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EFECTO DE LAS PRÁCTICAS DE MANEJO Y DEL PAISAJE SOBRE LOS GREMIOS DE ARTRÓPODOS EN CULTIVOS DE PAPAYA EN LA COSTA DE JALISCO, MÉXICO

TESIS

(**POR ARTÍCULO CIENTÍFICO**)

THE EFFECT OF FARMING PRACTICES AND LANDSCAPE ON ARTHROPOD FUNCTIONAL GROUPS IN PAPAYA CROPS. IS INTENSIVE MANAGEMENT WORTH IT?

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We argue that recent advances in ecological research make that general approach [to agriculture and conservation] anachronistic and call, rather, for solidarity with the small farmers around the world who are currently struggling to attain food sovereignty. They are environmentalist in their own right and the most powerful allies of those who want to conserve the biological diversity of our planet.

(Argumentamos que los avances en investigación ecológica recientes hacen una aproximación anacrónica [al tema de agricultura y conservación] y llamamos, en cambio, a la solidaridad con los pequeños agricultores alrededor del mundo quienes están actualmente lidiando con atender la soberanía alimentaria. Ellos son ambientalistas por derecho propio y los aliados más poderosos de aquellos que buscan conservar la diversidad biológica en nuestro planeta.)

-Ivette Perfecto

John Vandermeer

Angus Wright,

Nature's Matrix: Linking agriculture, conservation and food sovereignty, 2009

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RESUMEN

Los artrópodos pueden dividirse en gremios dependiendo de sus hábitos alimenticios y estos gremios pueden ser benéficos o perjudiciales para los sistemas agrícolas. Un ejemplo de lo anterior se hace evidente en el papel de los herbívoros y sus depredadores, mientras que los herbívoros pueden causar pérdidas substanciales a la producción, sus depredadores son capaces de contrarrestar estas pérdidas al brindar servicios ecosistémicos de control biológico.

En la literatura se identifican dos factores que afectan a las comunidades de artrópodos en los cultivos, por un lado están las prácticas de manejo que llevan a cabo los agricultores y por otro, el contexto del paisaje en el que se encuentran embebidos los cultivos. Por lo anterior, el objetivo de este estudio fue evaluar los efectos directos e indirectos de las prácticas de manejo y del paisaje circundante sobre los gremios de artrópodos y finalmente sobre el daño en el cultivo y la producción. Para esto se monitorearon 11 plantaciones de papaya en la costa de Jalisco, la cual se caracteriza por presentar parches de vegetación de bosque tropical seco (BTS) conservado. Cabe mencionar que México es centro de origen y diversificación de la papaya (*Carica papaya*) y que el 99% de las plantaciones actuales del país siembran una variedad cubana. La variedad cubana (Maradol) es más suceptible a plagas que la variedad nativa y esto repercute en las formas de manejo ya que esta variedad requiere un mayor uso de plaguicidas.

Para el análisis se planteó un modelo de ecuaciones estructurales en el que se incluyeron como variables exógenas el manejo; el paisaje y las propiedades del suelo y como variables endógenas la abundancia de artrópodos herbívoros y depredadores, el daño en las plantas y la producción final de frutos.

Los resultados mostraron que en cultivos con mayor intensidad de manejo, caracterizados por ser monocultivos con un alto uso de plaguicidas y fertilizantes químicos, la abundancia de artrópodos depredadores es menor y que esto tiene reprecuciones negativas en la producción de frutos. Mientras que la abundancia de plagas fue la misma para formas de manejo poco intensivas e intensivas, lo que muestra que el manejo intensivo no cumple su cometido de disminuir a las plagas. La producción resultó ser casi del doble en cultivos con manejo alternativo. Finalmente, el manejo alternativo parece ser una opción sustentable para la producción de papaya en la región y hace falta trabajo transdisciplinario para entender y desencadenar cambios en las decisiones de manejo de los agricultores.

ABSTRACT

Arthropods can be divided into guilds depending on their eating habits and these guilds can be beneficial or detrimental to agricultural systems. An example of the above is exhibited in the role of herbivores and their predators, while herbivores can cause substantial crop losses, their predators are able to counteract these losses by providing ecosystem services of biological control.

The literature identifies two factors that affect arthropod communities in crops, which are the management practices and the landscape context. The aim of this study was to evaluate the direct and indirect effects of management practices and the surrounding landscape on the arthropod guilds and finally on crop damage and yield. To asses the above, were monitored 11 papaya plantations on the Jalisco coast, which landscape is characterized by patches of preserved tropical dry forest vegetation (TDF). It is worth mentioning that Mexico is the center of origin and diversification of the papaya (*Carica papaya*) and that 99% of the current plantations in the country use a Cuban variety. The Cuban variety (Maradol) is more susceptible to pests than the native variety and it requires greater use of pesticides.

For the analysis, a structural equation model (SEM) was proposed in which management, landscape and soil properties were included as exogenous variables and the abundance of herbivorous and predatory arthropods, the crop damage and the final production of fruits as endogenous variables.

The results exhibited that in crops with higher management intensity, characterized by being monocultures with a high use of chemical pesticides and fertilizers, the abundance of predatory arthropods was lower than in less intensive management crops. While the abundance of pests was the same for all management practices, which demonstrates that intensive management does not fulfill its role of reducing pests. The yield was almost double in crops with alternative management practices. Finally, alternative management seems to be a more sustainable option for papaya production in the region and transdisciplinary work is needed to understand and trigger changes in farmer management decisions.

INTRODUCCIÓN

Los artrópodos cumplen funciones importantes en los ecosistemas debido a la diversidad de sus hábitos alimenticios y a sus dinámicas poblacionales, por esta razón resultan ser beneficiosos o perjudiciales para las actividades humanas. Se ha estimado que entre el 18 y el 20% de las pérdidas en los cultivos en agroecosistemas se pueden atribuir a artrópodos herbívoros (Oerke, 2006; Sharma et al., 2017). En este contexto, la presencia de depredadores y parasitoides de otros artrópodos cobra relevancia debido a que representan un servicio ecosistémico potencial de regulación de plagas para los diferentes cultivos (Isaacs et al., 2009; Zhang et al., 2007).

Se han identificado dos factores fundamentales que influyen en la diversidad y abundancia de los artrópodos al interior de los agroecosistemas, el primero se refiere al contexto del paisaje en el que se encuentra localizado el cultivo (Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Molina et al., 2015; Perfecto and Vandermeer, 2002; Thies et al., 2005; Weibull et al., 2003; Winqvist et al., 2011) y el segundo a las prácticas agrícolas (Attwood et al., 2008; Clough et al., 2007; Landis et al., 2000; Letourneau and Goldstein, 2001; Morales et al., 2001; Sosa-Aranda et al., 2018; Winqvist et al., 2011; Zehnder et al., 2007). Estudios previos han mostrado que las poblaciones de enemigos naturales de las plagas, es decir, artrópodos depredadores y parasitoides tales como escarabajos, crisopas y arañas, son más susceptibles que los herbívoros plaga a paisajes degradados, homogéneos y con baja cobertura de vegetación natural, así como a prácticas agrícolas intensivas, caracterizadas por monocultivos con un alto uso de pesticidas u otros insumos agrícolas químicos (Attwood et al., 2008; Bengtsson et al., 2005). Estos efectos en las comunidades de artrópodos se han asociado con la dependencia de los enemigos naturales de fuentes secundarias de alimentación (principalmente néctar u otras presas) y con sitios de refugio o anidación, que suelen encontrarse en ambientes naturales más complejos y con mayor heterogeneidad espacial (Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Karp et al., 2018). Aunado a esto, los enemigos naturales suelen ser menos resistentes a los plaguicidas que las plagas (Theiling and Croft, 1988).

A pesar de que existe una gran cantidad de estudios enfocados en cómo las prácticas agrícolas y la heterogeneidad del paisaje afectan a las comunidades de artrópodos (Bianchi et al., 2006; Chaplin-Kramer et al., 2011), sólo algunos han evaluado simultáneamente las poblaciones de plagas y las de sus enemigos naturales, y menos han tomado en cuenta los efectos en cascada que ambos pueden tener sobre el daño en el cultivo y la producción (Chaplin-Kramer et al., 2011; Grab et al., 2018; Letourneau and Bothwell, 2008). Si las decisiones de los agricultores sobre las prácticas de manejo se sustentan en un mejor desempeño del cultivo, la investigación en el campo de los agroecosistemas debería de considerar variables como el daño en las plantas y la producción.

CULTIVOS EN LOS BOSQUES TROPICALES SECOS DE MÉXICO

Los Bosques Tropicales Secos (BTS albergan una gran cantidad de especies endémicas (Gentry, 1995) y debido al cambio de uso de suelo para uso agrícola y ganadero, también presentan muchas especies en peligro de extinción. Sólo en México, el 60% de este tipo de vegetación se ha perdido debido al impacto de estas actividades humanas (Quesada et al., 2009). Por esta razón, es necesario y urgente encontrar prácticas de manejo sustentables para estas actividades económicas en la región (Quesada et al., 2009; Sánchez-Azofeifa et al., 2009). En los últimos años, es posible que los BTS se hayan visto afectados por el cultivo de papaya (var. Maradol), ya que dicho cultivo ha incrementado su producción en un 30% en el país (SAGARPA, 2017) y se estima que anualmente se producen 952 millones de toneladas de esta fruta en el país, equivalentes a 86.7 millones de dólares. A pesar de que México es centro de origen de papaya (*Carica papaya*), desde 1978 las variedades nativas han sido substituidas por la variedad cubana Maradol (SAGARPA, 2005). Hoy en día únicamente el 1% de los cultivos corresponden a variedades nativas mientras que Maradol abarca el 99% de las plantaciones (SAGARPA, 2017). Las papayas Maradol son susceptibles a múltiples enfermedades causadas por virus, principalmente el virus de la mancha anular, que es transmitido por artrópodos que succionan savia de las plantas. Entre estos herbívoros destacan los ácaros y áfidos, como la araña roja (*Tetranychus sp.*) y la mosquita blanca (Hemiptera: Aleyrodidae) (Castrejon Antonio, 2014). Generalmente, estos vectores son controlados con el uso de agroquímicos o favoreciendo la presencia de insectos benéficos como coccinelidos, crisopas, y otros depredadores.

El cambio de uso de suelo ha provocado que las regiones de BTS presenten parches de vegetación conservada, sucesión secundaria y cultivos. Resulta entonces interesante evaluar, tomando como ejemplo el cultivo de papaya, el efecto de la composición del paisaje y de las prácticas agrícolas a nivel local sobre la comunidad de plagas y sus enemigos naturales, y el efecto en cascada que estos factores pueden tener sobre el daño y producción del cultivo. El objetivo principal de esta investigación fue identificar estos efectos a través de un modelo de ecuaciones estructurales en cultivos de papaya con diferentes intensidades de manejo y con diferente porcentaje de bosque tropical seco (BTS) circundante. Las predicciones en torno a este objetivo fueron las siguientes: (a) un efecto negativo del manejo intensivo sobre la abundancia de plagas y de enemigos naturales por el uso de plaguicidas y (b) un efecto positivo del paisaje natural sobre los mismos, dado que habría mayor cantidad de recursos para ambos grupos. Asimismo, cultivos con una (c) mayor cantidad de enemigos naturales tendrían una menor cantidad de plagas si se da un control biológico y (d) que cultivos con mayor cantidad de plagas presenten un mayor daño en las hojas, y en consecuencia, (e) una menor producción de papaya. El modelo propuesto (Fig. 1) toma en cuenta la disponibilidad de fósforo como variable exógena ya que es un factor limitante para la productividad de las plantas en los BTS (Martinez-Yrizar and Sanford, 2011). Por lo anterior, Se esperaba que (f) los cultivos con una mayor cantidad de fósforo disponible tuvieran menor daño y mejores cosechas, independientemente del efecto de los artrópodos. Por otra parte, se esperaba que el uso intensivo de agroquímicos (pesticidas y fertilizantes) disminuyera el daño en las plantas (g) y aumentara la producción (h) como consecuencia del uso de fertilizantes y pesticidas respectivamente.

