Original Research Article

Population dynamics of arthropods in New Caledonian citrus orchards

ABSTRACT

Aims: Agroecological infrastructures are central to the preservation of arthropod populations and ecosystem services associated. There is little data on the population dynamics of New Caledonian citrus orchards. Thus, this study focuses on the response of arthropods to four management methods in the orchard: conventional management, inter-row vegetated, row mulching and edge windbreaks.
Place and Duration of Study: This study was conducted in the village of La Foa in New Caledonia. It took place over three months, from the end of February to the end of May 2022.
Methodology: To collect the greatest possible diversity of insects, four complementary trapping methods were used: pitfall traps, yellow plates, Malaise traps and sweeping bags. Once collected, the trapped insects are then sorted and identified. The sorting is done with a binocular magnifying glass. Insects are identified using specific determination keys, documentation, or with the help of the Reference Collection of Terrestrial Invertebrates of New Caledonia - Xavier Montrouzier (CXMNC),. When identification is not immediately possible, a morphotype number is assigned. For each species and morphospecies, a photograph is taken.Alpha and beta diversity was studied using rarefactions, Shannon index and Generalized Linear Models.
Results: A positive effect of agroecological infrastructures on insects' abundance and diversity was recorded. In contrast, low arthropod abundances and diversities were presented in the orchard under conventional management ($P < 0.001$). The mulch management was the parameter with a much higher insects' abundance. Moreover, the dynamics of the populations are generally correlated with the related infrastructures. Thus, the windbreaks acted as ecological corridors and the inter-row vegetation as refuge habitats for auxiliary insects.
Conclusion: These results demonstrate the damage of conventional agriculture on arthropod diversity in New Caledonian orchards.

Keywords: Entomological inventory, agroecological infrastructure, management methods, trophic guild, biological control, citrus, New Caledonian orchards

1. INTRODUCTION

New Caledonia is particularly vulnerable to the current mass extinction crisis of biodiversity affecting arthropod populations [1; 2; 3]. Although this decline is multifactorial, conventional agriculture plays a significant role [4]. This is caused by the homogenization of landscapes leading to the loss of semi-natural habitats, pesticide toxicity and mechanization of agricultural practices that reduce the diversity and abundance of plants on which insects directly depend [5; 6]. The decline of arthropods threatens the very functioning of agroecosystems. Indeed, their functions as detritivores, phytophagous, predators or parasitoids and, pollinators provide ecosystem services that directly affect production. These include pollination, pest regulation and recycling of organic matter, especially [7]. Their loss is therefore expected to have serious economic consequences in addition to ecological ones [8].
To limit as much as possible, the loss of biomass and diversity of arthropods and their related services, the development of agroecology and its biodiversity conservation practices are becoming a major issue [9]. These practices include agroecological infrastructures (AEI) that allow the development of natural or semi-natural habitats that function as refuges for insect biodiversity [10]. These include plant cover [7], windbreaks [11] and mulching [12]. Diversifying landscape heterogeneity in agricultural environments allows arthropods to access more diverse resources and habitats often accompanied by a general trend towards increasing arthropods abundance and diversity [13].

However, there are still few studies on the impact of management practices on insect communities in New Caledonia. Yet New Caledonian ecosystems are known for their important level of biodiversity [14]. Thus, the integration of AEIs in tropical agrosystems represents an important lever for biodiversity conservation. The objective of this study is to compare management methods in New Caledonian citrus orchards through the prism of arthropods abundance and diversity and bio-indicators. To this end, this study presents the response of arthropods through taxonomic and functional approaches to four management modes in fruit arboriculture. These practices correspond to conventional management, inter-row grassing, row mulching and windbreaks.

2. METHODOLOGY

2.1 Study Sites and Design

This study was conducted in the village of La Foa on the west coast of Grande Terre, 115 km northwest of Nouméa, New Caledonia. Data collection took place over three months from the end of February to the end of May 2022. This period was particularly marked by heavy rainfall episodes caused by La Niña and very high temperatures compared to seasonal norms.
Trapping was carried out weekly on four citrus orchards (Fig. 1). Two of the orchards are located at the Pocquereux Fruit Research Station of the New Caledonian Agronomic Institute. These are the experimental orchards of “Tazar” and “Dormeur” with various citrus varieties and mandarin trees respectively. The other two orchards are grower-owned Navel orange orchards. The citrus trees in each orchard produced fruit throughout the entomofauna trapping period.

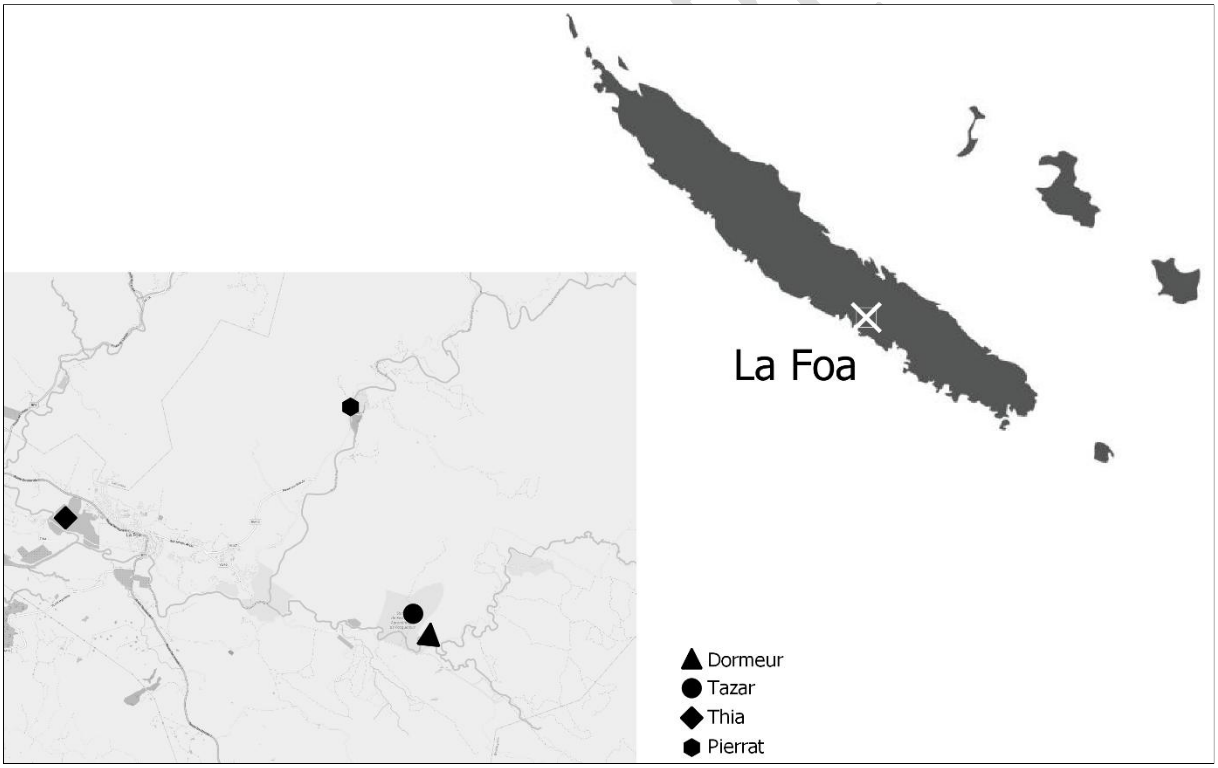

Fig. 1. Location of the orchards.

To standardize the sampling effort, an area of approximately 2,500 m² was delimited in each of the orchards, within which the surveys were conducted.

2.2 Characterization of Orchards and Bioindicators

2.2.1 Orchards

Each orchard has its own specific characteristics (Fig. 2).

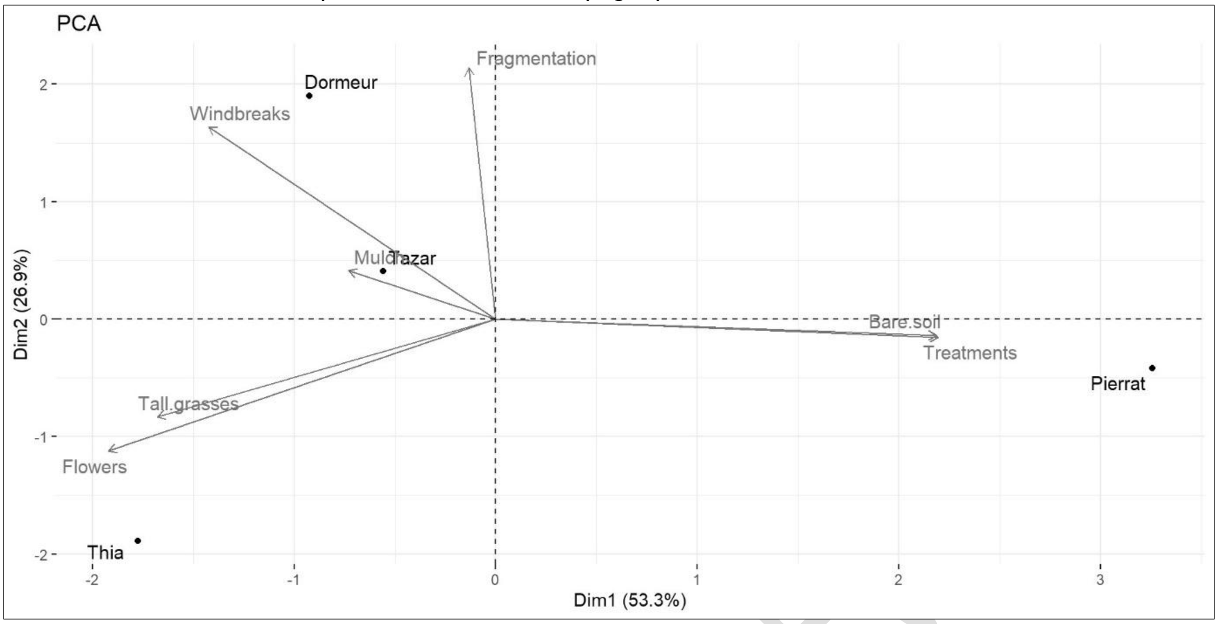

Fig. 2. PCA of the different orchards and their environmental characteristics.

"Pierrat" is the orchard run under conventional agriculture. It has no AEI, just seven windbreaks per hectare and a high percentage of bare soil. In this orchard, six insecticide applications and five herbicide applications are conducted every year, as well as an oil application every month.
"Dormeur" has AEIs of *Casuarina collina* hedges with approximately 231 trees per hectare. No insecticides are used in this orchard, but three herbicide treatments are conducted each year.
"Tazar" is the only orchard with an extremely high percentage of mulch. There are about 105 trees of *Casuarina collina* per hectare. There is no insecticide in this orchard and only one adjuvant herbicide treatment per year is applied.
"Thia" has been untreated for two years and has many flowers and tall grasses. There are 83 *Casuarina collina* per hectare acting as windbreaks.
All the orchards except Pierrat are grassed in the inter-rows.

2.2.2 Bioindicators Choice

2.2.2.1 Spiders

Spiders, through their functional diversity, cover the diverse levels of the trophic chain. Indeed, spiders are among the largest groups of generalist predators feeding on pests [15]. Their density is related to the structural complexity of the environment [16]. They are therefore of great interest to indicate the quality of habitats, especially at the plot level [17].

2.2.2.2 Mites

Mites have often been used as indicators of habitat diversity and quality, particularly in soils [18; 19; 20]. However, it should be borne in mind that mites have an extremely high diversity and are taxonomically poorly recognized, which makes their identification difficult. Indeed, mites have different behaviors, ranging from predatory to parasitic to phytophagous [21].

2.2.2.3 Orthopterans

Orthopterans such as crickets are also known to be indicators of undisturbed [22; 23] and unpolluted environments [24; 25].

2.2.2.4 Beetles

Beetles can be considered as representative of insects in general due to their taxonomic and ecological diversity [26].
At the family level, the Nitidulidae, Tenebrionidae and Chrysomelidae can be useful indicators, as their diversity is correlated with that of other taxa such as scorpions, millipedes, and some butterflies [27].

2.3 Trapping Methods

In an aim to collect as much insect diversity as possible, three complementary trapping methods were used.

2.3.1 Pitfall Traps

To intercept epigeous invertebrates that move on the ground, pitfall traps were set up. This trapping method consists of burying pots on the surface of the soil. These pots are filled with approximately 100 ml of coolant, which limits the decomposition of the trapped insects while avoiding evaporation of the liquid during the trapping period. Each pot is protected from the weather by a lid, which is made from a plate and nails.
As the orchards had a homogeneous structure, the placement of the pitfall traps was standardized as follows: three pitfall traps were randomly distributed in the borders, three in the rows and three in the inter-rows. No pitfall traps were placed in the inter-rows of the Pierrat plot because of the regular passage of agricultural machinery. This arrangement of traps is intended to differentiate the fluctuation of arthropods according to the layout of the plots.
The pitfall traps were collected every seven days.

