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Original Article

# Insects and spiders on *Acacia mangium* (Fabaceae) saplings as bioindicators for the recovery of tropical degraded areas

## Insetos e aranhas em plantas de *Acacia mangium* (Fabaceae) como bioindicadores na recuperação de área tropical degradada

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**Abstract**

*Acacia mangium* is a pioneer species with fast growth and frequently used in the recovery of degraded areas. The objectives were to evaluate insects and spiders, their ecological indices and interactions on *A. mangium* saplings in a tropical degraded area in recovering process. The experimental design was completely randomized with 24 replications, with treatments represented by the first and second years after *A. mangium* seedling planted. Numbers of leaves/branch, branches/sapling, and ground cover by *A. mangium* saplings, Hemiptera: *Phenacoccus* sp. and *Pachycoris torridus*; Hymenoptera: *Tetragonisca angustula* and *Trigona spinipes*, *Brachymyrmex* sp., *Camponotus* sp. and *Cephalotes* sp.; Blattodea: *Nasutitermes* sp. and Neuroptera: *Chrysoperla* sp.; abundance, species richness of pollinating insects, tending ants, and the abundance of Sternorrhyncha predators were greatest in the second year after planting. Numbers of Hemiptera: *Aethalium reticulatum*, Hymenoptera: *Camponotus* sp., *Cephalotes* sp., *Polybia* sp., *T. angustula*, *T. spinipes*, tending ants, pollinating insects, Sternorrhyncha predators and species richness of tending ants were highest on *A. mangium* saplings with greatest numbers of leaves or branches. The increase in the population of arthropods with ground cover by *A. mangium* saplings age increase indicates the positive impact by this plant on the recovery process of degraded areas.

**Keywords:** arthropods, diversity, Formicidae, pollinating insects, ecological interactions.

**Resumo**

*Acacia mangium* é uma espécie pioneira, de rápido crescimento e utilizada na recuperação de áreas degradadas. Os objetivos foram avaliar insetos e aranhas, seus índices ecológicos e interações com plantas de *A. mangium* em área tropical degradada em processo de recuperação. O delineamento experimental foi inteiramente casualizado com 24 repetições, com os tratamentos representados pelos primeiro e segundo anos após a plantio de *A. mangium*. Os números de folhas/galhos, galhos/plantas e cobertura do solo por plantas de *A. mangium*, de Hemiptera: *Phenacoccus* sp. e *Pachycoris torridus*; Hymenoptera: *Tetragonisca angustula* e *Trigona spinipes*, *Brachymyrmex* sp., *Camponotus* sp. e *Cephalotes* sp.; Blattodea: *Nasutitermes* sp. e Neuroptera: *Chrysoperla* sp.; a abundância, riqueza de espécies de insetos polinizadores, formigas cuidadoras e a abundância de predadores de Sternorrhyncha foram maiores no segundo ano após o plantio. Os números de Hemiptera: *Aethalium reticulatum*, Hymenoptera: *Camponotus* sp., *Cephalotes* sp., *Polybia* sp., *T. angustula*, *T. spinipes*, formigas cuidadoras, insetos polinizadores, predadores de Sternorrhyncha e a riqueza de espécies de formigas cuidadoras foram maiores em plantas de *A. mangium* com maior altura e número de folhas ou galhos. O aumento populacional de artrópodes e da cobertura do solo com o processo de envelhecimento das plantas de *A. mangium* indicam impacto positivo dessa planta na recuperação de áreas degradadas.

**Palavras-chave:** artrópodes, diversidade, Formicidae, insetos polinizadores, interações ecológicas.

## 1. Introduction

Human action usually degrades natural ecosystems, especially with agricultural systems management, necessary to maintain population and economic growth (García-Orth and Martínez-Ramos, 2011). The recovery of these areas is essential but slow (Amaral et al., 2013; Reis et al., 2015). Species of the Fabaceae family (Fabales)

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are used to recover degraded areas worldwide, especially with *Acacia mangium* Willd, due to the fast growth, rusticity, high adaptability to acidic and infertile soils and nitrifying potential (Wang et al., 2013; Caldeira et al., 2018; Silva et al., 2020). The high rates of nitrogen fixation by *A. mangium*, due to its symbiosis with diazotrophic bacteria, increases the biomass production and nutrient input via litter, favoring plant succession (Paula et al., 2018; Silva et al., 2020). *Acacia mangium* wood is used to build furniture, cabinets, frames, doors and window components, boxes and crates and to produce coal, coal briquettes and activated carbon (Hegde et al., 2013). Insects such as *Aethalion reticulatum* (Linnaeus, 1767) (Hemiptera: Aethalionidae), *Oncideres mirim* (Martins and Galileo, 1996) and *Oncideres ocularis* (Thomson, 1868) (Coleoptera: Cerambycidae), and *Trigona spinipes* (Fabricius, 1793) (Hymenoptera: Apidae) can damage *A. mangium* trees (Lemes et al., 2012, 2013; Silva et al., 2015, 2020).

