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# Life-form composition of spontaneous vegetation drives root biomass patterns in southeastern Amazonian agroforestry systems

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# Abstract

Agroforestry systems (AFS) enhance biodiversity and contribute to carbon storage in plant biomass and soil organic matter. Unraveling the ecological role of spontaneous vegetation and its relationship with belowground carbon pools helps clarify how this component influences ecosystem services, which remain poorly understood in early-stage systems. This study evaluated five AFS modules in southeastern Pará, Brazil, to assess how vegetation richness, density, and life-form composition influence fine- and coarse-root biomass. The modules combined cocoa, banana, cassava, pineapple, and maize, with an adjacent secondary forest serving as a control. Established on uniform edaphic conditions to isolate biotic effects, root biomass was sampled at 0–10 cm depth and spontaneous individuals ≤ 1.5 m were identified. Forest plots exhibited substantially higher root biomass (fine: 284 g·m⁻²; coarse: 58 g·m⁻²) compared to AFS modules (fine: 56–116 g·m⁻²; coarse: 1.5–7.2 g·m⁻²). Richness and density of spontaneous vegetation were negatively correlated with root biomass ($p < 0.01$), supporting a balanced-growth strategy where plants prioritize aboveground allocation in managed soils. Redundancy analysis revealed that vegetation life forms explained 65.2% of root variation; herbaceous species were strongly associated with fine roots, whereas woody life forms (trees, shrubs, and palms) correlated with coarse-root biomass. These findings highlight that life-form composition, rather than species numbers alone, is the primary biotic signature driving early belowground dynamics in AFS. Managing the balance between herbaceous and woody species can enhance soil carbon storage and align productive land use with restoration and climate mitigation goals.


# INTRODUCTION

Family or subsistence farming is one of the predominant forms of land use across the Amazon region (Costa et al. 2024). Traditionally, land preparation relies on the slash-and-burn system, in which primary or secondary forests are cut and burned to establish crops, initiating short cultivation cycles that persist only until soil fertility declines (Abrell et al. 2024; Bezerra et al. 2024). Historically, this system maintained a certain ecological balance through alternating phases of cultivation and fallow, during which abandoned areas regenerated naturally via secondary succession, partially restoring fertility and enabling new agricultural cycles (Siminski and Fantini 2007; Steenbock 2021). However, increasing demographic pressure and the reduction of available land for new clearings have progressively shortened fallow periods, intensifying land degradation and undermining the sustainability of smallholder agriculture (de Holanda Leite 2022; Kuchler 2022; Vieira and Proctor 2007). As a result, large areas of the southeastern Amazon now consist of degraded pastures and secondary forests with limited recovery potential, marked by soil erosion, nutrient loss, and carbon depletion (Souza Braz et al. 2011). In response to this scenario, agroforestry systems (AFS) have emerged as a sustainable alternative to the cycle of degradation, integrating trees and other perennial species with crops and/or livestock to restore ecological functions while maintaining productivity (Keprate et al. 2024). These systems enhance biodiversity, improve soil fertility, and promote carbon sequestration (Jose and Bardhan 2012; Isaac and Borden 2020), yet it remains unclear whether, and how, the richness, density, and life-form composition

of spontaneous vegetation (herbs, shrubs, trees, palms, and lianas) may influence root biomass and, consequently, the belowground carbon that sustains ecosystem recovery and resilience.

By integrating trees and other perennial woody species with agricultural crops and/or livestock, AFS promote greater structural and biological diversity than conventional monocultures (Nair 1993; Dmuchowski et al. 2024). This diversification supports high species richness, improves habitat heterogeneity, and enhances ecological functions such as pollination, seed dispersal, soil fertility and protection, and increases carbon sequestration, thereby strengthening key ecological processes in AFS (Barbosa et al. 2026; Nair et al. 2021). Moreover, the coexistence of multiple vegetation strata, comprising upper, middle, and lower canopy layers, enables AFS to store considerable amounts of carbon (C) in both plant biomass and soil organic matter (Jose and Bardhan 2012; Rocha et al. 2014; Ramos et al. 2017; Santos et al. 2019a). Studies in tropical regions have shown that tree-based agroforestry can provide up to 45% and 65% more benefits for biodiversity and ecosystems services than conventional production systems (Santos et al. 2019). For instance, in cocoa-based AFS in the Brazilian Amazon, total carbon stocks may reach 50–80 Mg C $ha^{-1}$, depending on species composition and management intensity (Ramos et al. 2017; Brasil et al. 2026). Thus, these systems can offset part of the carbon loss after forest conversion, highlighting their importance for climate policy and the Intergovernmental Panel on Climate Change (IPCC 2016) frameworks. Despite this growing evidence, most assessments have focused on aboveground components, without attention to spontaneous flora and belowground carbon pools, particularly fine roots, which are critical for nutrient uptake and rapid carbon turnover.

Additionally, agroforestry systems (AFS) can enhance the richness and functional diversity of spontaneous flora that emerges between crop rows and within the soil seed bank, promoting the establishment of tree and shrub species essential for ecological succession and natural regeneration (Lacerda et al. 2013, 2016). This vegetation layer is not merely a by-product of management practices but a dynamic component that contributes to ecosystem recovery by protecting the soil surface, reducing erosion, and improving microclimatic and hydric conditions. Through continuous litter input and root turnover, spontaneous species also stimulate nutrient cycling and organic matter accumulation, accelerating soil fertility restoration in degraded areas (Lacerda et al. 2016). Furthermore, Ramos et al. (2015) demonstrated that the arrangement and composition of planted tree species in AFS can function as environmental filters, directly influencing the richness, density, and life-form composition of spontaneous vegetation. These effects are ecologically significant because vegetation cover and structure strongly modulate root biomass and carbon dynamics (Lima et al. 2020; Peng and Chen 2021). Therefore, understanding the biological drivers of root production, beyond the intrinsic limitations of the soil matrix, is crucial to unraveling the ecological mechanisms that support AFS resilience in degraded Amazonian landscapes.

