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# Management practices and diversity of flower visitors and herbaceous plants in conventional and organic avocado orchards in Michoacán, Mexico

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**ABSTRACT**

Despite alleged advantages of organic over conventional farming, management effects on biodiversity are still little known. We related the diversity of herbs and flower visitors to management indicators in avocado orchards and hypothesized that inputs, practices, and context influence diversity of herbs and flower visitors. Using basic classification units, matrix correlation, and multivariate analysis of variance, we found that low-toxicity insecticides, infrequent herb cutting, and presence of forest areas were related to high biodiversity. Intensification of agricultural management reduced biodiversity both in organic and conventional management type. Our results advocate for an improved, integrative, management classification considering intensification and ecological context, besides input-type criteria.

**KEYWORDS**

Avocado; floral resources; inputs; biodiversity; pollinators

## 1. Introduction

Agroecosystems are ecological systems that have been transformed for the production of goods and are productive systems with well-defined biological, physical, and chemical boundaries (Conway 1985). The capacity of an agroecosystem to provide goods and ecosystem services depends largely on its biodiversity (Swift, Izac, and Van Noordwijk 2004) and management (Altieri 1999). At the same time, the quantity and quality of agronomic inputs and management practices are determinants of the productive and ecological sustainability of an agroecosystem (Abbona et al. 2007; Hansen 1996; Lançon et al. 2007;

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Mas and Dietsch 2003; Simon et al. 2010; Tilman et al. 2002). The general consensus is that conventional farming produces a loss of associated biodiversity and the deterioration of ecosystem processes (Giller et al. 1997). In recent decades, organic farming has emerged as an alternative to conventional farming. Organic farming forbids the use of synthetic chemical pesticides and fertilizers (Seufert, Ramankutty, and Foley 2012), and encourages sympathetic management of all habitats within a farm (Abaidoo and Dickinson 2002; Stanhill 1990; Van Diepeningen et al. 2006). Organic farms tend to register higher biodiversity (Bengtsson, Ahnström, and Weibull 2005; Gomiero, Paoletti, and Pimentel 2008; Hole et al. 2005) and to be more sustainable than conventional farms (Pimentel et al. 2005). Despite its claimed benefits, the organic farming industry has been criticized for the perceived lack of scientific methodology underpinning its farming methods (e.g., Kirchmann and Thorvaldsson 2000; Trewavas 2001). It has even been considered that natural products are good, but synthetic chemical products are bad *per se* (Kirchmann and Thorvaldsson 2000). However, no systematic data exists for many crops, including avocado, a tropical perennial produced in plantations.

In recent years, avocado (*Persea americana* Mill) has become a primary sector product with large global demand (Lemus et al. 2005; SAGARPA 2008). Mexico is the largest producer of avocado worldwide (31% of global production in 2010) and has the largest cultivated area in the world (27%; FAOSTAT 2015). The area of land cultivated with avocado in the country rose by 31% from 2000 to 2010, and this increase was accompanied by an intensification of management practices. More than 80% of the land dedicated to avocado cultivation is within the state of Michoacán, an area that accounts for 87% of the total national production (SAGARPA 2008). The intensification of avocado cultivation in Michoacán has led to the use of considerable quantities of fertilizers, insecticides, and herbicides, and to soil erosion and deforestation of natural forest areas (Barsimatov and Navia 2012; Bravo-Espinosa et al. 2012).

Organic certification of avocado production is in place in México since 1993 (Hattam, Lacombe, and Holloway 2012). In the state of Michoacán, 10% of avocado growing areas are organic (Vidales, Paniagua, and Jiménez 2014). Farms (both organic and conventional) in the region apply mostly organic fertilizers (composts and manures); herbaceous plants are considered as weeds and controlled using a weeding machine before harvesting the fruit (practice required by phytosanitary regulations). Despite these common practices, organic and conventional farms differ considerably in their methods for controlling weeds, pests, and diseases. Intensities and frequencies of agrochemical application may markedly differ across farms, even between farms of the same type. Because of this wide variation in management practices, simply classifying farms as conventional or organic may be a lowly description of relevant differences. It is likely that these terms do not fully identify true similarities and differences in terms of the biodiversity and the ecological processes the orchards sustain.

