Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Phytophagous insects and natural enemies on *Sapindus saponaria* L. (Sapindales: Sapindaceae) plants fertilized with or without dehydrated sewage sludge

Insetos fitófagos e inimigos naturais em plantas de *Sapindus saponaria* (Sapindales: Sapindaceae) adubadas com ou sem lodo de esgoto desidratado

J. L. Silva[a]*, G. L. Demolin-Leite[a], M. A. Soares[b], M. J. S. Cabral[b], W. Faustino-Júnior[b], Z. V. Caldeira[b], D. L. Teixeira[a], R. A. Sampaio[a], A. M. Azevedo[a] and J. C. Zanuncio[c]

[a]Universidade Federal de Minas Gerais – UFMG, Instituto de Ciências Agrárias, Montes Claros, MG, Brasil
[b]Universidade Federal dos Vales do Jequitinhonha e Mucuri – UFVJM, Departamento de Agronomia, Diamantina, MG, Brasil
[c]Universidade Federal de Viçosa – UFV, Departamento de Entomologia/BIOAGRO, Viçosa, MG, Brasil

Abstract

Management programs and efficient techniques are necessary to recover degraded ecosystems. The sewage sludge is rich in nitrogen (N) and with the potential to fertilize *Sapindus saponaria* L. (Sapinales: Sapindaceae), used in the recovery of degraded areas; this can affect the insect fauna. The study's objective was to evaluate, for 24 months, the abundance of chewing insects, dipterans, pollinators, and predators on *S. saponaria* plants fertilized with or without dehydrated sewage sludge in a degraded area. The experimental design was completely randomized (with the same characteristics) with two treatments (with or without dehydrated sewage sludge) and 24 replicates, each with one plant. The abundance of *Anastrepha* sp. (Tephritidae), *Cerotoma* sp. (Chrysomelidae), Curculionidae, *Musca domestica* L. (Muscidae), *Mantis religiosa* L. (Mantodea: Mantidae), Oxyopidae, Salticidae, Tettigoniidae (Orthoptera), and *Teudis* sp. (Anyphaenidae) was higher on fertilized plants. The abundances of *Teudis* sp. and *Tmarus* sp. (Thomisidae) and *M. religiosa* and *Teudis* sp. were positively correlated with chewing insects and Diptera, respectively. The population increase of insects and spiders on *S. saponaria* plants fertilized with dehydrated sewage sludge (bigger crowns) has shown to be suitable for recovering degraded areas with a higher number of niches and better food quality, improving the ecological indices of the area.

Keywords: arthropods, biodiversity, litter production, spiders.

Resumo

A degradação de ecossistemas torna necessário programas de manejo e técnicas eficientes para recuperá-los. O lodo de esgoto é rico em nitrogênio e com potencial para adubar *Sapindus saponaria* L. (Sapinales: Sapindaceae), utilizada na recuperação de áreas degradadas, mas isto pode afetar a fauna de insetos. O objetivo foi avaliar, durante 24 meses, abundância de insetos mastigadores, dípteros, polinizadores e predadores em plantas de *S. saponaria* fertilizadas ou não com lodo de esgoto desidratado, em área degradada. O delineamento experimental foi inteiramente casualisado com dois tratamentos (com ou sem lodo desidratado de esgoto) e 24 repetições, cada uma com uma planta. A abundância de *Anastrepha* sp. (Tephritidae), *Cerotoma* sp. (Chrysomelidae), Curculionidae, *Musca domestica* L. (Muscidae), *Mantis religiosa* L. (Mantodea: Mantidae), Oxyopidae, Salticidae, Tettigoniidae (Orthoptera) e *Teudis* sp. (Anyphaenidae) foi maior em plantas adubadas. A abundância de *Teudis* sp. e *Tmarus* sp. (Thomisidae) e *M. religiosa* e *Teudis* sp. foi, positivamente, correlacionada com as de insetos mastigadores e Diptera, respectivamente. O aumento populacional de insetos e aranhas em plantas de *S. saponaria*, adubada com lodo desidratado de esgoto (maiores copas), mostra ser adequado para a recuperação de áreas degradadas, tendo essas plantas um maior número de nichos e com alimento de melhor qualidade, melhorando os índices ecológicos na área.

Palavras-chave: artrópodes, biodiversidade, serapilheira, aranhas.

1. Introduction

Sapindus saponaria L. (Sapindales: Sapindaceae), a late secondary forest species up to 8 m tall (Lorenzi, 2008; Goebes et al., 2015), occurs from the state of Pará to Rio Grande do Sul, Brazil. This plant is used to recover degraded areas, in Brazilian and indigenous folk medicine, and its fruits in washing clothes due to the chemical

*e-mail: julialeticiasilva16@gmail.com
Received: January 26, 2023 – Accepted: March 13, 2023

compound saponin (Tsuzuki et al., 2007; Lorenzi, 2008). Insects associated with *S. saponaria* are poorly studied, but insecticidal properties (e.g., trypsin inhibitors) of leaf and fruit extracts of this plant were toxic to *Trigona spinipes* (Fabr.) (Hymenoptera: Apidae) (Macedo et al., 2011).

Sewage sludge, a residue rich in organic matter, has the potential for fertilization or the production of forest seedlings. This material is indicated for forest plantations and in the recovery of degraded areas to minimize the risk of toxic elements entering the human food chain (Kimberley et al., 2004; Martins et al., 2016), but its use can affect the fauna of insects (e.g., > N) (Jansson and Ekbom, 2002; Leite et al., 2011; Taiz et al., 2017). As a fertilizer, sewage sludge in agriculture and forestry can reduce production costs and environmental problems (Caldeira et al., 2014; Martins et al., 2016).

Insect diversity can be used to monitor the recovery of degraded areas as they respond to environmental changes through mutualistic relationships and pollination (Santos et al., 2006; Barah and Bones, 2015; Kishi et al., 2017). With large numbers of families and species, Coleoptera, Lepidoptera, and Hymenoptera (e.g., ants and bees) are indicators of the recovery of degraded areas (Barbieri Junior and Dias, 2012; Komonen et al., 2015; Kishi et al., 2017). Nutritional indices, chemical defenses, and factors, such as fertilization and age of host plants, impact the diversity of phytophagous insects and their natural enemies, including spiders (Bowers and Stamp, 1993; Coley and Barone, 1996; Leite et al., 2011). Sewage sludge increases plant development because it is rich in phosphorus and nitrogen - macroelements - and Cu and Zn – micronutrients, and consequently affects insects (Mass, 2010).

The diversity and abundance of herbivorous insects and their natural enemies are generally greater in larger trees (Ferrier and Price, 2004; Espírito-Santo et al., 2007; Leite et al., 2017). Plants of this type function as biogeographic islands (i.e., biogeographic island theory – BGI), on a small scale, with greater probabilities of extinction of rarer species in smaller BGIs (Kitahara and Fujii, 1997; Burns, 2016; Leite et al., 2017; Carvalho et al., 2020; Dourado et al., 2020; Silva et al., 2020, 2021; Mota et al., 2021).