Fine roots, owing to their dynamic nature and rapid turnover, represent one of the most active components of belowground ecosystems and contribute to the primary productivity of terrestrial environments (Jackson et al. 1997; Gill and Jackson 2000). They play a significant role in soil carbon and

nutrient cycling, regulating the input of organic matter through root exudation, respiration, and decomposition (Gill and Jackson 2000; Gordon and Jackson 2000; Valcarcel et al. 2007; Ratuchne 2016). Beyond their biomass and turnover rates, fine-root functional strategies are strongly influenced by symbiotic associations with mycorrhizal fungi, where gradients of fungal collaboration determine patterns of carbon allocation and nutrient acquisition, with major implications for ecosystem functioning and carbon stabilization (Bergmann et al. 2020). The continuous death and renewal of fine roots contribute to the formation of particulate and mineral-associated organic matter, processes that underpin long-term soil carbon sequestration in tropical systems (McCormack and Iversen 2019). For instance, depending on the species arrangement and management practices, there is an increase in carbon stocks (aboveground biomass, fine root biomass, litterfall production, fine root biomass and soil organic carbon stocks) in agroforestry systems, (Ramos et al. 2017). These findings underscore the importance of assessing multiple carbon reservoirs and understanding carbon dynamics in agricultural and natural systems. However, while soil chemical properties are often cited as primary drivers, recent evidence suggests that the biotic interactions promoted by spontaneous vegetation may exert a dominant influence on belowground architecture. Despite such advances, this biotic modulation of root biomass has not yet been evaluated, representing a key knowledge gap in tropical agroforestry research.

Understanding how the structure and composition of vegetation influence belowground carbon dynamics is essential for improving the ecological performance of agroforestry systems and guiding sustainable land management in tropical regions. Given this context, this study evaluated how different agroforestry arrangements affect the diversity of spontaneous vegetation and the accumulation of fine and coarse roots. We examined whether variations in vegetation structure and composition modify belowground biomass patterns within these agroecosystems. Specifically, we tested four hypotheses: (i) AFS arrangements influence the richness and density of spontaneous flora; (ii) AFS arrangements affect belowground biomass (fine and coarse roots); (iii) spontaneous vegetation modulates root biomass stocks in agroecosystems; and (iv) different life forms of spontaneous vegetation exert distinct effects on root biomass. To test these hypotheses, we conducted field surveys and soil sampling in five agroforestry modules and an adjacent secondary forest in Canaã dos Carajás, southeastern Pará, Brazil, analyzing the floristic composition, vegetation structure, and root biomass distribution across systems.

## MATERIALS AND METHODS

# Study Area

The study was conducted on a rural property located in the municipality of Canaã dos Carajás (6°16'46" S, 49°50'56" W), southeastern Pará (Fig. 1). The regional climate is classified as “Aw” (tropical with a dry winter) according to Köppen’s classification. The dry season occurs from May to October, while the rainy season extends from November to April. Mean annual precipitation is approximately 2,500 mm, and mean temperature is around 29°C (Siqueira et al. 2012). The predominant soils in the region are dystrophic red-yellow Argisols, with frequent occurrences of dystrophic red-yellow Latosols and dystrophic Litholic Neosols (ICMBio 2016).

On this property, five different AFS modules (M1–M5) were implemented, varying in species composition. The modules include cacao, banana, cassava, pineapple, and maize as common crops, differing in the associated species (Table 1). Each module covers approximately 2 ha, totaling 10 ha of demonstration area. To minimize edaphic noise and ensure that variations in root biomass could be attributed to biotic drivers, all modules were established on a site with the same land-use history (degraded pasture) and uniform topographic and edaphic conditions. This experimental control allowed for a comparative analysis of how different agroforestry arrangements modulate spontaneous vegetation and belowground carbon allocation under similar environmental constraints. In addition to the AFS modules, an adjacent secondary forest area was used as a control treatment (Oliveira et al. 2023).

## Characterization of Spontaneous Vegetation

The floristic survey was carried out one year after AFS implementation. Five 2 × 2 m plots were randomly established in each AFS module and in the secondary forest control area, totaling 30 plots and 120 m² of sampled area. The random allocation of plots ensured that the captured variation in spontaneous vegetation reflected the influence of the AFS overstorey and management rather than localized soil patches. In each plot, all individuals ≤ 1.5 m in height were identified and counted. Plant material was processed as herbarium specimens and analyzed by specialists, following the APG IV classification system (The Brazil Flora Group et al. 2021). Species were classified into functional life forms: herbs, lianas, trees-shrubs, and palms.

## Root Biomass Sampling

To estimate root biomass, three soil samples were randomly collected in each plot at 0–10 cm depth using a stainless-steel cylinder (196 cm³). Sampling was restricted to the topsoil layer where the most intense biotic interactions between planted crops and spontaneous vegetation occur. Samples were stored in plastic bags and refrigerated at 4°C until processing.

Soil samples were washed under running water through a 0.5 mm mesh (Leão et al. 2014). Roots were manually separated and classified as fine (≤ 2 mm diameter) or coarse (> 2 mm diameter) (Braga et al. 2017; Ramos et al. 2017). Root samples were dried at 70°C until constant weight and weighed on a precision analytical balance (0.0001 g) (Fig. 4). Root biomass was calculated as g $m^{-2}$ (Braga et al. 2017).