Conservation of the biodiversity associated to commercial crops may be of particular relevance in the case of avocado plantations, given that production is partially dependent on pollinators (Perez-Balam et al. 2012). Avocado trees are dichogamous, that is, male and female flower parts mature at different times of the day. This makes the crop dependent on cross-pollination (Davenport 1986; Nirody 1922; Stout 1923) via insects visiting the plants during both sexual phases (Ish-Am and Eisikowitch 1991; Sedgley 1987). Bees, wasps, and flies are considered the primary pollinators of avocado trees worldwide (Roubik 1995). However, avocado flowering is seasonal and the maintenance of pollinators requires the presence of other plant species in the orchards between avocado flowering periods. Herbaceous plants may provide alternative resources for pollinators and bring other benefits like biological control and soil quality and retention. In recent years, a series of alternative management practices has been promoted in intensively managed areas to increase the availability of pollen and nectar for pollinator species (Wratten et al. 2012). However, no studies are available on the diversity of herbaceous plants or on the interactions between plant diversity and flower visitors in avocado orchards.

Considering the importance of understanding the relationship between on-farm management practices and their influence on biodiversity, but also acknowledging the difficulty involved in directly measuring all factors and interactions (Bockstaller et al. 2009), appropriate indicators may help generating the required information from these productive ecosystems toward more sustainable management (Huerta et al. 2014). To date, avocado orchard management is widely reported under the overarching labels of organic or conventional and it is assumed that organic management is associated to higher biodiversity. However, to our knowledge, no data sustains this assumption, which is commonly used for public policy and in political speech. In this study, we evaluated biodiversity and management indicators in avocado orchards with two main goals: (1) evaluating the relationship between agricultural practices and biodiversity in avocado orchards, focusing on flower visitors and herbaceous plants; and (2) assessing the relationship between *organic* and *conventional* management and diversity of flower visitors and herbaceous plants, to evaluate whether these labels reflect the status of biodiversity conservation in avocado orchards relevant to the maintenance of natural pollination. We focused on the insects that visit (and sometimes pollinate) avocado flowers, and on the herbaceous flowering plants providing additional food resources for those insects, given the importance of identifying alternatives to revert the current global pollinator decline (Potts et al. 2010; Thormann et al. 2013). From now on, we will use the term biodiversity as a short reference to the two groups we studied and will specify total biodiversity when we refer to all biota.

## 2. Methods

### 2.1. *Study area*

Fieldwork was carried out in 10 avocado orchards in the state of Michoacán, Mexico, in the area known as the "Avocado belt of Michoacán." This mountain area (1,100–2,900 masl) has a temperate to warm-subhumid climate (mean annual temperature of 14–19°C; mean annual precipitation of 1,100–1,500 mm (APEAM 2012; Gutiérrez et al. 2010). The dominant natural vegetation is pine, oak, and mixed forests, and the primary crops are avocado and maize. These land covers co-occur in a highly dynamic land-use transformation landscape where avocado plantations expand at an unprecedented rate boosted by the high demand and prices of avocado (Bravo-Espinosa et al. 2012). Four conventional and six organic avocado orchards planted with Hass cultivars were studied between 2010 and 2012. The minimum distance between orchards was 1 km.

### 2.2. *Data collection*

We used two sets of indicators for this study: biodiversity data obtained from field samplings and management practices and ecological structure data obtained from a farm survey. Each set of indicators was separately used to examine the dissimilarity between orchards and to examine groupings of orchards according to their biodiversity and management.