Arthropod respond to environmental changes and thus used as bioindicators (Prosser et al., 2016; Pereira et al., 2018). The ecological indices (e.g. diversity) of these organisms allow to evaluated modifications on ecological structures, as reduction in the species richness in communities (Pereira et al., 2018). The reproduction, growth, and survival of phytophagous insects and of their natural enemies vary with fertilization, plant age, leaf mass, chemical and nutritional defenses (Bowers and Stamp, 1993; Oliveira et al., 2014) and their abundance and diversity are greater in larger plants as biogeographic islands (BGI) with decreased chances of endangered species extinction (Kitahara and Fujii 1997; Burns, 2016; Leite et al., 2017). Nevertheless, competition between arthropod groups by interference is common (Bhuyain and Lim, 2019, Leite et al., 2021a, b) with death, aggressive behavior, and the production of chemicals (e.g. pheromones) (Boulay et al., 2019). Competition on the exploratory activity includes resource depletion with high density-dependent mortality rates and reproduction failure (Boulay et al., 2019). Tending ants (e.g. *Camponotus* sp.) protect Hemiptera (e.g. *A. reticulatum*) against natural enemies in exchange of honeydew, a carbohydrate-rich food that contains glucose, fructose, sucrose, free amino acids, lipids, starch, minerals, and vitamin B (Stadler and Dixon, 2005; Zanuncio et al., 2015; Araujo et al., 2016).

The objectives of this research were to study the abundance, diversity, and species richness of insects and spiders as bioindicators and the possible interactions (competition, predation, and protocooperation) between arthropod groups on young *A. mangium* trees (saplings in the vegetative stage) in a tropical degraded area. Five hypotheses were tested: i) the crown of oldest *A. mangium* saplings is higher (highest BGI) with greatest litter production increasing the recovery of the degraded area; ii) abundance, diversity and species richness of herbivorous and pollinating insects and of predators and tending ants are greatest in oldest saplings due to their larger crowns (highest BGI); iii) the abundance of tending ants and predators can be directly proportional to that of Hemiptera phytophagous and prey, respectively; iv) the greatest abundance of ants can reduce that of predators and chewing insects, and v) competition between insects can occur.

## 2. Material and Methods

### *2.1. Experimental site*

The study was carried out in a degraded area (≈ 1 ha) at the "Instituto de Ciências Agrárias da Universidade Federal de Minas Gerais" (ICA/UFMG), city of Montes Claros, Minas Gerais State, Brazil (latitude 16º51'38 S, longitude 44º55'00" W, altitude 943 m) from April 2015 to February 2017 - 24 months. The area is degraded due to soil losses and changes in soil chemistry and hydrology (Milton et al., 1994; Whitford, 2001). This area, according to the Köppen climate classification, is dry tropical; with annual rainfall between 1,000-1,300 mm, dry winter, and average annual temperature ≥ 18 °C (Alvares et al., 2013). The soil is of the Neosol Litolic type with an Alic horizon (Santana et al., 2016), and its physical-chemical characteristics have been described (Silva et al., 2020).

### *2.2. Experimental design*

*Acacia mangium* seedlings were produced from seeds obtained on trees grown at the ICA/UFMG and planted in plastic bags (16 × 24 cm) in a nursery with a substrate with 30% organic compost, 30% clay soil, 30% sand, and 10% reactive natural phosphate (160g) in March 2014. In September of this year, 30 cm tall saplings were planted in holes (40 × 40 × 40 cm), spaced by two meters between each one, in six parallel lines on flat terrain and 2 m between lines, with four plants per line, and fertilized in a single dose, with 20 L of dehydrated sewage sludge/hole (Nogueira et al., 2007). The saplings were irrigated twice a week until the beginning of the rainy season. The design was completely randomized with 24 replications (one sapling each), with treatments in the first and second years after planting the *A. mangium* seedlings.

### *2.3. Vegetal mass produced and ground cover*

Numbers of leaves/branch and branches/sapling and the percentage of ground cover by litter, herbaceous and grassy plants were evaluated visually and monthly per plot (1 $m^2$) in the crown projection of each one of the 24 *A. mangium* saplings.

