BIODIVERSITAS
Volume 25, Number 1, January 2024
Pages: 205-213

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d250123

Agricultural landscape composition alters ant communities in maize fields more than plant diversity enrichment

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Manuscript received: 5 December 2023. Revision accepted: 22 January 2024.

Abstract. *Pasaribu DN, Rizali A, Tarno H, Priawandiputra W, Johannis M, Buchori D. 2024. Agricultural landscape composition alters ant communities in maize fields more than plant diversity enrichment. Biodiversitas 25: 205-213.* Fragmented natural habitats in human-modified landscapes play a crucial role in conserving biodiversity. Ants, as keystone species, are integral to terrestrial ecosystems, making it essential to comprehend the factors influencing their survival. This study investigates the impact of agricultural landscape composition and plant diversity enrichment (flowering plants) management on shaping ant communities in maize (*Zea mays* L.) fields. The research occurred in maize fields surrounded by other crops, semi-natural habitats, and housing areas in Malang District, East Java, Indonesia. The four agricultural areas were divided into control and treatment plots, considering landscape composition parameters, particularly Class Area (CA) and the Number of Patches (NP), measured within a 500 m radius. The landscape around the maize fields was characterized by manually digitizing land use. Six types of plant diversity enrichment were employed in this study: wild cosmos (*Cosmos caudatus*), white buttercup (*Turnera subulata*), sunflower (*Helianthus annuus*), long bean (*Vigna unguiculata*), ornamental bean (*Arachis pintoi*), and coral vine (*Antigonon leptopus*). The study was divided into the dry season (April-July 2022) and the wet season (September-December 2022). Ant sampling was conducted using pitfall traps and, based on generalized linear models, revealed that plant diversity enrichment management did not affect species richness, abundance, or composition of ants. Landscape composition positively influenced ant species richness but negatively impacted species composition, particularly the number of semi-natural habitat patches. Maize crop age also positively influenced ant species richness but negatively affected beta diversity. Wet season was also found to have a negative effect on beta diversity. In conclusion, the proportion of semi-natural habitats in agricultural landscapes and crop age contribute significantly to species richness and species composition of ants.

Keywords: Abundance, flowering plants, Formicidae, landscape scale, local scale, semi-natural habitat

INTRODUCTION

Agricultural intensification increases disturbance at the local level and reduces habitat heterogeneity at the landscape level, potentially adversely affecting biodiversity-driven ecosystem services (Daouti et al. 2022). This intensification results in local disturbances, exemplified by the use of pesticides and synthetic fertilization (Zhao et al. 2015). It contributes to reduced habitat heterogeneity at the landscape level, manifested by the loss of semi-natural habitats and decreased plant diversity (Emmerson et al. 2016). Both local and landscape-level fragmentation, coupled with habitat loss, are recognized as major threats to biodiversity (Fahrig et al. 2011; Horváth et al. 2019). The reduced area and increased isolation of habitat patches lead to decreased species richness, abundance, and alterations in community structure (Tscharntke et al. 2002; Bailey et al. 2010; Schüepp et al. 2011). Such habitat fragmentation and loss potentially modify landscape structure and local ecosystem function (Bennett and Saunders 2010). Biodiversity is crucial for agricultural sustainability; thus, biodiversity loss significantly impact overall sustainability (Harnowo et al. 2021).

Each species providing ecosystem services depends on a local scale; their spatial distribution at larger landscape scales often influences individual behavior, population biology, and community dynamics (Chase et al. 2020). Ecological processes and interactions exhibit characteristics that transcend a single habitat, emphasizing the importance of linking spatial patterns and ecological processes at landscape scales (Steffan-Dewenter et al. 2002). Biodiversity is influenced by various environmental factors at the local scale (e.g., quality and quantity of feeding and nesting resources and habitat types) as well as at the landscape scale (e.g., habitat fragmentation, composition, and configuration of landscape features) (Rollin et al. 2019).