#### 2.2.1. *Flower visitors and herbaceous plants*

Flower visitors of avocado trees and herbaceous plants, and the herbaceous plants were sampled within 10 orchards. The flower visitors of avocado trees were collected along a path surrounding 10 trees per orchard during the peak flowering period in 2010/2011 (two samplings) and 2011/2012 (one sampling). Flower visitors were collected by observation and capture during a 10-min walk around each tree. Flower visitors of herbaceous plants and the herbaceous plants were collected similarly but cross-walking ten 200-m$^2$ plots marked per orchard, in 2011 (one sampling), during the flowering period of the herbaceous plants. Only herbaceous plants with flowers potentially attracting insects were sampled; our data do not reflect, therefore, total plant diversity. A given floral resource type (either flowers of avocado or of herbaceous plants) was the only type of resource available in the orchard at the time of sampling. Insects were collected with an entomological net and placed in a lethal chloroform chamber. Herbaceous plants were collected and dried for identification. Insects and herbaceous plants were identified at the taxonomic level of species, whenever possible, or as morphospecies otherwise.

## 2.3. Data analysis

### 2.3.1. Biodiversity indicators

Considering that the Shannon index is a measure of entropy, we used Hill numbers, a transformation of this index as a measure of diversity (Hill 1973; Joost 2006). The true diversity of zero order, with values equivalent to species richness (0D = S), is insensitive to the relative abundance of species. The true diversity of order 1 (D(H´) weighs proportionally all species according to their abundance in the community, by means of the exponential of Shannon´s entropy index (Jost 2006). Field data was used to calculate Hill numbers or the effective number of species (Chao et al. 2014), as $q = 0$ (species richness) and $q = 1$ (the exponential of Shannon's entropy index), for species richness of visitors of avocado flowers (VAVO), species richness of visitors of flowers of herbaceous plants (VHER), and species richness of flowering herbaceous plants (HER). The diversity values of the three groups of organisms were correlated (Pearson correlation) with air temperature and humidity to avoid confounding effects of these environmental variables on richness and abundance of the organisms studied.

### 2.3.2. Ecological structure of the orchards

The survey on orchard management was based on the methodological framework proposed by Blazy et al. (2009) for evaluation of the diversity of agricultural systems and the creation of management prototypes. The survey included technical concepts (inputs and agronomic practices) and a description of the ecological structure of the orchard (Table 1). Data used to survey management practices were collected using semi-structured questionnaires and consisted of quantitative data (e.g., input characteristics and application frequency) and visits to the orchards along with farmers. Management variables considered in the survey were based on their influence on the diversity of flower visitors and herbaceous plants (Table 1). The collected data comprised a timetable of insect, disease, and weed control activities, the products used in each activity, and the frequency with which these products were used.

Indicators that did not differ among orchards or that were correlated with another indicator were eliminated in order to increase segregation among groups of orchards (Köbrich, Rehman, and Khan 2003). The selected management indicators were cutting frequency of herbaceous plants (number of times/year; CUT), application of herbicides (applied/not applied; APH),

**Table 1.** Indicator variables selected and values used for the analysis of the relationship between biodiversity and management in avocado orchards.