This study aimed to evaluate the abundance of chewing insects, dipterans, pollinators, and predators on *S. saponaria* plants and its defoliation by insects when fertilized with or without dehydrated sewage sludge, for 24 months, in a degraded area. The hypotheses tested were: i) fertilized plants will be larger (> BGI) with a higher abundance of phytophagous insects (Ferrier and Price, 2004; Espírito-Santo et al., 2007; Leite et al., 2017) and ii) the predators follow their prey (Auslander et al., 2003; Leite et al., 2017).

2. Materials and Methods

2.1. Experimental site

The study was carried out in a degraded area at the "Instituto de Ciências Agrárias (ICA)" of the "Universidade Federal de Minas Gerais (UFMG)," municipality of Montes Claros, Minas Gerais state, Brazil (latitude 16º51'38 S, longitude 44º55'00 "W, altitude 943 m) from March 2015 to February 2017 (24 months; insect collection period). The area is degraded by soil losses and changes in soil chemistry or hydrology (Milton et al., 1994; Whisenant, 1999). Köppen's climate (Alvares et al., 2013) classifies this area as a tropical dry climate, with an annual rainfall of 1000 – 1300 mm and dry winter. The soil is of litolic neosoil type (Santana et al., 2016) with average texture, total sand= 42.0 dags.kg^{-1}, silt= 36.0 dag.kg^{-1}, clay= 22.0 dag.kg^{-1}, pH–H_2O= 5.0, organic matter= 4.4 dag.kg^{-1}, P= 1.5 mg.dm^{-3}, K= 92.0 mg.dm^{-3}, Ca= 1.9 cmol$_c$.dm^{-3}, Mg= 0.8 cmol$_c$.dm^{-3}, Al= 2.4 cmol$_c$.dm^{-3}, H + Al= 6.7 cmol$_c$.dm^{-3}, cation–exchange capacity (CEC)= 5.3 cmol$_c$.dm^{-3}, and CEC at natural pH 7.0= 9.6 cmol$_c$.dm^{-3}.

2.2. Experimental design

Sapindus saponaria seedlings were produced from seeds of trees grown at the ICA/UFMG. Seedlings were planted in plastic bags (8 x 12 cm) in a nursery with a substrate mixed with 30% organic compost, 30% clay soil, 30% sand, and 10% reactive natural phosphate (160 g seedling^{-1}) in March 2014. The organic compost consisted of three parts by volume: two parts of gardening pruning debris (≤ 5 cm) and one part of tanned bovine manure. The soil pH in the pits (40 × 40 × 40 cm) was corrected with dolomitic limestone, increasing the base saturation to 50% (Kopittke and Menzies, 2007). Natural phosphate, gypsum, fritted trace elements (FTE), potassium chloride, and micronutrients were added according to the soil analysis (Nouvellon et al., 2012). One 30 cm high *S. saponaria* seedling was planted per pit spaced 2 m between them, in six parallel lines on flat terrain (similar characteristics), spaced 2 m between lines, four plants with and four without fertilization with dehydrated sewage sludge/line, in September 2014. These seedlings were irrigated twice a week from the beginning of the rainy season until no additional water was provided. The plants were pruned with a razor sterilized per plant when their branches reached 5 cm long, eliminating the additional ones and those up to 1/3 of crown height, leaving only the best stem. The pruned parts of each plant were left between their respective planting lines. The experimental design was completely randomized with two treatments (20 L of dehydrated sewage sludge/pit or no dehydrated sewage sludge) and 24 replications with one plant each. Twenty liters of dehydrated sewage sludge were placed per pit in a single dose during planting.

Dehydrated sewage sludge (5% moisture content) was collected at the sewage treatment plant – "Estação de Tratamento de Esgoto (ETE)" in the municipality of Juramento, Minas Gerais State, Brazil, about 40 km from the *S. saponaria* experimental site. The ETE is operated by the Minas Gerais Sanitation Company – "Companhia de Saneamento de Minas Gerais S.A. (COPASA)" with the capacity to treat 217 m^3 sewage day^{-1}. This system removes more than 90% of the organic matter. The sewage sludge passes through a solarization process in coarse sand tanks during three months in the ETE, which reduces the thermotolerant coliforms to a level accepted by the National Council for the Environment – "Conselho Nacional do Meio Ambiente (CONAMA)" (Resolution Nº 498) of the Ministry of the Environment- "Ministério do Meio Ambiente" of Brazil (http://conama.mma.gov.br/? option=com_sisconama&task=arquivo.download&id=797) for use in agriculture, which is <10^3 most likely number g^{-1} of total solids. The main chemical and biological characteristics of the dehydrated sewage sludge of this company were: pH–H_2O= 4.40, N= 10.4 $mg.kg^{-1}$, P= 2.9 $mg.kg^{-1}$, K= 5.8 $mg.kg^{-1}$, Cd= 0.1 $\mu g.g^{-1}$, Pb= 56.9 $\mu g.g^{-1}$, Cr= 46.7 $\mu g.g^{-1}$, and fecal coliforms= 4.35, most likely number g^{-1} (Nogueira et al., 2007).

2.3. Insects and spiders

Insects and spiders were counted by visual observation biweekly on the leaf adaxial and abaxial surfaces between 7:00 and 11:00 A.M. at the apical, middle, and basal canopy parts in the northern, southern, eastern, and western directions, with 12 leaves/plant/evaluation on the six months old 48 *S. saponaria* saplings (young trees) during 24 months. Insects and spiders were not removed from the plants during the assessment. The total sample effort was 27,648 leaves covering the entire plant (vertical and horizontal axes) to capture as many insect and spider species as possible, including the rarest. Insects and spiders found on the trunk (chest height) were collected, and defoliation was evaluated visually by the leaf area losses on a 0-100% scale with 5% increments for the leaf area removed (Sastawa et al., 2004; Mizumachi et al., 2006) for the 48 saplings/evaluation.

The evaluator approached carefully, firstly assessing the adaxial leaf surface and, if it was impossible to visualize the abaxial one, with a delicate and slow movement, lifting the leaf to visualize it. Insects with greater mobility that flew on approach were counted as long as they were recognized (e.g., Order). During the evaluation, the arthropods (insects and spiders) were not removed from the saplings. A few arthropod specimens (up to 3 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. Any visible arthropod not yet computed in previous evaluations was collected, coded, and sent to a taxonomist of its group.

2.4. Ecological Indices

Each replication (saplings) is the individuals collected on 12 leaves (three heights and four sides of the saplings). The ecological indices of abundance were calculated per group, for example, pollinators and treatment (with or without dehydrated sewage sludge)/tree using the BioDiversity Professional© software, Version 2 (1997) (Krebs, 1989). Abundance was the total number of individuals (Begon et al., 2007) per tree.

2.5. Statistics

Data of percentage of defoliation, numbers of chewing, defoliator, Diptera, pollinator, spiders, and predator insect species were submitted to the non-parametric statistical hypothesis, Wilcoxon signed-rank test (P< 0.05) (Wilcoxon, 1945) using the statistical analysis program "Sistema para Análises Estatísticas e Genéticas (SAEG)," version 9.1 (UFV, 2007) (Supplier: "Universidade Federal de Viçosa"). The data collected did not present a normal distribution. For this reason, they were analyzed using the non-parametric Wilcoxon test as the most powerful test locally among all the classification methods (Salov, 2014). Interactions between groups of phytophagous insects and their predators were analyzed by regression (P<0.05) with this statistical program. Simple equations (linear and quadratic responses) were selected based on the criteria: i) distribution of the data in the figures, ii) the parameters used in these regressions were the most significant ones (P <0.05), iii) P <0.05 and F of the analysis of variance of these regressions, and iv) the determination coefficient of these equations (R^2). The Spearman correlation matrix (linear response) was calculated among the most significant characteristics.

The matrices were submitted to correlation networks (Epskamp et al., 2012). The edge thickness was controlled by applying a cut of 0.26 value (from which the Spearman correlation became significant, meaning that only edges with $|r_{ij}|\geq 0.26$ were highlighted). These analyses were performed using the R software version 3.4.1 (R Core Team, 2014). The correlation network procedure was performed using the package *qgraph* (Epskamp et al., 2012).

3. Results

3.1. Fertilized plants × phytophagous insects

The percentage of defoliation by chewing insects and the abundance of individuals of *Anastrepha* sp. (Diptera: Tephritidae), *Cerotoma* sp. (Coleoptera: Chrysomelidae), Curculionidae (Coleoptera), *Musca domestica* L. (Diptera: Muscidae) and Tettigoniidae (Orthoptera) were higher on *S. saponaria* plants fertilized with dehydrated sewage sludge. In contrast, the numbers of *Stereoma anchoralis* Lacordaire (Coleoptera: Chrysomelidae) were higher on unfertilized plants. The abundance of *Nasutitermes* sp. (Blattodea: Termitidae), whose major visible damage was the formation of galleries on the plant trunk, was similar between treatments (Table 1). The number of leaves/saplings was positively correlated with those of *Cerotoma* sp., Curculionidae, and defoliation (Figure 1).

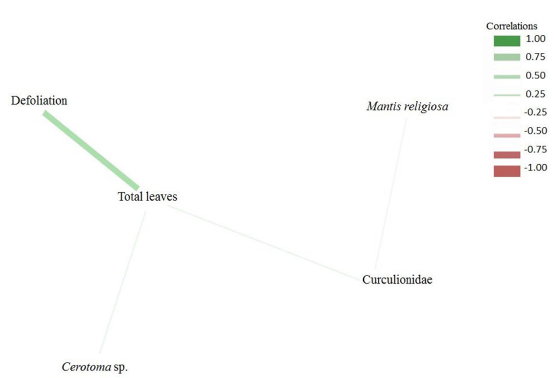

Figure 1. Estimated network structures based on Spearman correlation (P< 0.05) generated for the abundance of *Cerotoma* sp., Curculionidae, *Mantis religiosa*, and total leaves/tree and defoliation (%) on *Sapindus saponaria* saplings. n= 48.

Table 1. Abundance of phytophagous insects and defoliation (%) on *Sapindus saponaria* saplings (mean ± SE) with or without dehydrated sewage sludge.

Order: Family, species	Dehydrated sewage sludge		Wilcoxon test	
	With	Without	*VT**	*P*
Blattodea: Termitidae, *Nasutitermes* sp.§	9.79 ± 5.11	1.88 ± 1.88	1.4	0.08
Coleoptera: Chrysomelidae, *Alagoasa* sp.	0.17 ± 0.07	0.04 ± 0.04	1.4	0.08
Cerotoma sp.	0.17 ± 0.07	0.00 ± 0.00	2.1	0.02
Charidotis sp.	0.17 ± 0.13	0.00 ± 0.00	1.4	0.08
Diabrotica speciosa Germar	0.08 ± 0.05	0.00 ± 0.00	1.4	0.08
Eumolpus sp.	0.08 ± 0.05	0.00 ± 0.00	1.4	0.08
Lamprosoma sp.	0.08 ± 0.05	0.00 ± 0.00	1.4	0.08
Stereoma anchoralis Lacord.	0.00 ± 0.00	0.21 ± 0.13	1.8	0.04
Walterianella sp.	0.08 ± 0.08	0.00 ± 0.00	1.0	0.16
Wanderbiltiana sp.	0.04 ± 0.04	0.00 ± 0.00	1.0	0.16
Curculionidae: non identified	0.13 ± 0.06	0.00 ± 0.00	1.8	0.04
Lordops sp.	0.04 ± 0.04	0.08 ± 0.05	0.6	0.28
Tenebrionidae, *Epitragus* sp.	0.08 ± 0.05	0.00 ± 0.00	1.4	0.08
Parasyphraea sp.	0.04 ± 0.04	0.00 ± 0.00	1.0	0.16
Diptera: Otitidae, *Euxesta* sp.	0.08 ± 0.05	0.04 ± 0.04	0.6	0.28
Muscidae, *Musca domestica* L.	1.00 ± 0.35	0.04 ± 0.04	3.6	0.00
Tephritidae, *Anastrepha* sp.	0.17 ± 0.07	0.00 ± 0.00	2.1	0.02
Lepidoptera: non-identified	0.08 ± 0.05	0.00 ± 0.00	1.4	0.08
Orthoptera: Gryllidae, non-identified	0.00 ± 0.00	0.04 ± 0.04	1.0	0.16
Proscopiidae, *Cephalocoema* sp.	0.00 ± 0.00	0.04 ± 0.04	1.0	0.16
Romaleidae, *Tropidacris collaris* Stoll	0.46 ± 0.15	0.25 ± 0.09	0.8	0.22
Tettigoniidae, non-identified	1.33 ± 0.25	0.79 ± 0.23	1.8	0.04
Defoliation	5.49 ± 0.30	3.24 ± 0.34	4.3	0.00

n = 24 per treatment; VT* = value of the test; § = observed in the trunk.

3.2. Fertilized plants × natural enemies and pollinators

The abundances of individuals of Aranea, *Mantis religiosa* L. (Mantodea: Mantidae), Oxyopidae (Araneae), total protocooperative ants (Hymenoptera: Formicidae), Salticidae (Araneae), and *Teudis* sp. (Araneae: Anyphaenidae) were higher on *S. saponaria* plants fertilized with dehydrated sewage sludge. The abundance of *Tetragonisca angustula* Latreille and *Trigona spinipes* Fabr. (Hymenoptera: Apidae) on leaves of this plant was similar between treatments (Table 2). Diptera total and Curculionidae increased the abundance of *M. religiosa*. The highest abundances of chewing insects favored *Teudis* sp. and *Tmarus* sp. (Thomisidae), and that of Diptera increased *Teudis* sp. numbers (Table 3, Figure 1).

4. Discussion

The greater abundance of phytophagous arthropods *Cerotoma* sp., Curculionidae, and Tettigoniidae and defoliation in fertilized plants is due to the greater number of leaves/plant (>BGI), confirming the first hypothesis: >BGI> phytophagous insects (Ferrier and Price, 2004; Leite et al., 2017). Fertilization increases the size of trees and, consequently, the diversity and abundance of phytophagous insects (Ferrier and Price, 2004; Espírito-Santo et al., 2007; Leite et al., 2017) as they function, on a smaller scale, as a biogeographic island, where rare species are less likely to go extinct (Kitahara and Fujii, 1997; Burns, 2016; Leite et al., 2017). The damage by *Cerotoma* sp. and Curculionidae, defoliators, or boring pests of plants such as *Casuarina glauca* Sieber (Casuarinaceae), *Leucaena leucocephala* (Lam.) De Wit (Fabaceae), *Glycine max* (L.) Merrill (Fabaceae) and *Zea mays* L. (Gramineae) (Augustin et al., 2012; Lawal et al., 2014), on *S. saponaria* was low (≈5%, < control level = 20%). Despite the incidence of termites in both treatments, no damage was detected on the plants, similar to that on *Acacia auriculiformis* A. Cunn plants. ex Beth and *Acacia mangium* Willd. (Fabales: Fabaceae), fertilized with sewage sludge, where the increase in the number of leaves per tree favored the increase of *Nasutitermes* sp. (Dourado et al., 2020; Silva et al., 2020; Mota et al., 2021). This was

Table 2. Abundance of spiders and predators and pollinators insects on *Sapindus saponaria* saplings (mean ± SE) with or without dehydrated sewage sludge.

Order: family, species	Dehydrated sewage sludge		Wilcoxon test	
	With	Without	*VT**	*P*
Araneae: Anyphaenidae, *Teudis* sp.	0.13 ± 0.06	0.00 ± 0.00	1.8	0.04
Araneidae, non-identified	1.00 ± 0.36	0.29 ± 0.09	1.6	0.06
Oxyopidae, non-identified	0.46 ± 0.13	0.13 ± 0.06	2.1	0.02
Oxyopes salticus Hentz	0.04 ± 0.04	0.00 ± 0.00	1.0	0.16
Salticidae, non-identified	0.50 ± 0.19	0.04 ± 0.04	2.6	0.01
Uspachus sp.	0.13 ± 0.06	0.04 ± 0.04	1.0	0.15
Aphirape uncifera Tullgren	0.08 ± 0.05	0.04 ± 0.04	0.6	0.28
Sparassidae, *Quemedice* sp.	0.08 ± 0.05	0.04 ± 0.04	0.6	0.28
Tetragnathidae, *Leucauge* sp.	0.50 ± 0.41	0.04 ± 0.04	1.1	0.15
Thomisidae, *Aphantochilus rogersi* O.P.Camb.	0.13 ± 0.06	0.04 ± 0.04	1.0	0.15
Tmarus sp.	0.04 ± 0.04	0.04 ± 0.04	0.0	0.50
Hym.: Apidae, *Tetragonisca angustula* Latreille	0.08 ± 0.08	0.00 ± 0.00	1.0	0.16
Trigona spinipes Fabr.	0.21 ± 0.20	0.00 ± 0.00	1.0	0.16
Formicidae, total ants	24.29 ± 5.97	6.00 ± 2.21	4.1	0.00
Mantodea: Mantidae, *Mantis religiosa* L.	0.38 ± 0.13	0.08 ± 0.05	1.9	0.03

n = 24 per treatment; VT* = value of the test.

attributed to the greater contribution of organic matter in the sewage sludge (Dourado et al., 2020; Silva et al., 2020; Mota et al., 2021) as well as higher litter production per plant (Dourado et al., 2020; Silva et al., 2020). Termites can damage living or dead trees, including root systems and processed wood (Albuquerque et al., 2014). Despite the construction of galleries, in this study, the termites did not damage the trunks or cause the death of plants.

The greater abundance of natural enemies (e.g., spiders) is due to the high number of leaves/plant (> BGI) and, consequently, of their prey following them (Auslander et al., 2003), confirming the second hypothesis: >BGI> predators (Ferrier and Price, 2004; Leite et al., 2017). The BGI theory states that larger islands tend to support greater diversities and abundance of insects due to greater food availability, with a balance between the immigration of new species and the extinction of resident species (Gotelli, 2001; Begon et al., 2007; Silva et al., 2021). This theory has been used in smaller-scale environments, such as treetops (Patiño et al., 2017) on plants of *A. auriculiformis* (Dourado et al., 2020), *A. mangium* (Silva et al., 2020, 2021; Mota et al., 2021), *Caryocar brasiliense* A. St.-Hil. (Malpighiales: Caryocaraceae) (Leite et al., 2017), and *Terminalia argentea* Mart. and Zucc (Combretaceae) (Carvalho et al., 2020). The abundance of spiders (ex.: Aranea and Salticidae) on *S. saponaria* plants fertilized with dehydrated sewage sludge is probably due to the greater number of chewing insects (ex.: > *Tmarus* sp. spider), with the predators following their prey (Silva et al., 2020). Spiders reduced defoliation (r= -0.73; P= 0.003) by beetles, and the number of Lepidoptera mines (r= -0.62; P= 0.01) on *C. brasiliense* (Leite et al., 2012a,b). Spiders sampled on *S. saponaria* plants are obligatory predators, mainly of defoliating insect pests in tropical regions (Landis et al., 2000; Langellotto, 2002; Halaj et al., 2008; Leite et al., 2012b). Spiders can help control pests such as *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae) on *Malus domestica* Bork (Rosaceae) and *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae) on *Citrus sinensis* (L.) Osbeck (Rutaceae) (Amalin et al., 2001; Hogg et al., 2017) preying on them or killing their prey attached to their webs (Sunderland and Samu, 2000). The low density of bees (≈0.3 tree^{-1}), ≈28% of *T. angustula*, in *S. saponaria* plants may be due to the evaluations not including flowers, as this bee pollinates this plant (Fierro et al., 2012). Ants protect trees in agroforestry systems from pests such as chewing insects (e.g., Coleoptera and Lepidoptera) (Fernandes et al., 2005; Gonthier et al., 2013) and, along

Table 3. Simple regression analysis between the numbers of *Mantis religiosa* (Mrel.) with Diptera (Dip.); *Teudis* sp. (Teud.) with total chewing insects (Chew.) and Dip.; *Tmarus* sp. (Tma.) with Chew. on *Sapindus saponaria*/saplings.

Simple regression analysis	R^2	One way ANOVA	
		F	*P*
Mrel.= 0.09 + 0.01 x Dip.	0.17	9.3	0.00
Teud.= 0.01 + 0.004 x Chew.	0.17	9.3	0.00
Teud.= - 0.01 + 0.01 x Dip.	0.18	10.2	0.00
Tma.= - 0.01 + 0.003 x Chew.	0.11	5.4	0.03

ANOVA. n= 48, freedom degrees: treatment = 1, repetitions = 22, and residue = 23.

with other natural enemies, are important in agrosystem balance (Fernandes et al., 2005; Gonthier et al., 2013; Lima Junior et al., 2013). Mutualistic association between ants and plants reduced defoliation and the number of insect mines on leaves of *Acacia mangium* Willd. (Fabales: Fabaceae) and *C. brasiliense* (Leite et al., 2012a,b, 2016; Bertuol et al., 2008). These mutualistic relationships are important since ants protect trees from chewing insects (e.g., Coleoptera and Lepidoptera) and thus reduce damage by herbivory (Gonthier et al., 2013; Silva et al., 2021). *Solenopsis invicta* (Buren) (Hymenoptera: Formicidae) preyed eggs, small larvae, and pupae of *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) on *Gossypium hirsutum* L. (Malvaceae) and *G. max*; and *Pheidole* sp. (Hymenoptera: Formicidae) and *Solenopsis geminata* F. (Hymenoptera: Formicidae) preyed pests on *Oryza sativa* L. (Poaceae) and *Musa paradisiaca* L. (Musaceae) (Ruberson et al., 1994; Eubanks, 2001; Way et al., 2002; Abera-Kalibata et al., 2008). The greater abundance and richness of mutualistic ant species on *A. mangium* plants fertilized with dehydrated sewage sludge corroborates ant response through mutualistic relationships (Pérez-Lachaud and Lachaud, 2014; Chomicki et al., 2015; Sanches, 2015; Silva et al., 2021). The response of ants on trees fertilized with sewage sludge is important because these insects are indicators in degraded or recovering areas due to their mutualistic relationships (Economo et al., 2015; Pérez-Lachaud and Lachaud, 2014; Chomicki et al., 2015; Sanches, 2015; Dourado et al., 2020; Silva et al., 2021).

5. Conclusions

The largest canopy of *S. saponaria* (>BGI) fertilized with dehydrated sewage sludge increased soil cover (e.g., litter) and the abundance of phytophagous insects and their predators on these plants, indicating that it is a promising method to recover degraded areas. The plants fertilized with dehydrated sewage sludge host a high number of chewing insects, pollinators, and predators, due to the greater number of niches and better food quality, improving the ecological indices of the area.

Acknowledgements

To Dr. Antônio Domingos Brescovit (Instituto Butantan, São Paulo, Brazil- Aracnidae) and Dr. Ayr de Moura Bello (Fundação Oswaldo Cruz, Rio de Janeiro, Brazil- Coleoptera) for arthropod species identifications. The voucher number for spiders is IBSP 36921-36924 (Instituto Butantan, São Paulo, Brazil), and that for insects is 1595/02 and 1597/02 (Centro de Estudos Faunísticos e Ambientais, Universidade Federal do Paraná, Curitiba, Paraná, Brazil). To the Brazilian agencies "Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)," Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)," "Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG)," and "Programa Cooperativo sobre Proteção Florestal (PROTEF)" of the "Instituto de Estudos e Pesquisas Florestais (IPEF)" for financial support. This work was supported by the "Conselho Nacional de Desenvolvimento Científico e Tecnológico" (CNPq) [grant number 305057/2018-9] and "Fundação de Amparo à Pesquisa do Estado de Minas Gerais" (FAPEMIG) [grant number PPM-00080-17], Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) [Financing Code 001].

References

ABERA-KALIBATA, A.M., GOLD, C.S. and VAN DRIESHE, R.V., 2008. Experimental evaluation of the impacts of two ant species on banana weevil in Uganda. *Biological Control*, vol. 46, no. 2, pp. 147-157. http://dx.doi.org/10.1016/j.biocontrol.2008.04.017.

ALBUQUERQUE, A.C., MATIAS, G.R.R.S., OLIVEIRA, M.A.P., COUTO, A.A.V.O. and VASCONCELLOS, A., 2014. Urban termites of Recife, Northeast Brazil (Isoptera). *Sociobiology*, vol. 59, no. 1, pp. 183-188. http://dx.doi.org/10.13102/sociobiology.v59i1.675.

ALVARES, C.A., STAPE, J.L., SENTELHAS, P.C., GONÇALVES, J.L.M. and SPAROVEK, G., 2013. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, vol. 22, no. 6, pp. 711-728. http://dx.doi.org/10.1127/0941-2948/2013/0507.

AMALIN, D.M., REISKIND, J., PEÑA, J.E. and MCSORLEY, R., 2001. Predatory behavior of three species of sac spiders attacking citrus leafminer. *The Journal of Arachnology*, vol. 29, no. 1, pp. 72-81. http://dx.doi.org/10.1636/0161-8202(2001)029[0072:PBOTSO]2.0.CO;2.

AUGUSTIN, S., BOONHAM, N., DE KOGEL, W.J., DONNER, P., FACCOLI, M., LEES, D.C., MARINI, L., MORI, N., TOFFOLO, E.P., QUILICI, S., ROQUES, A., YART, A. and BATTISTI, A., 2012. A review of pest surveillance techniques for detecting quarantine pests in Europe. *Bulletin OEPP. EPPO Bulletin. European and Mediterranean Plant Protection Organisation*, vol. 42, no. 3, pp. 515-551. http://dx.doi.org/10.1111/epp.2600.

AUSLANDER, M., NEVO, E. and INBAR, M., 2003. The effects of slope orientation on plant growth, developmental instability, and susceptibility to herbivores. *Journal of Arid Environments*, vol. 55, no. 3, pp. 405-416. http://dx.doi.org/10.1016/S0140-1963(02)00281-1.

BARAH, P. and BONES, A.M., 2015. Multidimensional approaches for studying plant defense against insects: from ecology to omics and synthetic biology. *Journal of Experimental Botany*, vol. 66, no. 2, pp. 479-493. http://dx.doi.org/10.1093/jxb/eru489. PMid:25538257.

BARBIERI JUNIOR, C.A. and DIAS, A.M.P., 2012. Braconidae (Hymenoptera) fauna in native, degraded and restoration areas of the Vale do Paraíba, São Paulo state, Brazil. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 72, no. 2, pp. 305-310. http://dx.doi.org/10.1590/S1519-69842012000200011.

BEGON, M., TOWNSEND, C.R. and HARPER, J.L., 2007. *Ecologia: de indivíduos a ecossistemas*. 4ª ed. Porto Alegre: Artmed, 752 p.

BERTUOL, T.J., GALBIATI, C., PEREIRA, M.J.B. and AMARAL, A.M., 2008. Avaliação de mutualismo entre *Acacia mangium* Willd (Mimosaceae) e formigas (Hymenoptera: formicidae). *Revista Brasileira de Agroecologia*, vol. 3, no. 1, pp. 41-47.

BOWERS, M.D. and STAMP, N.E., 1993. Effects of plant-age, genotype, and herbivory on *Plantago* performance and chemistry. *Ecology*, vol. 74, no. 6, pp. 1778-1791. http://dx.doi.org/10.2307/1939936.

BURNS, K.C., 2016. Native–exotic richness relationships: a biogeographic approach using turnover in island plant populations. *Ecology*, vol. 97, no. 11, pp. 2932-2938. http://dx.doi.org/10.1002/ecy.1579. PMid:27870029.

CALDEIRA, M.V.W., FAVALESSA, M., GONÇALVES, E.O., DEMAELARMELINA, W.M.F., SANTOS, E.V. and VIEIRA, M., 2014.

Lodo de esgoto como componente de substrato para produção de mudas de *Acacia mangium* Wild. *Comunicata Scientiae*, vol. 5, no. 1, pp. 34-43.