# Statistical analysis

The effects of different AFS modules on species richness, individual density, and root biomass were evaluated using generalized linear models (GLMs). Negative binomial or Poisson distributions were applied to count variables, whereas Gamma distributions or linear regression models were used for

continuous variables. Adjusted means and multiple comparisons were obtained with the *emmeans* package using Tukey's test.

Associations between species richness/density and root biomass were examined using simple linear regressions ($R^2$ and p-values). To unravel the biotic modulation of belowground carbon stocks, the influence of vegetation life forms on root biomass was investigated through Redundancy Analysis (RDA) and Canonical Correspondence Analysis (CCA). These multivariate approaches were chosen to determine how the community structure of spontaneous vegetation explains the variance in root biomass across the different AFS arrangements, independently of soil abiotic factors. All analyses were performed in R Software.

# RESULTS

# Spontaneous Floristic Characterization

A total of 5,048 individuals, 97 species, and 35 botanical families were recorded. Five families accounted for more than 80% of the individuals: Asteraceae (2,180 ind.), Phyllanthaceae (861 ind.), Euphorbiaceae (479 ind.), Fabaceae (277 ind.), and Linderniaceae (259 ind.). Among the most abundant species, *Synedrellopsis grisebachii* (1,911 ind.), *Phyllanthus niruri* (577 ind.), *Acalypha alopecuroides* (373 ind.), and *Phyllanthus urinaria* (280 ind.) stood out, together comprising 62% of the total individuals.

Mean species richness varied across treatments, with lower values in FO and M1 (8.8 ± 1.3) and higher values in M3 (16.2 ± 1.8 spp.). Significant differences were restricted to the comparison between FO/M1 and M3 ($p = 0.0143$) (Fig. 2A). Individuals' density was lower in FO (14.6 ± 2.7 ind.m²) compared to all AFS modules, where values ranged from 32.8 to 67.8 ind.m². Significant differences were detected between FO and all AFS modules ($p < 0.05$), as well as between M1 and M3 ($p = 0.0192$) (Fig. 2B).

Herbaceous forms predominated in all AFS modules, representing 88% to 98% of the individuals. In contrast, the FO area was characterized by a higher proportion of tree/shrub forms (52%), followed by herbaceous individuals (41%). Liana density remained below 2.4% across all areas, while palms accounted for 5% of individuals in FO and were nearly absent in the AFS modules (Fig. 3).

## Root Biomass

Fine root biomass was significantly higher in FO (284.0 ± 52.6 g.m²) than in any AFS module (range: 56.3–116.0 g.m²; $p < 0.05$). No significant differences in fine root biomass were observed among the AFS modules (Fig. 2C). Coarse root biomass followed a similar pattern, being markedly greater in FO (58.4 ± 6.6 g.m²) compared to the modules (1.5–7.2 g.m²; $p < 0.001$), which showed no significant variation among themselves (Fig. 2D).

## Relationship Between Root Biomass and Spontaneous Flora

Fine and coarse root biomass exhibited negative linear correlations with both individual density and species richness across the sampled areas (Fig. 4).

The Redundancy Analysis (RDA) indicated that vegetation life forms explained 65.2% of the total variation in root biomass, with a significant global model ($F = 10.23$; $p = 0.001$). The first axis (RDA1) accounted for 42.7% of the variation and the second (RDA2) for 15.8% (Fig. 5A). The RDA biplot showed fine root biomass vectors aligning with the herbaceous group ($r = 0.76$), while coarse root biomass was associated with the trees-shrubs ($r = 0.69$) and palms ($r = 0.45$) groups.

The Canonical Correspondence Analysis (CCA) confirmed this distribution ($F = 9.87$; $p = 0.001$), with the first axis explaining 65.4% of the variation ($p = 0.001$) and the second 18.3% ($p = 0.045$) (Fig. 5B). The ordination scores demonstrated a consistent grouping of AFS modules associated with herbaceous dominance and fine root stocks, contrasting with the FO area associated with woody life forms and coarse root biomass.

Figura 3: Life forms of individuals in different agroforestry system modules (M1–M5) and in a forested area (FO) in the municipality of Canaã dos Carajás, southeastern Pará state, Brazil.

# DISCUSSION

Our hypotheses were partially supported. Differences in the richness and density of spontaneous vegetation among agroforestry modules confirmed that the arrangement and management of each system act as environmental filters shaping the spontaneous flora. However, contrary to expectations, fine and coarse root biomass did not vary among modules, suggesting that belowground carbon allocation in young agroforestry systems is still governed by the legacy of previous land use and the emerging biotic structure rather than by crop composition. Since all modules were established under uniform topographic and edaphic conditions and share the same land-use history, the observed stability in root biomass indicates that the physical-chemical soil matrix sets a baseline, while the functional composition of the spontaneous vegetation begins to modulate the spatial distribution of this biomass. The influence of spontaneous vegetation on root biomass was confirmed but occurred in an inverse direction to the traditional diversity–biomass relationship, indicating that, in managed soils, plants may follow a balanced-growth strategy, prioritizing aboveground allocation where light is the main limiting factor. Finally, the composition of vegetation life forms proved decisive, with herbaceous species more closely associated with fine roots and woody species (trees, shrubs, and palms) with coarse roots, emphasizing functional complementarity in carbon partitioning. This study contributes to advancing knowledge on the links between spontaneous flora and root dynamics in tropical agroforestry systems, an interface rarely explored.