| Type | | IN | C1 | C2 | C3 | C4 | O5 | O6 | O7 | O8 | O9 | O10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Biodiversity | $q = 0$ | VAVO | 12 | 16 | 12 | 6 | 23 | 15 | 28 | 13 | 13 | 14 |
| | | VHER | 14 | 5 | 31 | 14 | 29 | 32 | 19 | 20 | 23 | 18 |
| | | HER | 55 | 47 | 29 | 33 | 54 | 33 | 69 | 67 | 43 | 75 |
| | $q = 1$ | VAVO | 4.2 | 33.9 | 5.7 | 2.3 | 10.6 | 7.4 | 17.9 | 6.9 | 12.4 | 6.9 |
| | | VHER | 20.3 | 11.3 | 43.5 | 14.7 | 83.4 | 81.4 | 52.7 | 73.2 | 59.6 | 24.8 |
| | | HER | 363.9 | 252.9 | 128.2 | 163.7 | 294.4 | 162.4 | 430.5 | 471.6 | 247.4 | 479.6 |
| Management | Technical | TYP | C | C | C | C | O | O | O | O | O | O |
| | | APH | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | CUT | 10 | 6 | 10 | 10 | 4 | 6 | 2 | 2 | 3 | 3 |
| | | INS | 6 | 18.4 | 9.5 | 21.3 | 0.6 | 0.8 | 1.3 | 3 | 1.31 | 1.31 |
| | Ecological structure | FOR | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.2 | 0.2 | 0.1 | 0.3 | 0.2 |
| | | BEE | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 |
| Frequency of total insecticide applications per year | | | 6 | 7 | 8 | 10 | 3 | 6 | 4 | 6 | 7 | 7 |
| Mean toxicological category | | | 4 | 4 | 2.3 | 3.3 | 1 | 1 | 1.5 | 1.2 | 1 | 1 |

Biodiversity indicators: Hill numbers: $q = 0$ (species richness) and $q = 1$ (the exponential of Shannon's entropy index) for visitors of avocado flowers (VAVO), visitors of herbaceous plant flowers (VHER), and herbaceous plants with flowers (HER). Management indicators: cutting frequency of herbaceous plants (CUT, times per year), application of herbicides (APH, yes/no), index of nonsustainable use of insecticides (INS). Context variables: proportion of forest area within the orchard (FOR) and introduction of hives of *Apis mellifera* L. (yes/no, BEE). Type of management (TYP): conventional (C) or organic (O). Summary of data used to calculate INS: quantity of insecticides applied, mean toxicological category, and frequency of applications per year.

index of nonsustainable use of insecticides (calculated as defined below; INS). Indicators describing the ecological structure were introduction of *Apis mellifera* L. hives (presence, absence; BEE); and proportion of forest area within the orchard boundaries (FOR). The proportion of forest in the orchards was obtained from a 10-m resolution Quickbird multispectral satellite image of the region taken on May 2011. We tested (Pearson correlation, $\alpha = 0.05$) if forest area was dependent on orchard area.

Given the complexity and the number of factors associated with the indicators of insecticide use, we constructed an index based on the classification of Juraske et al. (2007): PestScreen, which establishes a ranking of insecticides that incorporates the toxic effects of pesticides in humans and their fate and exposure characteristics in different compartments of the environment such as biodiversity (rats, fish, and bees). The indicator is based on a value obtained (PestScore) from the analysis of the chemical toxicity that pertains to health and the environment with the release of chemical substances and information on the persistence of the environment, the potential for long-term transport and fractions of human population consumption, which is combined with the dose of pesticide application. The toxicity scale range is from 1 to 4 (1 = low, 2 = moderate, 3 = high, 4 = very high). However, the information available varies widely among the products applied; it is especially scarce for the organic products and does not consider all potential environmental issues. Therefore, this indicator should be interpreted cautiously. We calculated an index of nonsustainable use of insecticides (INS) for each orchard using the following equation:

$$INS = \sum^{\left(\frac{Cp}{4}\right)^2} P * Ap$$

where *Cp* represents the category of insecticides applied to the orchard (Table 2) (data obtained from PestScreen), which is divided by 4 (the highest toxicity value, to obtain the proportional toxicity value of the insecticide within the scale defined for this study. The different levels of this scale assumed the attributes of the toxicological classification in Table 2) and *Ap* represents the number of insecticide applications per year. As the index value increases, the non-sustainability grade of insecticides increases.

We used principal component analysis (PCA) to explore the indicators of management and ecological context that contributed most to orchard differentiation.

#### 2.3.3. *Relation between management and biodiversity*

We made three assessments. The first one explored the grouping of orchards generated by the dissimilarity analysis using two sets of indicators: biodiversity (the first two numbers of Hill, from flowers visitors and herbaceous plants) and management indicators (applied agronomical practices: CUT, APH, BEE, FOR,

**Table 2.** List of identified insecticidal products and their chemical compounds, assigned toxicological category based mainly on human risk level and, whenever available, also environmental impacts including pollution and toxicity to other groups of organisms, and type of product.

| Commercial name | Chemical compound | Toxicological category | Synthesis |
|---|---|---|---|
| Aldrin | Chlorinated hydrocarbon | 4 | Synthetic |
| Permethrin | Pyrethroid | 1 | Synthetic |
| Azadirachtin | Azadirachtins, tetranortriterpenoid | 1 | Synthetic |
| Calcium and sulfur (2:1) | Calcium polysulfide | 1 | Natural |
| *Argemone mexicana* L. | Flavonoids | 1 | Natural |
| Bacillariophyceae powder | Flavonoids | 1 | Natural |
| *Piscidia communis (Blake) L. M. Jchnst* | Isoflavones | 1 | Natural |
| Paraffinic acid 83% | Mineral oil | 1 | Natural |
| Spinosad | Spinosyn A and D | 2 | Synthetic |
| *Tagetes foetidissima* | Terpenoids | 1 | Natural |
| *Allium sativum* L., *Capsicum* sp., *Allium cepa* L. | Volatile sulfur compounds, allaicin, capsaicin | 1 | Natural |
| Gamma cyhalothrin | Pyrethroid | 2 | Synthetic |
| Polyglycolic ether of tridecanol | Polyglycolic ether of tridecanol | 2 | Synthetic |
| Lambda cyhalothrin | Pyrethroid | 4 | Synthetic |
| Malathion | Organophosphate, diethyl mercaptosuccinate | 4 | Synthetic |
| Spinetoram J + L | Spinetoram J + L | 3 | Synthetic |
| Imidacloprid | Imidacloprid | 1 | Synthetic |
| Cypermethrin | Pyrethroid | 2 | Synthetic |
| *Beauveria bassiana* | Parasitic fungus | 1 | Natural |
| *Saccharopolyspora spinosa* | Spynosins | 1 | Natural |
| *Tagetes lunulata* | Pirethrins | 1 | Natural |

and INS). We used management and biodiversity indicators based on a pairwise dissimilarity analysis between orchards using Ascending Hierarchical Classification (AHC). This analysis forms groups (of orchards) of similar individuals (classes) based on their description by a set of quantitative and qualitative variables (Mojena 1977). We obtained two clusters, one for biodiversity and one for management. We used Ward's minimum variance criterion for AHC (Ward 1963), and Euclidian distance as a dissimilarity index between orchards (Köbrich, Rehman, and Khan 2003). In the second analysis, we examined the correlation between the dissimilarity data generated for both sets of indicators: biodiversity and management. For that analysis, we assumed a cause–effect relationship between agronomic practices and biodiversity variables (Figure 1), considering that the biodiversity of the groups observed in the orchards may depend on the agronomic management practices locally applied, or that the agronomical management may determine the observed flower visitors and herbaceous diversity, that is, the more intense the agronomical practices, the lower diversity. We compared the sets of data of distance measurements (Smouse, Long, and Sokal 1986) using a Mantel test (Mantel 1967). In this case, we considered the two dissimilarity matrices generated by the AHC of each attribute (biodiversity and management) using the Pearson correlation coefficient, $\alpha = 0.05$, and 10,000 permutations (Smouse, Long, and Sokal 1986).

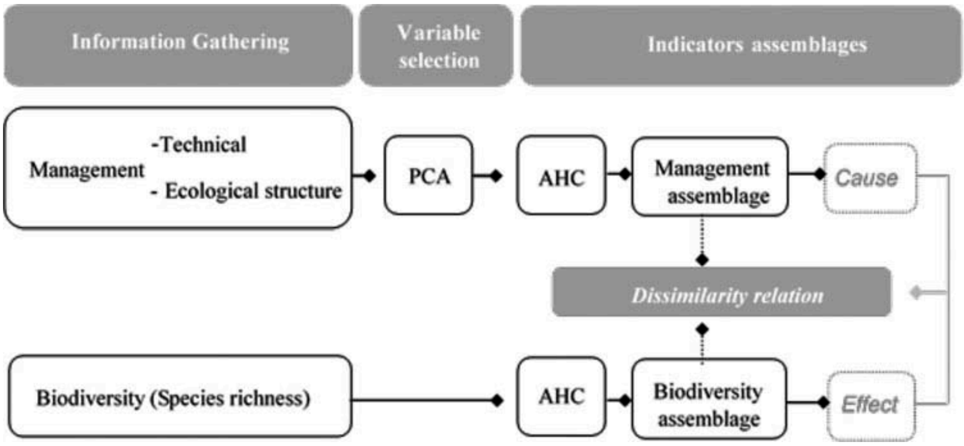


**Figure 1.** Methodological model used to generate related orchards according to biodiversity and management assemblages. The process comprised three phases: (i) data collection on management and biodiversity, (ii) the selection of variables via multivariate principal component analysis (PCA), and (iii) the related orchards via grouping with Ascending Hierarchical Classification (AHC) and comparison of dissimilarity matrices. The management data were obtained via surveys and interviews, and the biodiversity data were gathered directly in the field. A cause-and-effect relationship was assumed to exist between agronomic management and biodiversity, and this relationship was analyzed by comparing the matrices generated by the multivariate analysis.

The third analysis explored the linear relationships between conventional and organic management and biodiversity taking into account the biodiversity indicators (dependent variables): Hill: $q$ = 0 and $q$ = 1 for VAVO, VHER, and HER, and management indicators (explanatory variables): CUT, APH, INS, BEE, and FOR. We tested whether biodiversity indicators differed between conventional and organic orchards using one-way multivariate analysis of variance (MANOVA) ($\alpha$ = 0.05) and a redundancy analysis with 500 permutations ($\alpha$ = 0.05) of the linear relationships between management type and biodiversity. We used the biodiversity indicators (response variables): $q$ = 1 for VAVO, VHER, and HER, and the biodiversity indicators CUT, INS, and FOR as quantitative explanatory variables, and BEE and APH as qualitative explanatory variables in the redundancy analysis.

All analyses were performed using XLSTAT Version 19.5.47088 (Addinsoft SARL, Paris, France).

## 3. Results

### 3.1. *Biodiversity indicators*

The overall means for first Hill number ($q$ = 0) (±SD) were 15.2 ± 5.84 for avocado flower visitors, 19.3 ± 7.36 for herbaceous flower visitors, and

11.3 ± 5.06 for herbaceous plant species per orchard. According to agronomic management, conventional orchards had on average 11.5 ± 3.6 avocado flower visitors, 16 ± 9.4 herbaceous plant visitors, and 41 ± 10.5 herbaceous plants with flowers, and organic orchards had 17.7 ± 5.7, 23.5 ± 5.2, and 56.8 ± 15.8, respectively. The overall second Hill number ($q = 1$) values were 10.8 ± 8.8 (VAVO), 46.5 ± 26.3 (VHER), and 299.4 ± 124.3 (HER). Conventional orchards had on average 11.5 ± 13 (VAVO), 22.4 ± 12.6 (VHER), and 227.1 ± 91.08 (HER) and organic orchards had 10.3 ± 3.9 (VAVO), 62.5 ± 20.1 (VHER), and 347.6 ± 120.3 (HER) (Table 1). No significant correlations were observed between biodiversity variables (VAVO, VHER, HER) and average temperature and average relative humidity. We tested and found no correlation (Pearson correlation, $\alpha = 0.05$) when we examined if forest area was dependent on orchard area.

