salas Marina
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Rubén Martínez Camilo
Nombre y firma de la persona responsable de supervisar la actividad de retribución social en el programa de posgrado
(Co-director interno / externo)

Vidal Hernández García
Nombre y firma de la persona responsable de supervisar la actividad de retribución social en el programa de posgrado
(Co-director interno / externo)

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CONSTANCIA

A

Yesica Daniela Rodríguez Beltrán

Por su participación en el Curso-Taller:
Curso-Taller Género y Desarrollo Sustentable

Realizado el 20 de junio de 2024,
con una duración de 03 horas, Modalidad Presencial,
en la Subsede Villa Corzo.

Tuxtla Gutiérrez, Chiapas; a 20 de junio de 2024.

"Por la Cultura de mi Raza"

Dr. Rafael de Iesús Arauio González
Secretario Académico

LA SECRETARÍA ACADÉMICA DE LA
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CONSTANCIA

A la

Ing. Yesica Daniela Rodríguez Beltrán

Por su participación como Instructora en el Curso:

Diseño de Sistemas Agroforestales para la restauración productiva de suelos degradados

Realizado del 06 al 10 de mayo de 2024,
con una duración de 10 horas, Modalidad Presencial,
en la Subsede Villa Corzo.

Tuxtla Gutiérrez, Chiapas; a 10 de mayo de 2024.

"Por la Cultura de mi Raza"

Dr. Rafael de Jesús Araujo González
Secretario Académico

ANEXOS

Anexo 1. Tabla de las 5 familias más abundantes por gremio trófico y el porcentaje que representa

Gremio trófico	Familias	Abundancia	Porcentaje (%)
Detritivoro	Formicidae	9913	73.44
	Entomobrydae	1414	10.47
	Hodotermitidae	271	2.01
	Termopsidae	150	1.11
	Culicidae	126	0.93
	Others (40)	635	4.7
Fitófago	Cicadellidae	46	0.34
	Tetranychidae	32	0.24
	Thripidae	23	0.17
	Acrididae	19	0.14
	Gryllidae	18	0.13
	Others (12)	34	0.25
Depredador	Salticidae	147	1.09
	Vespidae	127	0.94
	Asilidae	80	0.59
	Muscidae	57	0.42
	Anyphaenidae	51	0.38
	Others (55)	292	2.16