### *2.4. Arthropods and their ecological indices and interactions*

All insects (Eusocial Formicidae) and spiders were counted between 7:00 A.M. and 11:00 A.M., by visual observation, every two weeks on the adaxial and abaxial surfaces of the first 12 leaves expanded per *A. mangium* sapling. These leaves were assessed, randomly, on branches (one leaf per position) in the basal, middle and apical parts of the canopy– vertical axis - (0 to 33%, 33 to 66% and 66 to 100% of total sapling height, respectively) and in the north, south, east and west directions - horizontal axis. A total of 12 leaves/sapling/evaluation were observed in each of the 24 *A. mangium* saplings starting six months after transplanting them and lasting 24 months, covering the entire sapling (vertical and horizontal axis), capturing the highest possible number of arthropods (insects and spiders), especially the rarest ones. The evaluator approached, carefully, firstly assessed the adaxial leaf surface and, if it was not possible to visualize the abaxial one, with a delicate and slow movement, lifted the leaf to visualize it. The leaf position of *A. mangium* saplings is generally tilted upwards, facilitating the visual assessment of arthropods. Insects with great mobility (e.g. Orthoptera), that flew, on approach, were counted as long as they were recognized (e.g. Order). The arthropods (insects and spiders) were not removed from the saplings during the evaluation.

A few arthropod specimens (up to three individuals) per species were collected using an aspirator (two hours per week), at the beginning of the study (between transplantation and first evaluation, six months after), stored in flasks with 70% alcohol, separated into morphospecies, and sent to specialists for identification (see acknowledgments). Any visible arthropod, not yet computed in previous evaluations was collected, coded and sent to a taxonomist of its group. The interactions between ants and Hemiptera due to their behavior of tending (i.e. consuming honeydew and antennating Hemiptera) identified them with protocooperation behavior on *A. mangium* saplings.

### 2.5. Statistical analysis

Each replication is the total number of individuals collected on 12 leaves (three heights and four sides of the sapling). The ecological indices (abundance, diversity, and species richness) were calculated per group (e.g. chewing insects) in the treatments (years 1 and 2) using the BioDiversity Professional, Version 2 software (© 1997 The Natural History Museum) (Krebs, 1989). Abundance and species richness are the total number of individuals and species, respectively, per sampling (Begon et al., 2007). Diversity was calculated using Hill's formula (1st order): N1= exp (H'), where H' is the Shannon–Weaver diversity indices, that calculates diversity and the current number of species (Hill, 1973).

The data on abundance, diversity, and species richness of phytophagous insects, pollinator insects and natural enemies were submitted to a non-parametric statistical hypothesis, Wilcoxon signed-rank test (P<0.05) (Wilcoxon, 1945) using the statistical software "Sistema para Análise Estatística e Genética" (SAEG), version 9.1 (SAEG, 2007) (Supplier: "Universidade Federal de Viçosa"). Data were also subjected to second degree or principal component regressions (PCR) (P<0.05), when linear to verify the possible interactions (e.g. protocooperation) between arthropod groups (e.g. tending ants and Hemiptera phytophagous). Simple equations were selected based on the criteria: i) data distribution in the figures (linear or quadratic response), ii) the most significant parameters were used in these regressions (p-value< 0.05), iii) p-value< 0.05 and *F* of the analysis of variance of these regressions, and iv) the determination coefficient of these equations ($R^2$). PCR uses principal component analysis, based on a covariance matrix to perform regression. It reduces the size of regression, excluding the dimensions contributing to collinearity, which are, linear relationships between the independent variables (Bair et al., 2006). The parameters used in these equations were significant (P<0.05) due to variable selection by the "Stepwise" method with the statistical software. The data presented in the text are the significant ones (P <0.05) and the rest are in the supplementary material I.

## 3. Results

### 3.1. Vegetal mass production and ground cover

Numbers of leaves/branch, branches/sapling, and ground cover (litter, herbaceous, and grassy plants) were higher on *A. mangium* saplings in the second year of planting (Table 1).