The agriculture management and the surrounding landscapes significantly impact biodiversity and ecosystem services. Conservation management, for example, is essential for supporting ecosystem services and maintaining biodiversity (Cordingley et al. 2016). The ecological engineering practice of manipulating habitat using diverse flowering plants for plant diversity enrichment can create suitable habitats for various species in fragmented agricultural landscapes (Duff et al. 2023). Plant diversity enrichment management is particularly beneficial for natural enemies or other beneficial insects by providing energy-rich nectar, a widely utilized food source for various insect orders, including Diptera, Coleoptera, and Hymenoptera (Nilsson et al. 2016). Additionally, plant diversity enrichment contributes to local-level diversity (He et al. 2022; Schmack and Egerer 2023). Increasing landscape complexity, achieved through composition, configuration, or heterogeneity changes, significantly and positively impacts biodiversity. More complex landscapes exhibit higher richness, abundance, and biodiversity than simple landscapes (Estrada-Carmona et al. 2022).

Diverse maize (*Zea mays* L.) agroecosystems harbor biodiversity and sustain ecosystem services, especially in complex landscapes, and when the diversity of organisms providing ecosystem services is maintained. Ants are an essential functional group capable of offering various ecosystem services, including biological control of pests, assistance in seed dispersal, enrichment of nutrient cycling, soil aeration, and organic matter accumulation (Offenberg 2015; Meadley-Dunphy et al. 2020; Zhou et al. 2023). The high ant diversity and distribution indicate a stable ecosystem with a high degree of elasticity (Latumahina et al. 2015). Ants in an area can serve as bioindicators due to their ecological importance, indicating sensitivity or tolerance to environmental conditions. This enables them to assess environmental conditions and describe the impact of changes in the landscape on habitat, community, and ecosystem dynamics (Alonso 2000; Andersen and Majer 2004).

Several studies have demonstrated that ants are highly sensitive to environmental changes. Intensive agricultural activities, human disturbance, and land conversion from forest to plantation are known to impact ant diversity and abundance (de Castro Solar et al. 2016; Rizali et al. 2021; Santos et al. 2018). Ants exhibit high sensitivity and rapid response, making them excellent indicators for assessing environmental conditions (Tiede et al. 2017). They are a critical taxon for comparing habitat diversity and monitoring environmental change because many species have specific habitat preferences and respond promptly to environmental disturbances (Lawes et al. 2017). Ants have been used extensively as bioindicators of habitat change in various countries, such as Australia and the United States of America (Andersen 2019; Ratchford et al. 2005).

The presence of ants in agroecosystems often depends on landscape heterogeneity and local habitat management. However, few studies have examined biodiversity or local or landscape complexity as ant maintenance drivers, such as those conducted in Central Java Province which focused on plant diversity enrichment (Widhiono et al. 2017), while those conducted by Muhammad et al. 2022 only focused on habitat condition and landscape composition in coffee agroforestry. Our research aims to investigate the relationship between local habitat modification and landscape composition in maize fields, specifically focusing on their impact on ants species richness, abundance, and species composition.

MATERIALS AND METHODS

Study sites

The study was divided into the dry season (April-July 2022) and the wet season (September-December 2022). Field research was conducted on land planted with maize in Bokor Village and Tumpang Village, Tumpang Subdistrict, Malang District, Indonesia (Figure 1).