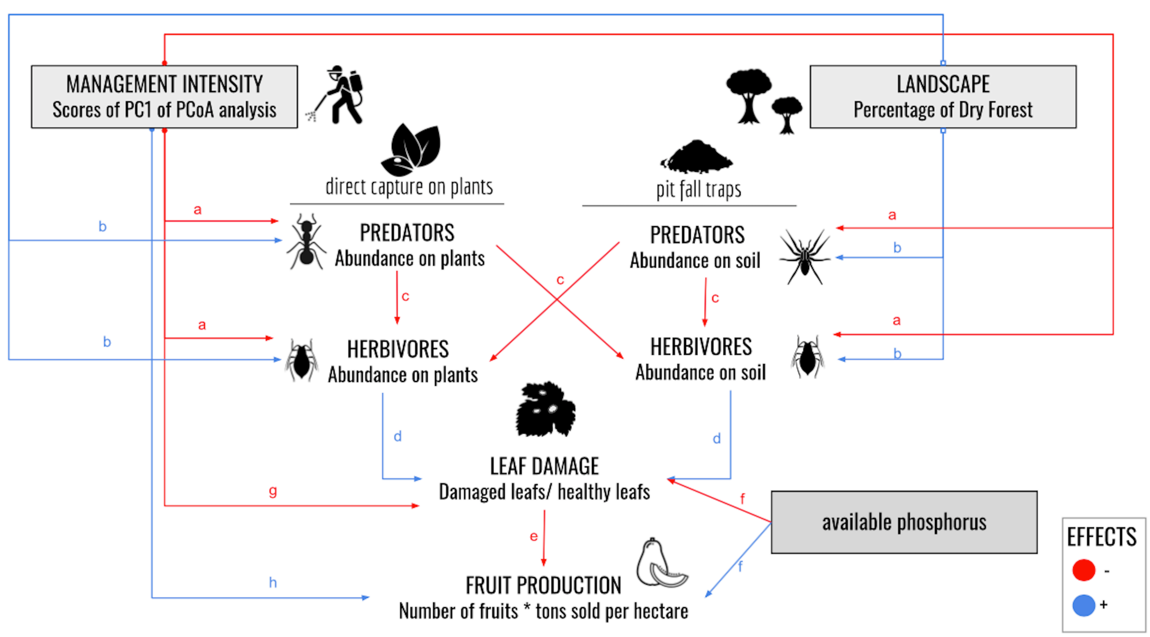

Figura 1. Modelo causal en el que se muestran las hipótesis de los efectos del manejo, el paisaje y el fósforo del suelo en las comunidades de artrópodos y el desempeño del cultivo de papaya. Las variables exógenas se muestran en cajas grises. El color de las líneas indica las relaciones hipotéticas, las líneas rojas se refieren a relaciones positivas y las azules a relaciones negativas.

ARTÍCULO ENVIADO A AGRICULTURE, ECOSYSTEMS AND ENVIRONMENT

The effect of farming practices and landscape on arthropod functional groups in papaya crops. Is intensive management worth it?

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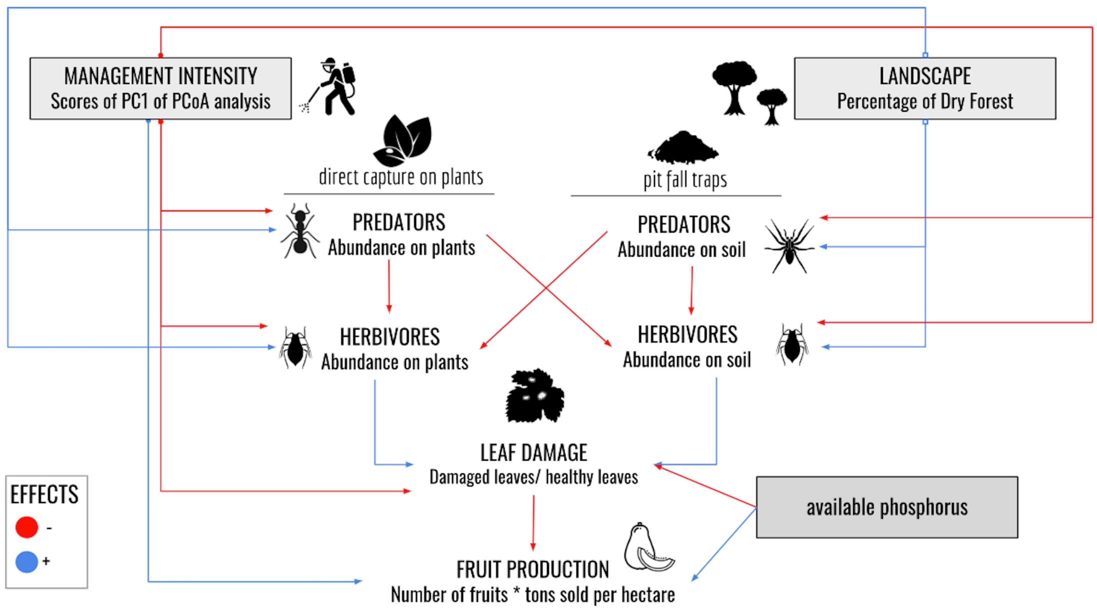
ABSTRACT

Arthropods can provide ecosystem services or disservices to agricultural systems. Whereas herbivores can cause substantial crop losses, natural enemies can offer pest regulation services that otherwise would be difficult to obtain. Two major factors affecting arthropod communities within plantations are farming practices and surrounding landscape. Previous studies have shown that natural enemies are less abundant in plantations within simplified landscapes and intense management practices, while herbivores do not always respond to these factors. Given the different roles of arthropods in plantations, we assessed the cascading effects that the surrounding landscape and different management practices can have on different arthropod guilds in papaya plantations, ultimately affecting plant damage and fruit production. A piecewise structural equation model was used to assess the direct and indirect effects of management practices and landscape upon herbivores and their natural enemies, and their cascading effects on papaya leaf damage and fruit production. We studied 11 papaya plantations in the surroundings of a tropical dry forest (TDF) in Jalisco, Mexico. The model indicated that there is a decrease of natural enemies with intensive conventional management, which had no effect on pest abundance. Furthermore, surrounding landscape had an effect on pest abundance and not on predators, but this effect was different between seasons. Even when pest abundance explained crop damage, this was not reflected on fruit production. Crop yield was explained by management practices, available phosphorus in soil and by the abundance of natural enemies.

Keywords: Herbivore; Pests; Carica papaya; Chamela-Cuixmala Biosphere Reserve; Yield; Crop damage; Structural equation models

GRAPHICAL ABSTRACT



1. INTRODUCTION

Arthropods can be beneficial or detrimental for human activities given their variety of ecological functions. In agroecosystems, 18-20% of global crop yield losses are attributable to herbivorous arthropods (Oerke, 2006; Sharma et al., 2017). In this context, the presence of predators and parasitoids of herbivores represent a potential ecosystem service for pest regulation of different crops (Isaacs et al., 2009; Zhang et al., 2007).

Two major factors that affect arthropod diversity and abundance within an agroecosystem are the landscape context (Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Molina et al., 2015; Perfecto and Vandermeer, 2002; Thies et al., 2005; Weibull et al., 2003; Winqvist et al., 2011) and farming practices (Attwood et al., 2008; Clough et al., 2007; Landis et al., 2000; Letourneau and Goldstein, 2001; Morales et al., 2001; Sosa-Aranda et al., 2018; Winqvist et al., 2011; Zehnder et al., 2007). Previous studies suggest that natural enemy populations, such as beetles, lacewings and spiders, are more susceptible than herbivores to poorer landscapes (e.g. homogeneous landscapes with low natural coverage) and to intensive management practices, characterized by monocultures with high use of pesticides and other agricultural supplies (Attwood et al., 2008; Bengtsson et al., 2005). These effects have been associated with supplementary food resources, nesting locations or refugee sites in more heterogeneous and complex natural landscapes (Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Karp et al., 2018). In addition, natural enemies may be less resistant to pesticides than herbivores (Perfecto et al., 2009; Theiling and Croft, 1988).

Even though there are many studies reporting how farming practices and landscape heterogeneity affect biodiversity, only few have simultaneously measured populations of both herbivores and their natural enemies (Bianchi et al., 2006; Chaplin-Kramer et al., 2011). Even fewer have taken into account the cascading effects of arthropods on damage and crop yield (Chaplin-Kramer et al., 2011; Grab et al., 2018; Letourneau and Bothwell, 2008), despite the attributes of plant performance are the reason behind management practices. If farmer's management decisions are based on crop performance, ecological research focusing on sustainable farming practices should evaluate variables of crop damage and productivity.

1.1 CROPS IN TROPICAL DRY FOREST OF MEXICO

Tropical Dry Forests (TDF) are home to a large number of endemic species (Gentry, 1995) and due to land-use changes, also from many endangered species (Trejo and Dirzo, 2000). Only in

Mexico, 60% of the original vegetation of these forests has been lost due to agriculture and livestock farming. For this reason, it is necessary and urgent to find sustainable practices for these economic activities (Quesada et al., 2009; Sánchez-Azofeifa et al., 2009). In particular, TDFs in Mexico have been affected by the increment in papaya production, which has increased by 30% from 2016 to 2017 (SAGARPA, 2017), producing 952 million tons in 2016, equivalent to 86.7 million dollars. Although Mexico is the center of origin of papaya (Carica papaya), since 1978 the Mexican varieties have been substituted for the Cuban variety Maradol (SAGARPA, 2005). Today 99% of the papaya crops correspond to Maradol variety and only 1% to the native varieties (SAGARPA, 2017). However, Maradol papayas are susceptible to multiple virus infections, primarily the papaya ring-spot virus, which is transmitted by sucking herbivores such as aphids, mites and whiteflies (Castrejon Antonio, 2014), that can be controlled with agrochemical inputs or by favoring the presence of beneficial arthropods.

Land-use change has created a mosaic of natural vegetation and crops in the TDF of México. Hence, it is interesting to evaluate the effect of both farming practices at a local scale and of landscape composition on arthropod community, specifically on herbivores and their potential predators, and the cascading effects they have on crop damage and fruit production. In this study we evaluated the existence of such cascading effects in papaya crops located along a gradient of farming practices and contrasting landscapes in terms of the percentage of surrounding tropical dry forest (Fig 1), using structural equation models. We expected to find (a) reduction in the that abundance of herbivores and of their natural enemies as intensity of management increased; (b) a positive effect of increased forest cover in the landscape on the same guilds, given that natural vegetation provides more resources for both groups. We also expected that (c) plantations with more predators and parasitoids would have less herbivore pests if there is a biological control, and (d) a positive relationship between herbivore abundance and leaf damage; and as a consequence, (e) reduced fruit production. The model considered phosphorous availability as an exogenous variable given its variation and limitation in most TDF, and is one of the limiting factors for plant productivity (Martinez-Yrizar and Sanford, 2011). For these reasons, we expected that plantations with higher phosphorus availability had less damage and greater fruit production (f), regardless from the effect of the arthropod community. On the other hand, the intensive management is expected to directly reduce the damage in plants (g) and increase production (h) as a result of the use of fertilizers and pesticides.

2. MATERIALS AND METHODS

2.1 STUDY REGION

This study was conducted in Tomatlán and La Huerta municipalities near the Chamela-Cuixmala Biosphere Reserve (CCBR), in Jalisco coastal region, Mexico (Fig 2). The vegetation in this region consists of tropical dry forests, where mean annual precipitation is 800.4 mm which mostly occurring during June to October, whereas severe drought can occur from February to April (Maass et al., 2017). The mean annual air temperature is 25.6 °C. Most of the agriculture activities occur near the alluvial areas and consist either in subsistence agriculture (maize and pastures), or cash crops such as mangos, watermelon and papaya cultivars. Even though Jalisco is not one of the Mexican states with major production of papaya, given the comparatively high yields per plant (around 56 tn ha^-1) and the prices of the fruit ($0.23 us kg^-1), this is one of the most profitable crops in the region compared with others, such as watermelon (31 tn ha^-1, $0.16 us kg^-1) or cucumber (49 tn ha^-1, $0.27 us kg^-1). Hence, around 466 ha of papaya are planted annually in this state (SAGARPA, 2017).

To evaluate the impact of management practices, landscape and phosphorous contents in the soil on arthropod communities within papaya crops, and their cascading effects on plant damage and fruit production, these variables were monitored from February to August 2016 in 11 papaya plantations. Plantations were located using Google Earth satellite images. We choose plantations that were near the coast, at the same altitude, whose surrounding landscapes conform a gradient of forest cover, which represented different farming practices, and where farmers agreed to let us monitor the arthropod population during the crop cycle.

2.2 FARMING PRACTICES

Farmers were interviewed regarding their management practices, including pesticide, herbicide and fungicide use, diversity of crops in the plantation, and application of foliar and soil fertilizers throughout the study period. We recorded whether the applied products were of synthetic or organic origin and whether they were obtained from industrial companies or were home-made by the farmers from local products (such as plants from the region or locally made manures and fertilizers) (Appendix A). All plantations had daily drip irrigation.

2.3 LANDSCAPE MATRIX CLASSIFICATION

A radius of 500 m around each plantation was considered to classify the landscape matrix given that previous studies have found that this is the range where a higher arthropod response to landscape is found (Chaplin-Kramer et al., 2011; Steffan-Dewenter, 2002). A visual classification was made with Google Earth Pro (http://www.earth.google.com) imagery from February 2015, considering three elements: (1) water bodies, (2) tropical dry forest, and (3) non-forested areas. The classification revealed a gradient in the composition of the landscape matrix of the plantations, which varied from 2% to 96% of natural coverage (tropical dry forest and water-bodies) (Fig 3, Appendix B). This natural coverage, dominated by tropical dry forest, was used for further analyses.

2.4 ARTHROPOD SAMPLINGS ON SOIL AND ON PLANTS

For soil-dwelling arthropods, five pitfall traps were distributed in each plantation, four traps on the margins of the plantation and one in the center, each one at least 10 m apart from the others. Each trap consisted of a plastic cup of 13 cm height and 7 cm in diameter, containing 25 ml of a water and detergent mixture, and sheltered by a plastic cap to protect samples from rain and predators (Duelli et al., 1999). Traps were collected after 5 days and samples were preserved in 70% ethanol. To determine the abundance of arthropods on papaya plants we systematically chose 30 plants per site, 6 on each of the four margins of the plantation and other 6 in the center. We collected all arthropods directly on each plant with an entomological aspirator. Both arthropod samplings, at soil and at plant level, were carried out in February (at the beginning of the crop cycle, dry season) and in August (at the end of the crop cycle, rainy season). All arthropods were preserved in 70% ethanol and identified to their lowest possible taxonomic level, morphospecies or families, and they were assigned to their functional group (predator or herbivore).