M1 exhibited the lowest species richness and density, which may be linked to the higher density of intercropped agronomic and forestry species introduced into this module (Table 1). As noted by Oliveira et al (2023), a greater number of cultivated species, combined with intensive management, can reduce the establishment of spontaneous plants. This pattern may be associated with the environmental

modifications generated by cultivated vegetation in M1, such as increased shading and litter deposition, which suppress the germination of heliophilous spontaneous species common in agroecosystems (Gomes and Christoffoleti, 2008). Furthermore, cultivating a wider variety of species can enhance the structural and morphological diversity of the system itself, which tends to limit the opportunities for spontaneous plants to establish, as already observed in early agroforestry successional stages (dos Santos et al. 2021). The 97 sampled species are consistent with findings from other studies of spontaneous flora in agroforestry systems (AFS) in Pará. For example, Bolfe and Batistela (2011) recorded 51 species in AFS in the Quatro Bocas District, Tomé-Açu municipality. Santos and Costa (2021) identified 32 species in a mahogany-based AFS in Oeiras, while Alves Filho et al. (2020) reported 81 species in a citrus-based AFS in Capitão-Poço. Similarly, Lacerda et al. (2013) found 126 species in diverse AFS established on degraded pasture in Tomé-Açu. These comparisons demonstrate that the floristic composition observed in the present study is within the expected range for AFS in the region, while also highlighting the strong influence of management and local environmental conditions.

In contrast, root biomass (both fine and coarse) did not differ significantly among AFS modules, contradicting the expectation that distinct species arrangements would influence belowground biomass. Instead, all modules were clearly differentiated from the forest, where high root biomass was associated with greater density and diversity of tree and shrub species (Valcarcel et al. 2007) and probably by the presence of a dense litter layer that promotes nutrient availability and soil moisture conservation (Garlet and Schumacher, 2020; Witschoreck et al. 2003). These results suggest that in young agroforestry systems, root biomass is shaped more by land-use history and the transition from pasture than by the specific arrangement of intercropped species. The consistency of these values across modules (56.3–116.0 g.m²) reinforces the premise that the biotic signature of the spontaneous flora is a dominant driver in this early successional stage, overriding potential localized edaphic variations. The root biomass values obtained here are also consistent with those reported in other ecosystems. Lopes et al. (2010) reported 141 g/m² in *Pinus taeda* L. plantations and 308 g/m² in an adjacent pasture in Cambará do Sul (RS). In secondary forests in Paragominas (PA), Silva (2019a) recorded 506.99 g/m². In cocoa (*Theobroma cacao* L.) and oil palm (*Elaeis guineensis* Jacq.) AFS in northeastern Pará, Ramos et al. (2017) reported fine root biomass ranging from 335 to 1067 g/m². Together, these results reinforce the distinction between forest and AFS environments and indicate that belowground biomass accumulation in early-stage systems still reflects the legacy of land degradation and soil recovery, rather than the influence of species arrangement alone.

Linear regression analyses further revealed an unexpected negative relationship between spontaneous flora richness/density and root biomass. Contrary to the commonly reported positive relationship between diversity and belowground biomass via niche complementarity (Meinen et al. 2009; Brassard et al. 2013). Our results suggest that in young agroforestry systems, resource allocation patterns may be better explained by the balanced-growth hypothesis (Garnier 1991). According to this framework, plants tend to invest preferentially in the organ where resources are most limiting for growth. In managed AFS soils, where localized management may alleviate belowground limitations, carbon is likely redirected toward aboveground organs to enhance vertical growth and light capture, resulting in reduced fine-root

biomass per individual. By contrast, in tropical forests, the combination of high species diversity, intense competition, and nutrient cycling through litter promotes greater fine-root proliferation, ensuring resource acquisition and supporting large aboveground biomass (Cusack et al. 2021). This finding suggests that functional traits, particularly morphological composition, may play a stronger role than species numbers alone in determining root allocation.

Multivariate analyses provided additional support for this interpretation. Redundancy analysis (RDA) demonstrated that vegetation life forms explained 65.2% of the variation in root biomass, with herbs strongly related to fine roots and woody plants (trees/shrubs and palms) to coarse roots. Canonical correspondence analysis (CCA) corroborated these patterns, highlighting the contrasting relationships between spontaneous herbs and woody species in shaping belowground biomass. This high explanatory power (65.2%) confirms that the "biotic signature" of the spontaneous vegetation is the primary predictor of belowground dynamics in this study, providing a robust ecological explanation even in the absence of detailed abiotic soil data. These results emphasize that spontaneous life forms, not only the arrangement of cultivated crops, are the main drivers of belowground carbon stocks in early-stage AFS.

The predominance of herbaceous individuals in AFS modules is a well-established pattern in agroecosystems due to their ecological strategies, such as high light affinity, prolific seed production, seed dormancy, and the formation of large soil seed banks (Lacerda et al. 2013, 2016; Costa and Mitja, 2009). Nevertheless, the occurrence of spontaneous native trees, shrubs, and palms is ecologically strategic. These life forms are indicators of forest regeneration potential, as they are central to successional processes (Vieira and Proctor, 2007; Silva et al. 2019). The results of RDA and CCA confirm that woody life forms exert a stronger influence on coarse root biomass than herbs, making them crucial for maintaining soil carbon stocks. It is important to emphasize that fine roots are highly dynamic, exhibiting turnover rates far exceeding those of coarse roots (Weemstra et al. 2020). Although they contribute less to total biomass, their high productivity enhances the release of root exudates and the incorporation of organic matter into the soil, contributing to nutrient cycling (McCormack and Iversen 2019; Shihan et al. 2022). In this context, herbaceous flora are the primary contributors to fine root biomass in early stages, while woody species concentrate coarse roots. Both play complementary roles: coarse roots provide structural support, while fine roots regulate short-term carbon dynamics. Far from being mere competitors, these plants can provide food and habitat for biodiversity (Marshall et al. 2003) and protect the soil against rainfall impact and radiation until the consolidation of cultivated crops (Kinyili et al. 2024).