2.3.2 Yellow Plates

To attract floricultural flying insects such as pollinators, yellow plates were used for their color. Each trap color brings a different species range and variation in abundance and diversity. Yellow is known to collect many Diptera, Hymenoptera and some Coleoptera.
Once a week, eight yellow plates are placed for two hours in the morning. Four are placed randomly in the inter-rows and four in the borders.
The insects are trapped in soapy water containing 5 mL of washing-up liquid per 1 L of water.

2.3.3 Grass Sweeping

The fauna sampling was completed by means of a sweeping bag. Sweeping allows the collection of all types of insects present on the paths or in the tall grass.
Each week, four sweepings per orchard were carried out randomly in non-fixed quadrats of 1 m². Then, a few undefined diagonals transect were swept to collect other insects in an opportunistic way.

2.4 Sorting and Identification

The trapped insects through the different techniques described above are then sorted and identified. Sorting is conducted with a binocular magnifying glass. The insects are identified using specific determination keys, documentation, or with the help of the Reference Collection of Terrestrial Invertebrates of New Caledonia - Xavier Montrouzier (CXMNC), which is available at the IAC.
When identification is not possible immediately, a morphotype number is assigned. For each species and morphospecies, a photograph is taken.

2.5 Statistical Analysis

All statistical tests and fitting of the models presented were performed with RStudio software (desktop version).

2.5.1 Rarefactions

The rarefaction curves correspond to the number of species observed (species richness) as a function of the number of individuals sampled. These curves are constructed by a series of random draws of a given number of individuals from the inventory. They were produced using the devtools, iNEXT and ggplot2 packages. They allow for easy visualization of alpha diversity while providing an extrapolation that helps predict true diversity given the expected number of species not detected by the sampling effort.

2.5.2 Shannon index

The Shannon index, generated with vegan package, is used to study the specific diversity of a population of individuals. That is, the number of species present in a stand. If the Shannon index is made up of a single species, then the index will be equal to 0. Note that Shannon is sensitive to variations in the importance of the rarest species.

2.5.3 Generalized linear models

As the abundance data are count data, the distribution of the data is not normal, so the statistical tests used are non-parametric. Theoretically, count-type responses follow a Poisson distribution with a Lambda parameter. Thus, generalized linear models (GLM) are performed with Poisson regression. However, many results from GLMs show over-dispersion. In this case, the quasi-Poisson error structure was added to the regression model.
For data with a normal distribution such as climate data, simple linear regressions (LR) were performed.
Each model is followed by Tukey's multiple mean comparison test where the multcomp package was used.
Thus, the aim of the linear regressions is to define a significant difference, which is statistical evidence that there is a difference between two model values.

3. RESULTS AND DISCUSSION

Table 1. Abundance of orders from different orchards.
The numbers in the lines followed by the same letter are not significantly different, P < 0.05.
Only orders with a relative abundance above 5% are represented.

	Dormeur	Pierrat	Tazar	Thia
Diptera	535 ab	832 b	719 ab	423 a
Acari	206 b	29 a	1614 c	320 b
Hymenoptera	297 a	660 b	661 b	549 ab
Hemiptera	535 b	832 a	719 c	423 b
Aranea	515 b	228 a	273 a	272 a
Orthoptera	687 b	193 a	271 a	197 a
Julida	273 b	24 a	312 b	400 b
Coleoptera	255 b	90 a	394 b	219 b
TOTAL	**3315 a**	**2205 a**	**5520 b**	**2845 a**

3.1 The management method in conventional farming

This study is related to many other studies that mention the massive destruction of insect biodiversity by conventional agriculture [28; 29; 30]. Indeed, in Pierrat's conventional orchard with numerous treatments and almost bare soil, the low presence of biodiversity (Table 2), especially of beetles ($P < 0.001$) which are a representative bioindicator of biodiversity, confirms the hypothesis that the application of broad-spectrum insecticides leads to a decrease in the diversity and density of insects on the land surface (Table 1).

Table 2. Shannon index of the four orchards.

	Dormeur	Pierrat	Tazar	Thia
Shannon	3.047908	2.825924	3.042488	3.327141

In this orchard, Diptera ($P < 0.001$) are highly abundant, including Phoridae ($P < 0.001$), a family of small flies resembling Drosophila (Table 2). They are found in a wide range of habitats and have varied feeding habits. Most species consume decaying organic matter. Others specialise in eating slug eggs or as parasites of many insects [31]. These Phoridae have a high potential for resistance to insecticides [32]. This would explain their numerous presences in this orchard under conventional agriculture.

Table 3. Abundance of Diptera families in different orchards.

The numbers in the lines followed by the same letter are not significantly different, P < 0.05. Only families with a relative abundance above 5% are represented.

	Dormeur	Pierrat	Tazar	Thia
Phoridae	247 a	592 c	324 b	203 a
Dolichopodidae	67 ab	59 a	92 b	61 ab
Muscidae	51 a	49 a	120 b	51 a
Drosophilidae	75 c	56 bc	23 a	35 ab
Others	45 a	56 a	99 b	53 a
TOTAL	**485 b**	**812 d**	**658 c**	**403 a**

Moreover, it is interesting to note that, in terms of hemipterans, the conventional orchard is the only one where Lygaeidae do not dominate, but where Aphididae are found on the contrary (Table 3).
Aphididae or aphids are plant-eating suckers widely recognised as pests and can cause a lot of damages [33], either directly by consuming the plant or indirectly by infesting the plant with viruses. Their presence can be related to the high abundance of ants which are known to favour aphids through mutualistic interactions (exchange of honeydew for protection) [34].

Table 4. Abundance of different orchards in hemipteran families.

The numbers in the lines followed by the same letter are not significantly different, P < 0.05. Only families with a relative abundance above 5% are represented.

	Lygaeidae	Aphididae	Miridae	Alydidae	Others
Dormeur	416 c	33 b	45 b	11 a	42 b
Pierrat	23 b	89 c	15 ab	1 a	22 b
Tazar	772 d	197 c	137 b	20 a	148 bc
Thia	192 b	45 a	31 a	145 b	52 a

3.2 The management method with grassing in the inter-rows

The presence of very diversified and flower-rich mixtures is highly beneficial for the insect's present [35]. Moreover, several studies have demonstrated the positive effect of inter-row vegetation on insect communities with a general trend towards increased abundance and diversity [9; 36; 37].
In two of the three grassed orchards, there were significantly more ants known to be favoured by the presence of vegetation cover [10].
In addition, spiders of the Lycosidae family, bioindicators of habitat quality, were significantly more abundant in the inter-rows ($P = 0,025$), as were orthopterans, indicators of undisturbed environments. In fact, the orchard with the highest number of orthopterans of the family Gryllidae is managed under conservation agriculture and has a high floristic diversity (Table 1).

3.3 The management method with mulching

Of the four orchards studied, the Tazar orchard with row mulch had significantly higher insect abundance, particularly of beneficial insects ($P < 0.001$) (Table 5). Numerous studies have shown that the presence of mulch in orchards can have a beneficial impact on pests [12; 38; 39].

Table 5. Abundance of beneficial insects in different orchards.

The numbers in the lines followed by the same letter are not significantly different, P < 0.05.

	Dormeur	Pierrat	Tazar	Thia
Beneficials	1669 a	1057 a	3466 b	1737 a

Mulch coverage is strongly correlated with the presence of saprophagous, particularly Oribatidae ($P < 0.001$) (Table 6). These are frugivorous and detritivores mites that feed on substrates and organic matter. They play a significant role in the decomposition process by consuming microbial populations or by fragmenting organic matter [40]. They are also recognised as indicators of soil diversity and quality.

Table 6. Abundance of Oribatidae, Formicidae and Lygaeidae in different orchards.

The numbers in the lines followed by the same letter are not significantly different, P < 0.05.

	Dormeur	Pierrat	Tazar	Thia
Oribatidae	170 b	27 a	1479 c	251 b
Formicidae	132 a	340 b	316 b	320 b
Lygaeidae	416 c	23 a	772 d	192 b

In the mulched orchard, there are many ants ($P < 0.001$) that are widely recognised as natural biological control agents that regulate pest populations in tropical regions [41]. However, many bugs of the family Lygaeidae ($P < 0.001$) considered as phytophagous biting-suckers are also present (Table 6).

Insects are more abundant in the inter-rows (Fig. 3). This can be linked to the importance of the inter-row grass cover($P < 0.001$). Thus, the movement of individuals between the mulched rows may justify this result.