2.5 LEAF DAMAGE

We measured papaya leaf damage by viral infection or herbivore consumption at the end of the agricultural cycle (August) in 30 randomly chosen plants of each plantation, 6 on each of the four margins of the plantation and other 6 in the center. We grouped damage plants in five observations per plantation for the statistical analysis. We quantified plant damage as the ratio between the number of leaves with signs of the virus or herbivore damage and the number of healthy leaves per plant: leaf damage per plant = damaged leaves/ healthy leaves. The major damage to papaya crops is caused by the ringspot virus (Appendix C).

2.6 FRUIT PRODUCTION

Fruit production is the most important variable for farmers, yet it is commonly not reported in scientific papers (Letourneau and Bothwell, 2008). To assess this yield measure, the fruits of the same chosen 30 plants (see above) in each plantation were quantified in August, before the harvest. Additionally, farmers were asked about the total yield $tn\ ha^{-1}$ sold to the middlemen at the end of the crop cycle. Because some fruits counted during the monitoring of plants failed to meet market quality standards to be sold, and the variation in quality and the number of fruits can be attributed to the effect of arthropods, we calculated a composite variable derived as a product of the indicators fruits per plant and tons sold per hectare: (Fruit production = fruits per plant * tons sold per hectare) to account for the balance between the two indicators of production.

2.7 SOIL SAMPLING AND ANALYSIS

Given that the variation in crop yield can result from the differences on edaphic conditions, which largely depend on farming practices but also on the intrinsic characteristics of each site, we assessed differences in available phosphorus (Bray method), at the beginning and the end of the crop cycle, which coincide with the dry and rainy season. Phosphorus is one of the limiting factors of plant growth in the region. We collected nine soil samples at random from each plantation and mixed to have a compound sample. Samples were taken with a soil sampler pedagogical probe at 0-15 cm depth. Afterwards, physical and chemical properties of soil were analyzed in the Soil Laboratory of the Technological Institute of Morelia Valley. The results of the analysis of available phosphorus (Bray method) in each season were used in further analyses.

2.8 STATISTICAL ANALYSES

2.8.1 MANAGEMENT FARMING PRACTICES

To summarize management practices we performed a Principal Coordinate Analysis (PCoA). A presence-absence matrix of each type of agricultural input was compiled and a Gower distance matrix calculated with gowdis function of FD package (Lalibert et al., 2014) of R. Then a PCoA ordination was run with the MASS package (Venables, 2002) in R software (R core team, 2018) using cmdscale function. PCoA analysis exhibited that there is a gradient of management intensity from conventional management to alternative management along the first axis of ordination (PC1), which explains 45.9% of the variation in management through sites (Fig 4). Lower values along PC1 were related to plantations with lower use of chemical inputs and more alternative or organic products, also with more than one type of crop (such as coconuts, mangos or sorghum). In contrast, higher values of PC1 were associated with conventional monocultures and the use of synthetic inputs. For this reason, we associated the PC1 with management intensity and use its values for each plantation in the structural equation model analysis.

A cluster analysis on the same distance matrix confirmed the existence of these two groups of plantations in relation to the type of practices performed, which we identify as alternative and conventional management, respectively (Appendix D). Clustering was done using an average agglomerative method in the hclust function of the “cluster” package (Maechler et al., 2018) for R. These two discrete categories were used to compare arthropod communities in a non-metric multidimensional analysis.

2.8.2 ARTHROPOD COMMUNITIES

To test differences in the composition of arthropod communities between papaya plantations we conducted permutational multivariate analysis of variance (perMANOVA). Three different tests were performed. The first compared dissimilarities between communities in plantations with two different management practices (alternative versus conventional farming) derived from the cluster analysis of management practices (Appendix D). The second analysis evaluated the differences in communities between seasons (dry and rainy season). The third analysis tested for differences between sampling methods, given that we trapped arthropods in soil and in plants. In the three cases, we calculated the dissimilarity between arthopod communities with a PERMANOVA analysis for which we used the *adonis* function of vegan package (Oksanen et al., 2018) in R and then we visualized those results with a non-metric multidimensional scaling analysis (NMDS) using Bray-Curtis distance with metaMDS function of vrgan package (Oksanen et al., 2018).

2.8.3 SAMPLE COVERAGE

To analyze arthropod sample completeness in both (1) pitfall traps and (2) captures on plants, we measure sample coverage using iNext package (Hsieh et al., 2016) in R (version 3.5.1.).

2.8.4 STRUCTURAL EQUATION MODEL

Structural equation models (SEMs) are a statistical tool that allows to understand complex ecological processes by testing hypothesis of multiple causality within a network (Grace, 2008; Grace et al., 2010; Lefcheck, 2016; Shipley, 2016). They are particularly useful to infer direct and indirect causes within a network, therefore allowing to assess the presence of cascading effects.

We first proposed a conceptual model of multiple causalities to explain production yield on papaya fields in relation to management practices, available phosphorus, surrounding landscape, arthropod communities, and papaya crop damage (Fig 1). The model was based on the hypothesis that intensive management practices and low percentage of forest surrounding the plantation would reduce the abundance of herbivores and their natural enemies, and that top-down effects that natural enemies could have on papaya plantation pests would consequently have cascading effects on leaf damage and fruit production (Fig 1). Additionally, we expected that plantations with more available phosphorus would have less plant damage and higher yields. To distinguish if there is an effect of the change in landscape resources on arthropod community we fitted two models, one for each season.

We fitted the structural equation models using a piecewise approach (Lefcheck, 2016; Shipley, 2016) in the piecewiseSEM package for R. Structural equations were fitted using mixed effect linear models, with site as a random effect on the intercept to account for the non-independence of observations within a site. Also, given the differences between the abundance of predators and herbivores, herbivore abundances were transformed to logarithm with base 10.

3. RESULTS

3.1 ARTHROPOD COMMUNITIES AND FUNCTIONAL GROUPS

During our study we collected 19,774 individuals, 80.94% were herbivores, whereas 19.06% were predators (Sample coverage in appendix E). The abundance of natural enemies was similar on plants and soils, but the abundance of herbivores was almost 5 times greater on plants (Fig 5). In addition, we detected that arthropod abundance of herbivores was more than 100-times greater during the rainy season than in the dry season.

Herbivores were dominated by Homoptera and Acaridae orders. The main herbivores collected were two-spotted spider mites (Tetranychus urticae), the white mite (Eotetranychus lewisi) (Acaridae), and unidentified whiteflies, tingids and leafhoppers (Homoptera). Other herbivores present were thrips (Thysanoptera); chrysomelids (Coleoptera) and a few Lepidoptera and Orthoptera individuals. The main groups of natural enemies were ants and wasps (Hymenoptera), followed by ladybugs (Coleoptera), lacewings (Neuroptera) and spiders (Araneae). The composition of arthropod communities sampled on plants differed from the arthropods collected with pitfalls according with the NMDS analysis (Appendix F, perMANOVA $p < 0.05$), and there were no differences between arthropod community composition on plantations with different farming practices (Appendix G, PERMANOVA $p > 0.05$).

3.2 MODELS OF DIRECT AND CASCADING EFFECTS

3.2.1 DRY SEASON MODEL

The best fitted model using the dry season data explained 23% of the variation found in predators in soil, 34% of predators in plants, 35% of herbivores in soil, 13% of herbivores in plants, 76% of plant damage and an impressive 98% of fruit production (Fig 6). D – separation test revealed that the hypothetical model (Fig. 1) had significant missing paths that made us reject the hypothetical model (F= 62.59, d.f.= 32, P=0.001), one between herbivores on plants and herbivores on soil (B=0.02, p≤0.05) and another between herbivores on plants and fruit production (B=0.04, p≤0.05). Therefore, our best fitted model includes this two missing paths (Fig. 6, F=23.5, d.f.=22, P=0.37). The model suggested that a high percentage of forest in the surrounding landscape was significantly correlated with lower abundance of herbivores on papaya plants (B = -0.34, p ≤ 0.005), but not with the abundance of natural enemies. Most of the herbivores captured on plants were sucking bugs, such as whiteflies, aphids and mites. In addition, as the intensity of management increased, the abundance of natural enemies (such as spiders, wasps, ants, ladybugs and lacewings) on plants decreased (B = -0.51, p ≤ 0.05). We found no relationship between the abundance of natural enemies and herbivores on plants nor in the soil. An increase in management intensity was also directly correlated with a decrease in fruit production (B = -0.58, p ≤ 0.05).

3.2.2 RAINY SEASON MODEL

This model explained 9% of variation found on natural enemies in the soil, 48% of natural enemies on plants, 20% of herbivores on plants, 59% of herbivores the in soil, 95% of plant damage and also a 97% of fruit production, as in the dry season (Fig 7). Unlike the model of the dry season, during the rainy season a high percentage of forest surrounding the plantation was related with greater abundance of herbivores in the soil (B = 0.77, $p \leq 0.001$), characterized by mites and bark beetles. However, this variable had no effect on herbivores found on plants. In correspondence with what was found during the dry season, plantations with intensive management practices had fewer natural enemies on plants (B = - 0.56, $p \leq 0.005$). Natural enemies were positively related to herbivore abundance in soil and on plants (B = 0.37, $p \leq 0.0005$; 0.38, $p \leq 0.0005$, respectively). Also, herbivore abundance on plants was positively related to leaf damage (B = 0.06, $p \leq 0.0005$) (Fig 10). We detected that herbivore abundance changed one order of magnitude from the dry season to the rainy season (Fig. 5 B). In addition, we found that fruit production decreased with increasing management intensity (B = -0.30, $p \leq 0.05$) and increased with higher availability of phosphorus (B = 0.40, $p \leq 0.01$).

D – separation test revealed that the hypothetical model (Fig. 1) had three significant missing paths that made us reject the proposed model (F= 49.5, d.f.= 30, P=0.014). Two unexpected paths relate the abundance of natural enemies on plants and on soil with increased papaya yields (B = 0.10, $p \leq 0.0001$; B= 0.06, $p \leq 0.0001$, respectively). And, the third missing path revealed that herbivores present in the soil also had a slight positive effect on fruit production (B = 0.02, $p \leq 0.05$). The best fitted model includes these paths (Fig. 7, F= 20.03, d.f. = 20, P=0.46). Finally, the number of damaged leaves did not show a significant relationship with fruit production.

4. DISCUSSION

Overall, our results suggest that conventional management techniques involving the use of chemical agricultural inputs do not increase papaya fruit production independently of landscape context. On the contrary, we found that intensive management had an adverse effect on local arthropod abundance with cascading effects that diminished natural enemies and their positive impact in fruit yield.

4.1 CONTRASTING EFFECTS OF LANDSCAPE COMPOSITION IN THE TWO SEASONS

The response of herbivores and their predators to the surrounding landscape seems to be highly inconsistent, context dependent and influenced by the characteristics of the type of landscape studied (Karp et al., 2018). Herbivores appeared to be more susceptible to the percentage of forest close to the plantations than to natural enemies. Previous meta-analysis however have reported that landscape has higher effect on natural enemies (Chaplin-Kramer et al., 2011; Rusch et al., 2016). This surprising result could be due to the dynamics of tropical dry forests and the seasonal changes in resources availability. In this system, during the dry season herbivores collected on plants, mainly sucking bugs, were more abundant in crops surrounded by homogeneous landscapes dominated by other crops, while during the rainy season, herbivores collected on soils, mainly mites and bark beetles, were more abundant in plantations surrounded by a high percentage of forest. One possible explanation for the observed changes in herbivore abundance in response to landscape context could be that during the dry season native plants in the forest lose their leaves, hence resources for herbivores become scarce and they are likely to rely on crop plants, which retain their leaves due to constant irrigation. Therefore, dry forest could represent a barrier for herbivores during the dry season but not during the rainy season, when more suitable food and microenvironments are likely to be found within the native vegetation. Nevertheless, the forest effect on herbivore abundance was unrelated to crop yield.

4.2 MANAGEMENT PRACTICES EFFECT

4.2.1 INTENSIVE MANAGEMENT REDUCES THE ABUNDANCE OF NATURAL ENEMIES

Other studies that also report greater herbivore responses to landscape context than to natural enemies (Grab et al., 2018; Karp et al., 2016) have discussed the possibility that natural enemies are likely to respond to finer spatial scales related to management practices more than to broader landscape structure. In this study, we found a negative correlation between the management intensity and natural enemy abundance. Hence, plantations with more than one type of crop and alternative practices had greater abundance of natural enemies, probably as a consequence of their foraging behavior and feeding requirements. For example they often depend on other sources of food besides preys, such as nectar (Grab et al., 2018; Karp et al., 2016). We did not find a difference in the abundances of herbivores between the two types of management, which indicates that the objective of applying insecticides is not being met. It is not the first time that it has been documented that intensive management is detrimental for natural enemy communities instead of herbivores (Bengtsson et al., 2005; Krauss et al., 2011; Letourneau and Goldstein, 2001; Meehan et al., 2011; Östman et al., 2003) and some studies actually report greater pest abundance when insecticides are applied (Krauss et al., 2011; Meehan et al., 2011) as herbivores can become resistant to the pesticides (Perfecto et al., 2009). Furthermore, the role of natural enemies has been equated in other studies to the effect of insecticides, so a decrease in this guild can have strong implications for pest control (Östman et al., 2003).