### 3.2. Arthropods and their ecological indices

Numbers of Blattodea: *Nasutitermes* sp. (Termitidae); Hemiptera: *Phenacoccus* sp. (Pseudococcidae), and *Pachycoris torridus* (Scopoli, 1772) (Scutelleridae); Hymenoptera: *Tetragonisca angustula* (Latreille, 1811) and *T. spinipes* (Apidae), *Brachymyrmex* sp., *Camponotus* sp., and *Cephalotes* sp. (Formicidae); and Neuroptera: *Chrysoperla* sp. (Chrysopidae) were higher on *A. mangium* saplings in the second year after planting. Abundance and species richness of pollinating insects, tending ants, and abundance of Sternorrhyncha predators were greater on *A. mangium* saplings in the second year. Numbers of *A. reticulatum*, *Camponotus* sp., *Cephalotes* sp., *Polybia* sp. (Hymenoptera: Vespidae), *T. angustula*, and *T. spinipes* were higher on *A. mangium* saplings with greatest numbers of leaves or branches. Abundances of tending ants, pollinating insects, Sternorrhyncha predators and species richness of tending ants were greater on *A. mangium* saplings with

**Table 1.** Number of branches/sapling and leaves/branch, percentage of ground cover per *Acacia mangium* (Fabaceae) sapling (mean ± SE) and planting year.

| Variables | Year | | TW* | |
|---|---|---|---|---|
| | First | Second | *VT*[£] | *P* |
| Leaves/branch | 22.90±0.65 | 43.92±2.94 | 5.42 | 0.00 |
| Branches/sapling | 34.40±1.64 | 49.20±3.32 | 3.53 | 0.00 |
| Ground cover | 14.66±1.57 | 37.00±2.99 | 4.62 | 0.00 |

*TW= Test of Wilcoxon; [£]VT= value of test; n= 24 per treatment.

bigger vegetal mass (e.g. *A. mangium* leaves). However, the numbers of Araneae: Araneidae and Oxyopidae; Coleoptera: *Cerotoma* sp., *Stereoma anchoralis* (Lacordaire, 1848) (Chrysomelidae), and total Coleoptera; Hemiptera: *Bemisia* sp. (Aleyrodidae), Membracidae, and *Bladina* sp. (Nogodinidae); Hymenoptera: *Apis mellifera* (Linnaeus, 1758) (Apidae), *Ectatoma* sp. and *Pheidole* sp. (Formicidae); and total Orthoptera were higher on saplings in the first year after planting. Abundance, species richness of chewing insects (higher defoliation), and spiders were greater on saplings in the first year. The number of *Pheidole* sp., and the abundance and species richness of chewing insects were lower on leafiest saplings (Tables 2-4).

### *3.3. Possible protocooperation, predation, and competition*

The numbers of *T. spinipes* and *Pheidole* sp. correlated, positively, with that of *A. reticulatum* and those of Araneidae with *Tropidacris collaris* (Stoll, 1813) (Orthoptera: Romaleidae) and *Parasyphraea* sp. (Coleoptera: Chrysomelidae). Diversity and species richness of Sternorrhyncha predators correlated, positively, with those of Hemiptera phytophagous, and abundance of spiders with that of chewing insects. However, the number of *Bemisia* sp. correlated, negatively, with that of chewing insects; those of *T. spinipes* and Dolichopodidae (Diptera) with tending ants; and those of *T. spinipes* with total predators (Table 4).

## 4. Discussion

A greater vegetal mass production and ground cover (e.g. litter) of *A. mangium* saplings (highest BGI) increased abundance of sap-sucking insects and tending ants in the second year after planting. Therefore, numbers of predators, defoliators and, in some situations, reduced, stirring competition between groups of insects (Leite et al., 2012a, b, 2017; Silva et al., 2020).

Larger canopies (e.g. branches/sapling) and ground cover (e.g. litter) of *A. mangium* saplings in the second year after planting confirm the first hypothesis that older sapling helps to recuperate a degraded area, corroborating the greater biomass production (wood, branch, leaf, and

**Table 2.** Order, family, and species of spiders (Class Arachnidae) and insects (Class Insecta), and percentage of defoliation by insects per *Acacia mangium* (Fabaceae) sapling (mean ± SE) and planting year.