Native tree, shrub, and palm species play a strategic role in secondary succession (Lacerda et al. 2016; Silva et al. 2019). Our results support this understanding, showing that the abundance of woody species exerts a stronger influence on root biomass than herbaceous vegetation, establishing them as a key group for maintaining belowground carbon stocks (Kaneda et al. 2022). Finally, it is crucial to recognize that root production and turnover enhance the availability of organic exudates, serving as an energy source for microorganisms responsible for mineralization and nitrogen fixation (Gill and Jackson, 2000), processes closely linked to soil organic carbon stocks (Valcarcel et al. 2007). Consequently, soils with

higher root biomass exhibit greater potential for carbon sequestration. From a management perspective, understanding and balancing the contributions of herbaceous and woody species is essential to prevent excessive herbaceous density from suppressing woody species establishment, which are crucial for long-term stability (Dmuchowski et al. 2024; Pardon et al. 2017). Continuous monitoring will be decisive for tracking changes in biomass allocation and functional dominance, supporting adaptive management strategies that reconcile biodiversity conservation with the maximization of belowground carbon sequestration.

# CONCLUSION

In young agroforestry systems, the arrangement of intercropped species primarily influences the density and richness of spontaneous vegetation but does not yet produce significant effects on belowground biomass. Instead, root biomass patterns at this early stage still reflect the legacy of previous land use and the transition from degraded states. Our findings reveal that the functional composition of vegetation life forms, rather than species numbers alone or localized soil variations, is the key driver shaping early subterranean ecosystem processes. Areas dominated by high density herbaceous spontaneous species exhibit lower total root biomass, whereas woody life forms (trees, shrubs, and palms) contribute proportionally more to coarse root development, highlighting a clear functional complementarity in belowground carbon allocation. These results demonstrate that the biotic signature of the spontaneous flora is a reliable predictor of belowground dynamics in recovering Amazonian landscapes. Therefore, managing the balance between herbaceous and woody components can enhance soil carbon storage, improve structural stability, and foster natural regeneration, effectively aligning productive land use with the long term goals of forest recovery and climate change mitigation.

# Declarations


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### Author contributions

TGS was the main author of the manuscript and contributed to all stages of manuscript preparation, data collection, and analysis. JAH, LHDA, PHP, AJPC, NMM and ABS contributed to field data collection and laboratory sample processing. FCBL conceptualized and supervised the research project, being responsible for experimental design, field coordination, statistical analysis, and manuscript revision.

### Data availability

The data supporting the findings of this study are securely stored at the Federal Rural University of Amazonia (UFRA), Campus Parauapebas. They can be made available by the corresponding author (Dr. Fernando Lacerda) upon reasonable request.

**Declarations Competing 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.

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## Table 1

Table 1 is available in the Supplementary Files section.