4.2.2 CASCADING EFFECTS OF MANAGEMENT INTENSITY ON FRUIT PRODUCTION

Interestingly, we found that the abundance of natural enemies had a direct positive effect on papaya yields, suggesting that alternative low-input management practices not only enhanced natural enemies (as shown above), but in doing so, it also favored yield (Appendix H). Contrary to our expectations, there was a positive correlation between herbivores and predators, which means that predators are not controlling herbivores, but that the abundance of predators is greater when there are more preys (some kind of a bottom-up control on predators). The same effect of herbivores on their predators has been identified in other studies (Morante-Filho et al., 2016; Scherber et al., 2010). Besides, papaya crops are annual, so it might be difficult to find a direct control because arthropod communities may not be settled. Nevertheless, damage caused by herbivores on plants did not correlate with fruit production.

If natural enemies, which were predominantly ants, coccinellid beetles and wasps, did not have an effect on yield through pest control, like they usually do (Ali et al., 2018; Cardinale et al., 2003; Grab et al., 2018; Liere et al., 2015; Östman et al., 2003) they should be performing other functions we did not measure. This, however, awaits further investigation. Hermaphrodite plants of papaya, like the ones of Maradol that we evaluated, can be self-pollinated even before the flower opens (Corrêa Damasceno Junior et al., 2009) but given our results, we think they may also benefit from external pollination. A study in coffee plants showed that fruit set was higher in branches were ants and pollinators were present, than in branches with pollinators alone (Philpott et al., 2006). Some other studies have demonstrated that ants and wasps can limit floral predation without interfering with plant pollinators (Assunção et al., 2014) and that ants decrease flower visit time by pollinators (Altshuler, 1999) but this, rather than being a conflict, could be beneficial for plant fitness because it can reduce selfing rates (Villamil, personal communication) (Villamil et al., 2018). Ant-pollinator conflicts in agroecosystems warrants further investigation, and we propose that it is possible that natural enemies have a dual function in ecosystem services, reducing herbivory and florivory, as well as increasing outcrossing. Ants might even pollinate papaya flowers, based on our personal observations.

Besides the effect of natural enemies on yield, phosphorus had a strong positive effect on fruit production. This was an expected result given that phosphorus is the main component of fertilizers. Although phosphorus availability is the main limiting resource for plant growth in the soils from this region (Campo et al., 2001), it was interesting that we did not find differences in phosphorus quantity among the different management practices. There is evidence that manures and alternative farming can increase phosphorus availability in the soil and have positive effects on crop weight (Karp et al., 2016). Our results suggest that low intensity management practices can have positive effects on crop performance without the side effects that conventional management have in ecosystems and human health.

4.3 IS INTENSIVE MANAGEMENT WORTH IT? A GLIMPSE OF FARMERS DECISIONS

The idea behind the use of agrochemicals is to reduce the abundance of pests, diseases and competition to ensure that plants grow healthy and have better yields. However, in this study, one of the variables that was most detrimental to the papaya crops was the intensity of management. This constitutes one of the few studies analyzing the role of management practices at different trophic levels of biotic interactions.

We highlight the adverse effects of intensive management on natural enemy community and on fruit production, and not on their main objective: decreasing herbivore abundance and crop damage. After socializing our results with the participant farmers, we found that those with alternative management practices agreed that in the long term, their agricultural practices conserve natural enemies and is less expensive than conventional practices, so they will continue with these practices. On the other hand, most of the farmers with intensive management practices knew that intensive farming can had adverse effects on beneficial arthropods and where bewildered with the difference in yield proportions found in our study. However, they manifested that they are unwilling to change their practices. The major reason behind this decision was that alternative farming requires more human effort given that farmers have to monitor the papaya plants every day to check for the presence of the virus and have to spend more time making their own supplies, like repellents and manures. Most of the farmers with intensive management practices have more than one papaya plantation in the region, usually on rented lands, so they cannot take intensive care of all of them, in contrast with farmers with alternative management practices, who have one or two plantations of their own.

5. CONCLUSIONS

The crops with intensive management had less beneficial arthropods and fewer harvests. On the other hand, there were no significant differences in the abundance of pest herbivores between conventional and alternative management forms, which indicates that the use of pesticides is not decreasing the pest abundance and it is affecting natural enemies. At the landscape scale, a high percentage of surrounding forest was associated with fewer plant herbivores during the dry season and an increase in soil herbivores during the rainy season, with no impact on final papaya production. Finally, alternative management seems to be a sustainable option for papaya production in the region and transdisciplinary work is needed if we want to trigger changes in farmers management decisions.

6. AUTHOR'S CONTRIBUTIONS

AMF-G and EV conceive the idea and design of the study, LDA-C and KB provide great insight for data processing and development, AMF-G and FMA analyzed the data. AMF-G wrote the manuscript. All authors improved the manuscript.

7. ACKNOWLEDGEMENTS

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8. REFERENCES (ver apartado final de referencias)

9. FIGURES AND TABLES

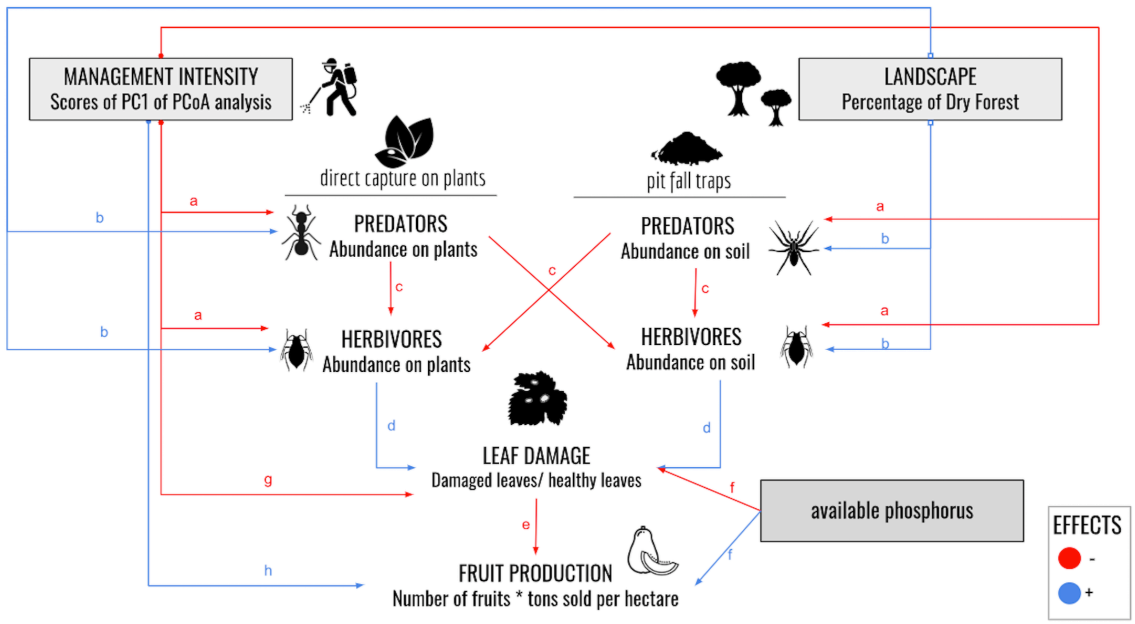


Figure 1. Hypothetical model used to test the effects of management, landscape and available phosphorus on arthropod communities and on papaya crop performance. Exogenous variables are indicated with gray boxes. Blue lines show positive relationships and red lines, negative relationships. The letters on the arrows refer to the hypotheses raised in the introduction section.

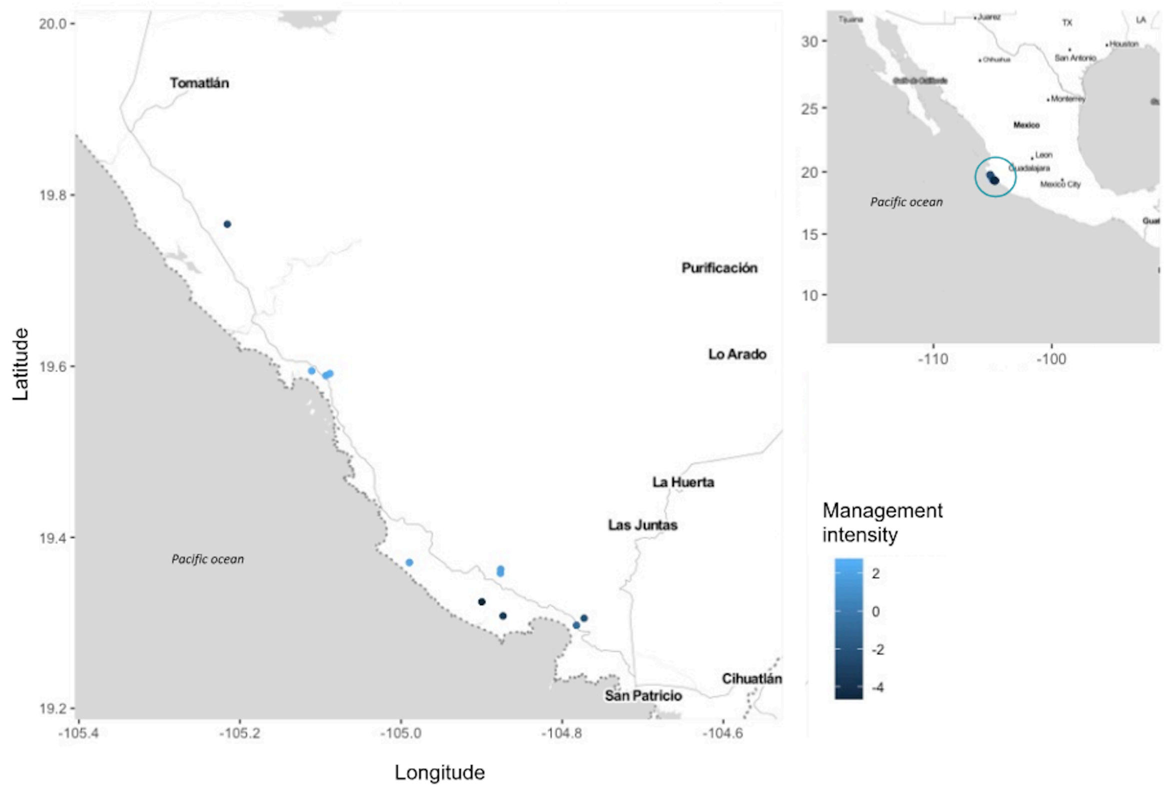


Figure 2. Location of the 11 plantations of papaya surveyed near the Chamela-Cuixmala Biosphere Reserve in Jalisco, México. The color of the dots indicates the intensity of management, derived from the PCoA analysis of management (Fig 3), where the lightest colors indicate more conventional management and the darkest more alternative management practices.

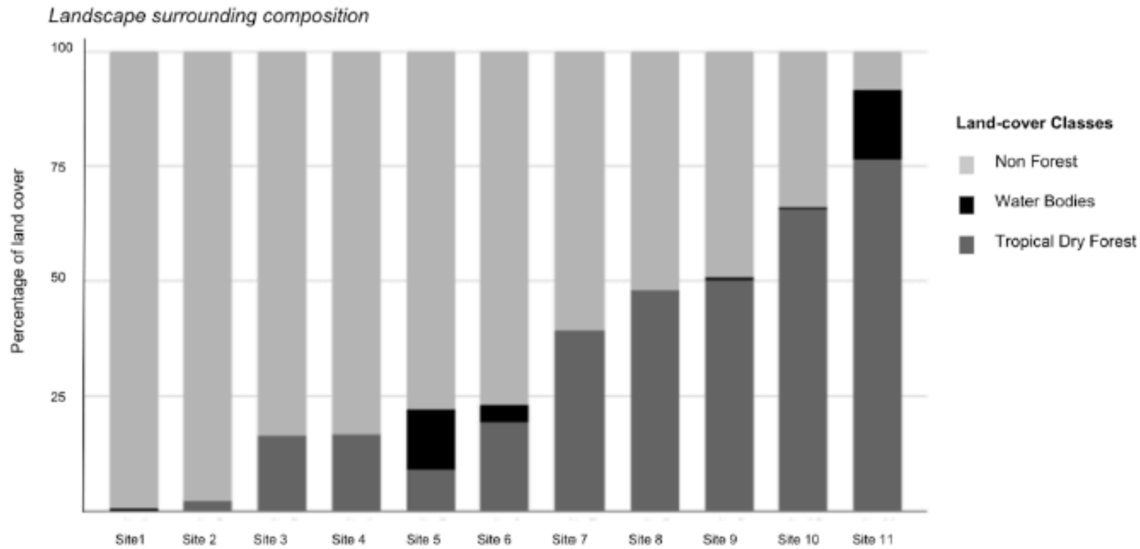


Figure 3. Percentage of different land-cover classes around each plantation (500m radius): (1) non-forest in light gray; (2) water-bodies in black; and (3) Tropical dry forest in dark gray.