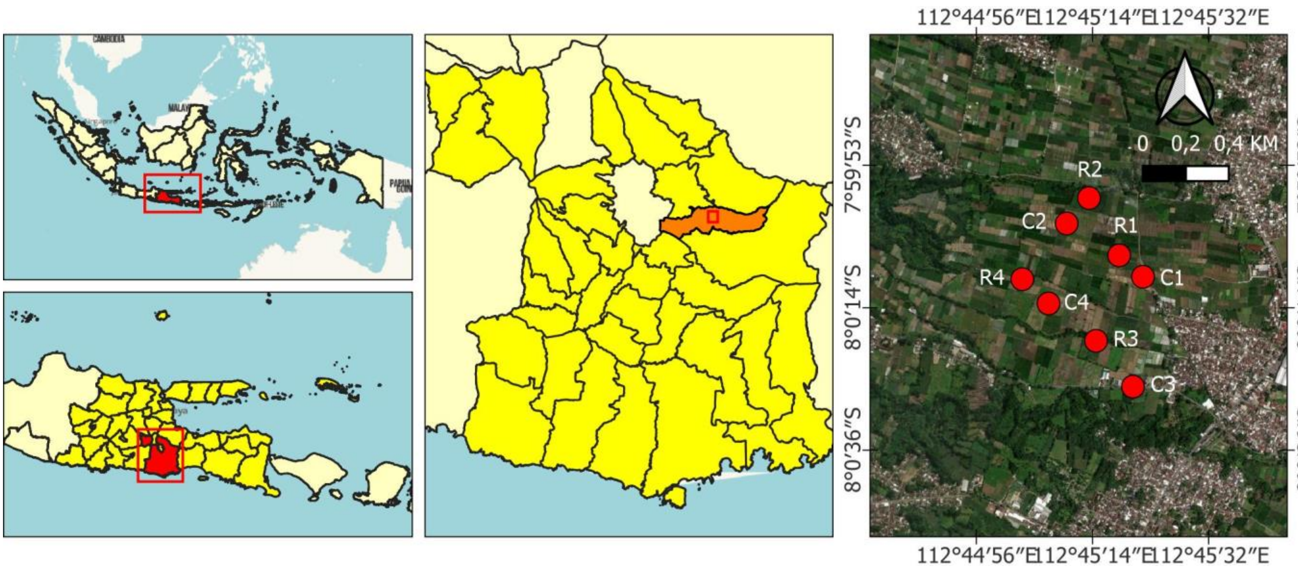

Figure 1. Distribution of the study site in Bokor Village and Tumpang Village, Malang District, East Java, Indonesia. Note: C1: control area 1, R1: plant diversity enrichment area 1, C2: control area 2, R2: plant diversity enrichment area 2, C3: control area 3, R3: plant diversity enrichment area 3, C4: control area 4, R4: plant diversity enrichment area 4

The research field comprised four distinct areas, each area consisted of a control plot and a treatment plot, making a total of four control plots and four treatment plots utilizing plant diversity enrichment. The control and treatment plots were at least 150 meters apart and consisted of three 5x5 m sub-plots. In each treatment plot, six types of plant diversity enrichment were planted: 25 wild cosmos (Cosmos caudatus), 25 white buttercups (*Turnera subulata*), 25 sunflowers (*Helianthus annuus*), 25 long beans (*Vigna unguiculata*), 25 ornamental beans (*Arachis pintoi*), and 10 coral vine (*Antigonon leptopus*) with a spacing of 20x30 cm. Subsequently, the surrounding plot was planted with maize crops spaced at 70x20 cm (Figure 2). The same approach was applied to the control plot, with a 5x5 m sub-plot also planted with maize crops. Routine maintenance for the maize crops, including watering, fertilizing, pesticide application, and weeding.

Sampling of ants

Ant collection was conducted using pitfall traps, the most commonly employed method for capturing foraging arthropods, including ants (Cheli and Corley 2010; Sheikh et al. 2018). Pitfall traps efficiently capture ground-dwelling ants, especially in areas with low leaf litter (Sheikh et al. 2018). Three transects were sampled for ants with a distance gradient in 5x5 m sub-plots, 0 m distance (J0), 10 m distance (J10), and 20 m distance (J20). The distance between one pitfall trap and another in one observation transect was 6 m (Figure 2), with each transect containing 100 maize crops. Three pitfall traps were placed at each sampling point, resulting in 12 pitfall traps per plot. Ant observations commenced when the maize crops were four weeks old, continuing for ten weeks with observations made for two-week intervals. Ant collection occurred 24 hours after pitfall trap installation. The captured arthropods were placed into a vial and sorted to isolate the ants. Subsequently, the sorted ants were transferred to a 1.5 mL Eppendorf tube containing 70% alcohol for later identification in the laboratory.

Ant specimens were identified using a stereo microscope, with identification carried out to the morpho-species level utilizing key identification books, specifically the "Identification Guide to the Ant Genera of the World" and "Identification Guide to the Ant Genera of Borneo" (Bolton 1994; Hashimoto 2003), as well as digital resources (https://www.antweb.org/). Ant identification was conducted at the Plant Pest Laboratory, Department of Plant Pests and Diseases, Faculty of Agriculture, Universitas Brawijaya and Biological Control Laboratory, Department of Plant Protection, Faculty of Agriculture, IPB University.