## Figures

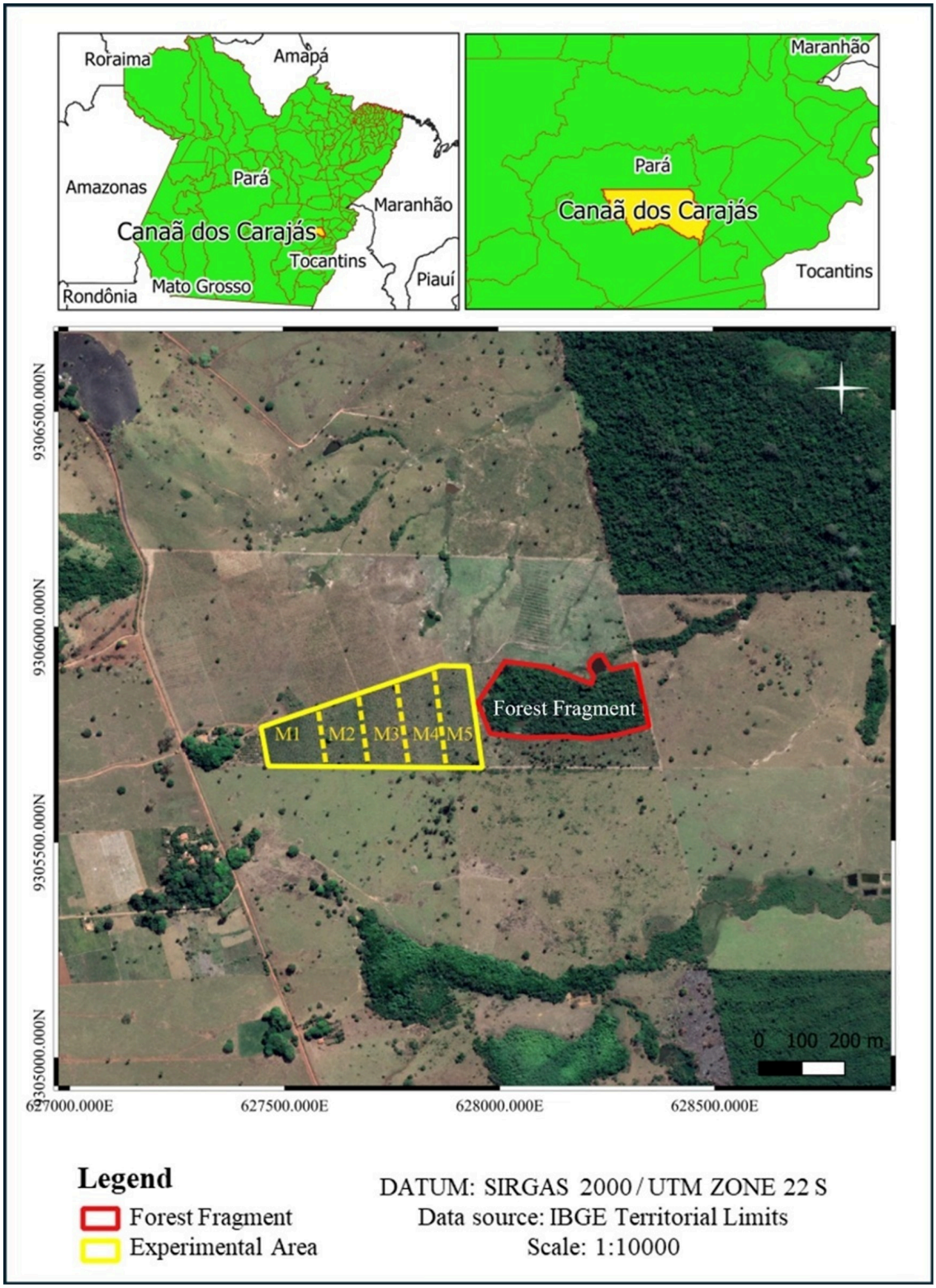



**Figure 1**

Location map of the experimental area, indicating the different agroforestry system modules (M1–M5) in the municipality of Canaã dos Carajás, southeastern Pará State, Brazil.

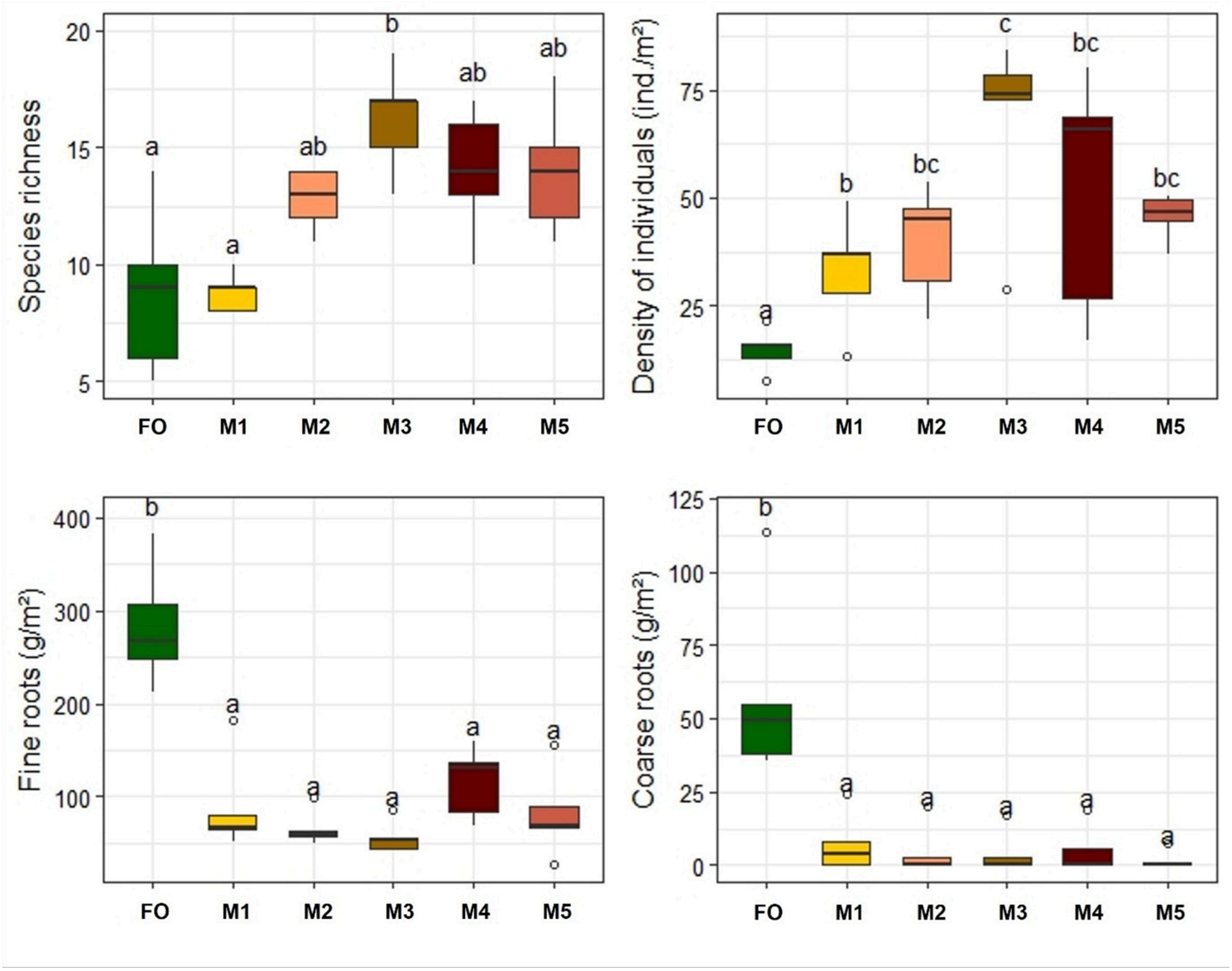



**Figure 2**

Species richness (A), individual's density (B), and fine (C) and coarse (D) root biomass in different agroforestry system modules (M1–M5) and in a forested (FO) area in the municipality of Canaã dos Carajás, southeastern Pará state, Brazil.