| Order: family, species | Year | | TW* | |
|---|---|---|---|---|
| | First | Second | *VT*£ | *P* |
| Ara.: Araneidae, none identified | 0.63±0.17 | 0.21±0.10 | 1.95 | 0.02 |
| Oxyopidae, none identified | 0.58±0.17 | 0.17±0.07 | 1.98 | 0.02 |
| Blat.§: Termitidae, *Nasutitermes* sp. | 6.46±5.30 | 29.92±14.07 | 2.31 | 0.01 |
| Col.: Chrysomelidae, *Cerotoma* sp. | 0.21±0.08 | 0.00±0.00 | 2.34 | 0.01 |
| *Stereoma anchoralis* Lacordaire | 0.21±0.13 | 0.00±0.00 | 1.77 | 0.03 |
| Total Coleoptera | 1.58±0.53 | 0.42±0.13 | 2.22 | 0.01 |
| Hem.: Aleyrodidae, *Bemisia* sp. | 2.71±1.09 | 0.04±0.04 | 2.12 | 0.01 |
| Membracidae, none identified | 0.46±0.17 | 0.33±0.33 | 2.18 | 0.01 |
| Nogodinidae, *Bladina* sp. | 0.13±0.06 | 0.00±0.00 | 1.77 | 0.03 |
| Pseudococcidae, *Phenacoccus* sp. | 0.00±0.00 | 2.21±1.18 | 2.06 | 0.01 |
| Scutelleridae, *Pachycoris torridus* Scopoli | 0.00±0.00 | 0.17±0.09 | 1.77 | 0.03 |
| Hym.: Apidae, *Apis mellifera* L. | 0.38±0.15 | 0.00±0.00 | 2.59 | 0.00 |
| *Tetragonisca angustula* Latreille | 0.33±0.13 | 1.04±0.22 | 2.63 | 0.00 |
| *Trigona spinipes* Fabr. | 0.67±0.28 | 4.00±1.30 | 2.63 | 0.00 |
| Formicidae, *Brachymyrmex* sp. | 3.04±1.02 | 37.17±10.56 | 2.62 | 0.00 |
| *Camponotus* sp. | 0.63±0.26 | 8.58±2.04 | 4.94 | 0.00 |
| *Cephalotes* sp. | 0.17±0.16 | 6.88±3.04 | 2.82 | 0.00 |
| *Ectatoma* sp. | 0.92±0.26 | 0.17±0.09 | 2.59 | 0.00 |
| *Pheidole* sp. | 4.00±0.74 | 1.13±0.29 | 3.06 | 0.00 |
| Neu.: Chrysopidae, *Chrysoperla* sp. | 0.00±0.00 | 0.13±0.06 | 1.77 | 0.03 |
| Total Orthoptera | 1.42±0.28 | 0.75±0.17 | 1.71 | 0.04 |
| Defoliation | 6.69±0.29 | 5.87±0.31 | 2.17 | 0.01 |

*TW= Test of Wilcoxon; £VT= value of test; §observed on trunck; n= 24 per treatment.

**Table 3.** Abundance, diversity and species richness of phytophagous chewing insects, Hemiptera phytophagous, pollinators, tending ants, Sternorrhyncha predators, and spiders per *Acacia mangium* sapling (Fabaceae) (mean ± SE) and planting year.

| Variables | Year | | TW* | |
|---|---|---|---|---|
| | **First** | **Second** | ***VT*£** | ***P*** |
| Chewer abundance | 3.08±0.67 | 1.29±0.24 | 2.32 | 0.01 |
| Chewer diversity | 2.61±0.53 | 2.10±0.48 | 0.56 | 0.28 |
| Chewer species richness | 1.96±0.30 | 1.21±0.19 | 1.80 | 0.03 |
| Hemiptera abundance | 8.29±4.14 | 6.04±2.63 | 0.99 | 0.16 |
| Hemiptera density | 2.10±0.54 | 1.48±0.31 | 0.32 | 0.37 |
| Hemiptera species richness | 1.67±0.26 | 1.13±0.19 | 1.44 | 0.07 |
| Pollinator abundance | 1.38±0.37 | 5.04±1.31 | 2.80 | 0.00 |
| Pollinator diversity | 1.11±0.28 | 0.99±0.23 | 0.13 | 0.44 |
| Pollinator species richness | 0.79±0.18 | 1.25±0.15 | 2.05 | 0.02 |
| Ant abundance | 10.63±1.59 | 56.88±11.24 | 3.54 | 0.00 |
| Ant diversity | 4.71±0.70 | 3.55±0.47 | 1.15 | 0.12 |
| Ant species richness | 2.63±0.25 | 3.21±0.30 | 1.68 | 0.04 |
| Predator abundance | 1.13±0.24 | 2.38±0.53 | 2.06 | 0.01 |
| Predator diversity | 1.23±0.31 | 1.50±0.35 | 0.49 | 0.30 |
| Predator species richness. | 0.83±0.15 | 1.04±0.16 | 0.98 | 0.16 |
| Spider abundance | 1.79±0.30 | 0.71±0.16 | 2.56 | 0.00 |
| Spider diversity | 1.57±0.58 | 0.85±0.27 | 0.28 | 0.38 |
| Spider richness | 1.33±0.22 | 0.67±0.15 | 2.21 | 0.01 |

*TW= Test of Wilcoxon; £VT= value of test; n= 24 per treatment.

bark) with old increase of *Acacia mearnsii* (De Wild, 1925), *Ateleia glazioviana* (Baill,1881) and *Mimosa scabrella* (Benth, 1842) (Fabales: Fabaceae), and *Eucalyptus grandis* (W. Hill ex Maiden, 1862) (Myrtales: Myrtaceae) (Eloy et al., 2018). The recovery of degraded areas is slow as reported for a deactivated gold mine in Diamantina, Minas Gerais State, Brazil, with 707 and 909 plants with a diameter ≥ 3.0 cm of 29 and 30 plant families, 57 and 64 plant genus, and 77 and 86 plant species in the first (2008) and second (2010) inventories, respectively (Amaral et al., 2013). The regeneration resilience of the Brazilian savannah (Cerrado)is, usually, high after the first cut, but the succession after almost four decades in Nova Xavantina municipality, Mato Grosso State, Brazil was still in an intermediate stage (Reis et al., 2015). This expresses the recovery potential of *A. mangium* plants with rapid growth, even in degraded soils, due to its efficient nitrogen fixation (Cipriani et al., 2013; Silva et al., 2020) and with flowers attracting pollinating insects (Wang et al., 2013; Caldeira et al., 2018; Silva et al., 2018, 2020).

Greater numbers of sap-sucking insects (e.g. *Phenacoccus* sp.) and the termite *Nasutitermes* sp., pollinators (e.g. *T. angustula*), tending ants (e.g. *Brachymyrmex* sp.) and Sternorrhyncha predators (e.g. *Chrysoperla* sp.) on *A. mangium* saplings, in the second year of planting, are, probably, due to the greater numbers of leaves (e.g. *Camponotus* sp.) and branches (e.g. *A. reticulatum*) on these saplings (highest BGI). The abundance and species richness of pollinating insects and tending ants, and abundance of Sternorrhyncha predators were also higher on *A. mangium* saplings in the second year of planting, probably, due to the higher vegetal mass production. This partially confirms the second hypothesis that with higher BGI allow greater abundance of herbivorous and pollinating insects and, consequently, tending ants and predators (Schmitz, 2008; Leite et al., 2017; Silva et al., 2020). The numbers of pollinating insects (e.g. *T. spinipes*) and tending ants (e.g. *Camponotus* sp.) were four to six times higher on *A. mangium* saplings, in the second year after planting due to their larger canopies, and, consequently, with bigger numbers of extrafloral nectaries (leaf base) with greater food supply (Hegde et al., 2013). These results validate those of *Brachymyrmex* sp., *Camponotus* sp., and *T. spinipes* on *Leucaena leucocephala* (Lam, 1996) (Fabales: Fabaceae) plants (Damascena et al., 2017), and *Brachymyrmex obscurior* (Forel, 1893) (Hymenoptera: Formicidae) on *Acacia pennatula* (Schltdl. and Cham. Benth, 1832) (Fabales: Fabaceae) plants (Moya-Raygoza, 2005). Taller *A. mangium* saplings, in the second year after planting, may have functioned as BGIs with high food supply and shelter for arthropods and reducing the extinction risks of rarer species (Kitahara and Fujii, 1997; Burns, 2016; Leite et al., 2017). Numbers of pollinating insects and *Nasutitermes* sp. were higher on *A. mangium* saplings with larger crowns, similar to that reported for galling insects on *Caryocar brasiliense* (A. St.-Hil., 1828) (Malpighiales:

**Table 4.** Relationships between abundance (Abun.) of chewing insects (Chew.), tending ants (Ants), spiders (Spid.), pollinating insects (Pol.), Hemiptera phytophagous (Hem.), Sternorrhyncha predators (Pred.) and total predators (Tot.Pred.), diversity (D.) of Hem. and Pred., species richness (S.R) of Chew., Hem., Ants and Pred., numbers of *Aethalium reticulatum* (Aret.), *Bemisia* sp. (Bem.), Araneidae (Aran.), *Camponotus* sp. (Camp.), *Cephalotes* sp. (Ceph.), Dolichopodidae (Doli.), *Parasyphraea* sp. (Para.), *Pheidole* sp. (Phei.), *Polybia* sp. (Poly.), *Tetragonista angustula* (Tangu), *Trigona spinipes* (Tspi.), *Tropidacris collaris* (Tcoll.), branches/sapling (Branches) and leaves/branch (Leaves) per *Acacia mangium* sapling (Fabaceae).