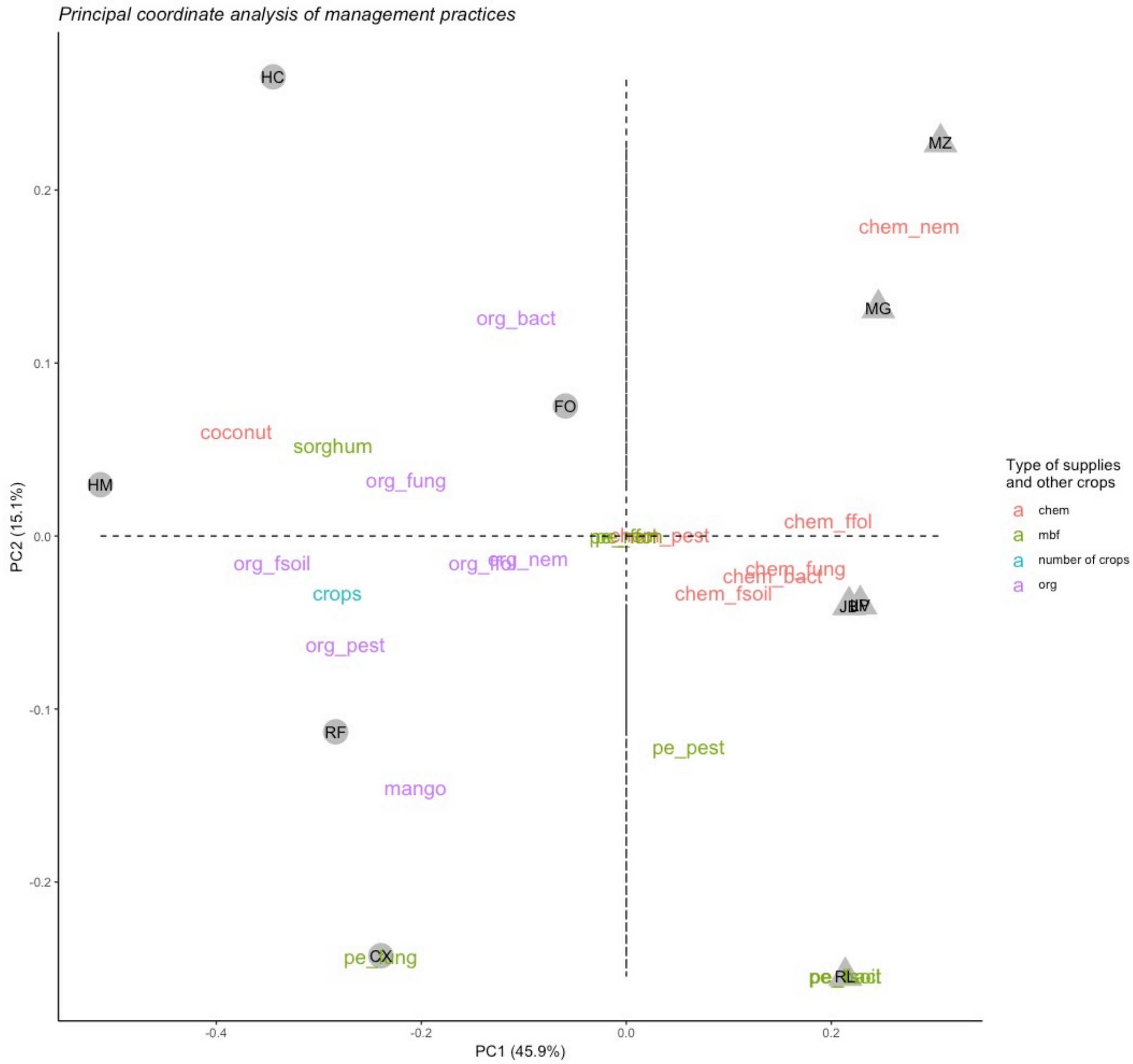


Figure 4. Principal Coordinate analysis (PCoA) used to classify management practices. PC1 represents a management gradient given the type of supplies that are used, "chem" = chemical, "mbf" = made by farmers, "org" = organic, besides the "number of crops" that indicates if the plantation had other crops, such as mango, coconut or sorghum. The sites with an alternative management are indicated in grey circles and the ones with conventional management are indicated with grey triangles.

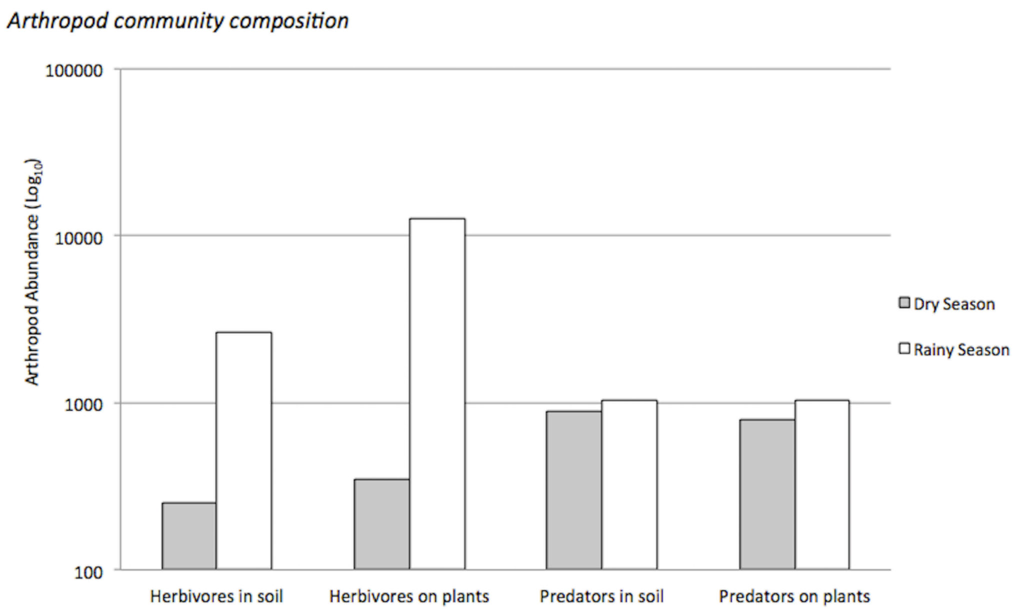


Figure 5. Arthropod community composition. Total abundance of herbivores versus natural enemies in soil and on plants, 80% of the arthropods collected correspond to herbivores.

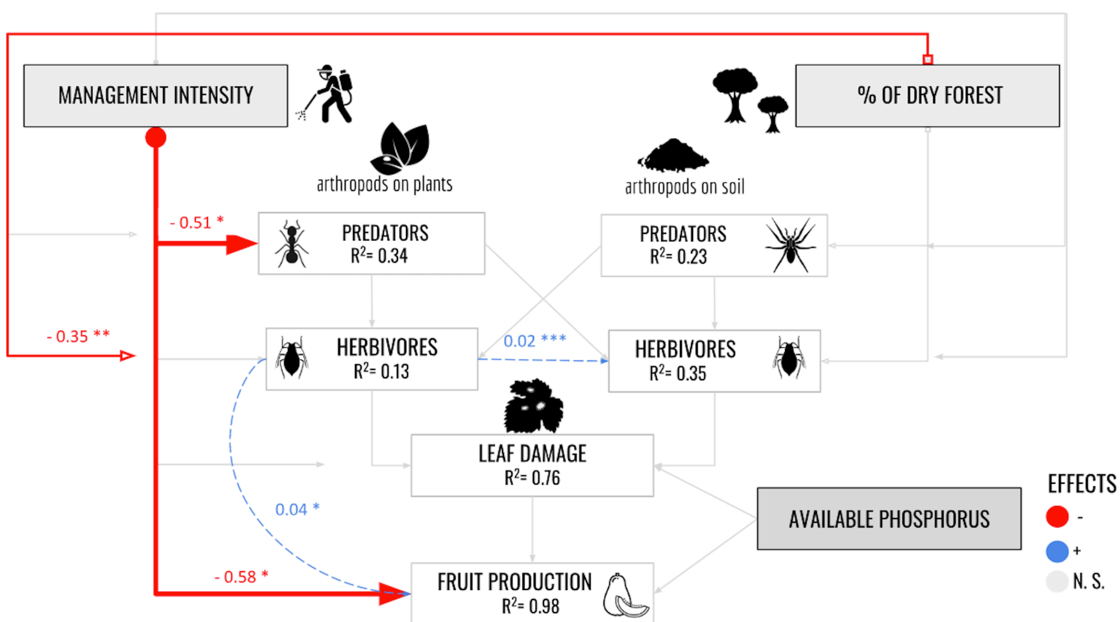


Figure 6. Dry season best fitted model (F=23.5, d.f.=22, *P*=0.37). Red and blue arrows represent significant pathways (*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$), red indicates negative correlations while blue indicates positive correlations. Solid lines show paths that were expected in the

hypothetical model and dotted lines are missing significant paths, obtained from the d-separation test, that suggest a better fitted model. Arrow thickness is proportional to the standardized effect sizes.

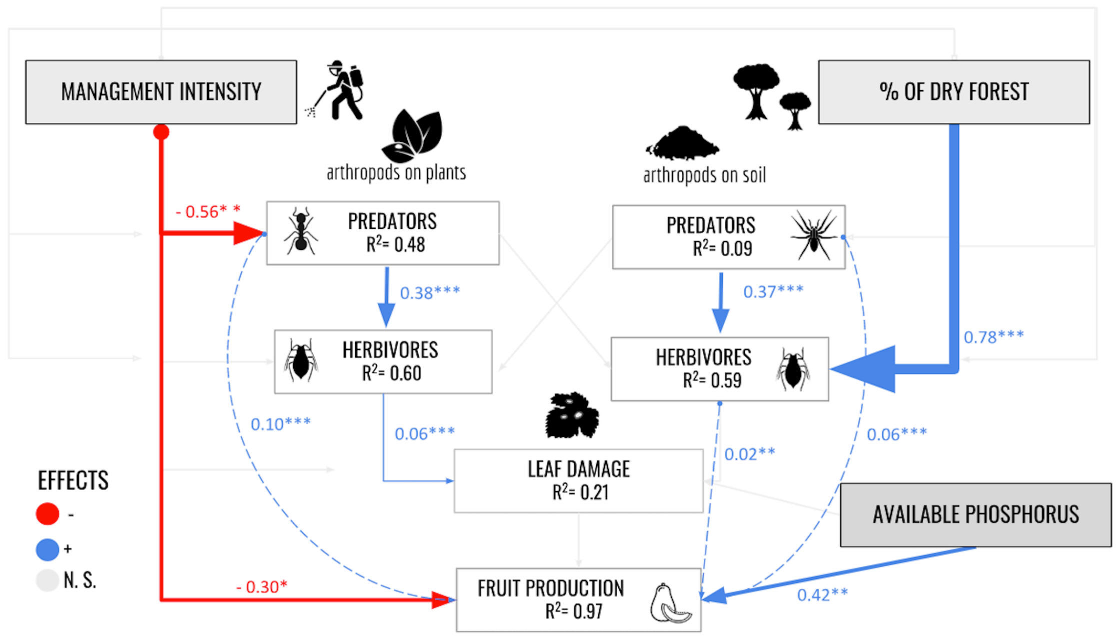


Figure 7. Rainy season best fitted model (F= 20.03, d.f. = 20, *P*=0.46). Red and blue arrows represent significant pathways (**P* < 0.05; ***P* < 0.01; ****P* < 0.001), red indicates negative correlations while blue indicates positive correlations. Solid lines show paths that were expected in the hypothetical model and dotted lines are missing significant paths, obtained from the d-separation test, that suggest a better fitted model. Arrow thickness is prop

10. APPENDIXES

APPENDIX A

Classification of management intensity and management categories based on the supplies and crops used. Management intensity and management categories are the result of a PCoA and a cluster analysis respectively.

			Organic						Chemical					
Site	Management intensity	Management category	Insecticide	Fungi-cide	Bacteri-cide	Nemati-cide	Foliar Fertilizer	Soil Fertilizer	Insecticide	Fungicide	Bacteri-cide	Nemati-cide	Foliar Fertilizer	Soil Fertilizer
HM	-4.506579261	Alternative	X				X	X				X		
HC	-3.501338906	Alternative		X	X	X	X	X	X					
RF	-2.472007362	Alternative	X	X	X	X	X	X	X	X				X
CX	-2.274673971	Alternative	X	X		X	X	X	X		X			X
FO	-0.724407142	Alternative	X	X		X	X		X		X		X	X
JB	1.852043149	Conventional				X				X	X		X	X
LV	2.089749361	Conventional				X			X	X	X		X	X
JP	2.089749361	Conventional				X			X	X	X		X	X
MG	2.330326154	Conventional					X		X	X	X	X	X	X
RL	2.516390704	Conventional					X		X	X	X		X	X
MP	2.600747913	Conventional			X				X	X	X	X	X	X

	Home-made extracts				Other crops in the plantation			
Site	Insecticide	Fungicide	Bactericide	Soil Fertilizer	Coconut	Mango	Sorghum	Total of crops
HM					X	X	X	3
HC		X			X			1
RF	X				X	X		2
CX	X	X				X		1
FO							X	1
JB	X							0
LV	X							0
JP	X							0
MG								0
RL	X		X	X		X		1
MP								0

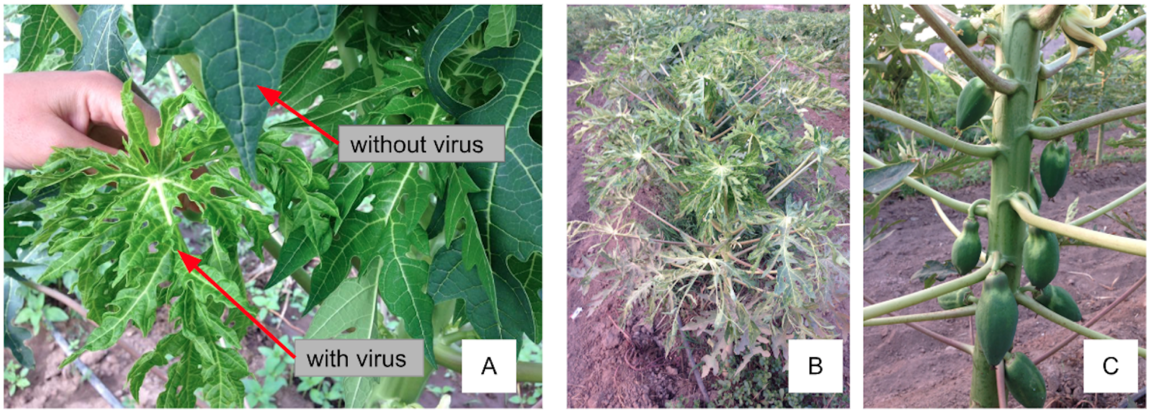
APPENDIX B

96% of natural cover

2% of natural cover

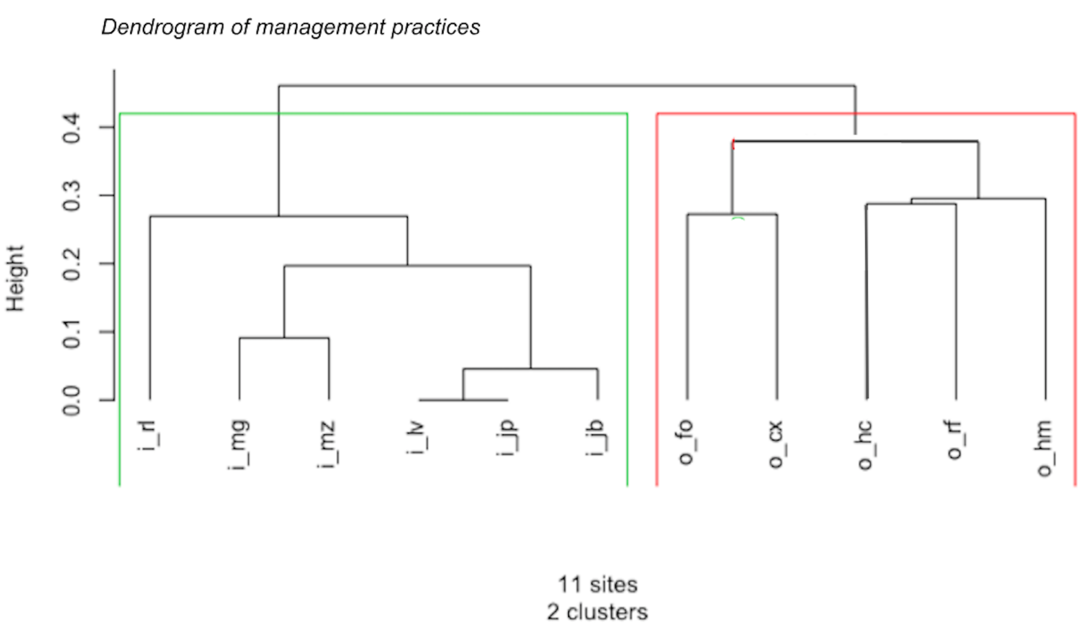
Examples of plantations surrounding landscapes (in a 500m radius) with high and low percentage of natural cover (tropical dry forest and water-bodies), red dot indicates the plantation.

APPENDIX C



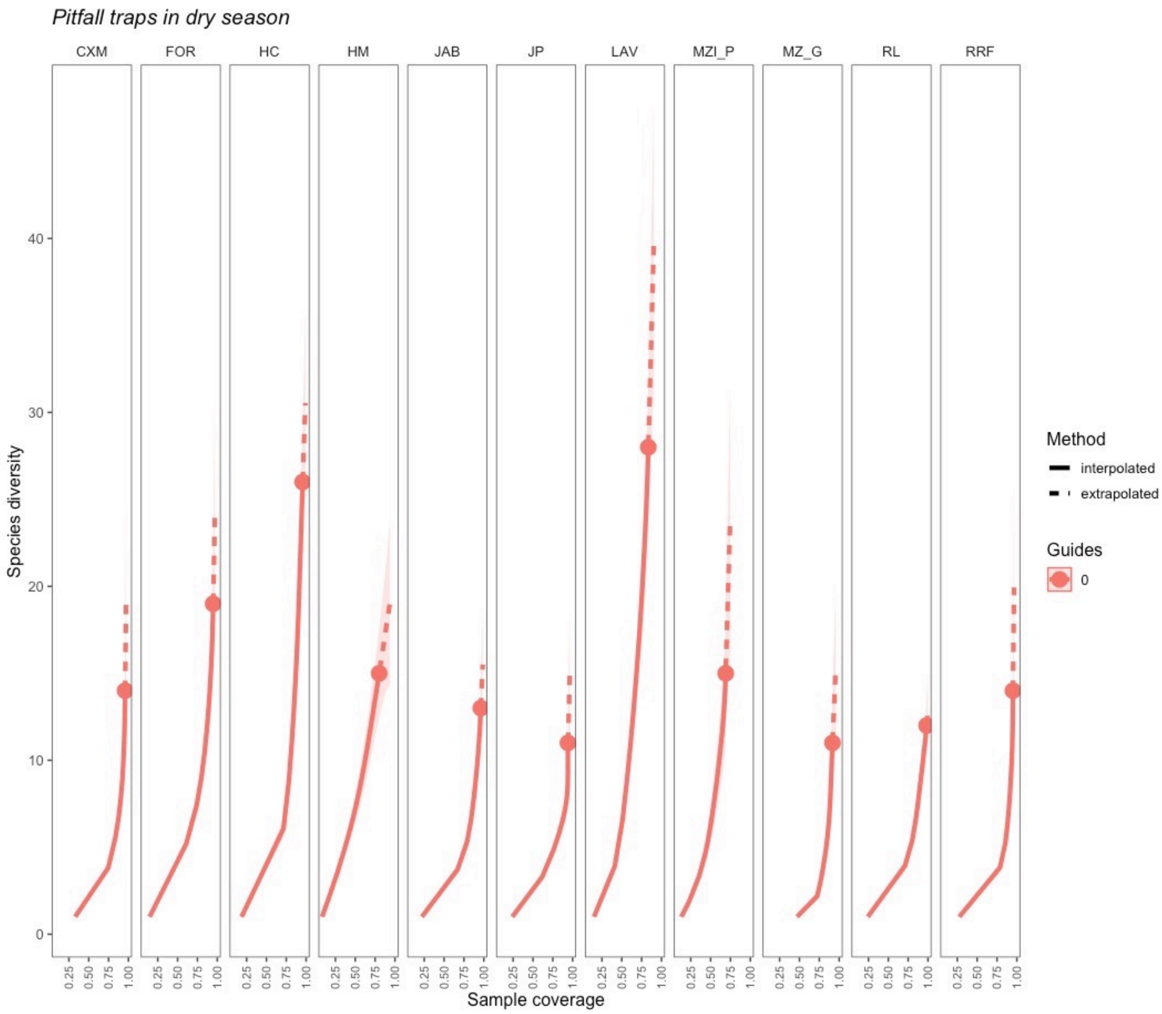
Plants with signs of virus, (A) a leaf of an infected plant vs. a leaf of a healthy plant, the color of the infected plant is brighter, the veins are more yellow and the margins of the leaves tend to curly. (B) A plant completely infected with the papaya yellow ringspot virus. (C) The fruits of a virus infected plant.

APPENDIX D

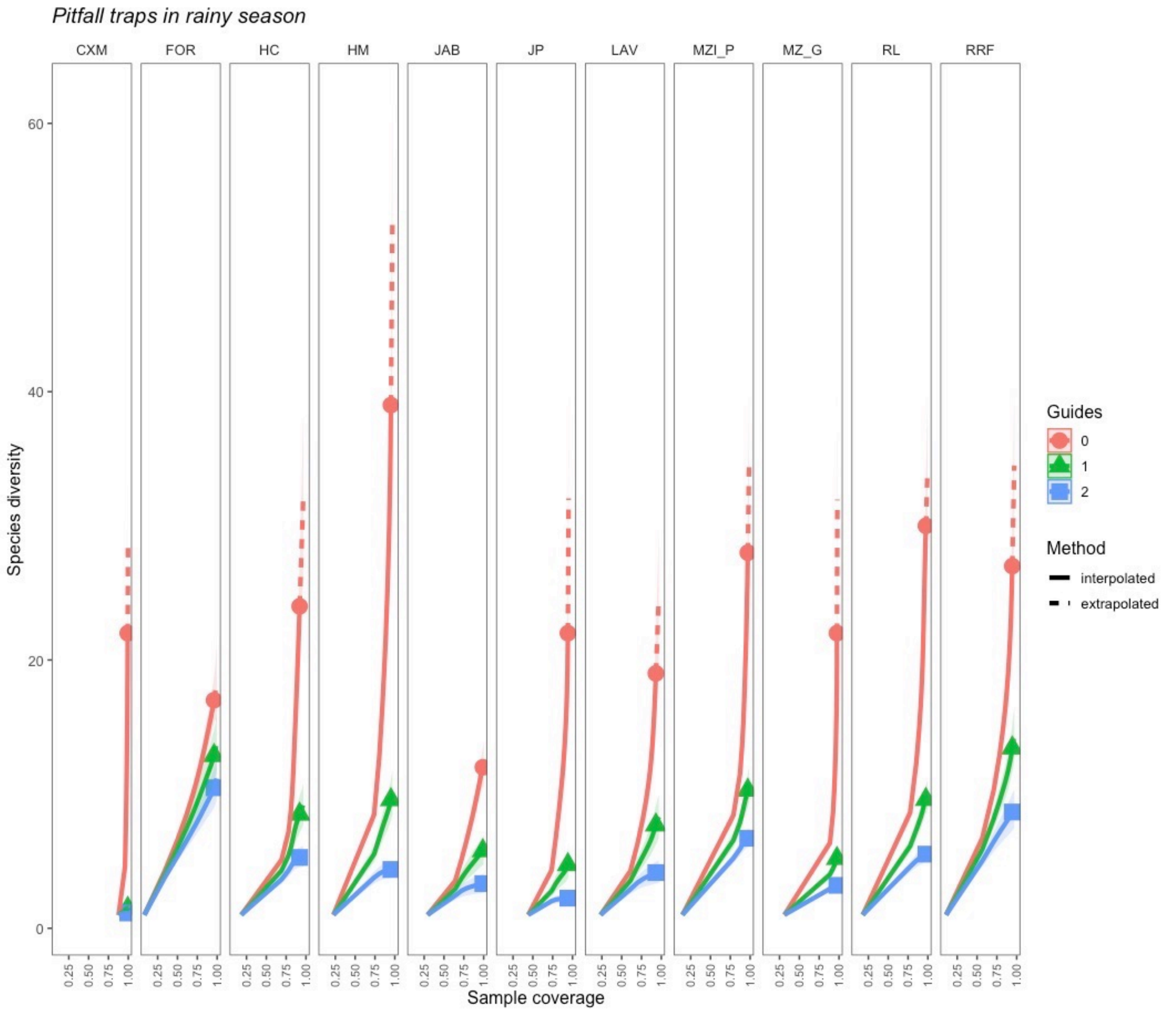


Groups of plantations with the same management practices. Green group: conventional management, red group: alternative management (Mantel significance r=0.71).

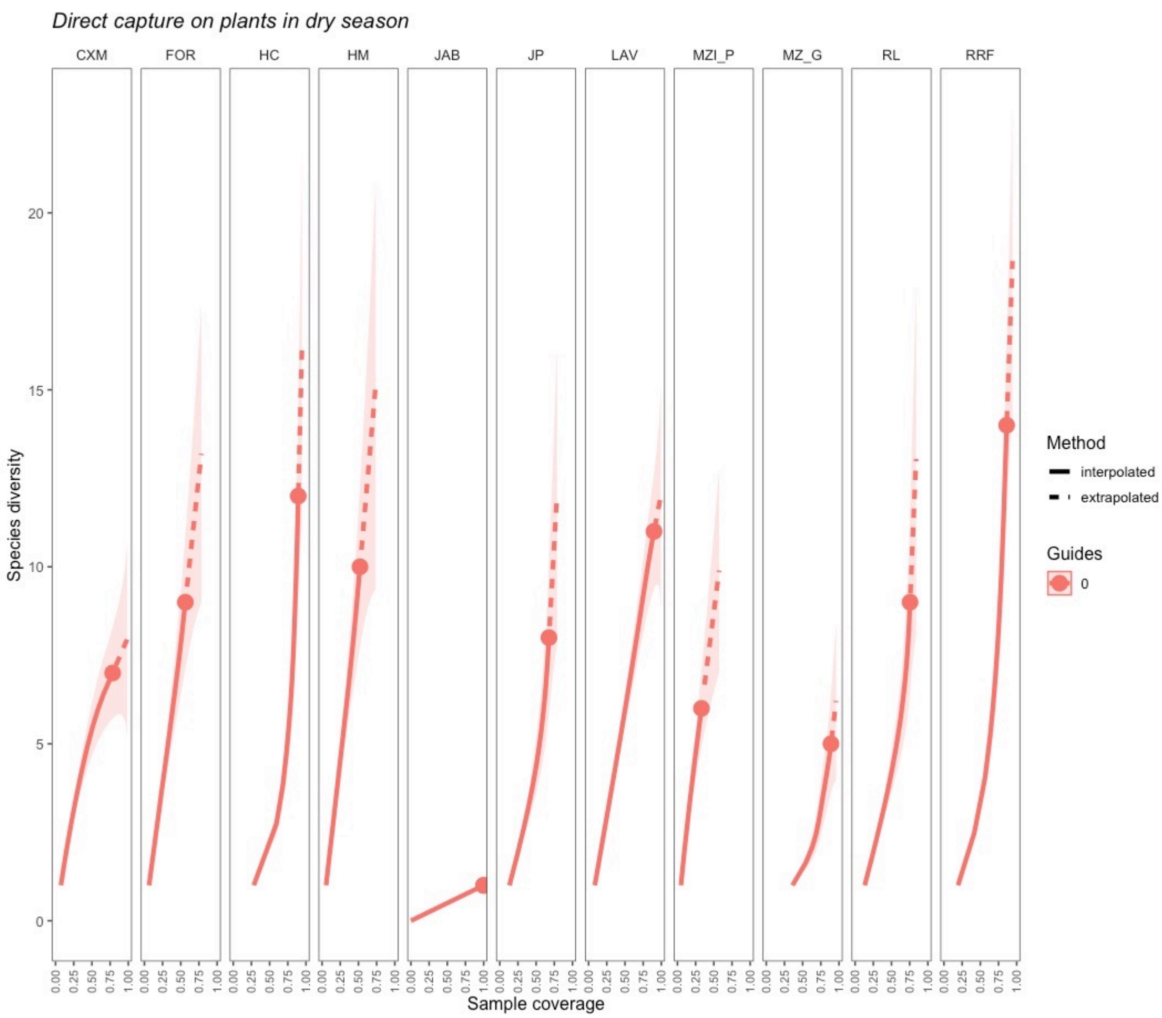
APPENDIX E



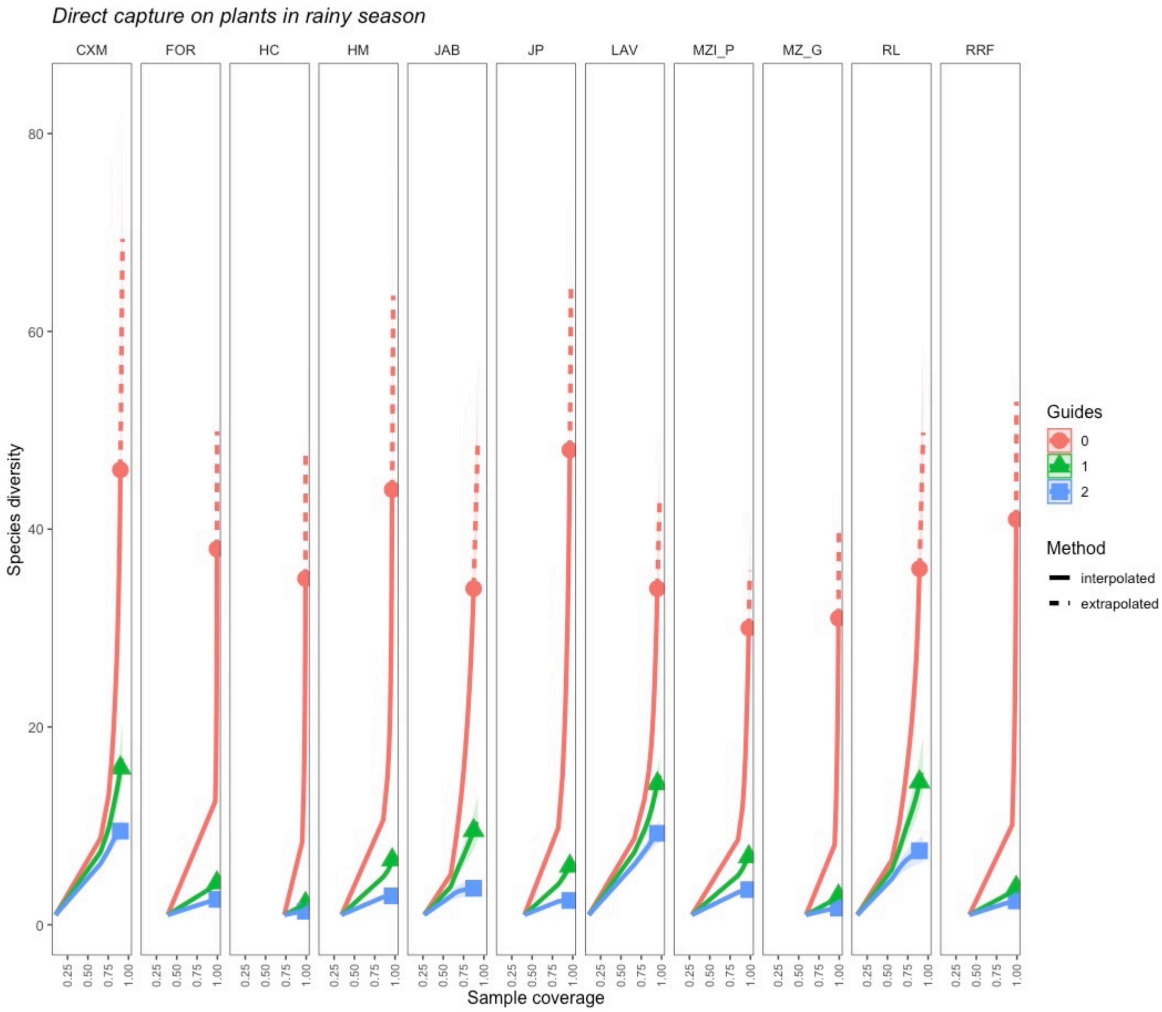
E.1 Sample coverage curves of arthropods captured in pitfall traps during dry season.



E.2 Sample coverage curves of arthropods captured in pitfall traps during rainy season.



E.3 Sample coverage curves of plant arthropods direct captures during dry season.



E.4 Sample coverage curves of plant arthropods direct captures during rainy season.

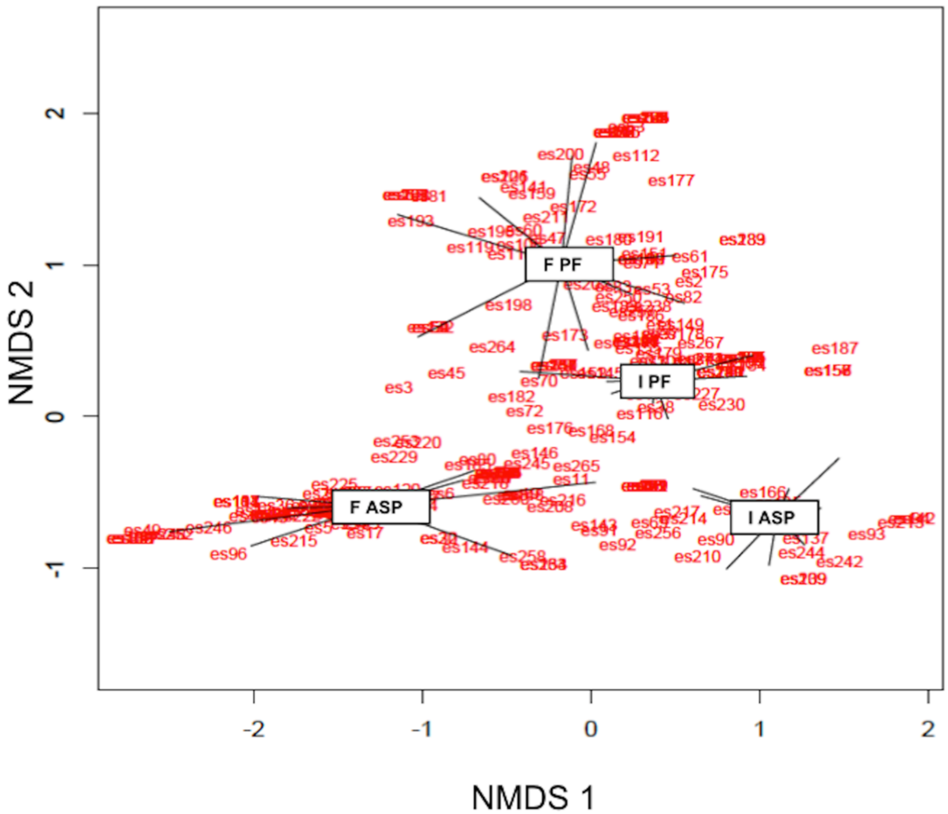
E.5 Sample coverage estimates for the pitfall traps for each plantation.

Pitfall traps				
Site	Dry Season		Rainy season	
	n	Sample coverage	n	Sample coverage
CX	144	0,9584	1236	0,9927
FO	133	0,9476	75	0,9611
HC	204	0,9562	150	0,9204
HM	34	0,801	350	0,9515
JB	105	0,9623	96	0,9902
JP	84	0,9408	188	0,9415
LV	90	0,8343	116	0,9315
MP	32	0,6895	337	0,9704
MG	71	0,9163	428	0,9743
RL	111	0,9823	363	0,9753
RF	142	0,9508	179	0,9443

E.6 Sample coverage estimates for the direct capture on plants for each plantation.

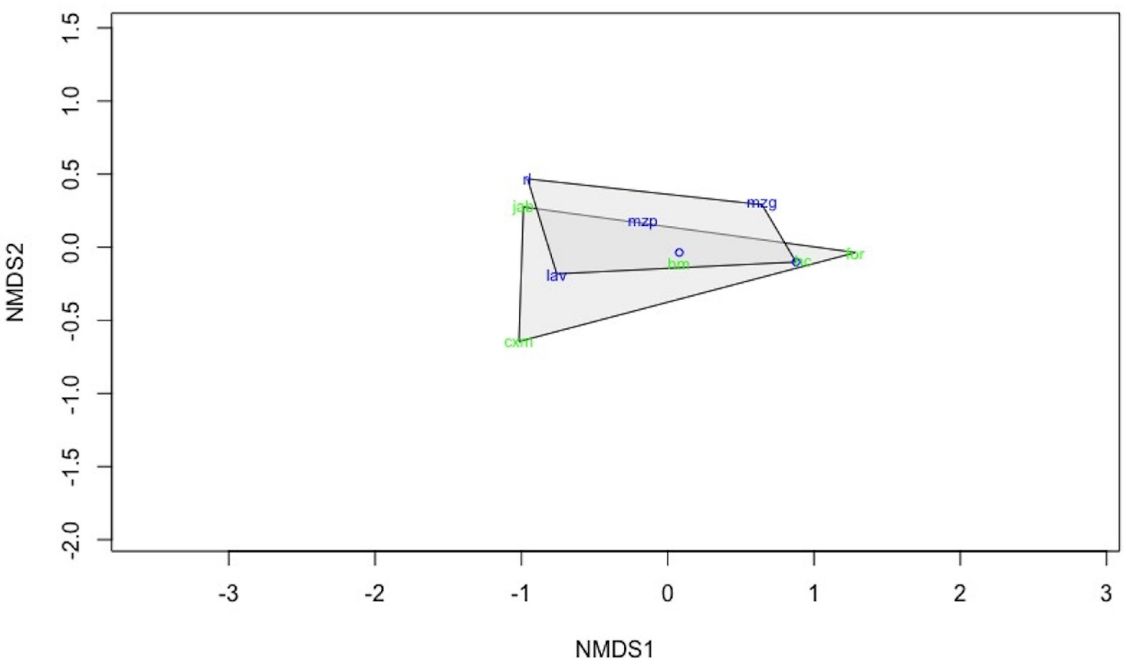
Plant direct captures				
Site	Dry Season		Rainy season	
	n	Sample coverage	n	Sample coverage
CX	11	0.7847	271	0.9005
FO	13	0.5628	3339	0.9952
HC	56	0.8941	1784	0.991
HM	14	0.5211	686	0.965
JB	1	1	150	0.8738
JP	15	0.6759	628	0.965
LV	27	0.8992	271	0.9485
MP	7	0.3304	494	0.9798
MG	17	0.8893	1247	0.9904
RL	20	0.7552	170	0.8945
RF	50	0.8624	1736	0.9908

