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How do different agricultural managements interfere with the Phytoseiidae mite (Acari: Phytoseiidae) community in apple trees?

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Original research

ABSTRACT

In this study we performed the sampling of phytoseiid mites in different apple production orchards, and we evaluated the richness and abundance of these mites, as well as their distribution in the different strata of the plants. Furthermore, we studied how the different apple tree cultivars affect the diversity and distribution of these predatory mites. Collections were carried out in apple orchards in three different production areas: 1- organic agriculture (Antônio Prado, RS); 2- conventional agriculture (Muitos Capões, RS); 3- regenerative agriculture (São Joaquim, SC). In total, seven orchards were evaluated, in Muitos Capões and São Joaquim, two orchards of the Fuji and Gala, whereas in Antônio Prado, three cultivars (Eva, Fuji and Gala) were considered. In each orchard, 40 plants were evaluated, and from each plant a median branch was randomly chosen from which a leaf was removed from the apical, median and basal thirds. The collected leaves were taken to the laboratory, they were observed and the mites found mounted in Hoyer's medium and identified. A total of 695 phytoseiid specimens were collected. Greater abundance was noted in the apical stratum of plants of the Gala cultivar, demonstrating the effect of cultivar and stratum on phytoseiid richness, abundance and distribution. *Neoseiulus californicus* (McGregor) (Phytoseiidae) was the main species in areas of conventional and regenerative cultivation, being present in all evaluated orchards, but with low occurrence in areas of organic management. In organic orchards, species of the genus *Euseius* [*Euseius mesembrinus* (Dean) and *Euseius inouei* (Ehara & Moraes)] (Phytoseiidae) were more abundant. The results suggest that producers consider less intensive use of pesticides and herbicides in orchards in order to maintain populations of predatory mites due to their potential for biological control.

Keywords *Euseius inouei*; *Euseius mesembrinus*; *Malus domestica*; *Neoseiulus californicus*; predatory mite

Introduction

Conventional agriculture is applied in several crops due to being highly productive, but it has substantial negative externalities, including loss of biodiversity, soil erosion, environmental pollution and risk to human health (Gomiero *et al.* 2011; Campbell *et al.* 2017). There is thus an urgent need to change the agricultural production system, aiming to achieve sustainable

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development (Raudonis *et al.* 2007; Walker *et al.* 2017; Zhu *et al.* 2018) and to ensure resource conservation (Willer *et al.* 2021). As an alternative to conventional management, the organic agriculture production has been developed in several countries (Gomiero *et al.* 2011; Smith *et al.* 2012; Caprio *et al.* 2015; Gomiero 2018; Sumberg and Giller 2022). Another alternative is regenerative agriculture: it aims at improving soil protection, not using machinery and maintaining soil covered by plants, spontaneous or not, but, if it is necessary, pesticides can be used to control pests (The soil association 2021).

Pesticide spraying modifies the environment, directly or indirectly affecting the interactions between species along the trophic and non-trophic chain (Dalkvist *et al.* 2009; Guedes *et al.* 2016; Zhao *et al.* 2020). Direct effects include mortality and various sublethal effects, while indirect effects include habitat changes, through contamination of food and shelter, and modification in species communities with associated interaction (Sánchez-Bayo 2021). Disruption of natural control is a key factor in pest outbreaks, where pesticides can reduce populations of predators, parasitoids and pathogenic organisms that naturally occur (Geiger *et al.* 2010; Janssen and Rijn 2021). Furthermore, the relationship between biodiversity and pest control is of great interest for sustainable agricultural production (Letourneau *et al.* 2011; Veres *et al.* 2013; Crowder and Jabbour 2014; Liere *et al.* 2017; Möth *et al.* 2021).

The conventional system prevails in apple production areas (*Malus domestica* Borkh: Rosaceae) in Brazil (Lorenzato and Secchi 1993; Monteiro 1994; Hardmann *et al.* 2003). However, more and more producers are interested in implementing a farming system less dependent on pesticides, especially in the state of Rio Grande do Sul (Kist *et al.* 2015). The Gala and Fuji cultivars are the most used and account for approximately 90% of the national production, while the Eva cultivar, associated with other recent ones, account for about 5% of the production (Fioravanço *et al.* 2010).

Phytophagous mites of the Eriophyidae and Tetranychidae families are considered as important apple pests (Ferla *et al.* 2018; Nascimento *et al.* 2020), particularly *Panonychus ulmi* (Koch) (Tetranychidae), *Tetranychus urticae* Koch (Tetranychidae) and *Aculus schlechtendali* (Nalepa) (Eriophyidae) (Nascimento *et al.* 2020; Kasap and Atlihan 2021). Recently, the quarantine species *A. schlechtendali* was recorded in Southern Brazil (Ferla *et al.* 2018; Nascimento *et al.* 2020). Phytoseiid mites are effective predators of phytophagous mites (McMurtry *et al.* 2013; Demite *et al.* 2014; Knapp *et al.* 2018). In apple growing areas in South America, *Neoseiulus californicus* (McGregor) is the most common species (Croft and McGroarty 1977; Monetti and Fernandez 1996; Khajuria 2009; Toyoshima *et al.* 2011). However, the effect of landscape management on the diversity and distribution of these predatory mites in apple production areas in southern Brazil is unknown.

The knowledge of abundance and diversity of natural enemies in apple plantations is expected to better understand their distribution and dispersion pattern, for the implementation of future pest management actions. We thus performed surveys of phytoseiid mites in different apple production orchards, and we evaluated the richness and abundance of these mites, as well as their distribution in the different strata of the plants. Furthermore, we studied how the different apple tree cultivars affect the diversity and distribution of these predatory mites.

Material and methods

Study areas

The study was conducted in the 2020-21 in apple orchards located in the municipalities of Antônio Prado (28°22'44"S 49°56'12"W) and Muitos Capões (28°23'23"S 51°15'12"W), state of Rio Grande do Sul, and São Joaquim (28°53'23"S 51°23'06"W), state of Santa Catarina (Figure 1).

Antônio Prado: In this locality, three cultivars were considered (Eva, Fuji and Gala). The surface of Eva's orchard was 2 hectares, and that of Fuji and Gala, 1 hectare/area. In all areas, the plantation density was 4 x 1.80 m (rows x trees). Soil was covered, with spontaneous plants

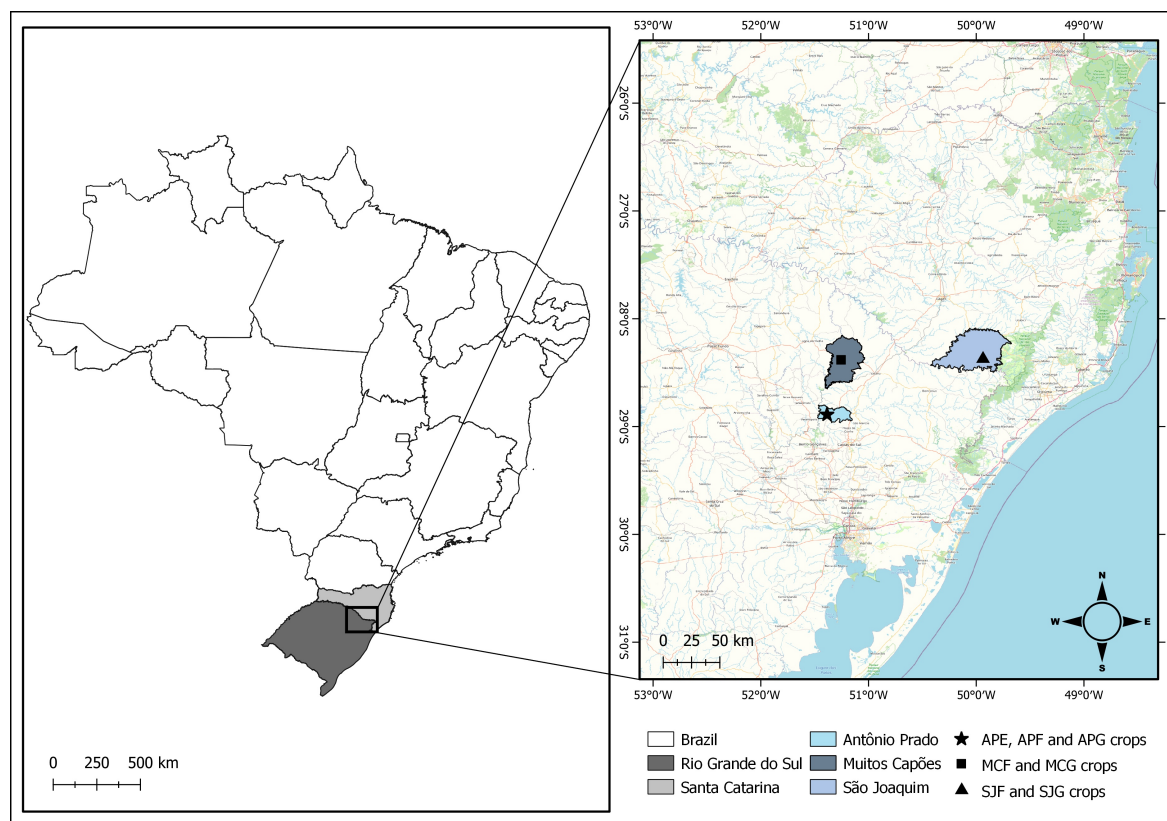


Figure 1 Collection points in apple-producing regions in the municipalities of Antônio Prado (organic management) and Muitos Capões (conventional management), Rio Grande do Sul, and São Joaquim (regenerative management), Santa Catarina, Brazil. Authorship: Castro, I. S.

and grasses, in association with soil litter. In these orchards, the spontaneously growing plants were maintained and when necessary, some were removed weeding. There was no spraying of synthetic pesticides, such as insecticides/acaricides and herbicides, in the sampled areas. However, the producers used Copper sulfate and lime (0,3%) mixed with Bordeaux mixture (0,5%) after the vegetative period, every 15 days, neem oil in the same period every 30 days for pest control, lime sulfur (8%) once in winter and Cera Trap® attractive trap for capturing fruit flies from thinning to harvest. In this way, the orchards of this locality were conducted under organic management.

São Joaquim: Two orchards were evaluated, one planted with the Fuji cultivar and the other planted with the Gala cultivar. The area was 5.5 hectares for each orchard, and the density plantation was 7 x 3 m (rows x trees). In both orchards, the soil was kept covered by weeds, grasses and weeds, in association with soil litter. Pigs, sheeps and chickens were kept grazing throughout the area, feeding on the weeds and fruit of the apple trees that fell. Whenever necessary, producers sprayed pesticides (Bordeaux mixture, Fenitrothion emulsifiable concentrate, Dodina concentrated suspension and Indoxacarb + Fipronil) to pest control. In this way, the orchards of this locality were conducted under regenerative agriculture.

Muitos Capões: Collections were carried out in two conventional orchards, one planted with Fuji and the other with Gala cultivars. The total area of the orchards was 240 hectares each, with a plantation density of 4.2 x 1 m (rows x trees). In both orchards, weeds were destroyed using herbicides (Glifosato, Cletodim concentrated suspension and saflufenacil) and weeding, and spraying of pesticides (Fosmete formulation, Dimetoato emulsifiable concentrate, Fenitrothion emulsifiable concentrate and Clorpirifós emulsifiable concentrate) to control pests was carried out frequently.

Sampling

In all the orchards, the evaluated trees were identified with ribbons. From the fifth row, counting from the edge, we selected 40 trees/orchard, and from each one, a median branch was collected from which three leaves were detached, one from each stratum of the plant: basal, median and apical. Collections were carried out monthly, totaling 120 leaves/orchard/month. In winter, when apple trees lose their leaves, buds from a median branch of each stratum were evaluated, totaling 120 buds/orchard/month and 40 for each stratum/orchard/month. The leaves or buds were individualized in plastic bags, and then packed in styrofoam boxes containing artificial ice (Gelo-x[®]) to keep them at a low temperature.

Climatological information on temperature (°C), relative humidity (%) and precipitation (mm) were obtained from meteorological stations close to the collection points, namely: Antônio Prado, information from the INMET meteorological station, municipality of Bento Gonçalves (A840); Muitos Capões, data from the INMET meteorological station, Vacaria (A880); São Joaquim, information from the Automatic Meteorological Station of Morro da Igreja (A845) (EMAMI).

Mite identification

The collected material was examined with the aid of a stereoscopic microscope (40×) and a fine-tipped brush. Mites removed from each leaf were mounted on slides with Hoyer's medium (Jeppson *et al.* 1975). After mounting, the slides were kept in ovens at 50-60 °C for an average period of 7 days. Identification was performed at the Acarology Laboratory of University of Vale do Taquari - Univates, Lajeado municipality. The Zeiss Axio Scope A1 phase contrast light microscope was used to observe the structures of the specimens (Sisgen: A8302CB). Adult mites were initially separated in families using the key provided by Walter and Krantz (2009). Subsequently, the genera were identified using the world literature about the groups collected (De Leon 1961; Chant and McMurtry 1994; 2007; Ferla *et al.* 2007; Camargo Barbosa and Demite 2023). Whenever possible, identification to species level was done by comparisons with original descriptions and redescrptions.

Statistical analyses

Constancy (C) was calculated according to Silveira-Neto *et al.* (1976), using the formula:

$$C = \frac{(P * 100)}{N}$$

where:

P = number of collections containing the species;

N = total number of collections carried out.

The result was classified as: Constant (Co) (C > 50%), Accessory (A) (25% < C < 50%) and Accidental (I) (C < 25%). Dominance (D) was defined using the formula:

$$D(\%) = \left(\frac{i}{t} \right) * 100$$

where:

i = total number of individuals of a species;

t = total number of individuals collected.

The result was grouped according to the categories established by Friebe (1983): Eudominant (Eu) (> 10%), Dominant (Do) (5% > 10%), Subdominant (S) (2% > 5%), Eventual (Ev) (1% > 2%) and Rare (R) (D < 1%) (Rodrigues 2017).

We observed whether the sampling effort was sufficient to represent all the richness of mites present in the orchards of each management system, where a rarefaction curve of Phytoseiidae species was calculated through interpolation/extrapolation according to the

number of individuals found in the areas. Rarefaction was calculated using the iNEXT package using the endpoint abundance data of 1200 species. The ggiNEXT function of the ggplot2 package was used to construct the rarefaction curve graph, using the R software (R Core Team 2023).

The total number of mite species was estimated from the Chao equation (Chao *et al.* 2014) using the 'specpool' function from the vegan package. We compared Phytoseiidae diversity dynamically using the Hill diversity profile curve (Hill 1973). The diversity of the seven orchards was compared using the Rényi exponential series ($\exp(H\alpha) = \exp[(1/1-\alpha) \ln \sum p_i^\alpha]$). This series includes the main diversity indices, from the most sensitive for rare species (low α value) to those that give greater weight to abundant species (high α values) (Tóthmérész 1995). In this series, $\alpha = 0$ corresponds to the total number of species, $\alpha = 1$ to the Shannon index, $\alpha = 2$ to the Simpson index and $\alpha \rightarrow \infty$ to the Berger-Parker index. To generate these estimates, we used a matrix of mites associated with the studied orchards, the diversity of profile was constructed using the 'renyi' function from the vegan package (Oksanen *et al.* 2018). The analyses were performed in the R software (R Core Team 2023).

We analysed the similarity in Phytoseiidae communities between the orchards. A Euclidean distance matrix was determined and using the factor extra package of the R software (R Core Team 2023) a dendrogram was constructed using the ward. D2 method. The dendrogram was used to separate the clusters according to the similarity of the orchards based on the abundance and diversity of species found in each area and then a cluster graph was constructed using the fviz_cluster function from the factoextra package, where abundance and richness information was plotted on the x and y axes, respectively. A multivariate analysis using the principal components method was performed to determine the main species responsible for the formation of orchard clusters. For this purpose, the FactoMineR (Lê *et al.* 2008) and factoextra (Kassambara and Mundt 2020) packages were used.

Regarding data on Phytoseiidae abundance, we initially compared data from areas that used different agricultural management systems (regardless of cultivar). Thus, Eva data were removed from this analysis, as this cultivar was not found in São Joaquim and Muitos Capões. We evaluated the abundance of Phytoseiidae among different management practices, cultivars, branch stratum and the interaction between these variables. Then, we evaluated the abundance in relation to areas with different cultivars, where the evaluated variables were: cultivars, branch stratum and the interaction of variables.

All abundance data were analyzed using a generalized linear model (GLM with Poisson distribution), and the Tukey test ($P < 0.05$) was used to determine differences between modalities. We used the SAS software (SAS Institute 2002) to perform the statistical analyses. Graphs were constructed using SigmaPlot® 11.0 software (Systat software, Inc.).

We used Phytoseiidae abundance data from the areas of each agricultural production system to analyse the relationship between the abundance of mites and abiotic parameters (monthly average temperature, relative humidity and precipitation). Then the data were subjected to multivariate regression analysis (Stepwise) using the SAS software (SAS Institute 2002). Curves were constructed using SigmaPlot® 11.0 software (Systat software, Inc.).

Results

A total of 695 phytoseiid specimens were collected, belonging to 10 species and seven genera. A greater number of species was found in the orchards of the Antônio Prado (organic management), with eight species collected on Eva, six on Fuji and four on Gala. In these orchards, the species of the genus *Euseius* (*Euseius mesembrinus* (Dean) and *Euseius inouei* (Ehara & Moraes)) were dominant in Eva, while *Metaseiulus eiko* (El-Banhawy) showed greater abundance in Fuji and Gala. A low number of species was observed in the orchards of Muitos Capões (conventional management) and São Joaquim (regenerative management). In São Joaquim, only *N. californicus* was observed on both Fuji and Gala. *Neoseiulus californicus*

was present in all the orchards considered, however, many more individuals were observed in the area of Muitos Capões, both on Fuji and Gala cultivars (Table 1).

The species rarefaction curve in orchards under organic management did not stabilize, indicating that more species might be present if more collections were carried out. However, in orchards using conventional and regenerative management systems, the species rarefaction curve stabilized, showing that sampling in these locations was sufficient to determine the number of species. The curve's confidence interval reveals a difference in the Phytoseiidae richness between the evaluated areas, where the areas with organic management, presented greater richness than the others (Figure 2).

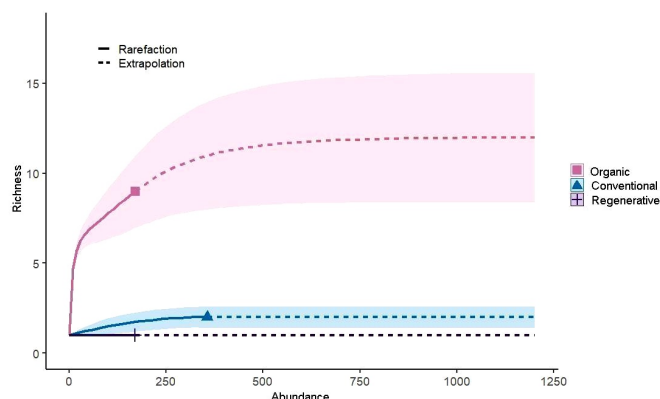


Figure 2 Mite species rarefaction curves: x-axis shows the abundance of Phytoseiidae mites; y-axis shows the richness of Phytoseiidae mites. The solid line indicates the interpolation (before the value) and the strikethrough line indicates the extrapolation (after the value) of the Hill number with order $q = 0$ showing the observed and expected richness in relation to the mean, respectively. The shadow indicates the 95% confidence intervals.

The diversity curves in the area conducted under organic management (Antônio Prado - Eva, Fuji or Gala) do not overlap the curves of the orchards conducted under conventional (Muitos Capões - Fuji or Gala) and regenerative management systems (São Joaquim - Fuji or Gala). However, the curves of the conventional and regenerative management systems overlap when the α value is equal to or greater than 1. Regarding the cultivars, considering only orchards with an organic management system, the cultivar Gala showed less diversity compared to the other apple cultivars. The cultivar Eva showed greater diversity than the cultivar Fuji when the

Table 1 Phytoseiidae associated with apple orchards in the municipalities of Muitos Capões, Antônio Prado, Rio Grande do Sul and São Joaquim, Santa Catarina, Brazil, collected between August 2020 and September 2021.

Species	Antônio Prado									Muitos Capões									São Joaquim									Total
	Eva			Fuji			Gala			Fuji			Gala			Fuji			Gala									
	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D							
<i>Amblyseus chiapensis</i>	1	I	Ev	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1						
<i>Arrenoseius sp.</i>	1	I	Ev	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1						
<i>Euseius mesembrinus</i>	49	Co	Eu	2	I	Eu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	51						
<i>Euseius inouei</i>	37	Co	Eu	1	I	Do	1	I	S	-	-	-	-	-	-	-	-	-	-	-	-	39						
<i>Galendromus annectens</i>	1	I	Ev	-	-	-	9	A	Eu	-	-	-	-	-	-	-	-	-	-	-	-	10						
<i>Metaseiulus eiko</i>	11	A	Do	6	A	Eu	18	A	Eu	-	-	-	-	-	-	-	-	-	-	-	-	35						
<i>Neoseiulus californicus</i>	5	A	S	5	A	Eu	11	A	Eu	161	Co	Eu	193	Co	Eu	63	A	Eu	106	A	Eu	544						
<i>Neoseiulus tunus</i>	10	A	Do	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10						
<i>Neoseiulus fallacis</i>	-	-	-	1	I	Do	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1						
<i>Proprioseiopsis cannaensis</i>	-	-	-	1	I	Do	-	-	-	1	I	Ev	1	I	Ev	-	-	-	-	-	-	3						
Total	115			16			39			162			194			63			106			695						
%	16.55			2.30			5.61			23.31			27.91			9.06			15.25									
Richness	8			6			4			2			2			1			1									

T = Total of mites; C = Constancy; D = Dominance; Co = Constant; A = Accessory; I = Accidental; Eu = Eudominant; Do = Dominant; S = Subdominant; Ev = Eventual; R = Rare

α value was low, indicating greater diversity for species considered rare, while the cultivar Fuji showed greater diversity as the α value increased, indicating greater diversity in relation to taxa (Figure 3).

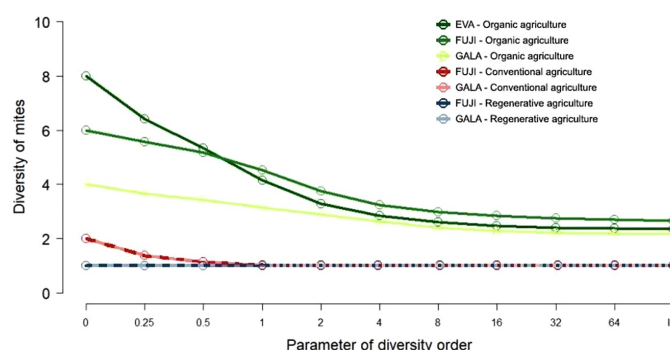


Figure 3 Hill number diversity profile. The x-axis shows the change in diversity indices over the Hill numbers; the y-axis displays the diversity level for measures on the x-axis. The left side of the x-axis is more sensitive to rare species, while the right side is more sensitive to the abundance of mite taxa. This continuum of values allows inferring the contributions of rare versus abundant species in a community. Some diversity indices on the x-axis can be inferred: 0 species richness; 1, Shannon-Wiener index; 2, Simpson index; inf, index Berger Parker.

The similarity analysis revealed differences both between different areas and different cultivars. The dendrogram and the cluster analyses (Figure 4A, B) show that the cultivar Eva is well separated from the other orchards, regardless of the management used. The orchards conducted under organic management (Fuji and Gala) formed a second cluster, distinct from orchards conducted under conventional and regenerative management and using the same cultivars (Figure 4A). Regarding the organic systems, the cultivar Eva is well separated from the other varieties, due to greater Phytoseiidae abundance and richness (Figure 4B).

The total variance explained by the two main axes was 80.7% (axes 1 and 2 explaining 56.3% 24.4%, respectively) (Figure 5). Orchards with conventional (Muitos Capões) and regenerative management (São Joaquim), which use pesticides, were grouped, related to *N. californicus*, and *Proprioseiopsis cannaensis* (Muma). The organic cultivation (Antônio Prado) areas were grouped into two clusters, one being Fuji and Gala, and the other Eva. These areas were related to the greatest diversity of species, being *Arrenoseius* sp., *A. chiapensis*, *E. inouei*, *E. mesembrinus* and *Neoseiulus tunus* (De Leon), the main species related to the Eva organic orchard, and *M. eiko* and *Galendromus annectens* (De Leon) with the Fuji and Gala organic orchards (Figure 5; Figure S1).

Significant differences in abundance of Phytoseiidae were observed when comparing the three types of management (Figure 6A; GLM: $F_{2,702} = 74.92$, $P < 0.001$). The highest abundance was observed in orchards with conventional management (Figure 6A). The lowest abundance was observed at the apical leaf level. However, there was no difference in the Phytoseiidae number between the median and basal levels (Figure 6A; GLM: $F_{2,702} = 13.05$, $P < 0.0001$). The cultivar Gala showed greater abundance than the cultivar Fuji (Figure 6B; GLM: $F_{1,702} = 10.40$, $P = 0.0013$). The variables management and stratum of the branch interacted (Figure 6C; GLM: $F_{4,702} = 3.76$, $P = 0.0049$), where greater abundance was observed in the apical, median and basal regions of the conventional management area. No difference was observed in the apical stratum of apple trees under organic and regenerative management, however, for the median and basal strata, the abundance differs between areas (Figure 6C).

Within the orchards of organic cultivation, a higher Phytoseiidae number was observed on the cultivar Eva, while no difference was observed between Fuji and Gala varieties (Figure 7A; GLM: $F_{2,350} = 29.60$, $P < 0.0001$). In these same orchards, we observed a higher mite abundance at the median and basal levels than at apical one (Figure 7A; GLM: $F_{2,350} = 8.25$,

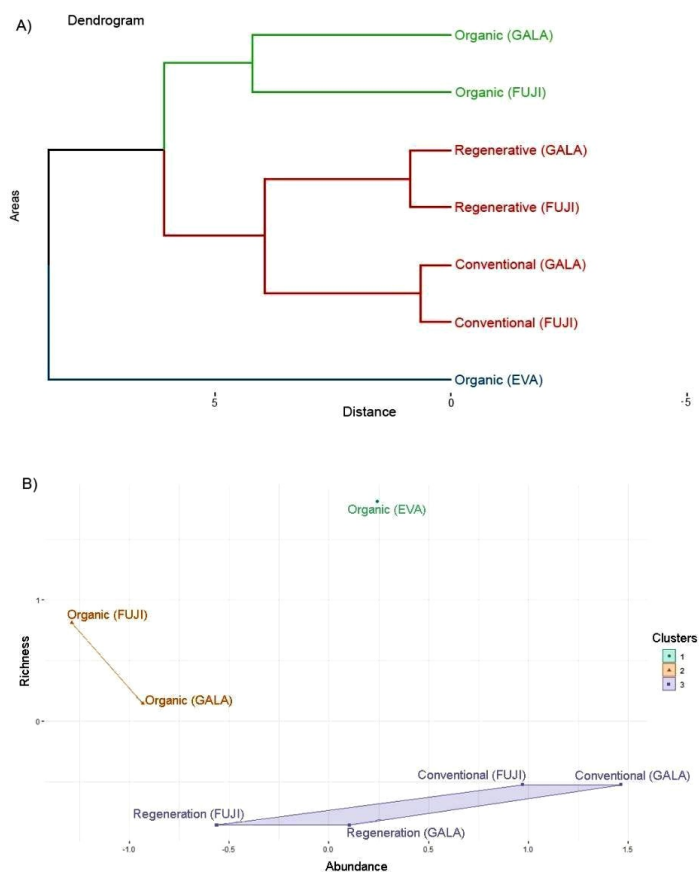


Figure 4 Similarity between areas with different agricultural management systems, considering the number and diversity of species. **A** – Dendrogram; **B** – Cluster Graph.

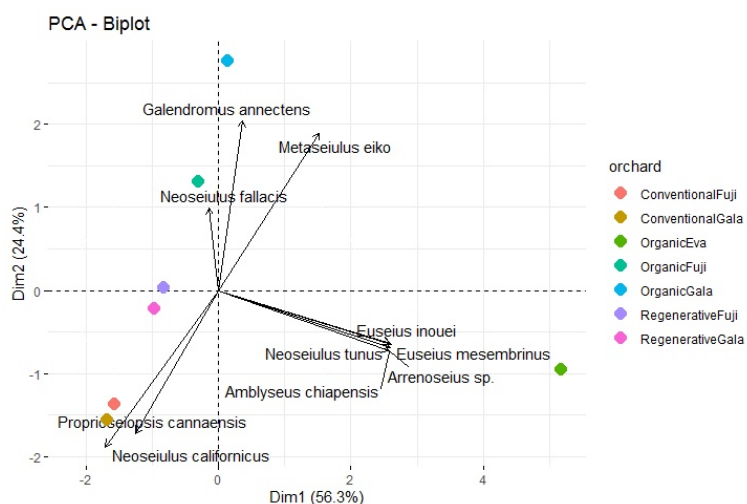


Figure 5 Biplot with the projection of variations in the factorial plane to determine the main species responsible for the variations between the orchards evaluated.

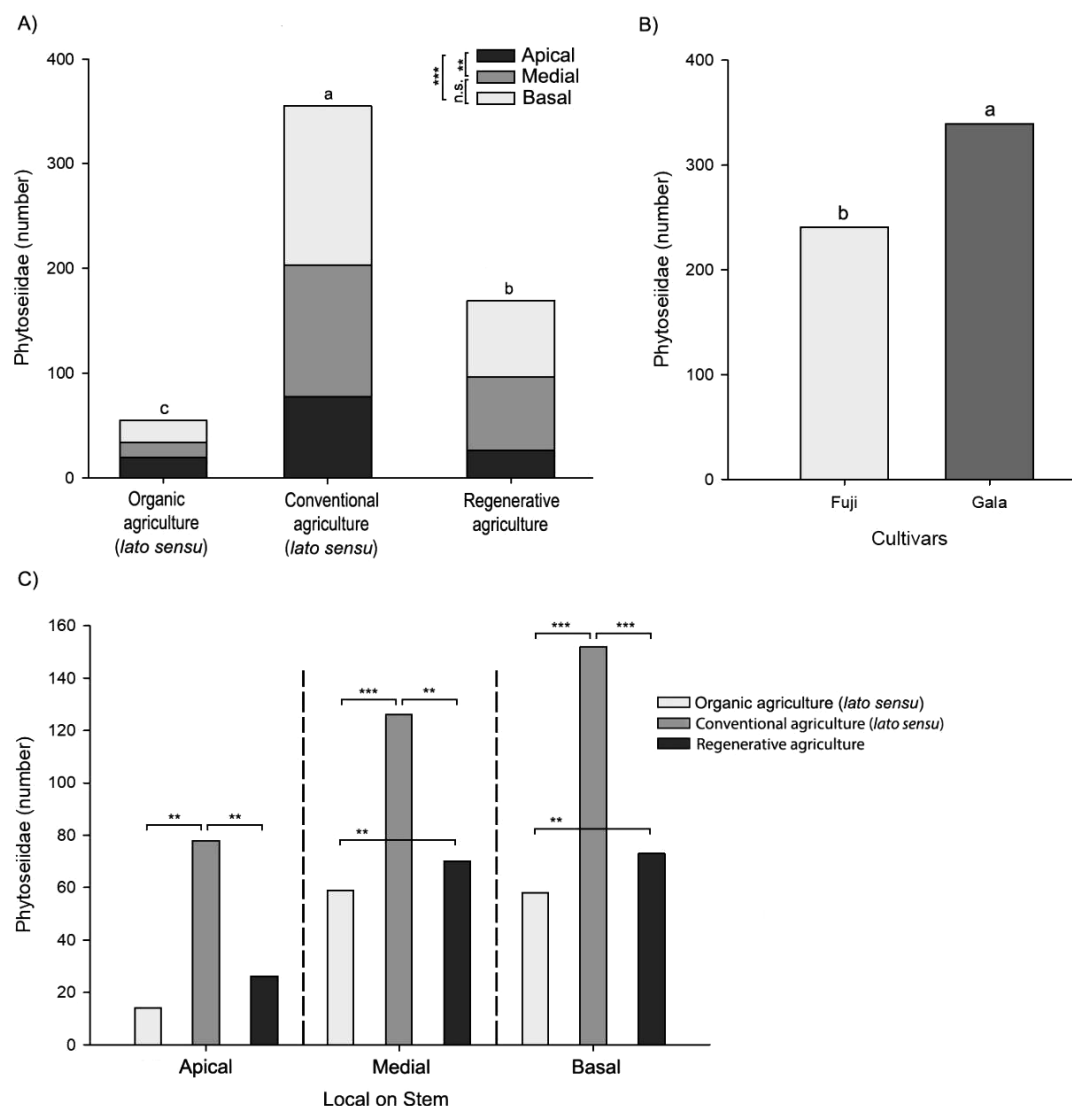


Figure 6 Abundance of Phytoseiidae in apple tree production areas with organic, conventional and regenerative management. **A** – number of Phytoseiidae in different areas and in different strata of the apple tree branch; **B** – number of Phytoseiidae in different apple tree cultivars; **C** – number of Phytoseiidae in relation to the interaction between different areas and leaf location on the branch. (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$).

$P = 0.0003$), whereas no difference in relation to the stratum of the branch was noted for the Fuji and Gala cultivars (Figure 7B; GLM: $F_{2,117} = 12.01$, $P < 0.0001$). Within orchards under conventional management, the density Phytoseiidae was not significantly different between the varieties Fuji and Gala, but their abundance was lower at the apical level than on basal part, median level showing intermediate densities (Figure 7C; GLM: $F_{2,234} = 7.66$, $P = 0.0006$). Within orchards under regenerative management, the abundance of Phytoseiidae was significantly different between the Fuji and Gala varieties (Figure 7E; GLM: $F_{1,233} = 6.22$, $P = 0.0133$). The density was significantly lower at the apical level than at basal and median ones (Figure 7F; GLM: $F_{2,233} = 6.76$, $P = 0.0014$).

The annual average precipitation, temperature and relative humidity in Antônio Prado were 102.075 mm, 17.64 °C and 74.40%; in Muitos Capões 118.975 mm, 15.41 °C and 80.43% and in São Joaquim 116.56 mm, 13.75 °C and 79.33%, respectively (EMBRAPA 2021). The stepwise analysis showed that the relative humidity variable affected the dynamics of the

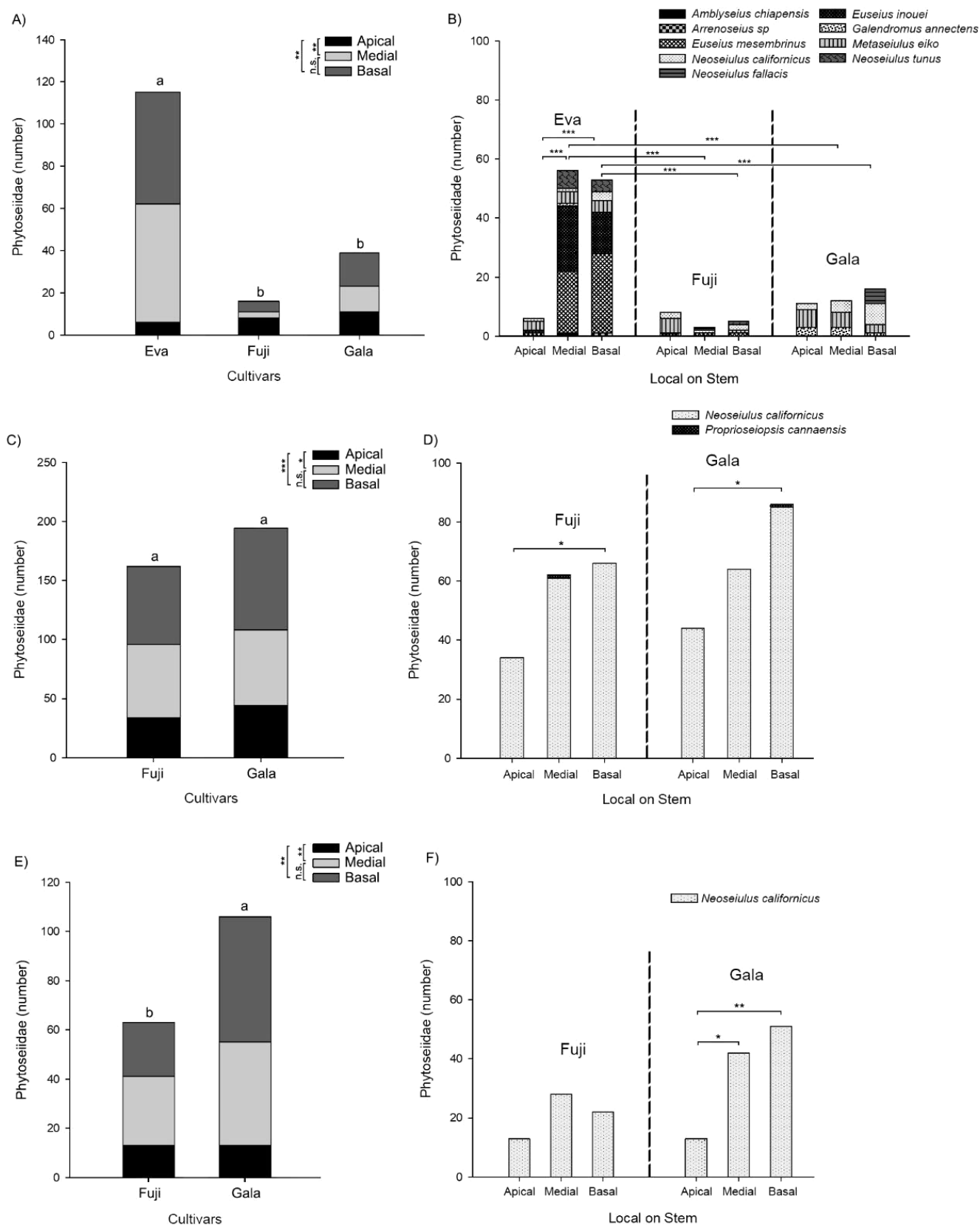


Figure 7 Phytoseiidae abundance in apple production areas **A** – Phytoseiidae abundance among cultivars in the organic management area; **B** – abundance of Phytoseiidae between the variety-leaf stratum interaction in the organic management area; **C** – abundance of Phytoseiidae among the cultivars in the conventional management area; **D** – abundance of Phytoseiidae among the leaf strata in the conventional management area; **E** – abundance of Phytoseiidae among cultivars in the regenerative management area; **F** – abundance of Phytoseiidae among the leaf strata in the regenerative management area. (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$).

Phytoseiidae population in the area with conventional management ($F_{3,8} = 4.39$; $P = 0.0419$). This variable explained 37.21% ($R^2 = 0.3721$) of the variation in abundance. In the area of organic and regenerative management, climatic variables did not interfere with the abundance of these predatory mites ($F_{3,8} = 2.85$; $P = 0.1051$; $F_{3,8} = 1.37$; $P = 0.3197$), respectively (Figure 8).

Discussion

In this study we performed the sampling of phytoseiid mites in different apple production orchards, and we evaluated the richness and abundance of these mites, as well as their distribution in the different strata of the plants. Furthermore, we studied how the different apple tree cultivars affect the diversity and distribution of these predatory mites. We observed that the diversity of Phytoseiidae mites was higher in apple orchards from the municipality of Antônio Prado (organic management) than from the municipalities of Muitos Capões (conventional management) and São Joaquim (regenerative management). Furthermore, the apple tree cultivar also had an important effect on the richness, abundance and distribution of these predatory mites. *Neoseiulus californicus* was found in all orchards, but with low occurrence in Antônio Prado orchards. In all areas, we did not observe such a significant effect of the abiotic variables of temperature, relative humidity and precipitation on the density of phytoseiid mites throughout the year. There was only a small effect of relative humidity in the conventional management area.

In this study, the apical stratum presented a lower density of predatory mites, being able to indicate that the median and basal regions of the branch could have greater availability of phytophagous mites or some alternative food, such as pollen (Monteiro 1994; Pascua *et al.* 2020). Furthermore, the apical region may be affected by solar incidence, which causes an increase in temperature on the leaf surface, influencing mite populations. Therefore, the mites could be looking for leaves in the middle and basal regions to settle, where the temperature and humidity would be ideal for their survival (Coombs and Bale 2013).

According to Maeyer *et al.* (1993), less intensive agricultural management allows for greater conservation of the diversity of natural enemies. Pesticide spraying is one of the main factors responsible for reducing arthropod diversity, especially natural enemies (Kropczynska and Tuovinen 1988; Meyer *et al.* 2009), while spontaneous vegetation allows the conservation of the diversity of these biological control agents in agricultural production areas (Altieri 1999, 2002). These plants can provide shelter and food for predatory mites, even in periods with unfavourable abiotic conditions or when prey is scarce (Landis *et al.* 2000; Tixier *et al.* 2000; Demite and Feres 2005). Even if spontaneous plants were present in the inter-rows of the regenerative management systems (São Joaquim), this area did not show greater diversity than the conventional management area (Muitos Capões) (where spontaneous plants were removed). As in both areas, pesticides were used (conventional area more frequently than the regenerative area), it could be assumed that the low Phytoseiidae in these orchards compared to the orchards under organic management (Antônio Prado) is related to the use of pesticides. However, the abundance of Phytoseiidae mites was higher in the conventional orchards than in the others. This result was due to the large number of individuals of *N. californicus*, a species that occasionally uses pollen as food (Pascua *et al.* 2020). The ability of a predatory mite to feed on alternative diets, particularly pollen, may limit the sublethal effects of pesticides (Pozzebon *et al.* 2014). However, the most probable hypothesis is that *N. californicus* might be resistant to pesticides, as already mentioned in other studies (Moraes *et al.* 2004; Meyer *et al.* 2009; Van Lenteren 2012; Yorulmaz-Salman and Ay 2013; Tixier *et al.* 2013, 2018; Ghazy *et al.* 2016; Knapp *et al.* 2018; Inak and Yorulmaz-Salman 2022).

The multivariate analysis grouped the orchards that use pesticides (Muitos Capões and São Joaquim) into one cluster and the organic cultivation areas (Antônio Prado) into two other clusters, one being Fuji and Gala, and the other with Eva. These groupings demonstrated the

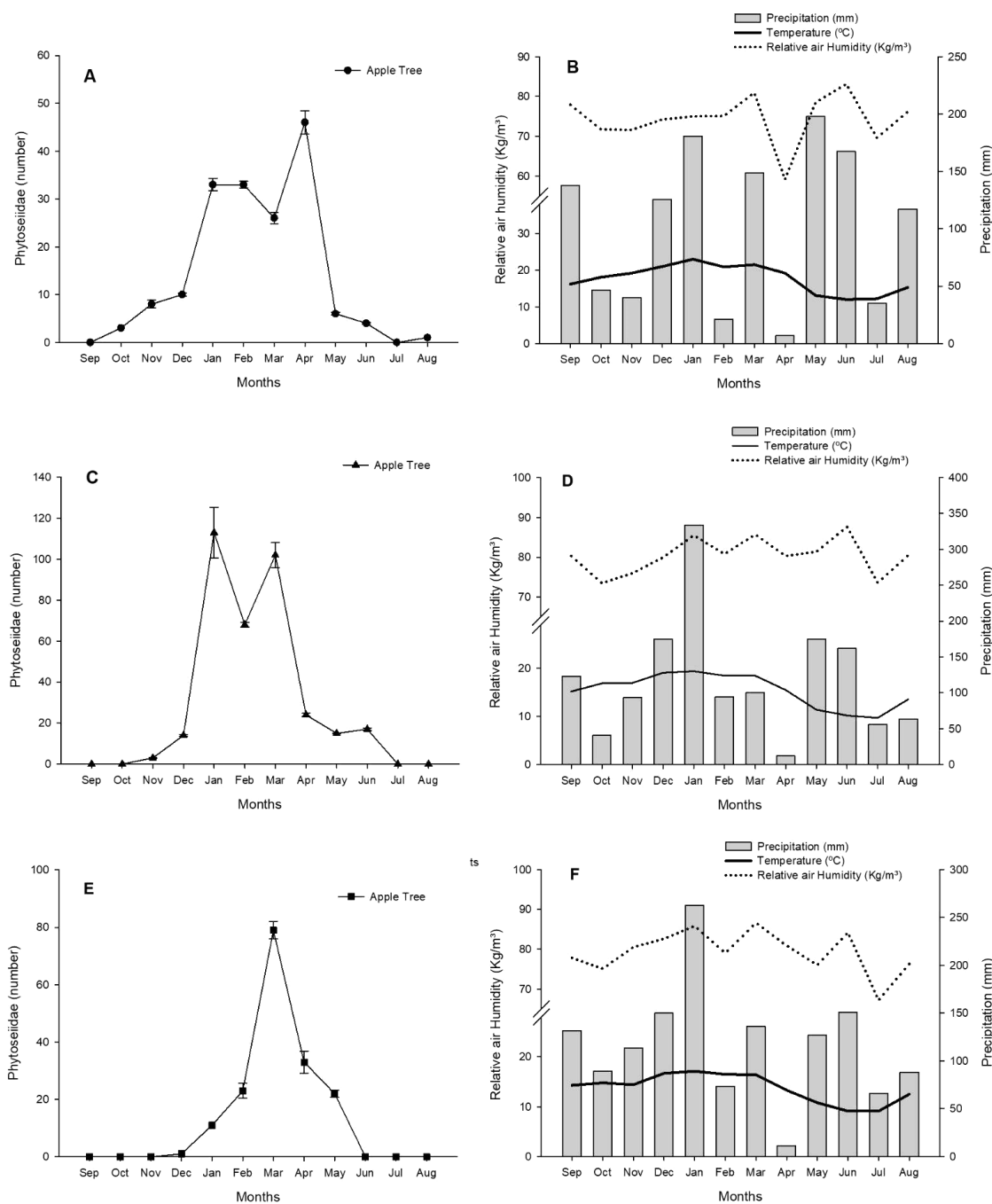


Figure 8 Phytoseiidae mite population dynamics and monthly averages of abiotic variables (temperature, precipitation and relative humidity) from September 2020 to August 2021. **A** – Phytoseiidae mite population dynamics in the organic management area (Antônio Prado); **B** – monthly averages of the abiotic variables in the organic management areas; **C** – Phytoseiidae mite population dynamics in the conventional management area (Muitos Capões); **D** – abiotic variables in areas under conventional management; **E** – Phytoseiidae mite population dynamics in the regenerative management area (São Joaquim); **F** – abiotic variables in regenerative management area.

different composition of acarine species in these areas, with *N. californicus*, one of the main species present in orchards that use pesticides. Even if densities of *N. californicus* were higher

in areas using pesticides, this species was also observed in all orchards evaluated in this study. In areas where these products were not used, the number of individuals of *N. californicus* was lower than in areas that use pesticides. A possible explanation is that without interference from pesticides, *N. californicus* is not able to thrive due to greater interaction with other predators. A study of lethal and non-lethal intraguild interactions between *Euseius stipulatus* (Athias-Henriot) and *N. californicus* showed that the first species negatively affected the population of the second, while the abundance of *E. stipulatus* was not affected by the introduction of a second predator (Abad-Moyano *et al.* 2010). A more in-depth study on the impact of *N. californicus* dominance is necessary, following pest populations in a long-term effect in areas with pesticide use, as well as studying the intraguild interaction between predators in areas without use of these chemicals.

In the organic management areas (Antônio Prado), we observed differences between the composition of the Phytoseiidae mite community between the different cultivars, where Eva had the highest number of species. Furthermore, Phytoseiidae abundance differs between Fuji and Gala cultivars. The plant architecture can affect mites in several ways: (i) species interactions (increase or reducing predation, cannibalism or competition) and (ii) pollen quantity (Kreiter *et al.* 2002; Schmidt 2014). The three cultivars considered have different leaf hairiness, which can have affected the density of Phytoseiidae mites.

Considering only the cultivar Eva, we observed that *E. mesembrinus* and *E. inouei* were constant and eudominant. Some species use fungal spores or pollen as a food source, in the absence of the prey mites (Gambaro 1998; Croft *et al.* 2004). This is the case of predatory mites of the genus *Euseius*, classified as generalist types IV, meaning that these predators develop well when feeding on pollen (McMurtry *et al.* 2013). The structural complexity of the leaf favors populations of Phytoseiidae type IV, by increasing pollen retention (Kreiter *et al.* 2002) on the surface, providing an alternative source of food in times of scarcity of prey (Schmidt 2014). There is a positive correlation between pollen retention and trichome density (Kreiter *et al.* 2002). However, it is necessary to carry out controlled studies to more accurately assess the effects of these structures on the behavior of these predators in apple plants.

This study shows the importance of producers considering the less intensive use of pesticides and herbicides in orchards in order to maintain populations of predatory mites due to their potential as agents acting in ecological services. Furthermore, the results suggest that the native fauna is able to maintain *A. schlechtendali* populations at acceptable levels for the cultivars studied.

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Author's contribution

PAR, MS and GLB with the sample collections, sample sorting on plants, slide mounting and identification; GLB and MS with morphological analysis; PAR with the analysis and concept of the manuscript; NJF with revisions.

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