| **Principal component regressions** | **$R^2$** | ***F*** | ***P*** |
|---|---|---|---|
| Aret.= -11.87+1.98xPheid.+1.12xTspi.+0.18xBranches | 0.26 | 5.24 | 0.00 |
| Aran.= 0.18+0.34xPara.+ 0.24xTcoll. | 0.22 | 6.15 | 0.00 |
| Pheid.= 4.76+0.05xAret.-0.07xLeaves | 0.19 | 5.18 | 0.01 |
| Tspi.= -2.80+0.13xBranches+0.10xAret.-0.13xAbun. Tot.Pred. | 0.25 | 4.76 | 0.01 |
| **Simple regressions** | | | |
| Abun. Chew.= 4.42-0.07xLeaves | 0.14 | 7.58 | 0.01 |
| Abun. Ants= -22.00+1.67xLeaves | 0.30 | 19.38 | 0.00 |
| Abun. Spid.= 0.85+0.18xAbun. Chew. | 0.14 | 7.21 | 0.01 |
| Abun. Pol.=- 1.40+0.11xBranches | 0.10 | 5.36 | 0.03 |
| Abun. Pred.= 0.24+0.05xLeaves | 0.10 | 5.25 | 0.03 |
| D. Pred.= 0.91+0.26xD. Hem. | 0.12 | 5.96 | 0.02 |
| S.R. Chew.= 2.66-0.03xLeaves | 0.14 | 7.20 | 0.01 |
| S.R. Ants= 1.67+0.04xLeaves | 0.16 | 8.76 | 0.00 |
| S.R. Pred.= 0.65+0.21xS.R. Hem. | 0.10 | 4.83 | 0.03 |
| Camp.= -3.60+0.25xLeaves | 0.20 | 11.52 | 0.00 |
| Ceph.= -13.10+0.50xLeaves | 0.45 | 37.67 | 0.00 |
| Tangu.= -0.20+0.03xLeaves | 0.16 | 8.96 | 0.00 |
| Bem.= -0.65+1.43xAbun. Chew.-0.10xAbun. $Chew.^2$ | 0.16 | 4.22 | 0.02 |
| Tspi.=-0.17+0.15xAbun. Ants-0.001xAbun. $Ants^2$ | 0.19 | 5.13 | 0.01 |
| Doli.= 0.64+0.03xAbun. Ants-0.0002xAbun. $Ants^2$ | 0.14 | 3.77 | 0.03 |

n=48.

Caryocaraceae) and *Macairea radula* (Bonpl. DC, 1828) (Myrtales: Melastomataceae), and *Carpatolechia proximella* (Hübner, 1796) (Lepidoptera: Gelechiidae) on *Picea abies* (L. Karst., 1753) (Pinales: Pinaceae) plants with larger crowns (Lara et al., 2008; Zvereva et al., 2014; Leite et al., 2017). On the other hand, the greater abundance, species richness, and defoliation on *A. mangium* saplings by chewing insects (e.g. *S. anchoralis* and *T. collaris*) and, consequently, predatory spiders (e.g. Araneidae), sap-sucking insects (e.g. *Bemisia* sp.), and tending ants (e.g. *Pheidole* sp.), in the first year after planting, are, probably, due to the rapid growth, softest leaves, higher nitrogen content (e.g. leaf protein and free amino acids in the sap) via fertilization of dehydrated sewage sludge (e.g. rich in nitrogen and other minerals) (Taiz et al., 2017; Silva et al., 2020). *Bemisia* sp. is an initial pest of annual crops and preferring new leaves of younger *Glycine max* (L., 1737) (Fabales: Fabaceae) - plants with higher free amino acid concentration in the sap (most nutritious food) (Cruz et al., 2016).