APPENDIX F



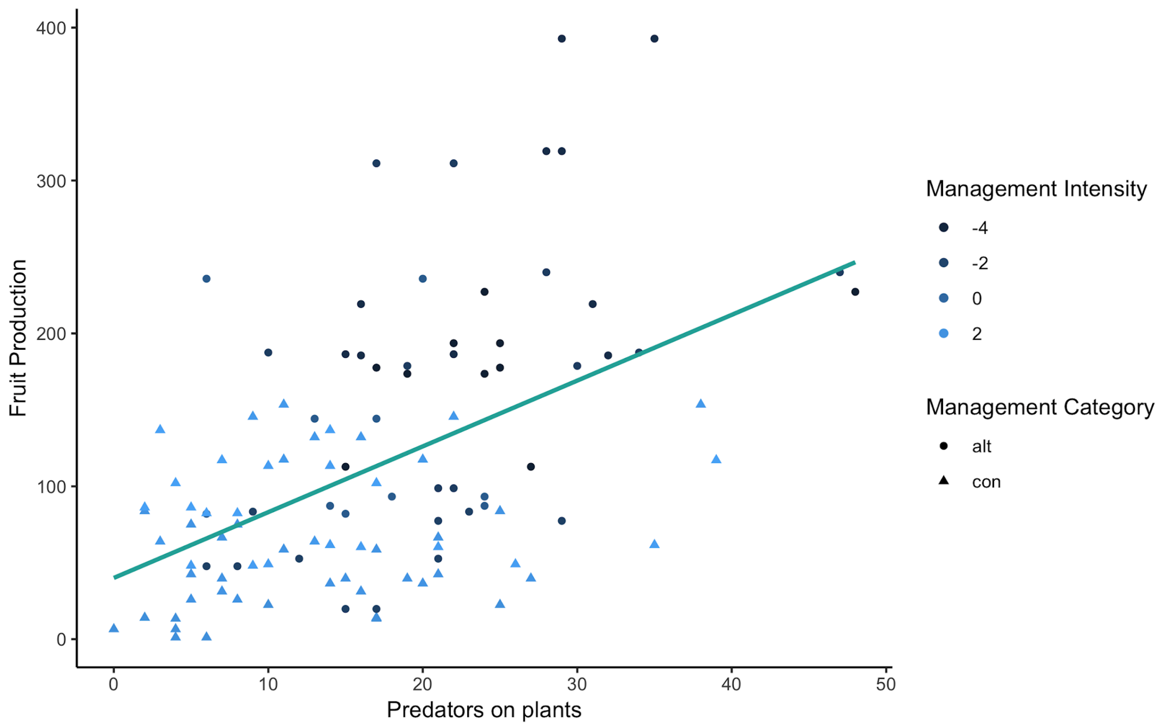
Ordination of arthropods trapped on plants and in soils and differences between the initial communities (dry season) and the final communities (rainy season), I=initial, F = final, ASP = arthropods collected on plants, PF =arthropods collected in soil. There are significant differences between arthropods collected in soil and on plants, and between the initial and final communities in plants (R^2 = 0.39, perMANOVA p≤ 0.05).

APPENDIX G



Arthropod community comparison between conventional and alternative farming. Polygons represent a convex hull, there are no significant differences between the arthropods present in alternative management (green sites) and in conventional management (blue sites) (perMANOVA P> 0.05).

APPENDIX H



Correlation between natural enemy abundance and fruit production. It is possible to notice that there is also an influence of management gradient on natural enemies and yield, alt= alternative management (dark blue), con= conventional management (light blue).

DISCUSIÓN

Los resultados de los modelos sugieren que el manejo convencional, que involucra un alto uso de insumos químicos, no incrementa la producción de frutos. Al contrario, el manejo intensivo tuvo un efecto directo negativo en la producción de frutos y en la diversidad local de artrópodos, con efectos en cascada provocados por la disminución de los enemigos naturales.

EFECTOS CONTRASTANTES DEL PAISAJE EN LAS DOS TEMPORADAS

Estudios recientes han mostrado que no existen patrones claros del efecto de la composición del paisaje sobre los herbívoros y los depredadores, sino que este efecto es dependiente del contexto y del tipo de vegetación predominante en el paisaje (Karp et al., 2018). En este estudio los herbívoros fueron más susceptibles que los enemigos naturales al porcentaje de bosque aledaño a la plantación, mientras que meta-análisis previos muestran que el paisaje suele tener mayor efecto en los enemigos naturales (Chaplin-Kramer et al., 2011; Rusch et al., 2016). Este resultado inesperado puede deberse a las dinámicas del bosque tropical seco y a sus cambios en la disponibilidad de los recursos entre estaciones. Durante la temporada de sequía los herbívoros colectados en plantas, principalmente herbívoros chupadores de salvia, fueron más abundantes en cultivos rodeados por paisajes homogéneos dominados por otros cultivos, mientras que durante la temporada de lluvias los herbívoros colectados en el suelo, principalmente ácaros y descortezadores, fueron más abundantes en plantaciones rodeadas por un alto porcentaje de bosque. Una posible explicación de estos cambios en la abundancia de herbívoros puede residir en que durante la temporada de sequía, las plantas nativas del bosque pierden las hojas y por ende los recursos para los herbívoros se vuelven escasos. Bajo este estrés es probable que éstos busquen alimento en los cultivos que se mantienen verdes debido al riego. De ser así, el bosque podría representar una barrera para los herbívoros durante la temporada de sequía, contrario a lo que sucede durante la temporada de lluvias, cuando es posible que encuentren una mayor cantidad de fuentes de alimento y microambientes dentro de la vegetación nativa. Cabe destacar que a pesar de que durante la temporada de lluvias la abundancia de herbívoros aumenta en plantaciones rodeadas por bosque, este el efecto no tuvo repercusiones desfavorables sobre el desempeño del cultivo. Otros estudios con resultados similares (Grab et al., 2018; Karp et al., 2016), donde también se ha detectado el efecto del paisaje sobre los herbívoros en vez de en los depredadores, han discutido que es probable que los enemigos naturales respondan a una escala espacial local relacionada con las prácticas de manejo, más que a una escala paisajística, lo cual se discute a continuación.

EFECTO DE LAS PRÁCTICAS DE MANEJO

En este estudio encontramos una correlación negativa entre la intensidad de manejo y la abundancia de enemigos naturales. En particular, plantaciones con intensidades bajas de manejo y con mayor diversidad de cultivos y herbáceas, tuvieron una mayor cantidad de enemigos naturales, probablemente como consecuencia de la facilidad para encontrar otras fuentes de alimento, como néctar en las demás plantas (Grab et al., 2018; Karp et al., 2016). Por otra parte, no encontramos diferencias significativas en la abundancia de herbívoros entre tipos de manejo, lo cual indica que el objetivo del uso de insecticidas (reducir la abundancia de plagas) no se cumple en estos cultivos. No es la primera vez que se documenta que el manejo intensivo es perjudicial para las comunidades de enemigos naturales en vez de sobre las de herbívoros (Bengtsson et al., 2005; Krauss et al., 2011; Letourneau and Goldstein, 2001; Meehan et al., 2011; Östman et al., 2003). Algunos estudios incluso reportan mayor abundancia de plagas cuando se aplican insecticidas (Krauss et al., 2011; Meehan et al., 2011), debido a que las plagas se pueden volver resistentes (Perfecto et al., 2009). El papel de los enemigos naturales se ha equiparado en otros estudios al efecto de los insecticidas, por lo que una disminución de estos puede tener fuertes implicaciones sobre el control de plagas (Östman et al., 2003).

EFECTOS EN CASCADA DEL LA INTENSIDAD DE MANEJO SOBRE LA PRODUCCIÓN DE FRUTOS

Adicionalmente, se encontró que la abundancia de enemigos naturales tiene un efecto positivo y directo en el incremento de la producción de papayas, lo que sugiere que el manejo alternativo de baja intensidad no solo aumenta las poblaciones de los enemigos naturales, sino que al hacerlo también incrementa la productividad de este cultivo. Contrario a lo esperado, la relación entre enemigos naturales y herbívoros fue positiva, es decir, los enemigos naturales no ejercieron un control sobre las plagas, sino que parece haber una mayor abundancia de depredadores donde hay más presas. Este efecto de los herbívoros sobre sus depredadores se ha identificado en otros estudios (Morante-Filho et al., 2016; Scherber et al., 2010). A pesar de que los herbívoros sí se relacionan con el daño en las plantas, el daño no se refleja en la producción, lo cual podría indicar que las plantas pueden sobre-compensar el daño como sucede en otros cultivos (Poveda et al., 2017).

Si los enemigos naturales, los cuales son predominantemente hormigas, coccinelidos y avispas, no tuvieron un efecto en la producción a partir del control de las plagas como se ha encontrado en otros estudios (Ali et al., 2018; Cardinale et al., 2003; Karp et al., 2018; Liere et al., 2015; Östman et al., 2003), esta cascada trófica puede deberse a factores que no fueron considerados en este estudio, en particular el papel de las hormigas como polinizadores. Las plantas hermafroditas de papaya pueden ser autopolinizadas y presentan cleistogamia (Corrêa Damasceno Junior et al., 2009), es decir, se auto fecundan antes de que abran las flores. Es posible que estas plantas podrían beneficiarse de eventos de polinización adicionales a su autopolinización, los cuales pueden tener relación con la presencia de hormigas. Un estudio en plantaciones de café, demostró que el "fruit set" era mayor en ramas con hormigas y polinizadores presentes, que sólo con polinizadores (Philpott et al., 2006). Otros estudios han demostrado que las hormigas y las avispas pueden limitar la depredación floral sin interferir con los polinizadores (Assunção et al., 2014) y que las hormigas disminuyen el tiempo de visita de los polinizadores (Altshuler, 1999) pero esto, más allá de ser un conflicto, puede beneficiar la adecuación de las plantas al reducir la endogamia que resulta de la autopolinización (Villamil et al., 2018). El conflicto entre hormigas y polinizadores en los agroecosistemas necesita mayor investigación y proponemos que es posible que los enemigos naturales tengan una doble función en los servicios ecosistémicos, por un lado reduciendo la florivoría y herbivoría y por otro, promoviendo el entrecruzamiento. Basados en nuestras observaciones personales, sería posible incluso que las hormigas polinizaran las flores de papaya.

Además del efecto de los enemigos naturales en la producción, el fósforo del suelo tuvo un efecto significativo en el incremento de las cosechas. Este resultado era de esperarse ya que el fósforo es uno de los elementos principales de los fertilizantes. Si bien la disponibilidad de fósforo es el recurso limitante para el crecimiento de las plantas de la región (Campo et al., 2001), resulta interesante que no encontramos diferencias en las cantidades de fósforo entre las diferentes formas de manejo, pero existe evidencia de que las compostas y las prácticas alternativas pueden aumentar la disponibilidad de fósforo en el suelo y tener efectos positivos en el peso de las cosechas (Karp et al., 2016).

¿EL MANEJO INTENSIVO VALE LA PENA? UN VISTAZO A LAS DECISIONES DE LOS AGRICULTORES

La idea detrás del uso de agroquímicos es reducir la abundancia de las plagas, enfermedades y de competencia para asegurar que las plantas crezcan saludables y tengan una mayor productividad. Sin embargo, en este estudio, una de las variables más perjudiciales para los cultivos de papaya fue la intensidad de manejo. Este trabajo constituye uno de los pocos estudios en que se analizan el impacto de las prácticas agrícolas en los diferentes niveles tróficos y uno de los resultados más relevantes del estudio destaca el efecto adverso del manejo intensivo sobre la comunidad de enemigos naturales y en consecuencia, de la producción de frutos, que no en su objetivo principal, el de reducir la abundancia de herbívoros plaga en el cultivo.

Después de compartir los resultados con los agricultores participantes, encontramos que los agricultores con prácticas alternativas coinciden con el resultado de que sus prácticas de manejo conservan a los enemigos naturales y que además son menos costosas que el manejo convencional, por lo que parece ser una opción de manejo sustentable en la región. En cambio, la mayoría de los agricultores que tienen un manejo convencional, a pesar de reconocer que sus prácticas de manejo tienen efectos negativos en las poblaciones de artrópodos benéficos y notaron que sus cosechas fueron menores en relación a las de la agricultura alternativa, manifestaron que no tienen la intención de modificar sus formas de manejo. La mayor razón detrás de esa decisión reside en que el manejo alternativo requiere mayor esfuerzo humano dado que los agricultores deben monitorear el estado de las plantas cada día para identificar la presencia de virus, además de que dedican más tiempo a la preparación de algunos de sus insumos, como los repelentes y compostas o abonos. Aunado a lo anterior, la mayoría de los agricultores con prácticas convencionales suelen rentar terrenos adicionales a los suyos, de modo que trabajan a la par varias plantaciones de papaya en la región y argumentan que no pueden tener un cuidado meticuloso en cada una. En cambio, los agricultores con manejo alternativo suelen ser dueños de las tierras que cultivan. Dentro de las razones por las cuales los agricultores toman decisiones de manejo, resulta relevante la tenencia de la tierra, ya que al ser dueños de la tierra, los agricultores toman mayor cuidado a largo plazo.

Los cultivos de papaya con manejo intensivo tuvieron menor cantidad de artrópodos benéficos y menores cosechas. Por otra parte, no se encontraron diferencias significativas en la abundancia de herbívoros plaga entre formas de manejo convencionales y alternativas, lo que indica que el uso de pesticidas no está disminuyendo a las plagas pero sí está afectando a los enemigos naturales en este cultivo. A escala de paisaje, un alto porcentaje de bosque aledaño se relacionó con menor cantidad de herbívoros en las plantas durante la temporada de sequía y un aumento en los herbívoros del suelo durante la temporada de lluvias, sin repercusiones en la producción final. El manejo alternativo parece ser una opción sustentable para la producción de papaya en la región y hacen falta trabajos multidisciplinarios que profundicen en las decisiones de manejo que tienen los agricultores.

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