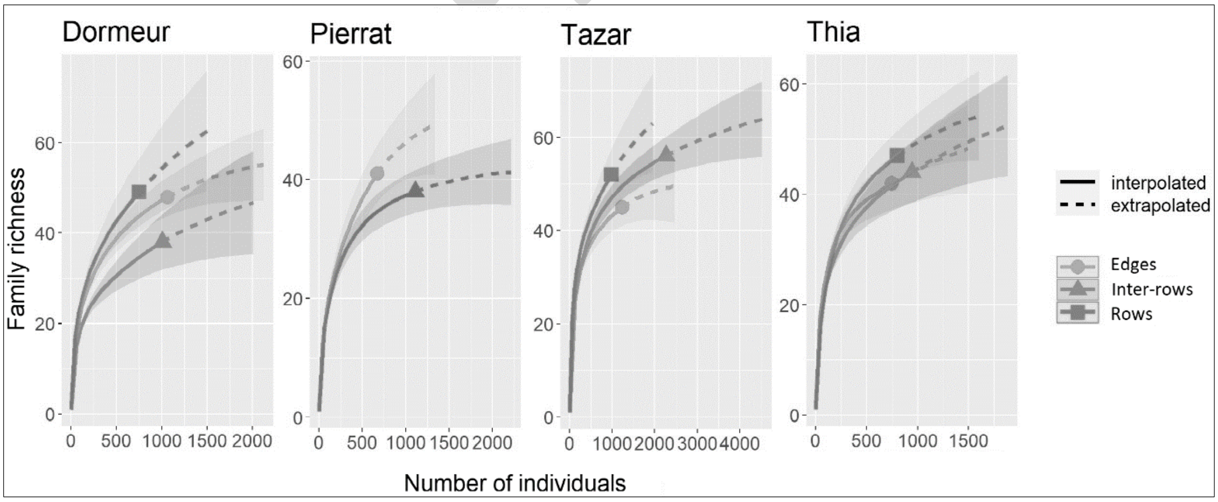

Fig. 3. Rarefactions of different orchards according to locations.

3.3 The management method with windbreaks

In landscape dynamics, ecological corridors such as windbreaks play a key role in increasing landscape heterogeneity. Indeed, the presence of uncultivated habitats in the landscape is favourable to predators and parasitoids [42; 43]. In the study plots, the windbreaks present are *Casuarina collina*. They occur as large trees, thriving on a wide range of mineral-deficient soils. It is an endemic species of New Caledonia and presents as the dominant species in disturbed land due to its rapid growth, suckering ability, and fire resistance, thus having a high potential for rehabilitation of degraded sites [44]. However, *Casuarina collina* margins are not known for their abundant biodiversity.

Therefore, little population difference exists between edges and orchards. It would seem that the host conditions are equivalent between these two locations. However, it should be noted that beneficial insects ($P < 0.001$) are more present in the borders of the Dormeur orchard, which has many windbreaks per hectare. In fact, two bioindicators of habitat quality, saprophagous mites ($P < 0.001$) and predatory spiders ($P < 0.001$), were significantly more abundant in the borders of this orchard (Table 7).

Table 7. Abundance of Acari, Aranea and beneficial insects in relation to Dormeur locations.

	Edges	Inter-rows	Rows
Acari	109 b	32 a	60 a
Aranea	340 b	103 a	45 a
Beneficials	729 b	384 a	285 a

4. CONCLUSION

In the context of the importance of conserving arthropod biodiversity by integrating AEIs into New Caledonian citrus orchards, this study revealed differences in insect abundance and diversity in each management mode.

Indeed, low arthropod abundances and diversity in the orchard under conventional management were revealed. In comparison, the orchards with agroecological infrastructures, such as inter-row grassing, windbreaks at the edges or mulching on the rows, had more varied and abundant vegetation and entomofauna.

The plot with mulch has a much higher abundance of insects. Population dynamics are generally correlated with the corresponding infrastructure. For example, windbreaks acted as ecological corridors and inter-row cover as refuge habitats for crop protection agents.

Thus, agroecological management methods make it possible to implement habitats that are essential for biodiversity. In a context of vulnerability of New Caledonian biodiversity, conservation measures should be implemented to preserve the diversity of arthropods and associated ecosystem services, as has already been done in other island contexts [45; 46].

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