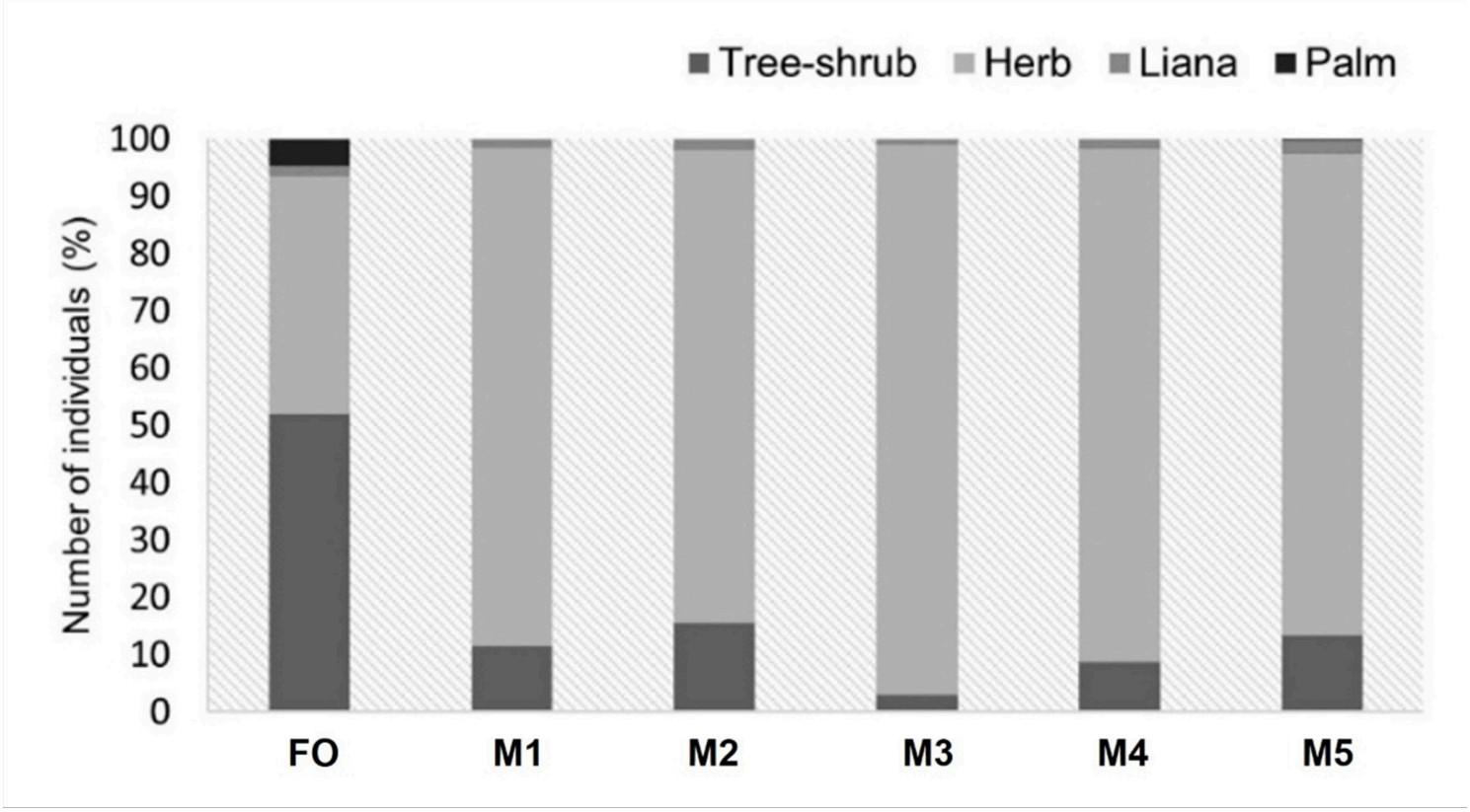



**Figure 3**

Life forms of individuals in different agroforestry system modules (M1–M5) and in a forested area (FO) in the municipality of Canaã dos Carajás, southeastern Pará state, Brazil.

