UNIVERSIDADE FEDERAL DE LAVRAS

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TEMPORAL POPULATION DYNAMICS OF THRIPIDAE AND APHIDIDAE IN COTTON AND NEIGHBOUR-CROPS

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Dissertação apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Entomologia, área de concentração Entomologia, para a obtenção do título de Mestre.

Prof. Dr. Luís Cláudio Paterno Silveira
Orientador

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ISADORA GOMES PERES DE SOUZA

TEMPORAL POPULATION DYNAMICS OF THRIPIDAE AND APHIDIDAE IN COTTON AND NEIGHBOUR-CROPS

DINÂMICA DE POPULAÇÃO DE THRIPS E APHIDIDAE EM ALGODÃO E CULTURAS VIZINHAS

Dissertação apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Entomologia, área de concentração Entomologia, para a obtenção do título de Mestre.

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We are driven by creativity and curiosity to push the frontiers of the knowledge.

(Autor desconhecido)

GENERAL ABSTRACT

Recently, the main challenge to increase cotton productivity worldwide is the plant susceptibility to pest attack. Studies into pest population dynamics are required to understand the complexity involving pest population fluctuation, and occasionally proliferation. Investigation into the interaction among pest population and abiotic and biotic factors such as temperature, precipitation, insecticide spraying, and other insect populations are still lacking, investigations that could provide information to lead a new path on pest management control. Therefore, in this study changing aspects on pests populations among cotton and neighbouring crops and their interaction with predicative variables was investigated. Considering cotton pest control based on the use of chemical products has shown several limitations. There is a need for better understanding on how the interactions among pest population, landscape complexity, agriculture management techniques, and climatic variables may affect pest dynamics in cotton crops.

Keywords: Conservation biological control. Cotton pests. Maize. Bean. Soybean. Predicative variables. Landscape management.

RESUMO GERAL

Mundialmente, o principal desafio para aumentar a produtividade de algodoeiro é a susceptibilidade da planta ao ataque de pragas. Estudos com ênfase em dinâmica populacional se fazem necessários para entender a complexidade envolvida na flutuação populacional e ocasionalmente na proliferação. Pesquisas sobre a interação de pragas, com fatores abióticos e bióticos, tais como, temperatura, precipitação, aplicação de inseticidas e a influência de outras populações de insetos ainda são uma lacuna. Essas informações poderiam subsidiar um novo direcionamento para o manejo de pragas em algodão. Desta maneira, neste trabalho foi avaliado as mudanças em populações de pragas em algodoeiro e culturas vizinhas e a interação com variáveis preditoras. Considerando as limitações do uso de produtos químicos no controle de pragas do algodoeiro, se faz necessário uma compreensão melhor da interação entre as populações de pragas, a complexidade do habitat, técnicas de manejo e as variações climáticas que podem afetar a dinâmica de insetos.

Palavras-chave: Controle biológico conservativo. Pragas de algodoeiro. Milho. Feijão. Soja. Variáveis preditoras. Manejo do habitat.

SUMÁRIO

FIRST PART

1 GENERAL INTRODUCTION

Cotton (*Gossypium* spp.) is member of the Malvaceae family, Malvoideae subfamily and Gossypieae tribe, which has nine genera (SEELANAN et al., 1997). Genus *Gossypium* spp. is native to tropical and subtropical regions, it is the genus of most economic importance, and has approximately 50 species described. The species *G. hisurtum*, *G. barbadense*, *G. arboreum* and *G. herbaceum* are commonly grown worldwide (FRYXELL, 1992).

The fiber is the main product of from the cotton plant, the result of its high commercial value which varies according to fiber quality. The global cotton fiber production is represented by 90% *G. hisurtum* and 5% *G. barbadense* (ZHANG et al., 2008). In Brazil, the species *Gossypium hirsutum* contributes with 90% of the fiber production, and has social and economic importance (PENNA, 2005).

Brazil fills the first position in productivity of non-irrigated cotton. The 2018 season reached a production of 4,785,086 tons, and the country is among the largest global exporters (ABRAPA, 2018; CONAB, 2018). In addition, Brazil is among the five biggest producers of cotton seed and fiber, besides China, India, EUA and Pakistan (ABRAPA, 2018). The cotton area planted was 1.146.063 ha in 2018, increasing more than 200,000 ha compared with 2017, which was 928,617 ha. Principal producer regions are the Midwest and Northeast, with the largest areas planted and under production in Bahia and Mato Grosso states (IBGE, 2018).

Minas Gerais is the biggest producer of cotton in the Southeast region, increasing 10 thousand tons (Season 2017/2018) of cotton lint production in the last 10 years. Furthermore, Minas Gerais has the same relation of lint productivity as Bahia and Mato Grosso states, 40 Kg/ha profitability (CONAB, 2018). The internal scenario is promising since Brazil is among the highest consumers of cotton lint (ABRAPA, 2018).

Cotton is a relevant challenge model to increase productivity and reduce impacts caused by pests (DEGUINE et al., 2008). In all cotton producing countries, pests and diseases are considered main factors contributing to reduce production (WU; GUO, 2005). In Brazil, around 50% of the cost of production is destined to phytosanitary control (RICHETTI et al., 2005).

The insect fauna associated with cotton cultivation is estimated to exceed 250 insect species in Brazil (DEGRANDE, 2008). These include species capable of attacking all plant organs (roots, leaves, stems, flower buds, squares, flowers, and bolls), representing a permanent risk during the crop cycle (SANTOS, 2007).

The advances in cotton management, as with the utilization of Bt GMO, started an alternative to insecticides spraying (BROKES; BARFOOT, 2018). However, any modification in production practices or insect management approaches may impact the abundance and diversity of insects in an agronomic cropping system. In this sense, since the introduction of new technologies, secondary pests such as aphids and thrips, became key pests in several producing regions (AZIMI et al., 2012). In additionally, growers often resort to repeated uses of several groups of insecticides to control sucking pests, stimulating insecticides resistance cases (BERNDT; POEHLING, 2004).

Thrips (Thysanoptera: Thripidae) are often abundant and damaging in many cotton-producing regions (SILVA el al., 2018). Generally, it feeds on the undersides of the cotton leaves, causing injury that can lead to dramatic deformation of seedling leaves (WILLIAMS et al., 2011). In extreme cases thrips damage can result in plant death; and the production of fruiting bodies may be delayed and can result in reduced yield and/or delayed maturity (LEI; WILSON, 2004). Thrips sometimes damage plants in mid to late season crops, causing distortion of the upper leaves, but this damage does not usually result in economic loss (WILLIAMS et al., 2011).

In Brazil, common blossom thrips, *Frankiniella schultzei* (Trybom, 1910) (Thysanoptera: Thripidae), is commonly associated with damage on cotton (MONTEIRO et al., 2001, 1999). *Frankliniella schultzei* is a polyphagous pest feeding on various ornamental and vegetable hosts (MILNE et al. 1996), having spread worldwide, it is mainly found in tropical and subtropical areas. It has been recorded on 83 species of plants among 35 families (PALMER, 1990). The major hosts of *F. schultzei* are cotton, groundnut, beans and pigeon pea. However, due to its polyphagous feeding behavior, *F. schultzei* also attacks tomato, sweet potato, coffee, sorghum, chilli pepper, onion and sunflower (HILL, 1975). Crops suffer economic damage due to *F. schultzei* in different part of the world.

The cotton aphid, *Aphis gossypii* Glover, 1877 (Hemiptera: Aphididae) deserves special attention because it occurs after germination and remains until harvest on many varieties of cotton (ARANTES et al., 1998; FURTADO et al., 2009). It can cause a 40% productivity reduction through direct damage (GABRIEL, 2010). Additionally, *A. gossypii* may cause indirect damage through the transmission of several debilitating plant viruses (CAMPOLO et al. 2014), such as Cotton Anthocyanosis Virus-(C.A.V.) and Cotton Vein Mosaic Virus (V.M.N.). These viruses can drastically reduce cotton productivity (SANTOS et al., 2004), reducing variations according to the susceptibility of the variety and other specific characters. *Aphis gossypii* is a worldwide polyphagous pest species. Populations of *A.*

gossypii can develop quickly and, when present on cotton seedlings in large numbers, cause extensive damage via direct feeding on the phloem sap (SATAR et al. 1999).

To suppress pest populations in cotton a rigorous plan is required. Currently, control is mainly based in the utilization of chemicals insecticides (LUTTREL et al., 2015). Yet, pest control in cotton based on the use of insecticides has demonstrated several limitations in terms of developing resistant individuals and major risks to human health. Furthermore, such use causes damage to ecosystems with consequent alterations of natural services regulation (LLANDRES, 2018).

The knowledge of crop stages and their relation to pest susceptibility is the first step to implement a pest management program (LUTTREL et al., 2015). The key challenge to pesticide substitution in cotton is finding sustainable, economically viable solutions, in line with advances in production. Research has an important role in developing new conceptions in pest control, especially boosting ecological solutions such as biological control of pests (GRAF et al. 2015). Many researchers, such as Pyenson (1938), Bleicher et al. (1979), Cruz and Passos (1985), Ramalho et al. (2000) have demonstrated ecological and economic importance of the use of biological control in cotton as an efficient alternative.

Among biological controls, one efficient mechanism to help fill chemical pest control gaps, is conservation biological control (CBC). Conservation biological control represents an important ecosystem service that benefits agricultural production (BENGTSSON, 2015) and is an alternative to dependence on pesticides to maintain yields; pesticides which are associated with environmental damage, human health risks and declining availability of effective products (BARZMAN et al., 2015).

However, the efficiency of biological conservation control depends on dynamic ecological factors and agriculture management, such as climate, natural occurrence of species and pesticide application (GUEDES, 2016; TSCHARNTKE, 2016). Factors guiding insect seasonal patterns of movement between crops and habitats, and the impacts of various agronomic activities on their populations, are worthy of more study (MICHAUD, 2018) Therefore, in this study, we investigated changing aspects of thrips and aphid populations among cotton and neighbouring crops (maize, bean and soybean) and their interaction with predictive variables (precipitation, temperature, number of insecticide applications, insecticide dose and number of thrips or aphids).

2 GENERAL CONCLUSIONS

Landscape management plays an important sustainable approach to complement suppressing pest population techniques and appears as a possibility to reduce pesticide applications on agriculture. Although neighbouring crops were not effective to reduce aphid populations, we demonstrated that growing soybean as cotton neighbour causes a significant decrease in thrips population. In addition, we recorded cotton aphid, *Aphis gossypii* and thrips *Frankliniella schultzei* as the dominant species of our study. Both important cotton pests in Brazil and highly polyphagous. They were strongly influencing all cotton treatments and neighbouring crops. Therefore, the development of a control management plan for these species is essential for cotton production in the region of our study, including natural enemies and selective insecticides.

In the present study, we analyzed five predicative variables (precipitation, temperature, number of insecticide application, insecticide dose and number of thrips or aphids). Although precipitation had a significant effect on dynamic variation of thrips abundance, none of the variables were able to explain the temporal variation of the aphid population. Therefore, I suggest that other variables may be involved, such as presence of natural enemies that is reported to affect aphid population dynamics.

One important next step is to perform experiments where the presence and/or abundance of natural enemies can be measured. In addition, special attention to the chemical insecticide management used for aphids and thrips control is necessary, given that in the present study insecticide did not have a significant effect on the pests' dynamic population, indicating a possible pest resistance case.

Finally, only landscape management is not enough to affect pest populations. Therefore, there is a need to better understand how the interactions among pest, landscape complexity, natural enemies, agriculture management techniques, and climatic variables may affect pest dynamics in cotton crops. In addition, future studies into aphids and thrips resistance to insecticides must be conducted.

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SECOND PART: ARTICLE

Article 1 – Discovering neighbouring crops, insecticide management, and climatic variables effects on aphids and thrips dynamics in cotton

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Article 1 - Discovering neighbouring crops, insecticide management, and climatic variables effects on aphids and thrips dynamics in cotton

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Key Messages

We investigated aphids and thrips dynamics in cotton and neighbouring crops.

Soybean reduces thrips abundance in cotton.

We found the lowest aphids abundance in maize and soybean.

Frankliniella schultzei (Trybom) and *Aphis gossypii* Glover were dominant species.

Precipitation reduces thrips abundance.

Broad-spectrum insecticides application had no effect on aphid and thrips populations.

ABSTRACT

Lately, aphids and thrips have become key pests in several cotton producing regions in Brazil. Therefore, identifying the factors affecting these pest population dynamics is an urgent need. Here, we investigated aphids and thrips changing population aspects among cotton and neighbouring crops. The experiment was carried out with three treatments: Cotton/Maize; Cotton/Soybean and Cotton/Bean. Samplings were performed between Nov/2018 and Jun/2019. We used four transects containing five yellow pan-traps each per treatment. We also recorded five predictive variables (precipitation, temperature, number of insecticide applications, insecticide dose and number of thrips or aphids) using local stations and records from the farmer. We found the lowest thrips abundance in cotton neighbour soybeans. However, the aphid abundance did not differ among treatments. When we compared the different neighbouring crops, we found the lowest aphids abundance in maize and soybean crops. We recorded higher aphid abundance in cotton treatments when compared with all neighbouring crops, and higher thrips abundance in cotton treatments when compared to bean and soybean. *F. schultzei* and *A. gossypii* were the dominant thrips and aphid, respectively, in all cotton treatments and neighbouring crops. Only precipitation had a significant effect on temporal variation in thrips abundance. Our results show that growing soybean as cotton neighbour is better for reducing thrips population compared to maize and bean. In addition, the development of a control management plan for *F. schultzei* and *A. gossypii* is essential for cotton production in the region of our study. Finally, the fact that insecticide did not have a significant effect on the pest dynamic population can indicate a case of pest resistance to the chemical groups used.

Keywords: Cotton pest management. Habitat management. Hierarchical partitioning.

Frankliniella Schultze.i Aphis gossypii

RESUMO

Nos últimos anos, pulgões e thrips se tornaram pragas primárias em muitas regiões produtoras de algodão. Desta maneira, se faz necessário identificar os fatores afetando a dinâmica dessas populações de pragas. Neste trabalho, foi avaliado as mudanças populacionais de thrips e pulgão entre algodão e culturas adjascentes. O experimento constituiu três tratamentos; Algodão/Milho; Algodão/Soja e Algodão/Feijão. As amostragens foram realizadas durante o período de Nov/2018 e Jun/2019. Foram utilizados quatro transectos contendo cinco armadilhas do tipo "prato-amarelo" (atrativas para pulgão e thrips) em cada tratamento. Também foram avaliadas cinco variáveis preditoras (precipitação, temperatura, número de aplicação de inseticidas, dose de inseticidas e número de thrips ou pulgões) utilizando a estação meteorológica local e os dados da fazenda. A menor abundancia de thrips foi encontrada em algodão vizinho a cultura da soja. No entanto, a abundância de pulgões não diferiu entre os tratamentos. Quando comparada as diferentes culturas vizinhas, foi encontrada a menor abundância de pulgões em milho e soja. Em todos os tratamentos a abundância de pulgões foi maior em algodão do que nas respectivas culturas vizinhas e maior abundância de thrips em algodão comparados a feijão e soja. *F. schultzei* e *A. gossypii* foram as espécies dominantes, respectivamente, em todos os tratamentos e nas culturas vizinhas. Somente a precipitação teve um efeito significativo na variação temporal de abundância para thrips. Os resultados sugerem que plantar soja vizinha de algodão é melhor para reduzir as populações de thrips comparado com milho e feijão. Além disso, se faz necessário um plano de controle para as espécies *F. schultzei* e *A. gossypii* para as regiões produtoras de algodão deste estudo. Por fim, o fato de inseticidas não apresentarem efeito significativo na dinâmica de população de pragas pode indicar um caso de resistência de insetos aos inseticidas aplicados.

Palavras-chave: Manejo de pragas de algodão. Manejo do habitat. Partição hierarquica.

Frankliniella Schultzei. Aphis gossypii

1 INTRODUCTION

Brazil is one of the largest exporters of cotton (Ridley and Devadoss 2014). Globally, an estimated 20–40% of the crop yield is lost to pests and diseases (FAO 2009). Reducing insect crop pests is a key priority, particularly since an estimated 70–100% increase in global food production will be required by 2050 to feed the burgeoning human population (FAO 2009; Tilman et al. 2011; Ray et al. 2013). Cotton seeding and it oil also can be used as nutrient to animals and humans.

Aphids and thrips have become key pests in several cotton producing regions in the last twenty years (Fernandes et al. 2011). Therefore, the use of insecticides has been the most widespread technique to control sucking pests (Fernandes et al. 2008). Consequently, a change in the current agricultural paradigm and the development of more environmentally friendly agricultural practices are strongly required (Masoni et al. 2017).

Recently, habitat management has been confirmed as a key approach in attempts to adopt regenerative agriculture (Pretty et al. 2018). Diversifying production systems with mixed crops, rotations, varietal mixtures or non-crop plantings can reduce pest colonization and population growth rates (Letourneau et al. 2011; Rusch et al. 2016). There are studies showing the contribution to pest management when the agricultural landscape contains a healthy and sufficiently diverse community of plants and arthropods (Masoni et al. 2017; González-Chang et al. 2019), but the presence of such diversity does not guarantee crop protection per se (Rusch et al. 2016; Gurr et al. 2017). Crop structure, chemical environment, and microclimate are factors that can affect pest suppression and are components of associational resistance (Ramert et al. 2002). However, which abiotic and biotic factors are acting and how they influence pest population suppression are still to be discovered (Rusch et al. 2017).