The increase in the numbers of predators (e.g. spiders) with that of phytophagous insects (e.g. defoliating), that of Araneidae with *T. collaris* and *Parasyphraea* sp., that of tending ants *Pheidole* sp. with *A. reticulatum*, and diversity and species richness of Sternorrhyncha predators with those of Hemiptera phytophagous on *A. mangium* saplings confirm the third hypothesis. The higher numbers of Hemiptera phytophagous and prey can result in greater numbers of tending ants and predators, respectively (Schmitz, 2008; Leite et al., 2012a). The direct correlation between sap-sucking insects and ants of the genera *Camponotus* and *Brachymyrmex* is due to the associations between these insect groups with mutual benefits (Novgorodova, 2015; Sanchez et al., 2020). This is similar to that reported for the greater numbers of *Dikrella caryocar* (Coelho, Leite and Da-Silva, 2014) (Hemiptera: Cicadellidae) and *Pseudoccocus* sp. (Hemiptera: Pseudococcidae) with *Crematogaster* sp. (Hymenoptera: Formicidae) on *C. brasiliense* trees (Leite et al., 2012a, 2015). Spiders reduced insect damage, especially by defoliators, in agroecosystems in the USA and Italy (Landis et al., 2000; Venturino et al., 2008), in 12 landscapes in the low mountain ranges of Central Hesse (Germany) (Öberg et al., 2008), and on *C. brasiliense* (Leite et al., 2012b) and *A. mangium* (Silva et al., 2020) trees in the cerrado and pastures in Brazil. The larger numbers of tending ants (e.g. *Pheidole* sp. with *A. reticulatum*), associated with sap-sucking insects may also have contributed to the greater abundance of chewing insects (e.g. *Cerotoma* sp.) and spiders (e.g. Oxyopidae), in the first year after planting *A. mangium* saplings. These facts confirm the fourth hypothesis that higher numbers of tending ants can decrease those of chewing insects and predators (Leite et al., 2012b; Wäckers et al., 2017). Trophobiotic interactions between ants (protection against natural enemies) and Sternorryncha (Hemiptera) (supplier of sugary substance - food) are one of the main mechanisms explaining the maintenance and superabundance of ants in ecosystems (Klimes et al., 2018) decreasing that of natural enemies, including Sternorrhyncha predators, with a negative impact on the biological control of sap-sucking insects (Wäckers et al., 2017; Kaneko, 2018; Tong et al., 2019). On the other hand, ants can reduce defoliation and fruit-boring insect populations (e.g. Coleoptera and Lepidoptera) on *C. brasiliense* trees (Leite et al., 2012b; Gonthier et al., 2013; Fagundes et al., 2017; Dassou et al., 2019) besides, being bioindicators of the recovery of degraded areas (Sanchez, 2015).

The greater abundance of chewing insects and *Bemisia* sp., in the first, and tending ants and *T. spinipes*, in the second year, after planting the *A. mangium* saplings and the reduction in the number of these sap-sucking and pollinating insects by the larger numbers of chewing insects and ants, confirm the fifth hypothesis that competition between insects can occur in those environments (Leite et al., 2017). The direct correlation between *T. spinipes* and *A. reticulatum* is similar to that of *Trigona hyalinata* (Lepeletier, 1836) (Santos et al., 2019) on *Clitoria fairchildiana* (Howard, 1967) (Fabales: Fabaceae) branches (Oda et al., 2009). The possible competition for honeydew produced by this sap-sucking insect between *T. spinipes* and tending ants (e.g. *Pheidole* sp.) on *A. mangium* saplings favor this bee with strong jaws, aggressivity and attacking and releasing repellent substances on potential predators or competitors (e.g. ants) for the honeydew - insects that suck sap and live in colonies (Schorkopf et al., 2009). The competition, for food and space, between *T. spinipes* x *A. mellifera* and *T. angustula* on cucurbits and *A. mangium* trees (Serra and Campos, 2010; Silva et al., 2020), and between four-leaf galling insects (Hymenoptera), aphids and beetles on *C. brasiliense* trees (Leite et al., 2012b, 2017) was also reported. Phylogenetic proximity favors the formation and maintenance of mixed species groups (eussocial or gregarious), probably, due to easier communication between members of similar size, lifespan, and displacement (Boulay et al., 2019). On the other hand, sharing similar ecological niches reduces the availability of food or reproductive partners through competition between species. The balance between the sharing of these resources and competition is crucial to understanding these species clusters and the disproportionate benefits for one species at the expense of anothers (Boulay et al., 2019).

## 5. Conclusions

The numbers of *T. collaris* (≈1/sapling) and *Bemisia* sp. (≈3/sapling) in the first year after planting, *A. reticulatum* (≈3/sapling) in the second year, and *Nasutitermes* sp. (≈30/sapling) and *T. spinipes* (≈4/sapling) in second year after planting on *A. mangium* saplings deserve attention since they are pests and harmful for this and many other plants. Both the vegetal mass production (e.g. branches) and ground cover (e.g. leaf litter) and the number of arthropods (e.g. tending ants) increased with the *A. mangium* saplings age. This correspondence indicates that the plant is a valuable alternative to recover degraded areas. Also, the increasing numbers of sap-sucking insects impact positively the numbers of tending ants and reduced those of predators, chewing insects, and *T. spinipes*, as the latter competes, with tending ants for food resources (honeydew) from *A. reticulatum*.

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## Supplementary Material

Supplementary material accompanies this paper.

**Supplementary material I.** Order, family, and spider (Class Arachnidae) and insect (Class Insecta) species per Acacia mangium (Fabales: Fabaceae) sapling (mean ± SE) and planting year

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