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Driving factors of the communities of phytophagous and predatory mites in a physic nut plantation and spontaneous plants associated

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Abstract Seasonal changes in climate and plant diversity are known to affect the population dynamics of both pests and natural enemies within agroecosystems. In Brazil, spontaneous plants are usually tolerated in small-scale physic nut plantations over the year, which in turn may mediate interactions between pests and natural enemies within this agroecosystem. Here, we aimed to access the influence of seasonal variation of abiotic (temperature, relative humidity and rainfall) and biotic (diversity of spontaneous plants, overall richness and density of mites) factors on the communities of phytophagous and predatory mites found in a physic nut plantation and its associated spontaneous plants. Mite sampling was monthly conducted in dicotyledonous and monocotyledonous leaves of spontaneous plants as well as in physic nut shrubs over an entire year. In the dry season there was a higher abundance of phytophagous mites (Tenuipalpidae, Tarsonemidae and Tetranychidae) on spontaneous plants than on physic nut shrubs, while predatory mites (Phytoseiidae) showed the opposite pattern. The overall density of mites on spontaneous plants increased with relative humidity and diversity of spontaneous plants. Rainfall was the variable that most influenced the density of mites inhabiting physic nut shrubs. Agroecosystems comprising spontaneous plants associated with crops harbour a rich mite community including species of different trophic levels which potentially benefit natural pest control due to increased diversity and abundance of natural enemies.

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Introduction

The physic nut (*Jatropha curcas* L.) shrub is considered a crop adapted to arid, stony and low fertility soils as well as supporting a wide rainfall range (Gubitz et al. 1999; Openshaw 2000; Severino et al. 2006). The diversity of uses of physic nut as well as its adaptation to dry climate regions increases its potential for cultivation, especially in regions where the climate and soil are unfavorable for most crops such as North and Northeast regions of Brazil. Therefore, physic nut has been considered a crop with potential to contribute to the development of those regions in Brazil (Arruda et al. 2004; Severino et al. 2006). However, physic nut suffers from the attack of a complex of pests that may affect yield. Among these pests, mites from the families Tarsonemidae, Tenuipalpidae and Tetranychidae represent the main damaging species, with distinction to the broad mite *Polyphagotarsonemus latus* (Banks) (Acari: Tarsonemidae) and the spider mite *Tetranychus bastosi* Tuttle, Baker & Sales (Acari: Tetranychidae) (Lopes 2009; Sarmento et al. 2011).

In Brazil, the excessive use of pesticides is in part due to the lack of knowledge of factors that regulate populations of pests and natural enemies. This information could, for example, facilitate the prediction of the attack and its magnitude, and reduce the economic damage (Fang 1995). Climatic factors are well known to influence the dynamics of pest and predatory mites in agricultural crops (Teodoro et al. 2008; Pedro Neto et al. 2010). In addition to climatic factors, spontaneous plants associated with crops may favour the occurrence of natural enemies in farming areas, which in turn, help to reduce the population of pests in adjacent crops (Tsitsilas et al. 2011; Cruz et al. 2012). Regarding the natural biological control in Brazilian physic nut fields, predatory mites of the family Phytoseiidae are known to play a key role in keeping pest mite populations in check (Sarmento et al. 2011). However, spontaneous plants can also harbour pests (Duso et al. 2004; Cruz et al. 2012) that could eventually spill over to crop fields. Therefore, studies on the diversity and abundance of phytophagous and predatory arthropods on spontaneous plants are important to determine strategies of biological control, assuming that both groups can naturally migrate to cultivated plants (Tscharntke et al. 2005). Here, we determined the effects of the abiotic factors temperature, relative humidity and rainfall as well as the influence of the biotic factors diversity of spontaneous plants, overall richness and density of mites on the communities of phytophagous and predatory mites on both physic nut and associated spontaneous plants.

Materials and methods

The surveys were carried out in a 4-year old physic nut plantation located around the city of Gurupi, Tocantins State, Brazil (11°48′29″ S, 48°56′39″ W, 280 m altitude). The regional climate is tropical according to Köppen (Brasil 1992), with two well defined seasons: rainy season, with total rainfall from November to April of 964.2 mm and means of relative humidity 80.6 ± 1.1 % (mean ± SE), and dry season, with total rainfall from May to October of 80 mm, mean relative humidity 59.4 ± 3.9 % and an average temperature of 26 ± 0.3 °C during the experimental period (INMET 2011). The native vegetation is a savanna-like vegetation known as Cerrado. No pesticides were applied during the course of our study.

Mite sampling on physic nut shrubs was monthly performed in 30 selected plants in the study area over a whole year. From each plant nine leaves were collected, three from each canopy stratum (bottom third, medium third and top third), located from the fourth to eighth fully expanded leaf from the branches. Spontaneous plants were monthly sampled by the inventory square method during an entire year (Braun-Blanquet and Bolòs 1979; Erasmo et al. 2004). Fifteen sampling points, each consisting of an area of 9 m^2 were installed among the rows of the physic nut plantation. At each sampling point, two iron squares (0.25 m^2) were hurled. Subsequently, plant species were identified and counted within each square. In total, fourteen species of spontaneous plants were found in association with *J. curcas* plants in the studied area: *Alternanthera tenella*, *Bauhinia angulata*, *Calopogonium mucunoides, Senna obtusifolia, Hyptis suaveolens, Helicteres guazumifolia, Peltaea riedelii*, *Sida cordifolia*, *Sida rhombifolia*, *Sida urens*, *Urena lobata*, *Waltheria americana*, *Andropogon gayanus* and *Urochloa mutica* (Cruz et al. 2012). We collected 10 leaves of each dicotyledonous species and 20 of each monocotyledonous because the second had a smaller leaf area than the first. Species richness and abundance were expressed in number of mite species and individuals per m^2 of leaf area for physic nut and spontaneous plants, respectively.

Mites were surveyed on leaves of both physic nut and spontaneous plants with a stereomicroscope (Tecnival SQF-F, Brazil) and the mites found were identified by Drs. Marçal P. Neto and Farid Faraji. Voucher species of mites were deposited in the collection of the Laboratory of Entomology of the Federal University of Tocantins. Species richness and abundance of mites were monthly obtained during an entire year based on adult mites collected.

We used hierarchical partitioning analyses to assess the relative contribution (in percentage of explained variance) of single biotic (diversity of spontaneous plants, overall richness and density of mites in physic nut and in the spontaneous plants) and abiotic (monthly means of temperature, relative humidity and precipitation) factors to mite densities inhabiting both spontaneous plants and physic nut shrubs. Partitioning analyses were conducted with the program R, version 2.3.1 (R Development Core Team 2006; Heikkinen et al. 2004, 2005).

Linear regression analyses were conducted between the density of mites (number of mites per m^2 of leaf area) in physic nut and in the spontaneous plants, with the biotic and abiotic factors. Repeated Measures ANOVAs were performed to compare the abundance of phytophagous and predatory mites on both spontaneous plants and physic nut shrubs throughout time. Data were $(x + 1)^{0.5}$ or log (x + 1) transformed in order to achieve a normal distribution. Linear regressions and Repeated Measures ANOVAs were performed using Statistica 8.0. (StatSoft 2004).

The Shannon-Wiener index (H') for plant diversity, chosen because it is appropriate for random samples of species (Shannon 1948), was calculated using the software Dives, version 2.0. (Rodrigues 2005). Species richness and abundance data used in the analyses mentioned above were expressed in number of mite species and individuals per m^2 of leaf area for physic nut and spontaneous plants, respectively. To obtain equivalence between leaf area, we chose the estimation methods that best fitted to leaf traits of each plant species studied. Thus, to obtain the leaf area of physic nut, we used the estimation method proposed by Severino et al. (2007). To calculate the leaf area of each spontaneous plant studied, leaf discs were made according to the spontaneous plant species and the following formula was used: Leaf area (LA) = (number of leaf discs × DA × LDM)/DDM, where

DA = Disc area; LDM = Leaf dry mass and DDM = Disc dry mass (Lucena et al. 2011), except for *S. rhombifolia* where we used the method proposed by Bianco et al. (2008).

Results

Sixteen phytophagous mite species belonging to the families Tarsonemidae, Tenuipalpidae and Tetranychidae and 24 phytoseiid species were found inhabiting physic nut shrubs and spontaneous plants during both seasons. Although other predatory mite families were found in our study, we decided to consider only phytoseiids as predators as they comprised the vast majority of such mites. Spontaneous plants harboured higher abundances of phytophagous mites in both the rainy and dry season whereas no such clear pattern was found for predatory mites. Overall, the most abundant phytophagous and predatory mite species were the tenuipalpid *Brevipalpus phoenicis* and the phytoseiid *Typhlodromalus clavicus*, respectively (Electronic appendix).

Time variation of phytophagous and predatory mites on physic nut shrubs and spontaneous plants

In the dry season, higher densities of phytophagous mites were found on spontaneous plants, while physic nut shrubs harboured higher densities of predatory mites of the family Phytoseiidae (Fig. 1a, b). On the other hand, in the rainy season higher densities of both phytophagous and predatory mites were found on spontaneous plants when compared to physic nut. Predatory mites of the family Phytoseiidae reached higher population peaks on physic nut shrubs from April to July and from December to January (Fig. 1a). There was no difference in population densities of phytophagous mites (Tetranychidae, Tenuipalpidae and Tarsonemidae) on physic nut and spontaneous plants throughout the year ($P = 0.074$; Fig. 1a, b).

Influence of biotic and abiotic factors on mite communities

The overall density of mites on spontaneous plants across time was mainly explained by spontaneous plant diversity (52.6 %) and relative humidity (21.3 %) (Fig. 2a), while rainfall (50.1 %) and temperature (22.7 %) were the most important factors influencing the overall density of mites on physic nut shrubs (Fig. 2b). The overall density of mites on spontaneous plants increased with relative humidity and with diversity of spontaneous plants (Fig. 3a, b), which are in agreement with partitioning results. The density of phytoseiid mites on spontaneous plants also increased with the diversity of spontaneous plants ($R^2 = 0.82$, $F_{1,10} = 45.696$, $P < 0.001$) highlighting the positive effect of plant diversity on predatory mites. Linear regression analyses showed no relationship between the density of mites found inhabiting physic nut shrubs and rainfall ($R^2 = 0.18$, $F_{1,10} = 2.262$, $P = 0.16$) and temperature ($R^2 = 0.09$, $F_{1,10} = 1.068$, $P = 0.33$) contrasting with partitioning results. There was also no correlation between the density of phytoseiids on physic nut shrubs and relative humidity ($R^2 = 0.06$, $F_{1,10} = 0.688$, $P = 0.43$) and with diversity of spontaneous plants ($R^2 = 0.20$, $F_{1,10} = 2.498$, $P = 0.15$). The density of phytophagous mites on physic nut and spontaneous plants did not correlate with relative humidity ($R^2 = 0.03$, $F_{1,10} = 0.339$, $P = 0.57$ and $R^2 = 0.01$, $F_{1,10} = 0.151$, $P = 0.71$, respectively). Likewise, the diversity index of spontaneous plants did not affect the density of phytophagous mites ($R^2 = 0.04$, $F_{1,10} = 0.412$, $P = 0.54$ for physic nut, and $R^2 = 0.14$,