CARVALHO, J.C.N., SILVA, F.W.S., LEITE, G.L.D., AZEVEDO, A.M., TEIXEIRA, G.L., SOARES, M.A. and LEGASPI, J.C., 2020. Does fertilization with dehydrated sewage sludge affect *Terminalia argentea* (Combretaceae) and associated arthropods community in a degraded area? *Scientific Reports*, vol. 10, pp. 11811. http://dx.doi.org/10.1038/s41598-020-68747-z. PMid:32678241.

CHOMICKI, G., WARD, P.S. and RENNER, S.S., 2015. Macroevolutionary assembly of ant/plant symbioses: pseudomyrmex ants and their ant-housing plants in the Neotropics. *Proceedings. Biological Sciences*, vol. 282, no. 18-19, pp. 20152200. http://dx.doi.org/10.1098/rspb.2015.2200.

COLEY, P.D. and BARONE, J.A., 1996. Herbivory and plant defenses in tropical forests. *Annual Review of Ecology and Systematics*, vol. 27, no. 1, pp. 305-335. http://dx.doi.org/10.1146/annurev.ecolsys.27.1.305.

DOURADO, L.R., DEMOLIN-LEITE, G.L., SOARES, M.A., TEIXEIRA, G.L., SILVA, F.W.S., SAMPAIO, R.A., ZANUNCIO, J.C. and LEGASPI, J.C., 2020. Ecological indices of phytophagous Hemiptera and their natural enemies on *Acacia auriculiformis* (Fabales: Fabaceae) plants with or without dehydrated sewage sludge application in a degraded area. *PLoS One*, vol. 15, no. 8, e0237261. http://dx.doi.org/10.1371/journal.pone.0237261.

ECONOMO, E.P., KLIMOV, P., SARNAT, E.M., GUENARD, B., WEISER, M.D., LECROQ, B. and KNOWLES, L.L., 2015. Global phylogenetic structure of the hyperdiverse ant genus *Pheidole* reveals the repeated evolution of macroecological patterns. *Proceedings. Biological Sciences*, vol. 282, no. 1798, pp. 20141416. http://dx.doi.org/10.1098/rspb.2014.1416.

EPSKAMP, S., CRAMER, A.O.J., WALDORP, L.J., SCHMITTMANN, V.D. and BORSBOOM, D., 2012. QGRAPH: network visualizations of relationships in psychometric data. *Journal of Statistical Software*, vol. 48, no. 4, pp. 1-18. http://dx.doi.org/10.18637/jss.v048.i04.

ESPÍRITO-SANTO, M.M., NEVES, F.S., ANDRADE-NETO, F.R. and FERNANDES, G.W., 2007. Plant architecture and meristem dynamics as the mechanisms determining the diversity of gall-inducing insects. *Oecologia*, vol. 153, no. 2, pp. 353-364. http://dx.doi.org/10.1007/s00442-007-0737-8. PMid:17453251.

EUBANKS, M.D., 2001. Estimates of the direct and indirect effects of red imported fire ants on biological control in field crops. *Biological Control*, vol. 21, no. 1, pp. 35-43. http://dx.doi.org/10.1006/bcon.2001.0923.

FERNANDES, G.W., GONÇALVES-ALVIM, S.J. and CARNEIRO, M.A.A., 2005. Habitat-driven effects on the diversity of gall-inducing insects in the Brazilian Cerrado. In: A. Raman, C.W. Schaefer and T.M. Withers, eds, *Biology, ecology, and evolution of gall-inducing arthropods*. Washington, DC: Science Publishers, pp. 693-708.

FERRIER, S.M. and PRICE, P.W., 2004. Oviposition preference and larval performance of a rare bud-galling sawfly (Hymenoptera: Tenthredinidae) on willow in Northern Arizona. *Environmental Entomology*, vol. 33, no. 3, pp. 700-708. http://dx.doi.org/10.1603/0046-225X-33.3.700.

FIERRO, M.M., CRUZ-LOPEZ, L., SANCHEZ, D., VILLANUEVA-GUTIERREZ, R. and VANDAME, R., 2012. Effect of biotic factors on the spatial distribution of stingless bees (Hymenoptera: Apidae, Meliponini) in fragmented neotropical habitats. *Neotropical Entomology*, vol. 41, no. 2, pp. 95-104. http://dx.doi.org/10.1007/s13744-011-0009-5. PMid:23950022.

GOEBES, P., BRUELHEIDE, H., HÄRDTLE, W., KRÖBER, W., KÜHN, P., LI, Y., SEITZ, S., OHEIMB, G. and SCHOLTEN, T., 2015. Species-specific effects on through fall kinetic energy in subtropical forest plantations are related to leaf traits and tree architecture. *PLoS One*, vol. 10, no. 6, pp. e0128084. http://dx.doi.org/10.1371/journal.pone.0128084. PMid:26079260.

GONTHIER, D.J., ENNIS, K.K., PHILPOTT, S.M., VANDERMEER, J. and PERFECTO, I., 2013. Ants defend coffee from berry borer colonization. *BioControl*, vol. 58, no. 6, pp. 815-820. http://dx.doi.org/10.1007/s10526-013-9541-z.

GOTELLI, N.J., 2001. *A primer of ecology*. 3rd ed. Massachusetts: Sinauer Associates, 265 p.

HALAJ, J., HALPERN, C.B. and YI, H., 2008. Responses of litter-dwelling spiders and carabid beetles to varying levels and patterns of green-tree retention. *Forest Ecology and Management*, vol. 255, no. 3, pp. 887-900. http://dx.doi.org/10.1016/j.foreco.2007.09.083.

HOGG, B.N., MILLS, N.J. and DAANE, K.M., 2017. Temporal patterns in the abundance and species composition of spiders on host plants of the invasive moth *Epiphyas postvittana* (Lepidoptera: tortricidae). *Environmental Entomology*, vol. 46, no. 3, pp. 502-510. http://dx.doi.org/10.1093/ee/nvx065. PMid:28379400.

JANSSON, J. and EKBOM, B., 2002. The effect of different plant nutrient regimes on the aphid *Macrosiphum euphorbiae* growing on petunia. *Entomologia Experimentalis et Applicata*, vol. 104, no. 1, pp. 109-116. http://dx.doi.org/10.1046/j.1570-7458.2002.00997.x.

KIMBERLEY, M.O., WANG, H., WILKS, P.J., FISHER, C.R. and MAGESAN, G.N., 2004. Economic analysis of growth response from a pine plantation forest applied with biosolids. *Forest Ecology and Management*, vol. 189, no. 1-3, pp. 345-351. http://dx.doi.org/10.1016/j.foreco.2003.09.003.

KISHI, S., SAKURA, N., YOSHIKAWA, T., HIRAIWA, M.K. and KATOH, K., 2017. Interaction between insects and insect-pollinated plants on Myake Island after a recent volcanic eruption: a comparison between vegetation types. *Journal of Asia-Pacific Entomology*, vol. 20, no. 3, pp. 964-970. http://dx.doi.org/10.1016/j.aspen.2017.07.006.

KITAHARA, M. and FUJII, K., 1997. An island biogeographical approach to the analysis of butterfly community patterns in newly designed parks. *Population Ecology*, vol. 39, no. 1, pp. 23-35. http://dx.doi.org/10.1007/BF02765247.

KOMONEN, A., ÖVERMARK, E., HYTÖNEN, J. and HALME, P., 2015. Tree species influences diversity of ground-dwelling insects in afforested fields. *Forest Ecology and Management*, vol. 349, no. 1, pp. 12-19. http://dx.doi.org/10.1016/j.foreco.2015.04.014.

KOPITTKE, P.M. and MENZIES, N.W., 2007. A review of the use of the basic cation saturation ratio and the "ideal" soil. *Soil Science Society of America Journal*, vol. 71, no. 2, pp. 259-265. http://dx.doi.org/10.2136/sssaj2006.0186.

KREBS, C.J., 1989 [viewed 30 June 2016]. *Bray-Curtis Cluster analysis* [online]. Available from: https://biodiversity-pro.software.informer.com/

LANDIS, D., WRATTEN, S.D. and GURR, G.M., 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Review of Entomology*, vol. 45, no. 1, pp. 175-201. http://dx.doi.org/10.1146/annurev.ento.45.1.175. PMid:10761575.

LANGELLOTTO, G.A., 2002. *Aggregation of invertebrate predators in complex-structured habitats: role of altered cannibalism, intraguild predation, prey availability, and microclimate*. College Park, Md: Department of Entomology, University of Maryland, 208 p. Doctoral Dissertation in Philosophy.

LAWAL, O.A., OGUNWANDE, I.A., SALVADOR, A.F., SANNI, A.A. and OPOKU, A.R., 2014. *Pachira glabra* Pasq. essential oil: chemical constituents, antimicrobial and insecticidal activities. *Journal of Oleo Science*, vol. 63, no. 6, pp. 629-635. http://dx.doi.org/10.5650/jos.ess13179. PMid:24881772.

LEITE, G.L.D., PICANÇO, M., ZANUNCIO, J.C., MOREIRA, M.D. and JHAM, G.N., 2011. Hosting capacity of horticultural plants for insect pests in Brazil. *Chilean Journal of Agricultural Research*, vol. 71, no. 3, pp. 383-389. http://dx.doi.org/10.4067/S0718-58392011000300006.

LEITE, G.L.D., VELOSO, R.V., ZANUNCIO, J.C., AZEVEDO, A.M., SILVA, J.L., WILCKEN, C.F. and SOARES, M.A., 2017. Architectural diversity and galling insects on *Caryocar brasiliense* trees. *Scientific Reports*, vol. 7, no. 1, pp. 16677. http://dx.doi.org/10.1038/s41598-017-16954-6. PMid:29192234.

LEITE, G.L.D., VELOSO, R.V.D.S., MARTINS, E.R., ZANUNCIO, J.C., FERNANDES, G.W., ALMEIDA, C.I.M., RAMALHO, F.S. and SERRÃO, J.E., 2012b. Population of herbivores insects on different sides of *Caryocar brasiliense* (Caryocaraceae) trees in the Brazilian Cerrado Region. *Journal of Medicinal Plants Research*, vol. 6, no. 43, pp. 5557-5565. http://dx.doi.org/10.5897/JMPR11.1355.

LEITE, G.L.D., VELOSO, R.V.D.S., ZANUNCIO, J.C., ALMEIDA, C.I.M.E., FERREIRA, P.S.F., FERNANDES, G.W. and SOARES, M.A., 2012a. Habitat Complexity and *Caryocar brasiliense* Herbivores (Insecta: Arachnida: Araneae). *The Florida Entomologist*, vol. 95, no. 4, pp. 819-830. http://dx.doi.org/10.1653/024.095.0402.

LEITE, G.L.D., VELOSO, R.V.D.S., ZANUNCIO, J.C., ALONSO, J., FERREIRA, P.S.F., ALMEIDA, C.I.M. and SERRÃO, J.E., 2016. Diversity of Hemiptera (Arthropoda: Insecta) and their natural enemies on *Caryocar brasiliense* (Malpighiales: Caryocaraceae) trees in the Brazilian Cerrado. *The Florida Entomologist*, vol. 99, no. 2, pp. 239-247. http://dx.doi.org/10.1653/024.099.0213.

LIMA JUNIOR, I.D.S., DEGRANDE, P.E., BERTONCELLO, T.F., MELO, E.P. and SUEKANE, R., 2013. Avaliação quantitativa do impacto do algodão-Bt na população de Araneae, Carabidae e Formicidae predadores ocorrentes sobre o solo. *Bioscience Journal*, vol. 29, no. 1, pp. 32-40. Available from: https://seer.ufu.br/index.php/biosciencejournal/article/ view/13304

LORENZI, H., 2008. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. 5ª ed. Nova Odessa: Instituto Plantarum, 384 p.

MACEDO, M.L.R., DIZ FILHO, E.B.S., FREIRE, M.G.M., OLIVA, M.L.V., SUMIKAWA, J.T., TOYAMA, M.H. and MARANGONI, S., 2011. A trypsin inhibitor from *Sapindus saponaria* L. seeds: purification, characterization, and activity towards pest insect digestive enzyme. *The Protein Journal*, vol. 30, no. 1, pp. 9-19. http://dx.doi.org/10.1007/s10930-010-9296-7. PMid:21127952.

MARTINS, M.N.C., SOUZA, V.V. and SOUZA, T.S., 2016. Genotoxic and mutagenic effects of sewage sludge on higher plants. *Ecotoxicology and Environmental Safety*, vol. 124, pp. 489-496. http://dx.doi.org/10.1016/j.ecoenv.2015.11.031.

MASS, K.D.B., 2010. *Biossólido como substrato na produção de mudas de timburi.* Cuiabá: Universidade Federal de Mato Grosso, 45 p. Dissertação de Mestrado em Ciências Florestais e Ambientais.

MILTON, S.J., DEAN, W.R.J., DU PLESSIS, M.A. and SIEGFRIED, W.R., 1994. A conceptual model of arid rangeland degradation. *Bioscience*, vol. 44, no. 2, pp. 70-76. http://dx.doi.org/10.2307/1312204.

MIZUMACHI, E., MORI, A., OSAWA, N., AKIYAMA, R. and TOKUCHI, N., 2006. Shoot development and extension of *Quercus serrata* saplings in response to insect damage and nutrient conditions. *Annals of Botany*, vol. 98, no. 1, pp. 219-226. http://dx.doi.org/10.1093/aob/mcl091. PMid:16709576.

MOTA, M.V.S., DEMOLIN-LEITE, G.L., GUANABENS, P.F.S., TEIXEIRA, G.L., SOARES, M.A., SILVA, J.L., SAMPAIO, R.A. and ZANUNCIO, J.C., 2021. Chewing insects, pollinators, and predators on *Acacia auriculiformis* A. Cunn. ex Beth (Fabales: Fabaceae) plants fertilized with dehydrated sewage sludge. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 83, e248305. http://dx.doi.org/10.1590/1519-6984.248305. PMid:34669795.

NOGUEIRA, T.A.R., SAMPAIO, R.A., FONSECA, I.M., FERREIRA, C.S., SANTOS, S.E., FERREIRA, L.C., GOMES, E. and FERNANDES, L.A., 2007. Heavy metals and pathogens in maize and cowpea intercropped, fertilized with sewage sludge. *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 11, no. 3, pp. 331-338. http://dx.doi.org/10.1590/S1415-43662007000300014.

NOUVELLON, Y., LACLAU, J.P., EPRON, D., LE MAIRE, G., BONNEFOND, J.M., GONÇALVES, J.L.M. and BOUILLET, J.P., 2012. Production and carbon allocation in monocultures and mixed-species plantations of *Eucalyptus grandis* and *Acacia mangium* in Brazil. *Tree Physiology*, vol. 32, no. 6, pp. 680-695. http://dx.doi.org/10.1093/treephys/tps041. PMid:22588515.

PATIÑO, J., WHITTAKER, R.J., BORGES, P.A.V., FERNÁNDEZ-PALACIOS, J.M., AH-PENG, C., ARAÚJO, M.B. and EMERSON, B.C., 2017. A roadmap for island biology: 50 fundamental questions after 50 years of The Theory of island biogeography. *Journal of Biogeography*, vol. 44, no. 5, pp. 963-983. http://dx.doi.org/10.1111/jbi.12986.

PÉREZ-LACHAUD, G. and LACHAUD, J.P., 2014. Arboreal ant colonies as 'hot-points' of cryptic diversity for Myrmecophiles: the weaver ant *Camponotus* sp. aff. *textor* and its interaction network with associates. *PLoS One*, vol. 9, no. 6, pp. e100155. http://dx.doi.org/10.1371/journal.pone.0100155. PMid:24941047.

R CORE TEAM, 2014 [viewed 30 June 2016]. *R: a language and environment for statistical computing* [online]. Vienna: R Foundation for Statistical Computing. Available from: http://www. R-project.org/

RUBERSON, J.R., HERZOG, G.A., LAMBERT, W.R. and LEWIS, J., 1994. Management of the beet armyworm (Lepidoptera, Noctuidae) in cotton: role of natural enemies. *The Florida Entomologist*, vol. 77, no. 4, pp. 440-453. http://dx.doi.org/10.2307/3495698.

SALOV, G.I., 2014. On the power of a new statistical test and two-sample Wilcoxon test. *Optoelectronics, Instrumentation and Data Processing*, vol. 50, no. 1, pp. 36-48. http://dx.doi.org/10.3103/S8756699014010051.

SANCHES, A., 2015. Fidelity and promiscuity in an ant-plant mutualism: a case study of *Triplaris* and *Pseudomyrmex. PLoS One*, vol. 10, no. 12, pp. e0143535. http://dx.doi.org/10.1371/journal.pone.0143535. PMid:26630384.

SANTANA, P.H.L., FRAZÃO, L.A., SANTOS, L.D.F., FERNANDES, L.A. and SAMPAIO, R.A., 2016. Soil attributes and production of *Eucalyptus* in monoculture and silvopastoral systems in the north of Minas Gerais, Brazil. *Journal of Agricultural Science and Technology B*, vol. 6, no. 1, pp. 361-370. http://dx.doi.org/10.17265/2161-6264/2016.06.001.

SANTOS, M.S., LOUZADA, J.N.C., DIAS, N., ZANETTI, R., DELABIE, J.H.C. and NASCIMENTO, I.C., 2006. Riqueza de formigas (Hymenoptera, Formicidade) da serapilheira em fragmentos de floresta semidecídua da Mata Atlântica na região do Alto do Rio Grande, MG, Brasil. *Iheringia. Série Zoologia*, vol. 96, no. 1, pp. 95-101. http://dx.doi.org/10.1590/S0073-47212006000100017.

SASTAWA, B.M., LAWAN, M. and MAINA, Y.T., 2004. Management of insect pests of soybean: effects of sowing date and intercropping on damage and grain yield in the Nigerian Sudan savanna. *Crop Protection*, vol. 23, no. 2, pp. 155-161. http://dx.doi.org/10.1016/j.cropro.2003.07.007.

SILVA, J.L., LEITE, G.L.D., GUANABENS, R.E.M., AZEVEDO, A.M., FERNANDES, G.W. and ZANUNCIO, J.C., 2021. Fertilization with dehydrated sewage sludge affects the phytophagous Hemiptera, tending ants, and Sternorryncha predators on *Acacia mangium*

(Fabaceae). *Annals of Applied Biology*, vol. 179, no. 3, pp. 345-353. http://dx.doi.org/10.1111/aab.12706.

SILVA, J.L., LEITE, G.L.D., TAVARES, W.S., SILVA, F.W.S., ARRUDA, R.S., AZEVEDO, A.M., SERRÃO, J.E. and ZANUNCIO, J.C., 2020. Diversity of arthropods on *Acacia mangium* (Fabaceae) and production of this plant with dehydrated sewage sludge in a degraded area. *Royal Society Open Science*, vol. 7, no. 2, pp. 191196. http://dx.doi.org/10.1098/rsos.191196. PMid:32257306.

SUNDERLAND, K. and SAMU, F., 2000. Effects of agricultural diversification on the abundance, distribution, and pest control potential of spiders: a review. *Entomologia Experimentalis et Applicata*, vol. 95, no. 1, pp. 1-13. http://dx.doi.org/10.1046/j.1570-7458.2000.00635.x.

TAIZ, L., ZEIGER, E., MOLLER, I.M. and MURPHY, A., 2017. *Fisiologia e desenvolvimento vegetal*. 6ª ed. Porto Alegre: Artmed, 888 p.

TSUZUKI, J.K., SVIDZINSKI, T.I.E., SHINOBU, C.S., SILVA, L.F.A., RODRIGUES-FILHO, E., CORTEZ, D.A.G. and FERREIRA, I.C.P., 2007. Antifungal activity of the extracts and saponins from *Sapindus saponaria* L. *Anais da Academia Brasileira de Ciências*, vol. 79, no. 4, pp. 577-583. http://dx.doi.org/10.1590/S0001-37652007000400002. PMid:18066429.

UNIVERSIDADE FEDERAL DE VIÇOSA – UFV, 2007 [viewed 30 June 2016]. *Sistema para Análises Estatísticas (SAEG) versão 9.1* [online]. Viçosa: Fundação Arthur Bernardes, UFV. Available from: http://arquivo.ufv.br/saeg/

WAY, M.J., JAVIER, G. and HEONG, K.L., 2002. The role of ants, especially the fire ant *Solenopsis geminata* (Hymenoptera: Formicidae), in the biological control of tropical upland rice pests. *Bulletin of Entomological Research*, vol. 92, no. 5, pp. 431-437. http://dx.doi.org/10.1079/BER2002185.

WHISENANT, S., 1999. *Repairing damaged wildlands: a process-orientated, landscape-scale approach: biological conservation, restoration, and sustainability*. Cambridge: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511612565.

WILCOXON, F., 1945. Individual comparisons by ranking methods. *Biometrics Bulletin*, vol. 1, no. 6, pp. 80-83. http://dx.doi.org/10.2307/3001968.