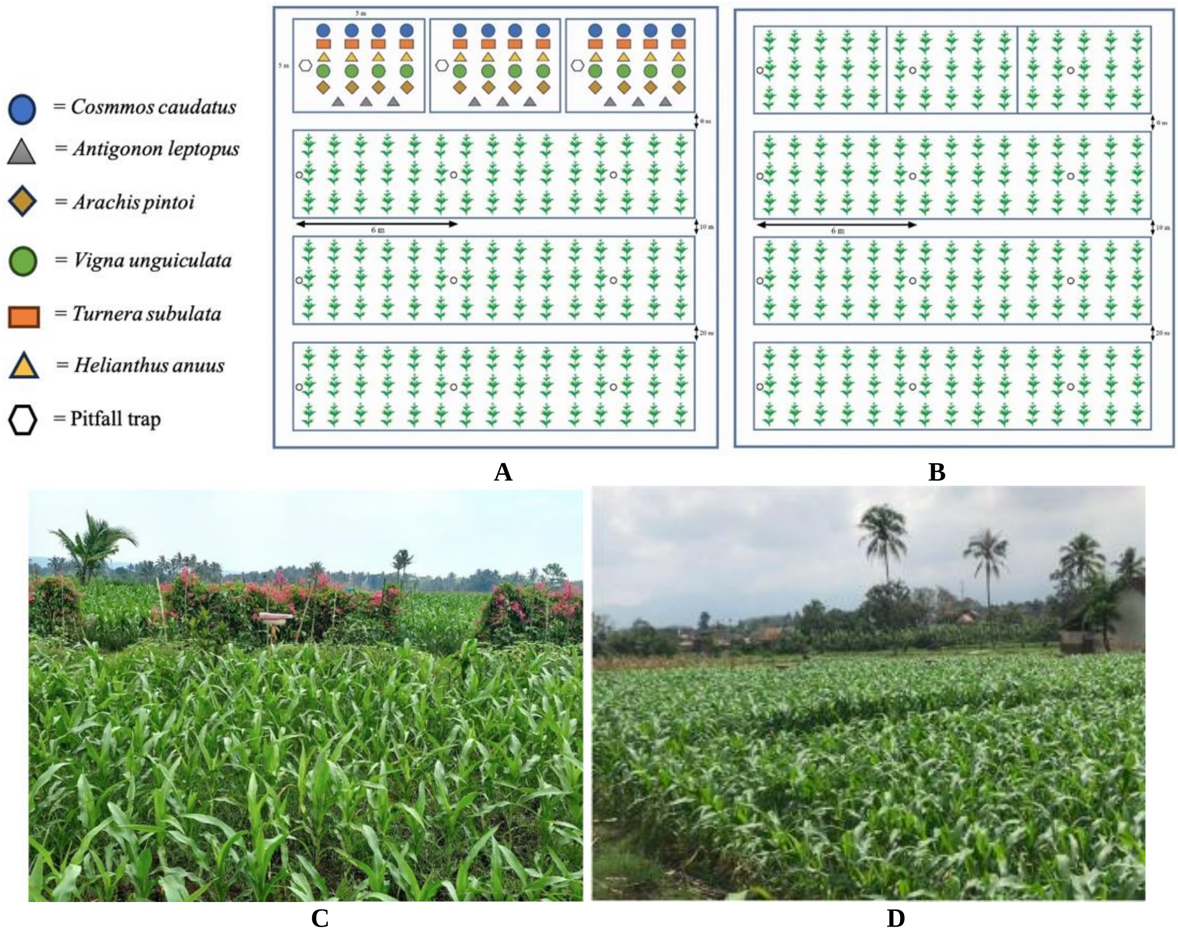

Figure 2. Planting design of treatment plots (A) and control plots (B). The surrounding conditions of the maize field (C) treatment plot and (D) control plot

Characterization of landscape composition

This study utilized eight landscapes, determined by the percentage of semi-natural habitats and the diversity of habitat types. At the landscape level, ground checking was conducted within a 500 m radius of each plot, facilitated by maps from Google Earth. A radius of 500 m is considered suitable for observing the interaction between insects and their surrounding habitats in the tropics (Klein et al. 2006). Land use was documented during the field inspection. The results of ground checking were subsequently digitized using QGIS (QGIS Development Team 2023). Landscape parameters in the analysis, namely Class Area (CA) and Number of Patches (NP) of semi-natural habitats and maize cropland at each study site, were calculated with the LecoS (landscape ecology statistics) Plugin (Table 1). CA represents the area of land use (ha), and NP indicates the number of fragments. The greater the CA and NP values of a class of landscape elements, the more dominant that element is in the landscape (Yaherwandi et al. 2006). Land use was classified into six categories: semi-natural habitat, annual cropland, perennial cropland, maize cropland, open area, and housing area (Figure 3).