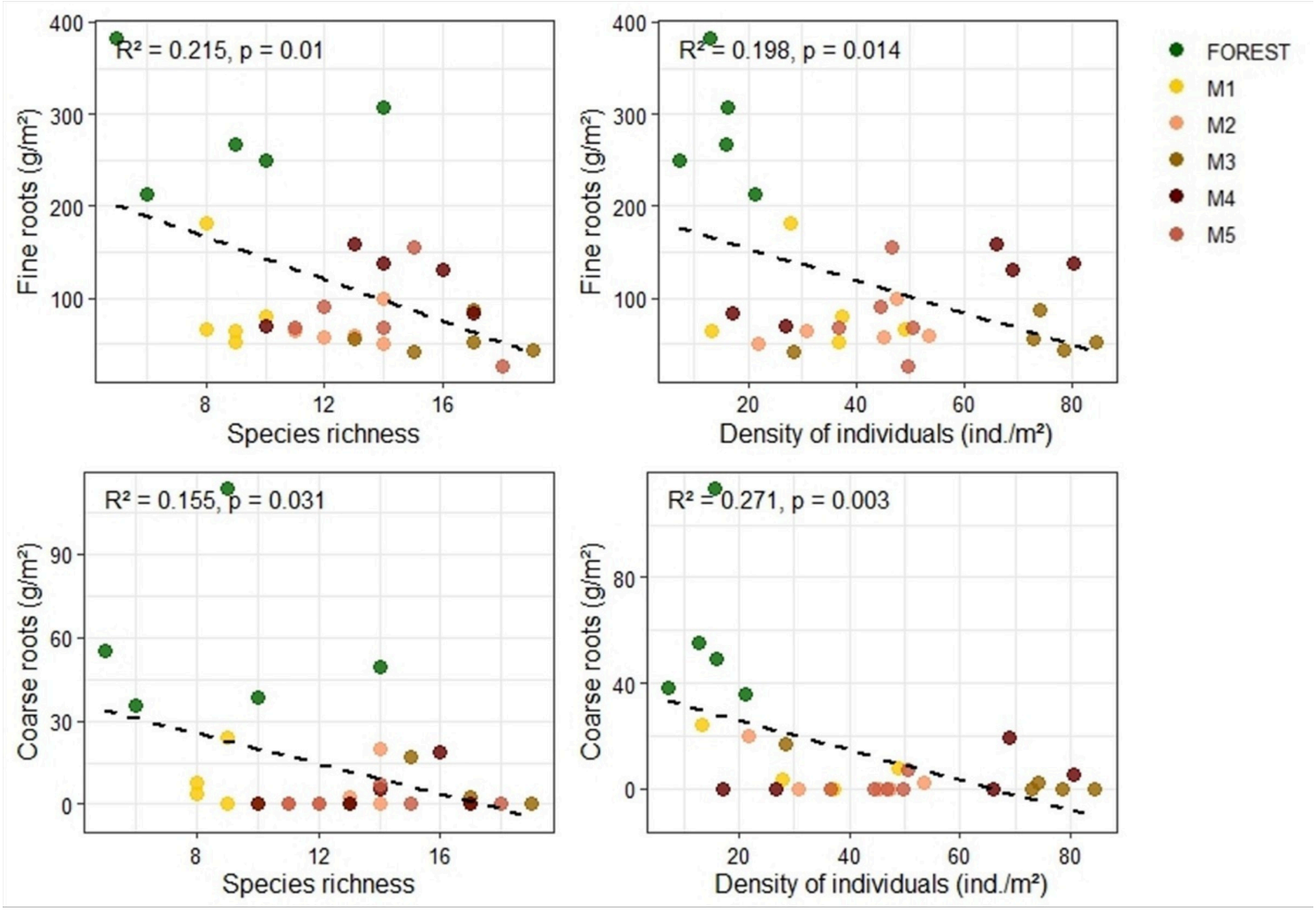



**Figure 4**

Relationship between root biomass (fine and coarse roots) and individual density and species richness in agroecosystems and in a forested area in the municipality of Canaã dos Carajás, southeastern Pará state, Brazil.

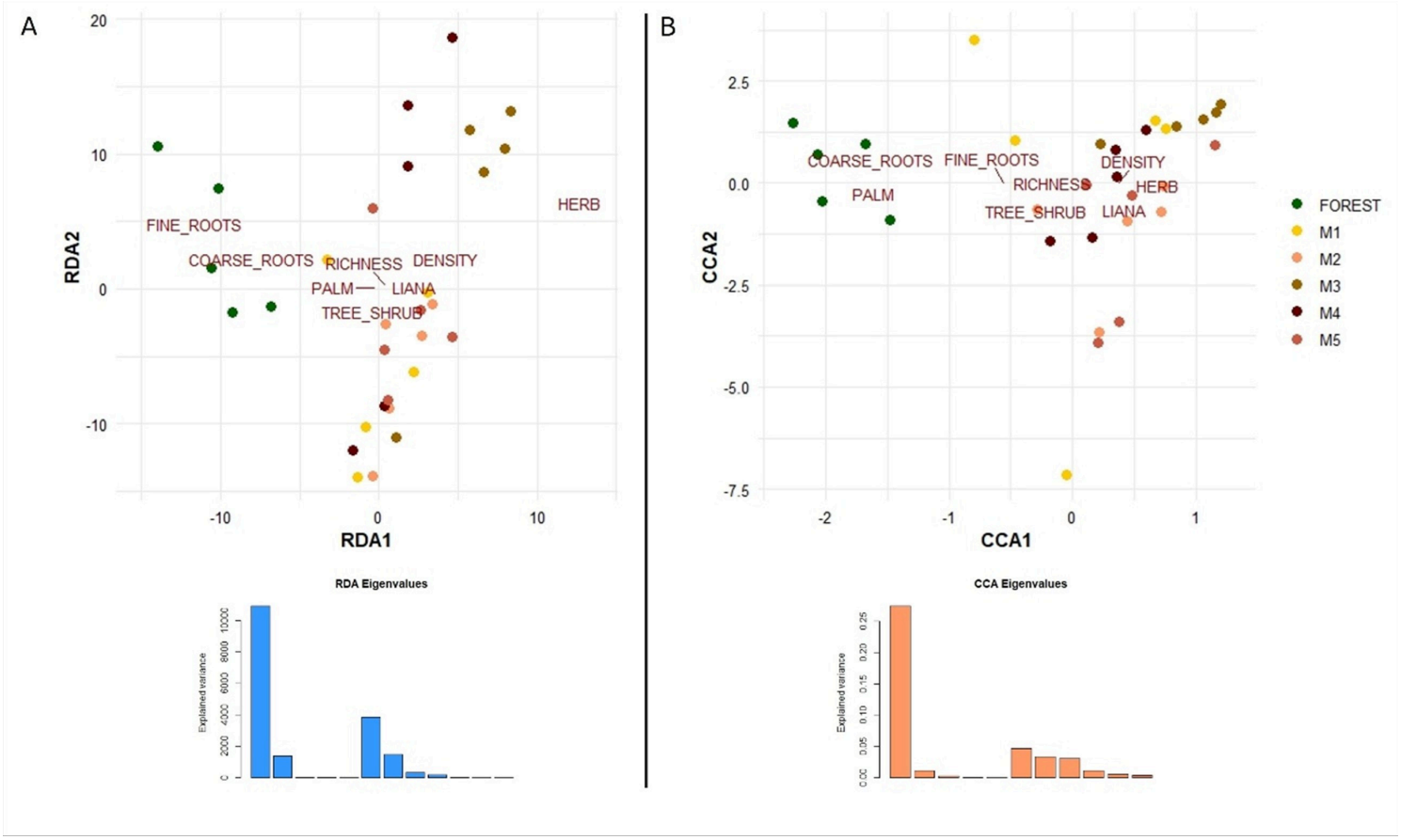



**Figure 5**

Redundancy analysis (A) and canonical correspondence analysis (B) biplots showing the relationships between vegetation life forms, root biomass, and community attributes across AFS modules.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx