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Original Article

Land use around influences the entomological community in lettuce horticultural systems

O uso do solo ao redor dos sistemas hortícolas de alface influencia sua comunidade entomológica

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Abstract

The complexity of the agroecosystem can also be assessed by the different land uses in the system and the surroundings, being a relevant way to assess the heterogeneity of the landscape and the effects on the community of interest, in this case, entomofauna. Thus, the objective of this work is to verify how the use of soil in the surroundings of Chilean lettuce horticultural systems, in the Coquimbo Region, alters the entomological community of the crop. Insect sampling was conducted (February 2021 to March 2022) using yellow pan traps. Two sites will be sampled on each of the seven studied lettuce crops. Land use and land cover classes were defined: Forests, water bodies, shrub vegetation, grasslands, barren lands, impermeable surfaces, and urban areas. After land use and land cover classification, buffers of 500 to 5,000 m were created around each data collection point. For data analysis, the percentages of land use of different classes were compared with the ecological attributes: Abundance of insects, abundance of insect pests, richness of entomological families and types of oral apparatus (licker-sucker, mandible, picker-sucker, and sucker). Land uses at different distances from horticultural systems affected the entomological community.

Keywords: agronomy, agroecosystem, entomology, horticulture, pest insects.

Resumo

A complexidade do agroecossistema também pode ser avaliada pelos diferentes usos do solo no sistema e no entorno, sendo uma forma relevante de avaliar a heterogeneidade da paisagem e os efeitos na comunidade de interesse, neste caso, a entomofauna. Assim, o objetivo deste trabalho é verificar como o uso do solo no entorno dos sistemas hortícolas de alface chilena, na região de Coquimbo, altera a comunidade entomológica da cultura. A amostragem de insetos foi realizada (fevereiro de 2021 a março de 2022) utilizando armadilhas amarelas. Serão amostrados dois locais em cada uma das sete culturas de alface estudadas. Foram definidas classes de uso e cobertura da terra: Florestas, corpos d'água, vegetação arbustiva, pastagens, terras áridas, superfícies impermeáveis e áreas urbanas. Após a classificação do uso e cobertura do solo, foram criadas zonas tampão de 500 a 5,000 m em torno de cada ponto de recolha de dados. Para análise dos dados, foram comparados os percentuais de uso da terra das diferentes classes com os atributos ecológicos: Abundância de insetos, abundância de insetos-praga, riqueza de famílias entomológicas e tipos de aparelhos bucais (sugador-lambedor, mandíbula, sugador-colhedor e sugador). Os usos da terra em diferentes distâncias dos sistemas hortícolas afetaram a comunidade entomológica.

Palavras-chave: agronomia, agroecossistema, entomologia, horticultura, insetos pragas.

1. Introduction

Agricultural systems can be as complex as natural ecological systems, being influenced by the types of crops, management, edaphoclimatic conditions, and land use in and around the systems (Martello et al., 2023). The

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complexity of agricultural systems and their surroundings directly affects the entomological community that visits the system, even affecting the relationship between the entomofauna and the environment. Less complex agricultural systems tend to have less complexity in the entomofauna and may even dominate insect pests and/or a smaller number of beneficial insects for the crops of interest (Cappellari and Marini, 2021).

The complexity of the agroecosystem can also be assessed by the different land uses in the system and the surroundings, being a relevant way to assess the heterogeneity of the landscape and the effects on the community of interest, in this case, entomofauna (Santos et al., 2021a). The use of the surrounding soil for entomofauna is relevant for this group, especially due to the flight capacity and movement of insects, being affected or influencing a considerable distance from the places that are found, depending on the group, due to the ability to fly (Martello et al., 2023).

Less complex environments composed of matrices that are inaccessible or inhospitable to the entomofauna community can reduce the ability of these insects to feed and reproduce (Cappellari and Marini, 2021). Environments such as cities with a high degree of urbanization or exposed soil tend to be barriers for groups of entomofauna, as well as large monocultures tend to be an adequate matrix for increasing the number of insect pests. The opposite is also valid, in which natural environments, with greater complexity of vegetation, and habitats, increase the diversity of the entomofauna found, as well as their beneficial effects when of interest (Pedley and Dolman, 2020; Batary et al., 2021).

Another relevant aspect to consider regarding the influence of land use on entomological communities is the diversity of morpho functional groups that exist among insects. Insect variations, which we can call functional traits, are affected in different ways by the landscape (Caitano et al., 2020). Among these traits, one of the most striking is the mouth apparatus, which defines the feeding habits of the species and thus all of its behavior (Castro et al., 2017).

Agricultural soil is a valuable resource, but its improper use can have negative consequences for the entomological community and, ultimately, for agricultural production itself. The traditional approach to pest control based on chemical pesticides tends to have a devastating impact on insect biodiversity in agricultural fields (Corwin, 2013; Qin et al., 2014).

One of the primary challenges stems from the non-specific nature of chemical pesticides, which have the potential to indiscriminately eradicate both pest species and beneficial insects (Dara, 2019). Beneficial insects, including bees, butterflies, and other pollinators, hold a pivotal role in food production by facilitating the fertilization of plants. Furthermore, the presence of natural predators of pests, such as ladybugs and parasitoid wasps, contributes to the natural regulation of pest populations (Eigenbrode et al., 2018).

However, the overuse of pesticides not only results in the mortality of these beneficial insects but can also drive the emergence of resistance among pest populations, thereby demanding increased pesticide usage. This perpetuates a harmful cycle that poses a threat to the well-being of the agricultural ecosystem and has the potential to negatively affect crop production (Goulson, 2020; Sánchez-Bayo, 2021).

The impact of pesticide use on agricultural soil is diverse and iatrogenic. Pesticides can be toxic to a wide range of soil organisms, including beneficial bacteria, fungi, earthworms, and other microorganisms (Martins et al., 2016). These organisms play a crucial role in organic matter decomposition and the release of nutrients that plants require for growth. Therefore, indiscriminate pesticide use can negatively affect soil biodiversity. By targeting pests, they not only have the potential to kill beneficial insects but also disrupt the composition and function of the soil microbiota, which can reduce the soil's ability to cycle nutrients and maintain a healthy structure (Parra et al., 2022). Additionally, pesticides can leach or wash from the soil into groundwater or surface water, leading to water contamination and posing a risk to the overall ecosystem (Pathak et al., 2022).

Research has demonstrated the effectiveness of Integrated Pest Management (IPM) in soil utilization for agriculture and the sustainable control of insect pests and diseases in vegetables (Ahuja et al., 2015). IPM offers a promising alternative to the traditional pesticide approach and presents numerous advantages for both the entomological community and agriculture at large. It promotes biodiversity conservation by employing biological methods, such as the release of beneficial insects, for pest control (Stenberg, 2017). This contributes to maintaining a natural balance within the agricultural ecosystem. By integrating cultural, chemical, climatic, and biological methods, IPM reduces the necessity for extensive use of chemical pesticides, thereby safeguarding the well-being of the entomological community (Dara, 2019).

Maintaining healthy populations of beneficial insects and natural predators of pests enhances natural pollination and pest control, which in turn benefits crop production, such as lettuce and other vegetables. This also promotes sustainable agricultural practices by reducing pesticide dependency and encouraging the adoption of environmentally friendly methods (Singh et al., 2020).

Studies have demonstrated that traditional methods relying heavily on pesticides can impact pollinating insects through the use of insecticides (neonicotinoids, organophosphates, carbamates, and pyrethroids), herbicides, and fungicides (Sánchez-Bayo, 2021). It is important to emphasize that not all pesticides have a significant negative impact on pollinators, and their effect can depend on factors such as dosage, application frequency, and usage methods. However, the accumulation of exposure to various types of pesticides and the combination of stressors, such as habitat loss and food scarcity, can be particularly detrimental to pollinators (Pathak et al., 2022). Therefore, it is crucial to use pesticides responsibly and adopt agricultural practices that minimize risks to pollinators while promoting their conservation (Eigenbrode et al., 2018).

In Chile, several studies have provided evidence of the excessive presence of pesticides in soil, water, and air within agricultural areas (Climent et al., 2019a, b; Cortes et al., 2020; Llanos et al., 2022), as well as in pollinating insects like bees (Balsebre et al., 2018; Bridi et al., 2018; Mejías et al., 2019; 2021). These pesticides persist in the soil over the long term due to their intensive year-round use. This underscore concerns regarding environmental contamination in soils and potential impacts on biodiversity and food security.

Thus, given the complexity of the landscape of horticultural systems and entomological communities, the objective of this work is to verify how the use of soil in the surroundings of Chilean lettuce horticultural systems, in the Coquimbo Region, alters the entomological community of the crop. Specifically, we also aimed to verify whether insects from different groups of oral apparatus are affected, in addition to comparisons between abundance, family richness, and abundance of insect pests and land uses.

2. Material and Methods

2.1. Studying areas

The study was carried out in the Pan de Azúcar, Coquimbo Region, Chile, one of the regions with the highest production of leafy vegetables in Chile -along with Valparaíso and Metropolitan Regions- and the one with the most balanced application rates between integrated pest management (approximately 55%) and traditional management (approximately 45%) (Correa et al., 2017).

The climate in the Pan de Azúcar area is characterized by mild winters and cool summers due to its proximity to the sea. However, winter frosts are recurrent, especially in dry years. Precipitation is scarce and concentrated in winter (Sierra et al., 2013). The current rainfall regime is associated with a drought condition, with an average of 63.1 mm, concentrating its precipitation between the months of May and August, according to the Pan de Azúcar station (CEAZA), located within the premises of the "Instituto de Investigaciones Agropecuarias" (INIA Intihuasi) (Coordinates: 30.075°S 71.239°W).

The physical characteristics of the soil correspond to a loamy-clay texture, with little organic matter presence, a shallow water table, and reduced microbial activity. The constant replacement of natural habitats with monoculture systems in the territory has increased the dependence of agroecosystems on external inputs, as well as susceptibility to pest infestations due to the decreased self-regulation capacity of ecosystems, caused by excessive and prolonged use of pesticides (Salas, 2019).

Considering all these limitations, this sector is characterized by the constant cultivation of horticultural species throughout the agricultural season. The most important horticultural species cultivated in the region are artichokes, green beans, and lettuce. The latter species represents the most cultivated at the regional level, covering an area of 1,725 hectares (INE, 2022), equivalent to 24.6% of the cultivated area at the national level. Approximately 90.0% of the lettuce cultivation in the region is carried out in the Pan de Azúcar sector (INE, 2022).

Seven lettuce cultivation sites, all situated within the Pan de Azúcar sector, were selected for sampling and comparison. These sites were designated with site numbers and abbreviated names and were subsequently classified as low pesticide usage and high pesticide usage (Table 1). This classification was implemented to safeguard the privacy of the participating companies and farmers involved in the research.

2.2. Insect collection

Insect sampling was conducted for 14 months (between February 2021 and March 2022) using yellow pan traps, following a method modified by Bellamy et al. (2018) to adapt the sampling to the lettuce crops visited in this study. Two sites were sampled on each of the seven studied lettuce crops. The sites were chosen along a transect running from (1) the middle of the farm, referred to as the inside site, and (2) 30 m from the edge of the lettuce crop.

There were five replicate yellow pan traps at each site, separated at least 5m apart from each other, following Sutherland (2006) and Brown and Matthews (2016). The 30 m from the edge site has been chosen to minimize the possibility of differing edge effects on crops of different sizes, functioning as a standardized point of comparison between the selected lettuce crop fields. The inside point was approximately 100 m from the edge of the field. Traps were kept in each place for 24 hours.

Yellow pan traps are passive collection tools that operate on the premise that the color is an attractant for flying insects, especially Hymenoptera, Coleoptera, Lepidoptera, Diptera, and Hemiptera (Vrdoljak and Samways, 2012). The

Table 1. Location of sampling sites.

Site	ID	Method	Years	Area (ha)
1	Low pesticide load 1	IPM	2-3	8
2	Low pesticide load 2	IPM	2-3	8
3	Low pesticide load 3	IPM	2-3	4
4	High pesticide load 1	Exclusive and scheduled use of insecticides.	7-9	1,200
5	High pesticide load 2	Exclusive and scheduled use of insecticides.	7-9	400
6	High pesticide load 3	Exclusive and scheduled use of insecticides.	7-9	20
7	High pesticide load 4	Exclusive and scheduled use of insecticides.	7-9	60

Site = number of areas; ID = area identification; Method = Plague management method; Years = Average of insecticide applications per lechuga cultivation cycle; Area = Average of insecticide applications per lettuce cultivation cycle).

yellow color is widely used to attract different groups of insects, including herbivorous pests (Francese et al., 2010), parasitoid wasps (Parisio et al., 2017), and pollinators (Wilson et al., 2008). The Pan traps used are bright yellow plastic bowls, 20 cm in diameter and 3 cm deep, placed just atop de ground. A 300 mL solution composed of 1/3 Propylene Glycol and 2/3 water was added to each trap.

The specimen's identification was conducted to family and then morphospecies, using a LEICA S8AP0 stereomicroscope with a LEICA MC170HD camera attached. After the entomological identification, one specimen of each morphospecies from each sampling location was mounted in an entomological pin, labeled, and deposited in the entomological collection present in the laboratory, the others were labeled and preserved in alcohol 70º, according to their sample.

To evaluate the insect community captured in the yellow pan traps, the community was evaluated in total insect abundance, pest insect abundance (these insects are known to cause damage in horticulture), entomological family richness (family richness was used because several groups were not determined at the species level, but only different morphs within the family) and types of mouthparts (licker-sucker, mandibulate, piercing-sucker and sucker) according to morphological observation. In total, 98 entomological families were recorded, with the main families of pest insects for lettuce being the families Aphididae, Thripidae, Agromyzidae, Noctuiodae and Aleyrodidae. Other families also found were: Anthomyiidae, Cicadellidae, Curculionidae, Gelechiidae, Lygaeidae, Pentatomidae, Plutellidae and Pseudococcidae.

The main insects considered pests for lettuce that were found in the areas were: *Nasonovia ribisnigri* (Hemiptera: Aphididae), *Myzus persicae* (Hemiptera: Aphididae), *Frankliniella occidentalis* (Thysanoptera: Thripidae), *Liriomyza huidobrensis* (Diptera: Agromyzidae), *Copitarsia decolora* and *Agrotis bilitura* (Lepidoptera: Noctuiodae) and *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae). Insects that perform biological control were: *Chrysocharis phytomyzae* (Brèthes, 1923) (Hymenoptera: Eulophidae), *Allograpta pulchra* (Shannon, 1927) (Diptera: Syrphidae) and *Orius insidiosus* (Say, 1832) (Hemiptera: Anthocoridae).

2.3. Satellite images

Images from the China-Brazil Earth Resources Satellite program (CBERS-4A) satellite were used, with an image date of October 9, 2020 (10/09/2020), obtained free of charge from the National Institute for Space Research (INPE). The spectral bands of the WPM camera of this satellite originally had 8 m of spatial resolution but can be merged with a panchromatic band to obtain images with 2 m of spatial resolution, considered a high resolution.

In the present study, spectral bands 2, 3, and 4 of the WPM sensors were used, stacked in the combination RGB 4-3-2 (band 4-red, band 3-green, band 2-blue), thus covering a range spectral range between 0.45 µm and 0.69 µm. The RGB image was merged with the panchromatic band (band 0: 0.45-0.90 µm) with 2m spatial resolution, resulting in a false color RGB image also with 2 m resolution, which was used for classification. land use and cover.

2.4. Classification of land use and cover

The land use classification method was the classification supervised by Maximum Likelihood, used when the intention is to classify the image into prefixed classes of interest (Santos et al., 2021b). To carry out this process, it was first necessary to carry out training. This consisted of selecting small samples of pixels in the image (along all available spectral bands), containing a few hundred pixels representative of the targets of interest, with recognized features or patterns, or identified with the help of other sources (Meneses and Sano, 2012). Thus, the classification algorithm, based on parametric methods, was trained to identify, and group the pixels within the corresponding classes, as close to reality (Santos et al., 2021b).

Land use and land cover classes were defined based on publications by Hernández et al. (2016) and Zhao et al. (2016), who made a detailed classification of land use and land cover for the entire Chilean territory in 2014 and were: Forests, water bodies, shrubland, grasslands, barren lands, and impermeable surfaces. In the present study, the urban areas class was also included, due to the proximity of large urban centers in the areas of interest. In the region, forest is classified when it exceeds 10% of trees and has more than an average hectare with more than 50 m in width and can also be classified as dense or tall shrubland. The vegetation of Pan de Azúcar corresponds to the Mediterranean desert shrubland of *Oxalis vigorosa* and *Heliotropium stenophyllum*. This type of vegetation corresponds to very open shrubland dominated by the shrubs Heliotropium stenophyllum and Oxalis vigorosa. It is present in coastal areas of the south of the regions of Ataca and north of Coquimbo 0-300 m, bioclimatic floors thermomediterranean upper hyperarid and lower arid hyperoceanic.

After land use and land cover classification, buffers of 500 m, 1,000 m, 2,000 m, and 5,000 m were created around each data collection point, so that it was possible to verify the influence of land use and land cover classes on the parameters observed at different distances. The buffers were then crossed with the classification, from which quantitative information on land use and cover was obtained for the different distances concerning the points of interest. All steps involving remote sensing, geoprocessing, and map-making were performed in the geographic information system QGIS version 3.0 (Figure 1).

2.5. Statistical analysis

For data analysis, the percentages of land use of different classes were compared: Forests, water bodies, shrub vegetation, grasslands, barren lands, and impermeable surfaces in different radii of the landscape buffer (500 m, 1,000 m, 2,000 m, and 5,000 m) with the ecological attributes: Abundance of insects, abundance of insect pests, richness of entomological families and types of oral apparatus (licker-sucker, mandible, picker-sucker, and sucker). The variables of the different land use classes are considered continuous variables and predictor variables. The different buffer radii were inserted as categories, but each buffer radius presenting its own set of continuous land use variables.

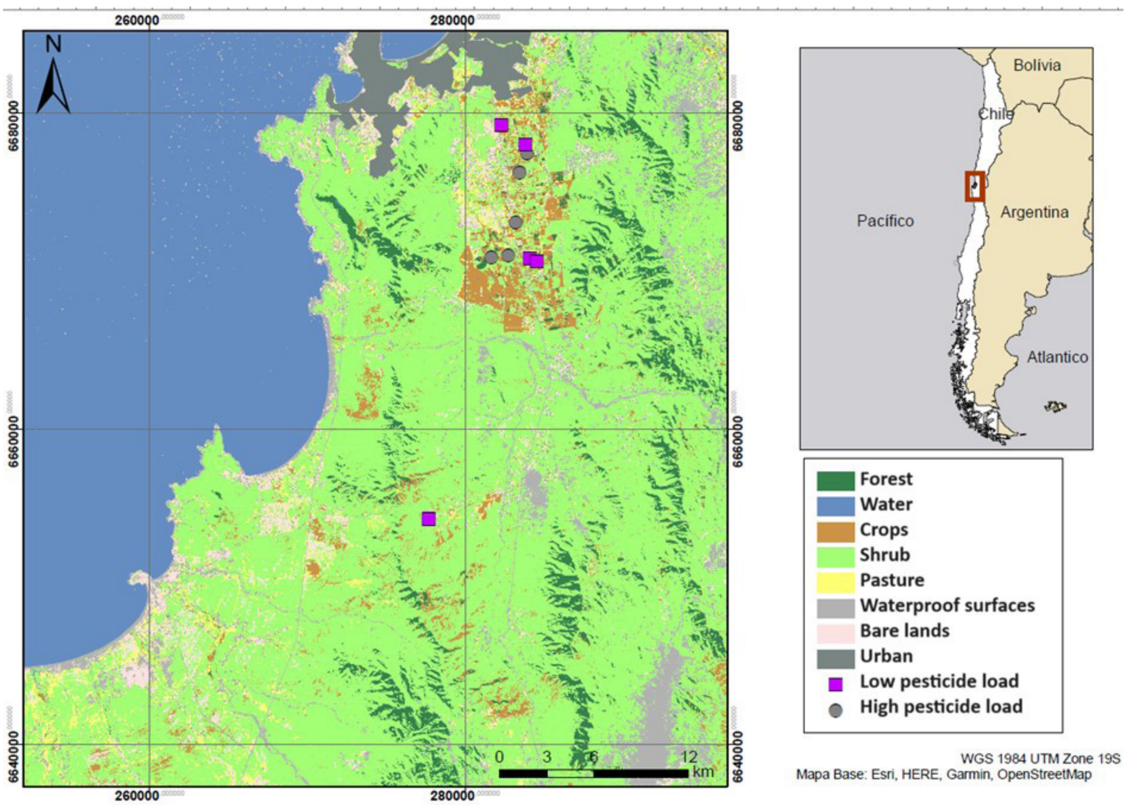

Figure 1. Map with the approximate location of the different lettuce culture sites studied in Chile.

The comparison was performed using multiple regression (General Regression Model; GRM) using all variables under consideration, but generating pairwise comparisons, observing the criterion of 95% statistical significance (p-value; without correction), standard error deviation, the t-value of each comparison, and the beta coefficient (ß). Only the relationships that showed significance were presented in the table for observation of the beta coefficient and the relationship between the variables.

3. Results

Land uses at different distances from horticultural systems affected the entomological community. Land uses that directly affected the entomological community were the forest within a 500 m radius of the horticultural system, crops also within a 500 m radius, impermeable surfaces within a 2,000 m radius, and the urban area within a 5,000 m radius.

The percentage of forest at 500 m positively influenced the abundance of insects (b=5.35; p=0.032), the number of mandibulate insects (b=3.261; p=0.01), and negatively the insects considered pests (b=-7.077; p=0.02), insect family richness (b=-3.052; p=0.006) and number of licking-sucking insects (b=-1.986; p=0.008). The percentage of crops within a radius of 500 m positively influenced the richness of insect families (b=2.857; p=0.021) and the number of licking-sucking insects (b=2.367; p=0.023). This same soil uses negatively influenced the number of mandibulate insects (b=-3.04; p=0.035).

The percentage of impermeable surfaces at a 2000 m radius positively influenced insect family richness (b=3.02; p=0.033) and the number of licking-sucking insects (b=2.04; p=0.044). The percentage of urban areas at 5000 m also positively influenced the insect family richness (b=2.42; p=0.033) and the number of licking-sucking insects (b=1.77, p=0.041). The types of oral apparatus piercing-sucker and sucker were not related to land use change (Table 2).

4. Discussion

The greatest effects on the entomofauna community were within 500 m of the horticultural cultivation surroundings. The highest percentage of forest in 500 m increased the number of insects, reduced the number of pests, reduced the number of suckers, and increased the number of mandibles. That is, the percentage of forest increasing was a benefit for the entomological community of interest in lettuce cultivation.

Among the most relevant results of this work, the understanding that changing land use around the plantation can alter the entomofauna is relevant, as it highlights that not only cultivation and management are important. Other works have already stood out, showing how changes in the landscape alter the entomological community and how this affects cultivation.

Table 2. Attributes of the general regression model between different land uses and aspects of the entomological community of lettuce horticultural systems.

		Param.	Std.Err	t	p	Beta (ß)
Forest 500	Abundance	0.00003	1.64E-06	19.45	0.032	5.35
	Pests	-0.00004	1.64E-06	-30.3	0.02	-7.07
	Family richness	-0.0101	9.85E-05	-103.31	0.006	-3.05
	Licking-sucking	-0.00018	2.53E-06	-74.49	0.008	-1.98
	Mandibulate	0.00017	2.87E-06	62.28	0.01	3.26
Crops 500	Family richness	0.017	0.0005	29.73	0.021	2.85
	Licking-sucking	0.0004	1.54E-05	27.29	0.023	2.36
	Mandibulate	-0.0003	1.74E-05	-17.84	0.035	-3.04
Impermeable surfaces 2,000	Family richness	0.021	0.001	19.07	0.033	3.02
	Licking-sucking	0.0004	2.86E-05	14.27	0.044	2.04
Urban 5,000	Family richness	0.77	0.04	18.85	0.033	2.42
	Licking-sucking	0.016	0.001	15.23	0.041	1.77

In studies of tomato cultivation in the Brazilian Cerrado, Franceschinelli et al. (2017) found that the abundance of bees pollinating the crop increases with greater coverage of surrounding native vegetation, with smaller bees (*Exomalopsis* spp.) being more affected by areas closer to crops and larger bees (*Centris* and *Bombus* spp.) are influenced by areas that are more distant from cultivation. The authors' results reinforce the relevance of maintaining natural habitats around tomato crops to increase the assemblage of pollinating bees in the crop. In another work, Nadeem et al. (2021) highlight that sucking insect pests are a major threat to cotton crops, (*Gossypium hirsutum* L.) and that the age of the plant, the stage of the crop, and the surrounding habitats affect the population fluctuation of pests, as well as the abundance of predators.

While our results align with studies conducted abroad (Ahuja et al., 2015; Franceschinelli et al., 2017) the novelty lies in the Chilean study's discovery that the most significant effects on the entomofauna community occurred within 500 m of horticultural fields. Additionally, a higher percentage of nearby forests increased the number of beneficial insects, reduced pest populations, minimized the need for reapplication, and enhanced the presence of mandibulate insects. In essence, an increased forest percentage proved beneficial for the entomological community of interest in lettuce cultivation compared to conventional pest control methods.

For the most part, insects with licking-sucking mouth apparatus were affected by negative changes in the landscape, such as changes in the use of the original vegetation, directly affecting cultivation. Apparently, insects, even beneficial crops, prefer native vegetation over lettuce crops. But the diversification of surrounding environments causes an increase in insects in agricultural crops. Mandibulate insects were associated with beneficial changes to the landscape, such as higher percentages of native vegetation or reduction in crop areas, with this group of insects being mostly insects considered predators of other insects (Nadeem et al., 2021).

Our results show, even if with a smaller effect, that the increase in land uses of impervious surfaces and urban areas, causes patterns of increase in the richness of insect families or an increase in the number of sucking insects. It is known that changing land use, even in environments other than the natural one, can cause changes in the community that may seem beneficial, but are not necessarily. Environmental change causes an imbalance, which, even if momentarily, alters the entomological community/population. Currently, several groups of fauna are being trained related to population/community expansion in urban areas, with many groups benefiting from urban expansion, causing an increase in these population groups. In a similar work, Adorno et al. (2022) identified that with the increase in the urban area in the Brazilian Cerrado, cases of malaria and leishmaniasis increased by 62% and yellow fever by 33%, all diseases spread by dipteran vectors. Freitas et al. (2023) *Melipona rufiventris* (Hymenoptera: Apidae) can reach distances of 2500 meters, but the return decreases as the distance increases and can be affected by changes in land use.

The findings from this study represent the first research in Chile comparing Integrated Pest Management (IPM) with the traditional intensive pesticide approach in the context of lettuce horticultural systems and how it affects the entomological community within these crops. Therefore, this study underscores the positive impact of IPM in lettuce horticulture by reducing the heavy reliance on chemical pesticides. IPM promotes the use of alternative pest control methods, such as assessing soil permeability and the presence of nearby forests, alongside proper crop management, all of which reduce the need for pesticides.

Furthermore, our research demonstrates that the IPM strategy allows for the conservation of beneficial soil organisms, including natural pest predators and pollinators, as supported by previous studies in various crop types (Ahuja et al., 2015; Bueno et al., 2021; Parra et al., 2022). By maintaining healthy populations of these organisms, we observed that the necessity for pesticides could be reduced, promoting a natural balance within the ecosystem and avoiding overapplication and unnecessary agrochemical use.

We believe that IPM, with its holistic approach that considers factors like weather conditions, crop diversity, and soil health in pest management, addresses the root causes of pest issues and prevents future outbreaks (Dara, 2019). Consequently, IPM mitigates the risk or vulnerability to reduced crop yields.

However, agricultural producers in Chile have limited awareness of the advantages of using IPM to control crop pests (Sun et al., 2022). Various studies with agricultural workers in Chile have shown limited use of personal protective measures and the excessive application of various hazardous pesticides in fruit and vegetable cultivation (Ramírez-Santana et al., 2018; Muñoz-Quezada et al., 2014; Zúñiga-Venegas et al., 2022). This phenomenon is also observed in international studies, where the combination of limited awareness of climatic variables influencing IPM efficiency and the use of traditional methods with agrochemicals that make pests more resistant, thereby eliminating beneficial insects for pollination and natural pest control, leads to a dependency on a pesticide-based pest control approach (Rahman, 2022).

While there are regulations and guidelines for terrestrial and aerial pesticide applications to regulate and control pesticide usage, studies revealing the presence of multiple residues in environmental, food, and hazardous pesticide matrices among the agricultural population highlight the challenges faced by authorities in monitoring the vast agricultural land and the limitations in enforcing resolutions prohibiting hazardous pesticide use (Muñoz-Quezada et al., 2012, 2020). Moreover, the regulations for terrestrial pesticide applications only require a 50 m distance from other properties or rural communities, rendering this measure ineffective in proving that nearby populations or other adjacent crops are not exposed to environmental drift. An alternative to mitigate this situation lies not only in increasing application distances in crops but, as demonstrated in this study, in the possibility of incorporating forests as a natural barrier to prevent environmental drift and foster beneficial insect development for crops.

Therefore, IPM represents an effective strategy for reducing the impact of pesticides on agricultural soil and the environment, necessitating implementation as a central component of both national and regional agricultural development policies in Chile. By promoting more sustainable agricultural practices centered around biodiversity conservation, IPM contributes to the long-term health of the soil and the well-being of agricultural ecosystems.

5. Conclusion

The greatest effects on the entomofauna community were within 500 m of the horticultural cultivation surroundings. The highest percentage of forest in 500 m increased the number of insects, reduced the number of pests, reduced the number of suckers, and increased the number of mandibles. That is, the percentage of forest increasing was a benefit for the entomological community of interest in lettuce cultivation. For the highest percentage of crops at 500 m, that is, in areas that are close to other crops, the effects were negative. It increased the number of licking-sucking insects and reduced the number of mandibulate insects.

Agricultural land use exerts a significant impact on the entomological community, which plays a pivotal role in food production and the well-being of agricultural ecosystems. The traditional pesticide-based approach can be detrimental to this community, affecting agricultural soil quality, eradicating beneficial insects, and fostering resistance issues in pests.

Integrated Pest Management (IPM) emerges as an effective and sustainable solution to address these challenges. In the context of lettuce and vegetable production in Chile, where knowledge about IPM is limited, education and promotion of this strategy are imperative. By embracing IPM, a balance can be struck between agricultural production and biodiversity conservation, ensuring long-term food security and the well-being of the entomological community.

These findings underscore the significance of adopting sustainable agricultural practices and the effective implementation of regulations for responsible pesticide use. Furthermore, they highlight the need to continue researching and monitoring pesticide presence in the environment to gain a deeper understanding of its impact on agricultural ecosystems and biodiversity health.

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