Data analysis

The effects of landscape composition, treatment plot, maize crop age, and other factors on species richness, abundance, and species composition of ants were analyzed using a generalized linear model (GLM) without interactions (Ulina et al. 2019) and using a quasi-poisson distribution to account for overdispersion (Zuur et al. 2009). Explanatory variables included class area (CA.semi) and number of patches (NP semi) of semi-natural habitats, class area (CA maize) and number of patches (NP.maize) of maize fields, season, plant diversity enrichment treatment, and crop age (weeks after planting). Species composition (beta diversity) of ants was calculated based on an additive diversity portioning approach (Gering and Crist 2002) where beta diversity resulted from gamma diversity (total ant species in one season) minus alpha diversity (species richness per maize crop age) (Rizali et al. 2013). Differences in ant species composition in dry and wet seasons, between treatment and control plots, and maize crop age of the study were analyzed using analysis of similarity (ANOSIM) based on the Bray-Curtis dissimilarity index with the vegan package. All analyses were performed using R statistical software 4.2.1 (R CoreTeam 2022).

Table 1. The landscape composition of each maize field was calculated as the number of patches of semi-natural habitat (NP.semi) and maize field (NP.maize) and the area (in ha) of semi-natural habitat (CA.semi) and maize field (CA.maize) per landscape (500 m radius)

Plot code	Landscape composition			
	NP. semi	CA. semi	NP. maize	CA. maize
C1	3	2.08	15	26.17
C2	2	3.44	17	30.45
C3	3	15.34	8	14.40
C4	4	8.68	14	30.98
R1	3	3.69	15	30.74
R2	3	3.85	20	27.56
R3	4	16.90	9	23.14
R4	5	12.41	14	28.49

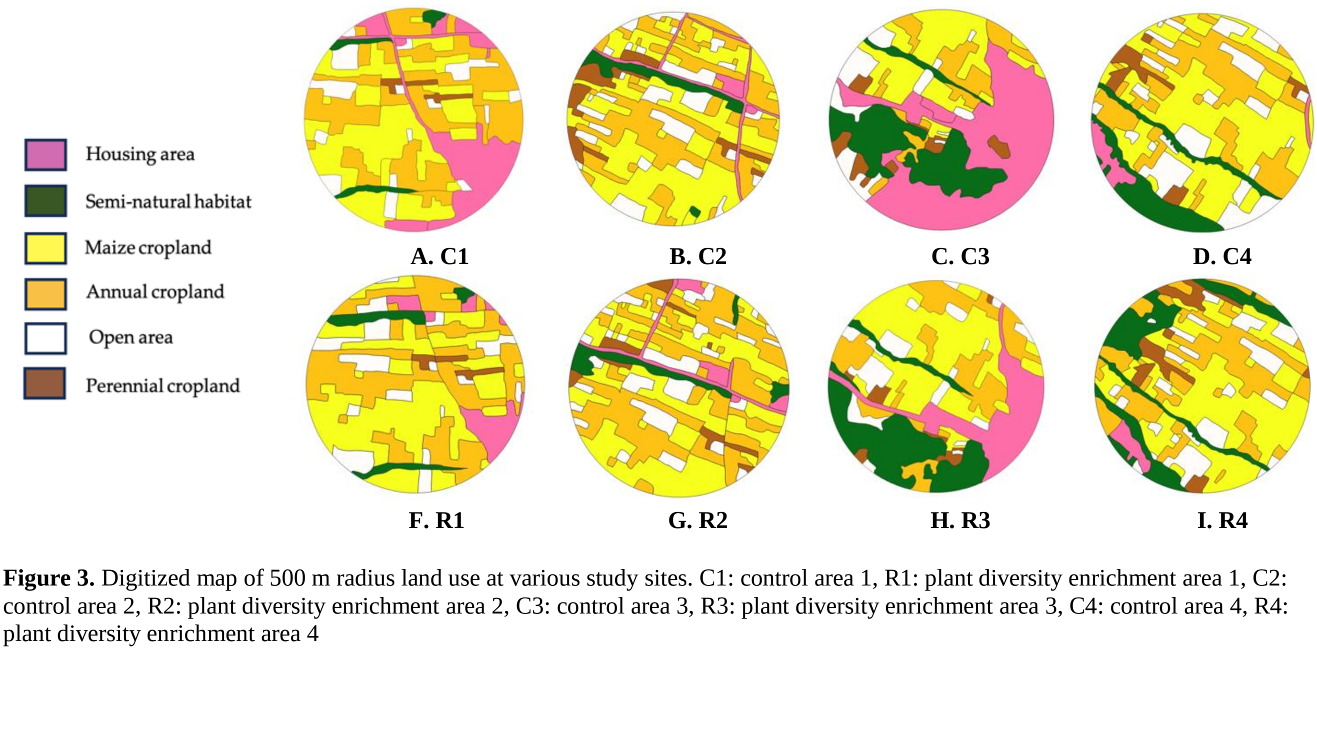

Figure 3. Digitized map of 500 m radius land use at various study sites. C1: control area 1, R1: plant diversity enrichment area 1, C2: control area 2, R2: plant diversity enrichment area 2, C3: control area 3, R3: plant diversity enrichment area 3, C4: control area 4, R4: plant diversity enrichment area 4

RESULTS AND DISCUSSION

Diversity and abundance of ants

Ant diversity throughout the control and treatment areas totaled 1941 individuals belonging to 4 subfamilies, 22 genera, and 40 species (Table 2). The subfamily with the highest ant species richness was the Myrmicinae subfamily (16 species), followed by the Formicinae subfamily (10 species), Ponerinae subfamily (9 species), and Dolichoderinae subfamily (5 species) (Table 2). In total, 801 individuals were found in the dry and 1,140 in the wet seasons. Ten species were found in both the dry and wet seasons. *Iridomyrmex* sp1 was the most abundant ant species (455 individuals), followed by *Lophomyrmex* sp1 (424 individuals) and *Lophomyrmex* sp2 (281 individuals) (Table 2). Plot R4 had the highest species richness (15 species) in the dry season, while plot R2 had the highest species abundance (227 individuals). In the wet season, plot R2 and R3 had the highest species richness (12 species), and the highest species abundance was observed in plot C3 (281 individuals). Plot C2 and C3 (6 species) exhibited the lowest species richness and abundance in the dry season, while in the wet season, plot C3 had the least species richness and abundance (6 individuals) (Table 3).

Ant species composition

Differences in ant species composition during the dry and wet seasons, between treatment and control plots, and among maize crop age stages were compared using pairwise similarity analysis (ANOSIM) based on the Bray-Curtis dissimilarity index. The results of the ANOSIM pairwise analysis revealed that ant species composition significantly differed between the dry and wet seasons (Table 4). However, ant composition in comparisons between control and treatment plots showed no significant differences ($P = 0.442$). Similarly, ant composition in all comparisons of maize crop age exhibited no significant differences in composition ($P>0.05$).

Effect of landscape composition on ant diversity

As a result of landscape characterization across the study sites, maize fields emerged as the dominant element in the agricultural landscape (Figure 3). GLM analysis indicated that landscape composition did not significantly impact ant diversity. However, our findings revealed that the number of semi-natural habitat patches and maize crop age influenced species richness and composition. On the other hand, the season only affected ant species composition (Table 5). The number of semi-natural habitat patches positively affected ant species richness but negatively affected ant species composition. More semi-natural habitat patches in agricultural landscapes corresponded to higher ant species richness. In contrast, the wet season negatively impacts ant species composition, signifying a reduction in species composition during this season.

Table 2. The abundance of ant species was collected in two seasons (dry and wet seasons) in a maize field in Malang. Morphospecies are based on external morphological differences

Morpho-species	Dry total	Wet total	Grand total
Dolichoderinae			
Iridomyrmex sp1	233	222	455
Iridomyrmex sp2	9		9
Tapinoma sp1	1	12	13
Tapinoma sp2		1	1
Technomyrmex sp1	1		1
Formicinae			
Anoplolepis gracilipes	83	44	127
Camponotus sp1	5		5
Nylanderia sp1	85	21	106
Nylanderia sp2	16	136	152
Nylanderia sp3	4		4
Paraparatrechina sp1		1	1
Plagiolepis sp1		12	12
Polyrhachis sp1		6	6
Polyrhachis sp2		1	1
Prenolepis sp1	1		1
Myrmicinae			
Cardiocondyla sp1	10		10
Cardiocondyla sp2	2		2
Cardiocondyla sp3	1	59	60
Cardiocondyla sp4	4		4
Crematogaster sp1		4	4
Lophomyrmex sp1	124	300	424
Lophomyrmex sp2	62	219	281
Monomorium sp1	16		16
Monomorium sp2	1		1
Monomorium sp3	4		4
Monomorium sp4	21		21
Pheidole sp1		38	38
Pheidole sp2		26	26
Strumigenys sp1		2	2
Tetramorium sp1	8		8
Tetramorium sp2	1		1
Ponerinae			
Diacamma sp1		4	4
Hypoponera sp1	1		1
Hypoponera sp2	3		3
Hypoponera sp3	1		1
Leptogenys sp1	1	1	2
Leptogenys sp2	1		1
Odontoponera sp1	102	1	103
Odontoponera sp2		19	19
Pachycondyla sp1		11	11

Table 3. Species richness (S) and abundance (N) of ants collected during the dry and wet seasons from 4 observations across sub-plots in different maize field plots in Malang, East Java, Indonesia

Plot code	Dry season		Rainy season		Total	
	S	N	S	N	S	N
C1	7	30	10	239	12	269
C2	6	65	8	89	13	154
C3	6	6	11	281	14	287
C4	14	117	7	31	18	148
R1	9	136	10	163	14	299
R2	13	227	12	88	20	315
R3	11	130	12	174	16	304
R4	15	90	11	75	20	165
Total	28	801	22	1140	40	1941

Table 5. A generalized linear model relating ant species richness, abundance, and species composition to the number of patches (NP.semi) and class area (CA.semi) of semi-natural habitat, number of patches (NP.maize) and class area (CA.maize) of maize field, season, plant diversity enrichment treatment, crop age (weeks after planting). Level of significance: (●):P<0.1; (*): P<0.05; (***): P<0.001

Variable	Species richness			Abundance			Species composition		
	Estimate	SE	P	Estimate	SE	P	Estimate	SE	P
NP.maize	0.017	0.040	0.662	-0.046	0.092	0.614	-0.007	0.009	0.454
CA.maize	-0.006	0.024	0.784	-0.058	0.055	0.298	0.002	0.004	0.643
NP.semi	0.237	0.135	0.085●	-0.040	0.330	0.903	-0.056	0.027	0.048*
CA.semi	-0.017	0.035	0.618	-0.062	0.080	0.435	0.002	0.007	0.737
Season-Wet	0.198	0.134	0.146	0.352	0.317	0.271	-0.346	0.029	<0.001***
Treatment-enrichment	0.279	0.168	0.102	0.581	0.416	0.167	-0.058	0.035	0.108
Crop age	0.062	0.030	0.043*	0.065	0.070	0.353	-0.014	0.006	0.029*

Table 4. ANOSIM pairwise analysis of the different seasons, treatments, and maize crop ages. Level of significance: (*): P<0.05

Pairwise test	R	P
Dry vs Wet	0.191	0.026 *
Treatment vs Control	0.020	0.442
Age (weeks after planting):		
4 vs 6	-0.046	0.715
4 vs 8	-0.054	0.724
4 vs 10	0.136	0.054
6 vs 8	-0.013	0.548
6 vs 10	0.090	0.148
8 vs 10	-0.016	0.524

Discussion

Our results indicated that plant diversity enrichment management in maize fields did not significantly affect species richness and abundance of ants. The effectiveness of plant diversity enrichment in enhancing plant biodiversity in agroecosystem appears suboptimal, given the limited number of flowering plants compared to the main crop. However, a study by Shrestha et al. (2019) demonstrated that plant diversity enrichment increased insect abundance in agricultural land. Yuniasari et al. (2021) also found that plant diversity enrichment on the lower surface of the main plants also affects the diversity and species richness of ants in coffee plantations. Because plant diversity enrichment provides nectar and pollen, ants can also obtain prey from other insects that visit the plant diversity enrichment so that ants can easily obtain prey (Sumini and Bahri 2020). Additionally, it is suspected that the positioning of the treatment plot in the center of the maize field may have hindered ants' access to biodiversity sources due to the existing maize crops. Island biogeography theory by MacArthur and Wilson (1967) suggests that biodiversity and the number of species inhabiting an island are influenced by the size of the land and the degree of isolation. Larger and less isolated islands tend to have more species, while smaller and more isolated islands have fewer species (in Vogiatzakis and Griffiths 2008). Nevertheless, differences in ant composition were observed between the treatment and control plots. The diversity and biomass of plant enrichment also influence ant composition regarding the food sources produced. Species composition and plant biomass strongly influence the presence and activity of ants. The higher composition of ants in the treatment plots suggests an intrinsic demand for the resources and biotope condition patterns required by the ant species. Plant species diversity influences ants establishment and foraging parameters (Achury et al. 2022).

