

Effects of Lac-Maize Agroforestry System on Ground-Dwelling Ant Diversity and Functional Groups: Postprint

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Abstract

To reveal the impacts of lac-corn agroforestry systems on ground ant community diversity and functional groups, we investigated ground ant species composition, species diversity, community structure similarity, indicator species, and functional groups using pitfall traps in three plot types in Lüchun County, Yunnan Province: lac forest, lac-corn agroforestry, and corn dryland. The results demonstrated that the lac-corn agroforestry model supported higher ground ant species richness and numbers of rare species. Compared with corn dryland, ant species richness increased by 41% and rare species numbers increased by 85% in lac-corn agroforestry. Both lac-corn agroforestry and lac forest exhibited higher ant diversity, with species richness and ACE estimates significantly greater than those of corn dryland, while ant abundance in lac-corn agroforestry was significantly higher than in both lac forest and corn dryland. Ground ant species assemblages differed among the three plot types, with species associated with lac forest and lac-corn agroforestry distinct from those of corn dryland. Indicator species varied across the three plot types: corn dryland was characterized by *Iridomyrmex anceps* and *Pheidole yeensis*; lac-corn agroforestry by *Dolichoderus incisus*, *Acantholepis xichangensis*, and *Monomorium chinense*; and lac forest by *Aphaenogaster feae*, *Crematogaster ferrarii*, *Tetramorium aptum*, *Aphaenogaster beccarii*, and *Pseudolasius silvestrii*. The functional group composition of ants in lac-corn agroforestry was intermediate between corn dryland and lac forest, with species numbers, abundance, and proportions of Opportunists (OPP), Subordinate Camponotini (SC), Cryptic species (C), and Climate specialists (CS) significantly higher than in corn dryland. The habitat complexity of lac-corn agroforestry plays a positive role in ground ant diversity conservation, representing a favorable model for balancing environmental protection and economic sustainable development.

Full Text

Introduction

Rapid population growth and social development have intensified conflicts between human activities and ecological conservation, making the balance between economic development and biodiversity protection a central focus of ecological research [1-3]. Consequently, studies on the ecological consequences of land-use change and its impacts on ecosystem functions have gained increasing attention [4-5]. Agroforestry represents a composite system that organically combines crops and forestry based on management objectives and ecological principles to achieve optimal comprehensive ecological benefits [6-7]. Agroforestry systems can enhance sustainable land management effectiveness and ecological benefits [8] while supporting greater species survival and offering higher biodiversity conservation value [9-10]. While previous research has primarily examined how agroforestry development affects biodiversity conservation [11-12], fewer studies have investigated the relationship between biodiversity and ecosystem functions within these systems.

Lac insects (*Kerria* spp.) are resource insects with significant economic value, whose secretions are widely used across various industries [13-14]. Lac plantations are extensively distributed in the semi-arid and semi-humid valleys and mid-mountain regions of southwestern China, representing an important source of income for local farmers. In these lac-producing regions, lac production and agricultural cultivation often occur simultaneously, with lac host trees, understory crops, and surrounding farmland forming lac-based agroforestry systems. Previous studies have explored how lac agroforestry enhances soil fertility, provides fuelwood, conserves water and soil [15], and protects arthropod species richness [16-19]. However, research on arthropod functional groups—key indicators of composite ecosystem functions—remains limited.

Ants (Hymenoptera: Formicidae) play crucial roles in ecosystems [20-22] and serve as excellent bioindicators [23-24]. Ant functional groups are species assemblages with similar ecological characteristics [25] that can respond to changes in ecosystem functions [26-27]. This study compares ground-dwelling ant communities across lac-corn agroforestry systems, lac plantations, and cornfields, examining community structure, indicator species, functional group composition, and variations among different functional groups across habitat types to reveal the role of lac-corn agroforestry in ant diversity and ecosystem function conservation, providing a theoretical foundation for using lac agroforestry to protect local biodiversity.