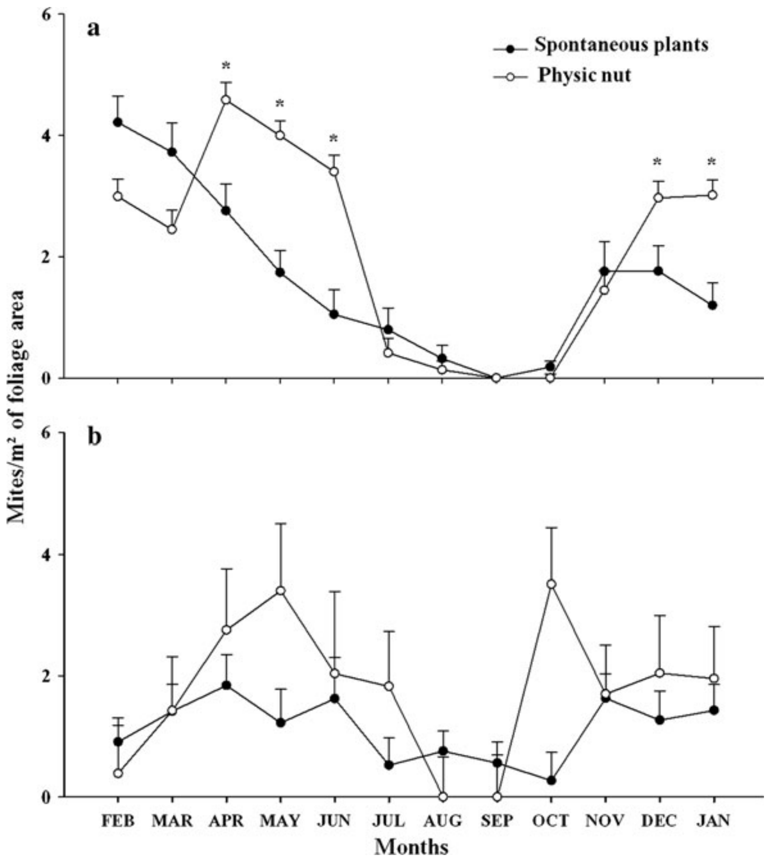

Fig. 1 Population dynamics of **a** phytoseiid ($F_{10,410} = 9.815$, $P < 0.001$) and **b** phytophagous (Tenuipalpidae, Tarsonemidae and Tetranychidae) ($F_{11,198} = 1.7030$, $P = 0.074$) mites on physic nut shrubs and spontaneous plants. *Asterisks* represent statistical significance within each month based on Unequal N tests. *Error bars* represent standard error

$F_{1,10} = 1.689$, $P = 0.22$ for spontaneous plants). Therefore, relative humidity and spontaneous plant diversity, which strongly affected the overall mite population on spontaneous plants, did not influence the community of phytophagous mites on these plants. Similarly, relative humidity and spontaneous plant diversity did not affect predatory and phytophagous mites on physic nut shrubs.

Rainfall affected the density of mites on physic nut (Fig. 2b), but due to the low variance explained, it was not expressed by the regression ($R^2 = 0.18$, $F_{1,10} = 2.262$, $P = 0.16$).

Relationship between spontaneous plants and phytoseiid mites

The diversity of spontaneous plants was positively correlated with species richness ($F_{1,10} = 20.079$, $P = 0.001$, $R^2 = 0.668$), diversity ($F_{1,10} = 10.084$, $P = 0.01$, $R^2 = 0.502$) and abundance ($F_{1,10} = 45.696$, $P < 0.001$, $R^2 = 0.82$) of phytoseiid mites (Fig 4a–c).

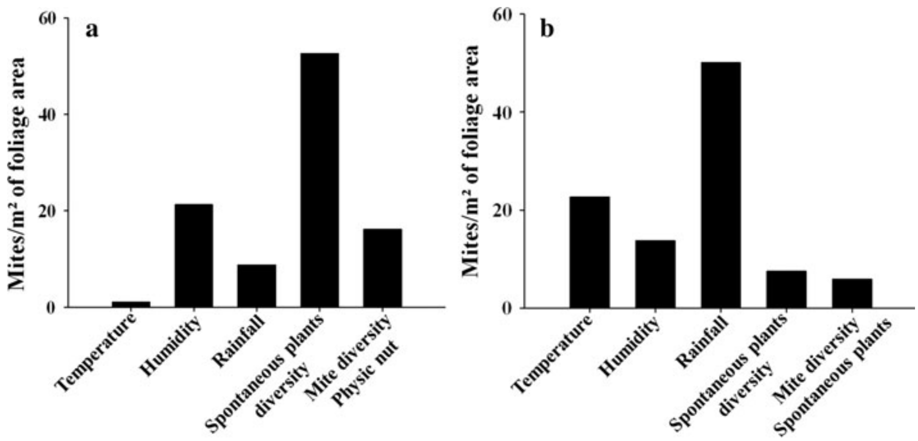

Fig. 2 Percentage of explained variance of biotic and abiotic factors for the density of the mite community inhabiting **a** spontaneous plants and **b** physic nut shrubs. The Shannon-Wiener index was used as a proxy for the diversity of spontaneous plants

Discussion

Our results indicate that the communities of pest and predatory mites inhabiting either spontaneous plants or physic nut shrubs were differently affected by local environmental factors. The density of predatory mites inhabiting spontaneous plants was lower at the beginning of the dry period. These results matched to the decrease of spontaneous plants diversity in the early dry season compared to the rainy season, suggesting that the diversity of plants affect the population of natural enemies, possibly due to food resources reduction (phytophagous mites and/or pollen) (Gardiner et al. 2009). It is well known that the occurrence and abundance of predatory mites of the family Phytoseiidae are generally enhanced by increasing vegetation diversity, since these plants provide alternative food sources and shelter (Addison et al. 2000; Zacarias and Moraes 2002; Demite and Feres 2005). Among the fourteen spontaneous plant species studied here, only five of them persisted in the field during the whole year (*Andropogon gayanus, Bauhinia angulata, Helicteres guazumifolia, Peltaea riedelii* and *Urochloa mutica*). Among which, the plant species *P. riedelii* produces an abundant quantity of pollen over the year that has the potential to be used as food source to supplement the diet of the predators *I. zuluagai* and *E. concordis* in physic nut, mainly when prey is absent or scarce (Marques et al. submitted). These predatory mites were not found in high densities in this study (electronic appendix), but have been considered promising in controlling *P. latus* and *T. bastosi* on physic nut (Sarmento et al. 2011; Cruz et al. 2012; Marques et al. submitted).

Phytophagous mites did not respond to plant type (physic nut or spontaneous plants) over time. However, for the same periods in which the predator population was lower, the lowest density of phytophagous mites was found (August and September), indicating that the seasonality affected both types of mites.

Apart from climatic factors (Hernandes and Feres 2006; Teodoro et al. 2008; Pedro Neto et al. 2010), leaf structures may also determine the abundance of some phytoseiid mites on plants (van Rijn and Tanigoshi 1999; Sudo et al. 2010). However, physic nut shrubs does not have trichomes, domatia or any structure known to be important for maintenance of predatory mites (Kreiter et al. 2002; Sudo et al. 2010). However, this plant

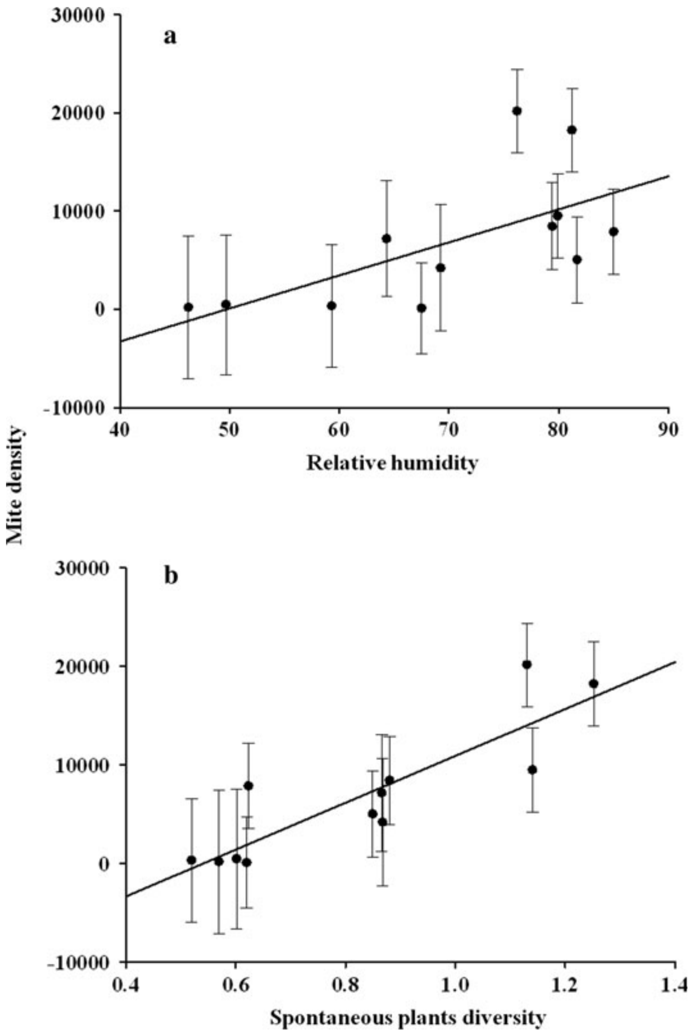

Fig. 3 Relationships between mite density (mite/m^2 of foliage area) on spontaneous plants and **a** relative humidity of air (%) ($y = -16{,}732.90 + 336.45x$, $F_{1,10} = 7.134$, $P = 0.023$, $R^2 = 0.416$); and **b** spontaneous plants diversity (Shannon-Wiener index) ($y = -12{,}841.36 + 23{,}770.98x$, $F_{1,10} = 31.495$, $P < 0.001$, $R^2 = 0.759$). *Error bars* denote standard error

host harbours several species of phytophagous mites and of other feeding habits that can serve as alternative food for predatory mites. For instance, the phytoseiid mites *I. zuluagai* and *E. concordis* are commonly found associated with the tetranychid mite *T. bastosi* in physic nut plantations of the region (Sarmento et al. 2011). This may explain the high density of phytoseiids found on physic nut shrubs during periods of low diversity of spontaneous plants. Additionally, the phytoseiid *T. clavicus* was the most abundant predatory mite found in physic nut in both the dry and rainy seasons. Furthermore, a preliminary trial to maintain a colony of *T. clavicus* in the laboratory offering either *P. latus* or *T. bastosi* as prey was highly successful (unpublished data).

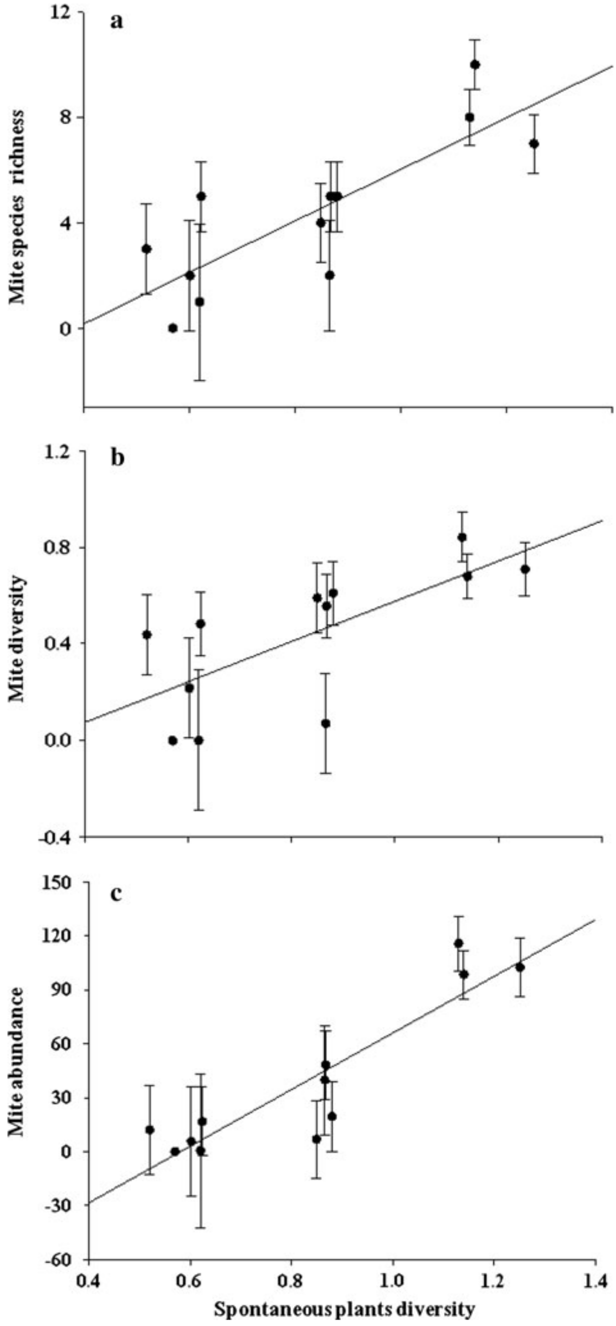

Fig. 4 Relationships between spontaneous plants diversity and **a** mite species richness (number of mite species/m^2 of foliage area); **b** mite diversity (Shannon-Wiener index) and **c** abundance of Phytoseiid mites/m^2 of foliage area found on 14 spontaneous plants species. Mean values ± standard errors are given

Pollen and nectar provided by spontaneous plants are important alternative food sources for predatory mites, especially in times of shortage of phytophagous mites, as well as morphological structures in leaves of spontaneous plants can provide shelter and oviposition site (Bellini et al. 2005). The diversification of agroecosystems promoted by the use of the natural diversity of spontaneous plants favours the abundance of natural enemies, which, in turn, can reduce pest population (Lemos et al. 2011). This factor may explain the similar density of phytophagous mites on physic nut shrubs and on spontaneous plants found here. Physic nut shrubs could benefit from this reservoir of a diverse community of mites by having its own population of pests regulated due to the abundance of predators coming from spontaneous plants (Gravena et al. 1993). Pedro Neto et al. (2010) observed that the variation in the population of mites was negatively affected by rainfall in Brazilian coffee (*Coffea arabica* L.) plantations. This correlation was also observed here, where the overall mite density was lower in months with high rainfall. The local climate is characterized by seasonal fluctuations in precipitation, relative humidity and temperature, which interfered in the population of mites found on both physic nut and its associated spontaneous plants. However, in each type of plant (physic nut or spontaneous), the population dynamics of mites is affected in different ways. In spontaneous plants, the variation in density of mites was mostly influenced by the diversity of these plants. The highest density of predatory mites and the lower values of pest mites in physic nut shrubs in the dry season were determined by a balanced environment for the diversity of the agroecosystem, generated from the association with spontaneous plants (Gravena et al. 1993).

Plant diversity has been shown to influence the biological control of pests by increasing populations of natural enemies (Issacs et al. 2009). Monteiro et al. (2002), for example, found a greater abundance of the predatory mite *Neoseiulus californicus* McGregor (Acari: Phytoseiidae) with the maintenance of spontaneous plants between rows of apple trees. Similarly, Palevsky et al. (2008) found a positive correlation between relative humidity and occurrence of phytoseiid mites.

Agroecosystems comprising spontaneous plants associated with crops harbour a rich mite community which could benefit the natural biological control of pests due to increased diversity and abundance of natural enemies (Andow 1991; Altieri 1999; Letourneau et al. 2011). Additional studies are underway to determine the suitability of pollen of each spontaneous plant species found in association with physic nut plantations to the maintenance of predatory mites and regulation of pest mites in physic nut plantations.

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