Differences between the dry and wet seasons did not significantly affect ant species richness and abundance. However, variation was observed in the number of species and abundance between the dry and wet seasons. A study by Wanna et al. (2022) reported that differences in the wet and dry seasons had no significant impact on ant diversity in Thailand. Dantas and Fonseca (2023) emphasized that ant diversity is influenced by factors such as food diversity, temperature, humidity, and rainfall. These factors can either increase or decrease the number of foraging ants. The abundance of ants found during the wet season aligns with the findings of Sakchoowong et al. (2015) which state that ants forage more in the wet than in the dry seasons. The increased activity is attributed to lower temperatures, higher soil moisture content, and increased litter during the wet season, creating favorable conditions for ants and their prey. Consequently, these conditions contribute to high ant abundance and population levels.

Differences in the age of maize crops positively affected ant species richness. The variation in maize crop age is directly linked to the availability of food for ants. As the age of the maize crop increases, a corresponding increase in the number of ant species is observed. This pattern aligns with findings from previous studies that highlighted the influence of crop age and tree age on insect community and diversity (Sakchoowong et al. 2015; Rizali et al. 2012; Azim et al. 2020). In particular, increasing tree age is a significant factor in ant presence, attributed to the availability of nesting sites and microhabitat structures (Andersen 2000).

The increasing number of semi-natural habitat patches indicates fragmentation in the agricultural landscape. The number of semi-natural habitat patches in this study positively correlated with ant species richness. Research conducted by Lucey et al. (2014) also found that ant species richness increases with a more significant proportion of natural habitat around oil palm plantations. Rösch et al. (2015) argue that multiple small fragments of habitat support more insect species and abundance than a single large fragment in the same habitat area. Previous study has consistently demonstrated this pattern, confirming that patch size influences ant diversity, with more ant species found in smaller areas than larger ones (Dauber et al. 2006). Susilawati et al. (2017) found that the proximity of natural habitats to agricultural land can increase diversity and species richness, which means that the closer the distance between agricultural land and natural habitats, the more species richness increases. This finding underscores that increasing patches in natural habitats can encourage ant diversity. Bianchi et al. (2006) explain that natural habitats provide crucial resources such as food sources, shelter and nesting sites, and alternative hosts or prey for beneficial insects. Additionally, areas with small natural habitat fragments exhibit a noticeable edge effect that can extend throughout the entire region. As edge effects increase, habitats along edges allow for greater biodiversity (Murcia 1995). Natural habitat fragmentation increases the number of edges in the landscape, leading to physical changes like radiation, moisture, temperature, wind speed, and soil nutrients. The proliferation of edges in the landscape also results in biological changes, such as alterations in species composition, competition, and predation (Benítez-Malvido and Arroyo-Rodríguez 2008). Maintaining semi-natural habitats promotes an increase in beneficial insect populations. It directly influences the balance of insect populations, making protecting these habitats in agricultural landscapes an effective strategy for enhancing beneficial insect populations (Alignier et al. 2014).

In conclusion, this study suggests that agricultural landscape composition exerts a greater influence on ant community diversity than plant diversity enrichment management at the local level. Landscape composition positively affected ant species richness but negatively impacted ant species composition, particularly in the number of semi-natural habitat patches. This implies that semi-natural habitats play a significant role in conserving ants within maize fields. Furthermore, maize crop age positively affected the ant species richness, but negatively influenced ant species composition. Nonetheless, effective agroecosystem management at the local level is crucial as it shapes and determines the overall quality of agroecosystems at the landscape level. Understanding the responses of ecologically essential groups, such as ants, allows us to infer the potential impact of biodiversity loss on animal-mediated ecosystem processes. This knowledge enhances our understanding of how habitat complexity within maize fields can influence biodiversity.

ACKNOWLEDGEMENTS

We are grateful for the support by PT. Syngenta Indonesia for granting permission to conduct our field research in their maize field and funding to conduct field research. We are particularly grateful to Gita Eka Rahmawati, Fahmi Risyad Sulthoni, Dearosa Permana, Muhammad Harianto, Mega, Risa, Azqia, Utan, and Faiz Nashiruddin Muhammad for their involvement in the identification of ants and assistance during the field experiment.

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