1.1 Study Area

The study was conducted in Niu Kong Township, Lüchun County, Yunnan Province (23°02' N, 102°09' E) at elevations ranging from 900 to 1,150 m. The region has a mean annual temperature of 19.1°C and annual precipitation of

1,687 mm, characterized by a mountain monsoon climate. This area has a long history of lac production, primarily through pure lac plantations and lac agroforestry systems, with lac-corn intercropping being the most common pattern. Both lac plantations and lac agroforestry systems utilize host plants for rearing *Kerria yunnanensis* in rotation. The lac insect has two generations annually: the winter generation (October to May) and summer generation (May to October), with both lac secretion and honeydew production being higher during the summer generation.

Host plants in lac plantations are primarily *Dalbergia balansae*, *Dalbergia obtusifolia*, and *Ficus semicordata*, with planting densities of 825–900 trees · hm² and canopy densities of 45%–65%. The main understory herbs are *Ageratina adenophora* and *Eupatorium odoratum*. In lac-corn agroforestry plots, the host plant is *Dalbergia balansae* at densities of 300–450 trees · hm² with canopy densities of 25%–35%. Corn (*Zea mays*) is cultivated underneath at approximately 40,000 plants · hm². Cornfields are established on cleared slopes with long-term corn cultivation at densities similar to lac-corn agroforestry systems. Both lac-corn agroforestry plots and cornfields were planted with corn during May–October 2012 and left fallow from October to April the following year. During the corn cultivation period, weeding and fertilization were performed 1–2 times. No pesticides were applied in any experimental plots. During the fallow period, dominant herbs included *Eupatorium odoratum*, *Crassocephalum rubens*, and *Bidens pilosa*.

Three habitat types were selected: lac plantation (L), cornfield (D), and lac-corn agroforestry (M). Two plots of each type were established, each measuring 150 m × 200 m, with inter-plot distances exceeding 1 km. All selected plots faced southward with similar slopes. Site characteristics are summarized in .

1.2 Survey Methods

Surveys were conducted twice in late October 2012 and late April 2013 using pitfall traps to investigate ground-dwelling ant communities. Within each plot, 15 pitfall traps were arranged in a 5 × 3 grid pattern (trap diameter: 60 mm, height: 90 mm) with consistent trap placement sequences across plots. Traps were spaced 10 m apart and filled with 50 mL of ethylene glycol (50%) as trapping solution. After 48 hours, ants were collected from traps and preserved in 75% ethanol in centrifuge tubes for laboratory identification to species level using relevant literature [21–22]; specimens that could not be identified to species were treated as morphospecies.

1.3 Analysis Methods

Data from both surveys were pooled for analysis. Ant abundance data were converted using a 6-level scoring system (1: 1 individual; 2: 2–5 individuals; 3: 6–10 individuals; 4: 11–20 individuals; 5: 21–50 individuals; 6: >50 individuals) to prevent over-representation of certain species in a few samples [28–29].

- 1) **Species composition:** For each plot, we tallied ant species and individual numbers. Dominant (>10% of total abundance), common (1-10%), and rare (<1%) species were identified based on each species' abundance percentage [22]. Species rarefaction and extrapolation curves based on sample number were generated using the iNEXT package in R [30].
- 2) **Diversity:** Using every five trap samples as a unit, we calculated ground-dwelling ant abundance, species richness (S), and ACE estimates [31-32] for each plot. These diversity indices were computed using EstimateS software [33]. One-way ANOVA with LSD post-hoc tests in SPSS 18 was used for multiple comparisons of ant abundance, species richness S, and ACE estimates among the three habitat types. Species richness S and ACE estimates were log-transformed before analysis to test for homogeneity of variance.
- 3) **Community structure similarity:** Non-metric multidimensional scaling (NMDS) analysis was performed using R statistical software to assess community structure similarity. Principal coordinate analysis (PCO) was also conducted, yielding consistent results with NMDS.
- 4) **Indicator species analysis:** Indicator species were identified using the IndVal method based on transformed abundance data, with significance determined through 1,000 permutations.
- 5) **Functional group analysis:** Following Andersen [48], ants were classified into seven functional groups at the genus level: Dominant Dolichoderinae (DD), Subordinate Camponotini (SC), Climate Specialists (CS), Cryptic Species (C), Generalized Myrmicinae (GM), Opportunists (O), and Specialist Predators (SP). The proportions of different functional groups in each habitat were calculated based on ant abundance. For each group of five traps, we calculated species richness and abundance for each functional group, with differences among cornfields, lac plantations, and lac-corn agroforestry systems compared using one-way ANOVA in SPSS 18.0.

2.1 Effects of Lac Agroforestry on Ground-Dwelling Ant Species Composition and Abundance

A total of 11,781 individual ants were collected, belonging to 78 species, 37 genera, and 7 subfamilies. Cornfields yielded 4,457 individuals (4 subfamilies, 22 genera, 41 species); lac-corn agroforestry plots yielded 4,430 individuals (7 subfamilies, 30 genera, 58 species); and lac plantations yielded 2,894 individuals (6 subfamilies, 30 genera, 60 species).

While the numbers of common and dominant species were similar across habitat types, lac-corn agroforestry had the highest number of rare species, whereas cornfields had the lowest (). Both lac-corn agroforestry and lac plantations facilitated rare species conservation, providing habitats for ant species with smaller populations.

Species accumulation curves rose and then plateaued, indicating adequate sampling. Extrapolation curves predicted substantially higher ant species numbers in lac plantations and lac-corn agroforestry compared to cornfields ([Figure 1: see original paper]).

2.2 Effects of Lac Agroforestry on Ground-Dwelling Ant Diversity

Lac-corn agroforestry and lac plantations supported higher ground-dwelling ant diversity than cornfields. Significant differences in ant abundance were detected among the three habitat types [$F(2, 15) = 5.406$, $P = 0.017$], with lac-corn agroforestry significantly higher than both lac plantations and cornfields, which had the lowest abundance. Species richness (S) differed significantly among habitats [$F(2, 15) = 32.535$, $P < 0.01$]; lac-corn agroforestry and lac plantations showed no significant difference but were both significantly higher than cornfields. ACE estimates also differed significantly [$F(2, 15) = 4.456$, $P = 0.030$], with lac-corn agroforestry and lac plantations showing no significant difference but both significantly exceeding cornfields ().

2.3 Similarity of Ground-Dwelling Ant Community Structure Among Habitat Types

Lac plantations and lac-corn agroforestry exhibited similar ground-dwelling ant community structures, both distinctly different from cornfields ([Figure 2: see original paper]). PCO analysis corroborated NMDS results, confirming community similarity between lac plantations and lac-corn agroforestry and their dissimilarity to cornfields. Species composition analysis revealed that *Paratrechina vividula* and *Pheidole yeensis* were strongly associated with cornfields; *Aphaenogaster beccarii* with lac plantations; and *Monomorium chinensis*, *M. orientale*, *Crematogaster rogenhoferi*, *Polyrhachis proxima*, and *Cardiocondyla wroughtonii* with both lac-corn agroforestry and lac plantations ([Figure 3: see original paper]).

Indicator species differed among the three habitat types (). Cornfields had two indicator species: *Iridomyrmex anceps* and *Pheidole yeensis*. Lac-corn agroforestry had three: *Dolichoderus incisus*, *Lepisiota xichangensis*, and *Monomorium chinensis*. Lac plantations had five: *Aphaenogaster feae*, *Crematogaster ferrarii*, *Tetramorium aptum*, *Aphaenogaster beccarii*, and *Pseudolasius silvestrii*, with *Crematogaster* and *Aphaenogaster* species being honeydew feeders.

2.5 Functional Group Analysis of Ground-Dwelling Ants in Different Habitat Types

Land use directly influenced ground-dwelling ant functional group composition, with different groups responding variably to land-use intensity ([Figure 4: see

original paper]).

Generalized Myrmicinae comprised over 50% of ant functional groups across all habitats, reaching 70% in cornfields—higher than in lac plantations and lac-corn agroforestry. Lac plantations supported higher proportions of Opportunists, Subordinate Camponotini, and Cryptic Species than the other habitats, while cornfields had the lowest proportions. The proportion of Cryptic Species in lac-corn agroforestry was similar to cornfields but significantly lower than in lac plantations. Lac-corn agroforestry had higher proportions of Climate Specialists and Specialist Predators than both other habitats, with cornfields showing the lowest proportions. Dominant Dolichoderinae occurred only in cornfields.

Functional group abundance and species richness varied among habitats. Overall, lac plantations and lac-corn agroforestry supported significantly higher ant abundance and species richness than cornfields. Climate Specialists, Opportunists, and Subordinate Camponotini showed particularly lower abundance and species richness in cornfields compared to the other two habitats. Most functional groups showed similar abundance and species richness between lac plantations and lac-corn agroforestry. Cryptic Species showed no significant differences in abundance or species richness across all three habitats. Climate Specialist abundance in lac-corn agroforestry was significantly higher than in lac plantations and cornfields (lowest), though species richness did not differ significantly. Generalized Myrmicinae abundance in lac-corn agroforestry was significantly higher than in lac plantations and cornfields, while species richness showed no significant differences. Opportunist abundance and species richness in lac plantations were significantly higher than in cornfields; lac-corn agroforestry showed significantly higher species richness but not abundance compared to cornfields. Subordinate Camponotini abundance in lac-corn agroforestry was significantly higher than in cornfields, though species richness did not differ significantly among habitats. Specialist Predator abundance in lac-corn agroforestry was significantly higher than in lac plantations and cornfields, while species richness in lac plantations was significantly higher than in cornfields ().

Discussion

Ecosystems with complex habitat structure and abundant food resources better support ant diversity conservation [39–44]. This study found that lac plantations and lac-corn agroforestry had 46% and 41% more ground-dwelling ant species, respectively, and 23% and 63% higher ant occurrence frequencies compared to cornfields. One key reason is that honeydew secreted by lac insects significantly increased ant species richness and frequency in forested habitats. Although lac-corn agroforestry hosted fewer lac insects than pure lac plantations, its ground-dwelling ant abundance approached that of lac plantations while species richness exceeded it. Additionally, lac plantations and lac-corn agroforestry provided more complex habitats than cornfields. The honeydew ejected onto plants and ground surfaces created additional food resources for ants at different strata, increasing habitat heterogeneity and supporting higher

ant populations and occurrence frequencies—consistent with findings from coffee plantation ant community studies [45]. Diversity analyses revealed that lac-corn agroforestry overall supported higher ant diversity than lac plantations ([Figure 2: see original paper]), likely because lower tree density and canopy cover in lac-corn agroforestry allowed more understory arthropods to thrive, providing ants with additional protein resources and indirectly enhancing ant diversity. Lac plantations and lac-corn agroforestry particularly benefited small-population ant taxa, increasing rare species diversity without affecting common species (Table 2), demonstrating high conservation value.

Biodiversity generally declines with increasing land-use intensity [46]. Although lac-corn agroforestry and cornfields had similar corn cultivation timing and management intensity, while lac plantations only experienced moderate disturbance during lac harvesting and insect release, lac-corn agroforestry ant community structure remained similar to lac plantations and dissimilar to cornfields. This indicates that honeydew significantly influenced ant community structure, mitigating diversity loss from disturbance. Species composition and indicator species analysis showed that *Pheidole yeensis*, *Paratrechina vividula*, and *Iridomyrmex anceps* were associated with cornfields—species favoring open, dry, disturbed habitats [26]—confirming high disturbance intensity in cornfields. In contrast, lac-corn agroforestry and lac plantations hosted honeydew-feeding taxa such as *Aphaenogaster* and *Crematogaster*, which occurred exclusively in these habitats, demonstrating that lac-corn agroforestry provides clear protection for honeydew-feeding ants.

Functional group classification reduces system complexity and better reflects organism-environment relationships [47–49]. This study revealed that ground-dwelling ant functional groups responded distinctly to land use and disturbance. Generalized Myrmicinae genera (*Pheidole*, *Monomorium*, *Crematogaster*) are dominant in warm habitats, replacing Dominant Dolichoderinae in non-dry-hot environments [50]. Dominant Dolichoderinae and *Pheidole* species typically inhabit open, disturbed habitats, indicating that all three habitat types experienced some disturbance. However, *Pheidole* comprised 76.7% of ants in cornfields—far exceeding lac-corn agroforestry (41.3%) and lac plantations (26.7%). Moreover, Dominant Dolichoderinae occurred only in cornfields, confirming that cornfields experienced the highest disturbance intensity and environmental stress.

Note: Figure translations are in progress. See original paper for figures.

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