Therefore, in this study, we sampled thrips and aphids in conventional cultivation systems growing cotton neighbouring maize, cotton neighbouring bean and cotton neighbouring soybean in order to answer the following questions: 1) Which cotton treatment has the lower number of thrips and aphids? 2) Which neighbour-crop has lower number of thrips and aphids? 3) Which thrips species is dominant in cotton treatments and neighbouring crop? 4) Is the abundance of aphids and thrips higher in cotton treatments or in the respective neighbouring crop? 5) Which predictive variables (precipitation, temperature, number of insecticide application, insecticide dose and number of thrips or aphids) better explain the temporal variation in thrips and aphids populations?

2 MATERIALS AND METHODS

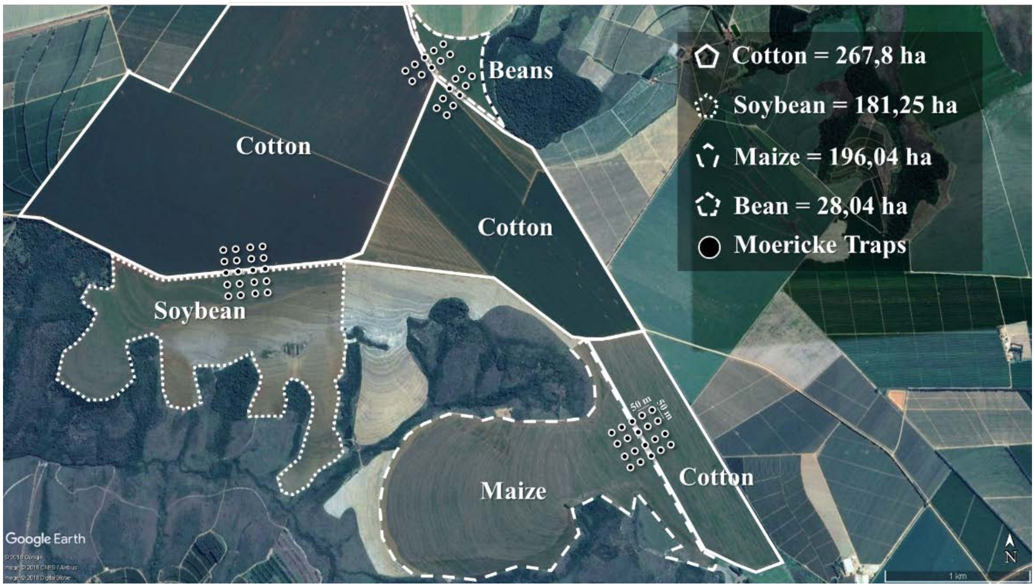
2.1 Study site

The study was performed in Coromandel municipality, Minas Gerais state, Brazil (18°39'03"S; 46°52'18"W), 1080 m of altitude. The local climate is Aw by the Köppen climate classification, which stands for hot and humid summers and dry winters. Average annual rainfall is 1.638,2 mm, most between October and April, and the average annual temperature is 21.8°C (Santos and Ribeiro, 2004).

Experiments were set up in a commercial cotton cultivation (*Gossypium hirsutum*) neighbouring maize (*Zea mays*), cotton neighbouring bean (*Phaseolus vulgaris*) and cotton neighbouring soybean (*Glycine max*) composed the area site (Figure 1). The studied cultivation areas ranged from 28.04 to 597.29 ha.

1. Cotton was sown on December fourth with spacing of 0.76 m between line, and 6.5 plants m^{-1}, totaling 85,000 plants ha^{-1}.
2. Maize was sown on November twentieth with spacing of 0.76 m between line, and 5.5 plants m^{-1}, totaling 72.000 plants ha^{-1}.
3. Beans were sown on November twenty five with spacing of 0.5 m between lines, and 12.5 plants m^{-1}, totaling 250.000 plants ha^{-1}.
4. Soybeans were sown on November twenty two with spacing of 0.5 m between line and 20.85 plants m^{-1}, totaling 417,000 plants ha^{-1}.

Figure 1 – Aerial photo of the sampling site (Google Earth®) showing crops and pan trap lines. Coromandel, MG, 2018 and 2019.



Fonte: Do Autor (2020)

2.2 Sampling design and insect identification

The experiment was carried out using three treatments: T1) Cotton/Maize; T2) Cotton/Soybean and T3) Cotton/Bean. Samplings were performed starting from one week before cotton sowing to one week before cotton harvest, totaling 12 sampling dates between November/2018 and June/2019.

In each treatment the sampling was conducted using yellow pan traps distributed in four transects 100 m distant from each other. In each transect a set of five yellow pan traps (15 x 4.5 cm) was installed and separated by 50 m: two traps stayed within the cotton, two within the neighboring crop and one within them both, in the intersection between the fields. In total the sampling effort was 20 traps for each treatment (cotton + neighboring crop, Figure 1). Traps remained active for 48 hours, containing salt solution (NaCl 5%) and drops of neutral soap.

All thrips and aphids were collected and placed in vials with 70% alcohol until identified by a trained person, using available taxonomic keys and reference collections from the Entomology Museum of the Federal University of Lavras.

2.3 Climatic variables

Climatic data (average precipitation and temperature) were gathered from an automatic station of the Cooxupé Meteorology Monitoring System (SISMET), installed in Coromandel - MG.

2.4 Insecticide application

We collected insecticide management data from the farm records. We used insecticides of broad-spectrum application and dosage used during the entire season. We considered only cotton crop and insects recorded on cotton for this analysis. The chemical groups covered were avermectin, organophosphates, neonicotinoid, phenilpyrazole, carbamate, benzoylurea, ketoenol, pyrethroid, nicotine and organosulfur. These data comprised two predictive variables, number of insecticide applications and insecticide dose.

2.5 Statistical analysis

We checked data for normality using the Shapiro–Wilk test (Shapiro and Wilk 1965) and for homoscedasticity using Bartellet’s test. Afterward, we combined (summed) the two points from each transect to make one replicate, so that we had four replicates for each treatment. We used generalized linear mixed models (GLMMs) to verify the effect of different cotton treatments and different neighbouring crops (explanatory variables) on the number of individuals (response variable) of thrips and aphids, cotton treatments and neighbouring crop type as a fixed factor and number of samples as a random factor. We used a negative binomial error distribution with log link function for abundance of thrips and aphids as these data showed overdispersion, preventing the use of Poisson error. We then undertook contrast analysis to test pairwise differences (Crawley 2012). These analyses were carried out using the “glmer.nb” function for negative binomial model in the “LME4” package using R version 3.3.1 software (R Development Core Team 2019c).

We also used GLMMs to verify differences in thrips and aphid abundance between cotton and its respective neighbouring crops. We used a negative binomial error distribution with log link function for abundance of thrips and aphids as these data showed over dispersion, preventing the use of Poisson error. We then undertook contrast analysis to test pairwise differences (Crawley 2012). In addition, we used GLMMs to verify differences among thrips species in each cotton treatment and each neighbouring crop, treating thrips species as a fixed factor and number of samples as a random factor. We used a negative binomial error distribution with log link function for abundance of thrips species as these data showed overdispersion, preventing the use of Poisson error. We then performed the same approach regarding the first paragraph of the statistical analysis section.

Finally, we used hierarchical partitioning analysis to examine the independent effects of five predictive variables (precipitation, temperature, number of insecticide applications, insecticide dose and number of thrips or aphids) on the temporal variation of aphids and trips abundance on cotton. We used number of thrips or aphids as predicative variable considering the fact of these insects fills the same guild and could be affecting each other abundance. This method provides an estimate of the independent effects of each explanatory variable on the response variable (Chevan and Sutherland 1991; Mac Nally 2000). We evaluated competing models based on the R^2_{dev} statistic, determining the significance of effects with a randomization test with 999 interactions (Mac Nally 2000, 2002). Hierarchical partitioning and associated randomization tests were implemented using the “hier.part” package using R version 3.3.1 software (R Development Core Team 2019).

3 RESULTS

We recorded 7263 individuals from three thrips species: *Frankliniella schultzei, Haplothrips gowdeyi* (Franklin, 1908), *Caliothrips phaseoli* (Pergande, 1895), and other insects of the genus *Frankliniella* spp., and 1584 individuals of the aphid *Aphis gossypii*.

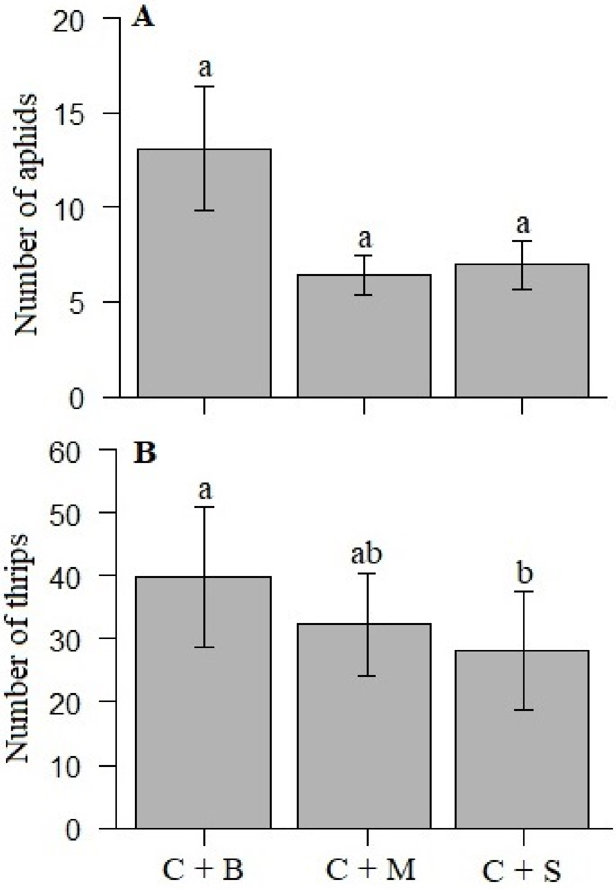
In the cotton+bean treatment, in the cotton we recorded 1755 individuals of thrips and 576 aphids, in bean we recorded 769 thrips and 284 aphids. In the cotton+maize treatment, in cotton we recorded 1421 thrips and 283 aphids, in maize we recorded 1650 thrips and 79 aphids. In the cotton+soybean treatment in cotton we recorded 1236 thrips and 306 aphids, in soybean we recorded 432 thrips and 56 aphids. Of the 5 taxa, 4 were recorded in all treatments and neighbouring crops, only *Haplothrips Gowdeyi* was not recorded in maize.

We found no significant differences for aphid abundance among cotton treatments ($\chi^2_{(2,118)}$ = 5. 71, p = 0.057) (Fig. 2A). However, we found the lowest thrips abundance in cotton + soybean ($\chi^2_{(2,118)}$ = 8.42, p = 0.014) (Fig. 2B).

When we compared the different neighbouring crops, we found the lowest aphid abundance in maize and soybean crops ($\chi^2_{(2,118)}$ = 13.16, $p < 0.01$) (Fig. 3A). However, we found no significant differences for thrips abundance among the different neighbouring crops ($\chi^2_{(2,118)}$ = 3.72, p = 0.15) (Fig. 3B).

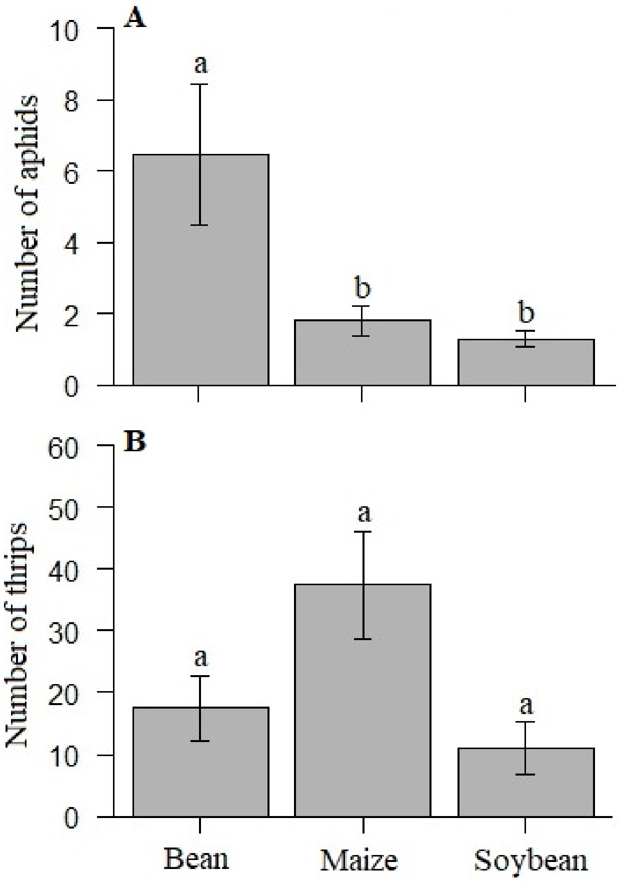
Finally, we found higher aphid abundance in cotton treatments when compared with all neighbouring crops; bean ($\chi^2_{(1,75)}$ = 9. 80, $p < 0.01$), maize ($\chi^2_{(1,75)}$ = 18.10, $p < 0.001$) and soybean ($\chi^2_{(1,75)}$ = 8.28, p = 0.04) (Fig. 4A). We also found higher abundance of thrips in cotton treatments when compared with bean ($\chi^2_{(1,75)}$ = 4.77, p = 0.028) and soybean ($\chi^2_{(1,75)}$ = 3.87, p = 0.049). However, we found no difference among cotton and maize crop ($\chi^2_{(1,75)}$ = 1.96, p = 0.0160) (Fig. 4B).

Figure 2 – Average abundance of aphids (A) and thrips (B) sampled in different cotton treatments: C + B = Cotton and bean as neighbor; C + M = Cotton and maize as neighbor, and C + S = Cotton and soybean as neighbor. Error bars represent ± SE. Different letters above the bars indicate significant differences among cotton treatments ($p < 0.05$). Coromandel, MG, 2018 and 2019.



Fonte: Do Autor, 2020

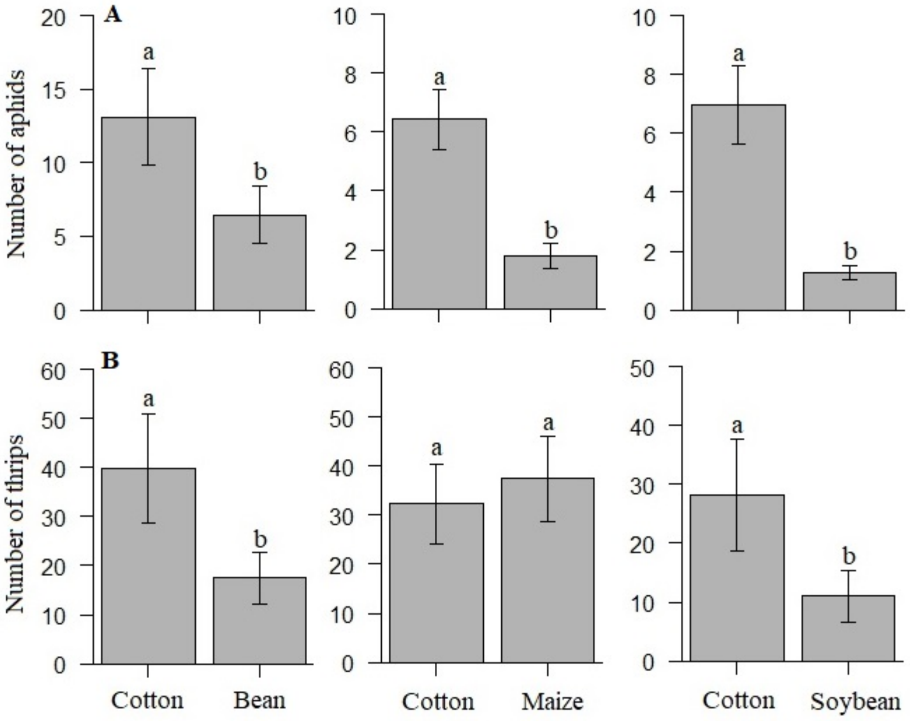
Figure 3 – Average abundance of aphids (A) and thrips (B) sampled in different neighbor-crops. Error bars represent ± SE. Different letters above the bars indicate significant differences among neighboring crops ($p < 0.05$). Coromandel, MG, 2018 and 2019.



Fonte: Do Autor, 2020

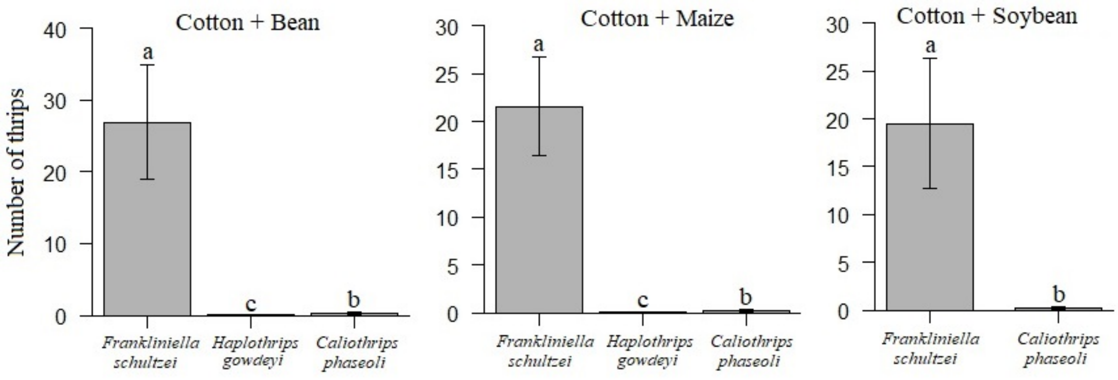
We identified three thrips species in our study: *Frankliniella schultzei* (Trybom, 1910), *Haplothrips gowdeyi* (Franklin, 1908) and *Caliothrips phaseoli* (Pergande, 1895). We recorded the dominance of *Frankliniella schultzei* in all cotton treatments; cotton + bean as neighbour ($\chi^2_{(2,118)} = 2509.60$, p < 0.001), cotton + maize as neighbour ($\chi^2_{(2,118)} = 2178.80$, p < 0.001) and cotton + soybean as neighbour ($\chi^2_{(2,118)} = 1864.80$, p < 0.001) (Fig. 5).

Figure 4 – Average abundance of aphids (A) and thrips (B) sampled in cotton and its respective neighbour. Error bars represent ± SE. Different letters above the bars indicate statistically significant differences between cotton and its respective neighboring crop ($p < 0.05$). Coromandel, MG, 2018 and 2019.



Fonte: Souza, 2020

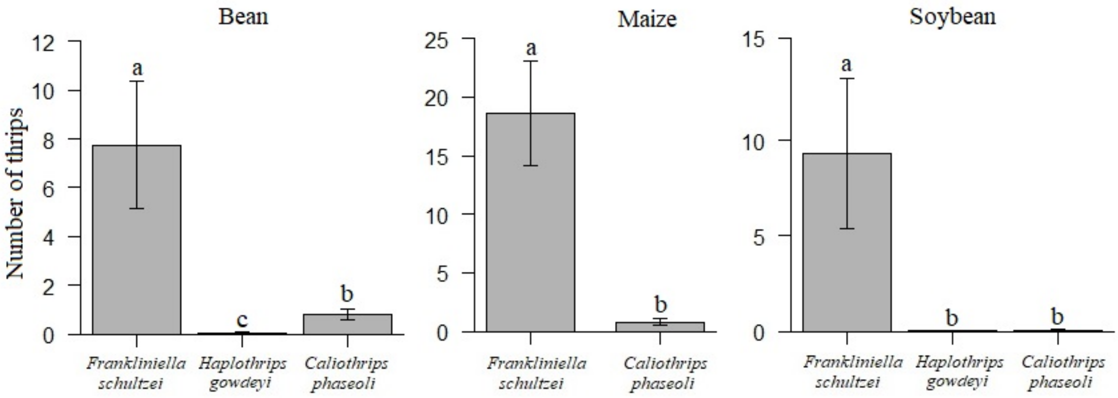
Figure 5 – Average abundance of thrips species in different cotton treatments. Error bars represent ± SE. Different letters above the bars indicate significant differences among thrips species ($p < 0.05$). Coromandel, MG, 2018 and 2019.



Fonte: Do Autor, 2020

We also found *Frankliniella schultzei* dominant in all neighbouring crops; bean ($\chi^2_{(2,118)}$ = 44.75, p < 0.001), maize ($\chi^2_{(2,118)}$ = 101.44, p < 0.001) and soybean ($\chi^2_{(2,118)}$ = 75.88, p < 0.001) (Fig. 6).

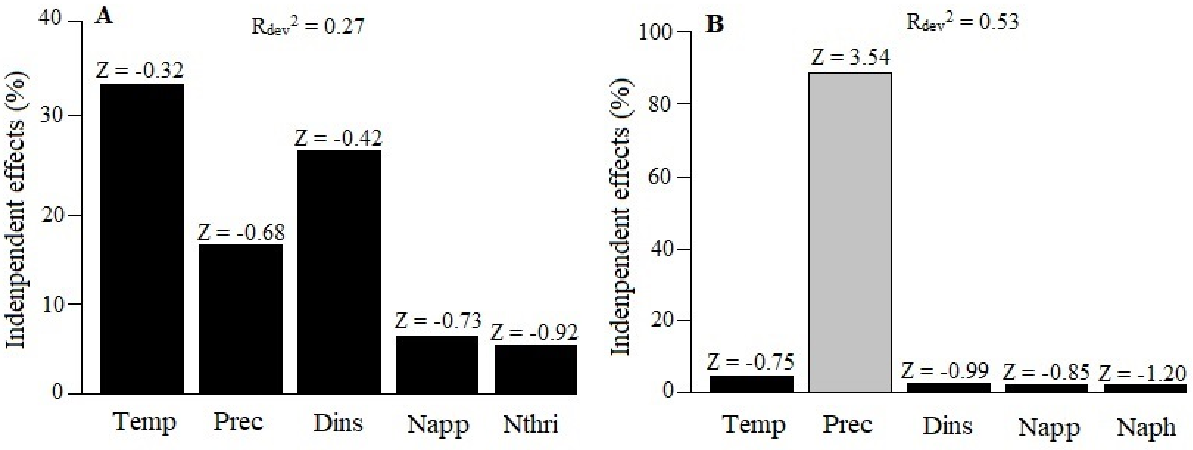
Figure 6 – Average abundance of thrips species in different neighboring crops. Error bars represent ± SE. Different letters above the bars indicate statistically significant differences among thrips species ($p < 0.05$). Coromandel, MG, 2018 and 2019.



Fonte: Do Autor, 2020

The hierarchical partitioning analysis showed no significant effects of the five predictive variables on temporal variation in aphids abundance (Fig 7A). However, this analysis showed that only precipitation had a significant effect on temporal variation in thrips abundance (89.26% independent effect, p < 0.05) (Fig 7B). Models including the five predictive variables explained 53 and 27% of the temporal variance in the abundance of thrips and aphids, respectively (Fig 7A,B).

Figure 7 – Hierarchical partitioning analysis for temporal variance in the abundance of aphids (A) and thrips (B) with percentage distribution of the independent effects of predictive variables: temperature (Temp), precipitation (Prec), insecticide dose (Dins), number of insecticide applications (Napp), number of aphids (Naph) and thrips (Nthri). Gray bar represents significant effect on thrips abundance ($p < 0.05$). R^2_{dev} is the total variation of data explained by the model. Coromandel, MG, 2018 and 2019.



Fonte: Do Autor, 2020

4 DISCUSSION

1) Which cotton treatment has the lowest number of thrips and aphids? Thrips populations were lower in soybean as cotton neighbour, showing that soybean is the most effective neighbour crop in reducing thrips population and consequently its attack in cotton. *Aphis gossypii* was the only Aphidae recorded in all cotton and neighbouring crops, showing no significant differences for abundance among cotton treatments. It is the main cotton aphid (Holman 2009), and one of the most dangerous polyphagous species worldwide It also has a fast development (EBERT and CARTWRIGHT 1997; CARLETTO et al. 2009). This reason may help to explain the dominance of this species in cotton treatments and neighboring crops in our study.

2) Which neighbouring crop has the lowest number of thrips and aphids? Among neighbouring crops, we found the lowest aphid abundance in maize and soybean crops. Since it has been reported that those different individuals of *Aphis gossypii* have different preferences for hosts (Liu et al. 2002), our result indicate that these *Aphis gossypii* sampled are possibly more adapted to bean compared to maize and soybean. We found no significant

differences for thrips abundance among the different neighbouring crops. This result corroborates with that found by (Nyasani et al. 2012). They found no significant differences in the numbers of *F. schultzei* hosted by monocrop bean compared with other associated crops. The fact that *F. schultzei* is often found colonizing maize, bean and soybean (Palmer 1990) demonstrates it plasticity to colonize different crops.

3) Which species of thrips is dominant? *Frankliniella schultzei* was dominant in all cotton treatments and neighbouring crops. There is a consensus in the literature that this species is the main cotton thrips in Brazil (Monteiro et al. 2001), and well adapted to polyphagy in many crops (Kakkar et al. 2012).

The most common thrips control used worldwide includes insecticides applied as systemic in-furrow granules and sprays, or seed treatments (COOK et al. 2011). However, resistance of *F. schultzei* to insecticides has been reported (CLUEVER et al. 2016; HUSETH et al. 2018; PAPIERNIK et al. 2018), so this is a recent challenge to integrated pest management in cotton. Another alternative is the biological control utilizing predators and commercially available entomopathogens, which provide an approach which is less likely to lead to control agent resistance (Bara and Laing, 2020).

4) Is the abundance of aphids and thrips higher in cotton treatments or on its respective neighbouring crop? We found higher aphid abundance in cotton treatments when compared with its respective neighbouring crop, and higher abundance of thrips in cotton treatments when compared with bean and soybean. It is known that *F. schultzei* and *A. gossypii* have different dynamics depending of the host-association (Milne et al. 2007; Carletto et al. 2009), which are related to the fact that dominant species are often associated with cotton (Monteiro et al. 2001; Furtado et al. 2009). Otherwise, there is a lack of reports comparing thrips and aphid populations on cotton, soybean, maize and bean.

5) Which predictive variables better explained the temporal variation in thrips and aphid populations? The predictive variables measured could not explain the temporal variation of the aphid abundance. The present findings were in agreement with Lu et al. (2015), indicating that other variables may be involved, that we did not measure, such as presence of natural enemies (Conway et al. 2006; Ali et al. 2016). Either Alyokhin et al. (2011) found that weather factors contributed to the regulation of aphid populations, directly or through natural enemies, and potato aphids were affected by predators and diseases.

In this paper only precipitation presented a significant effect on temporal variation in thrips abundance, explaining 89.26% of the variation, which corroborates with the results found by Morsello et al. (2014). Temperature and precipitation are the major factors found affecting thrips population dynamics (Keough et al. 2018). Precipitation has both positive and negative effects on thrips in the field, because precipitation can kill their juvenile stages and suppress flight activity of adults, decreasing thrips dispersal (Morsello and Kennedy 2009; Chappell et al. 2013). In some cases, dispersal was affected up to 5–6 week after precipitation occurred (Morsello et al. 2010). However, precipitation also benefits the growth of host plants, which would increase thrips population growth (Keough et al. 2018). Therefore caution is advised when iterating precipitation results versus thrips population dynamics.

5 CONCLUSIONS

In conclusion, we demonstrated that growing cotton with soybean as a neighbor is better for reducing thrips population compared to maize and beans. Nevertheless, no neighbouring crop was efficient to reduce the aphid population in the cotton crops. There is a need to develop a control management plan for *F. schultzei* (and other thrips) and *A. gossipy* on cotton production in the region studied, since these species were, respectively dominant in all cotton treatments and in the neighbouring crops. Finally, only precipitation had a significant effect on temporal variation in thrips abundance. Our results show that special attention is necessary regarding the chemical insecticide management used for aphids and thrips control in the area, given that insecticide (predictive variables) did not have a significant effect on pest dynamic population. This unexpected result can indicate a case of pest resistance to the chemical groups used.

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Author Contribution Statement

IGPS: conceptualization conducted the experiments, curation and wrote the manuscript. CMAC: analytical tools and analyzed data. LCPS: supervision and designed research. All authors read and approved the manuscript.

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