### 3.2. *Management indicators*

We selected five variables of management (Table 1). Application of compost, season of application, and quantity and quality of applied compost were not considered because all farmers applied it in a similar manner. Herbicides (APH) were applied in only one orchard to control the growth of herbaceous plants in the drip irrigation areas. However, herbaceous plants were controlled with mechanical cutters in all orchards. Annual cutting frequency (CUT) was identified as an important attribute. Insecticides were applied in all orchards, but the toxicological classifications of the applied products and the number of applications per year differed among orchards. The index with most sustainable use of insecticides was with category 1 and low-frequency application (2–7 applications/year) and the least sustainable pesticide use applied 3–4 category products with high toxicological characteristics with high application frequency (10 applications/year). There was no statistically significant relationship between the sizes of the forest area and the orchard ($r = 0.518$, $p = 0.125$).

The first three factors of the PCA explained 90.5% of the total observed variance and were retained (Table 3). The factorial weight of the indicators belonging to the first component indicated that the application of insecticides, the cutting frequency of herbaceous plants, and the proportion of forest in the orchard were the most important indicators. The most important indicator in the second component was the introduction of beehives and in the third component the application of herbicides. The contribution of each indicator to the total variance in each component was greater than 50%.

**Table 3.** Factorial weights and contribution of the variables of the first three factors generated in the principal component analysis (PCA).

| | Factorial weight | | | Variable contribution | | |
|---|---|---|---|---|---|---|
| Variable | F1 | F2 | F3 | F1 | F2 | F3 |
| FOR | −0.811 | 0.459 | −0.133 | 22.372 | 24.499 | 2.455 |
| HIV | 0.538 | 0.731 | 0.402 | 9.846 | 62.045 | 22.256 |
| CUT | 0.858 | −0.134 | 0.194 | 25.019 | 2.077 | 5.193 |
| HER | −0.628 | −0.297 | 0.711 | 13.416 | 10.229 | 69.787 |
| INS | 0.929 | −0.100 | −0.047 | 29.347 | 1.151 | 0.309 |
| Eigenvalue | 2.942 | 0.860 | 0.725 | | | |
| Explained variance (%) | 58.839 | 17.209 | 14.507 | | | |
| % accumulated | 58.839 | 76.048 | 90.555 | | | |

## 3.3. *Relation between management and biodiversity*

### 3.3.1. *Dissimilarity of biodiversity and management indicators among orchards*

Biodiversity indicators generated three groups of orchards in the HCA. The first group included the conventional orchard C3 and the organic orchards O5, O6, O8, and O9. Orchards C1, O7, and O10 were in the second group and C2 and C4 in the third group. Intraclass variances for the first, second, and third groups were 580, 550, and 693, respectively (Figure 2a). Management indicators generated also three groups of orchards. The first grouped all organic orchards, the second conventional C1 and C3, and the third C2 and C4. Intraclass variances for the first, second, and third groups were 6.09, 7.13, and 4.71, respectively (Figure 2b). Therefore, classification based on management clearly separated the conventional and organic orchards but classification based on biodiversity mixed some of the conventional and organic orchards.

### 3.3.2. *Relationship between dissimilarity in biodiversity and management*

The Mantel correlation analysis showed that the biodiversity and management distance matrices were significantly correlated ($r = 0.498$, $p = 0.001$). This indicates that the species richness of visitors of avocado tree flowers, of herbaceous plant flowers, and of other herbaceous plants in the avocado orchards was influenced by management practices.

### 3.3.3. *Linear relationships between biodiversity and management*

The difference between the vectors of the means for the two types of management was significant (MANOVA, Wilks' lambda = 0.590, $p < 0.0001$). Redundancy analysis indicated that management indicators explain the variation in flower visitors and flowering plants. The permutation test was significant (PseudoF = 1.25, $p < 0.0001$); axis 1 supported 98.77% of inertia, which represents 54.81% of total inertia (Figure 3).

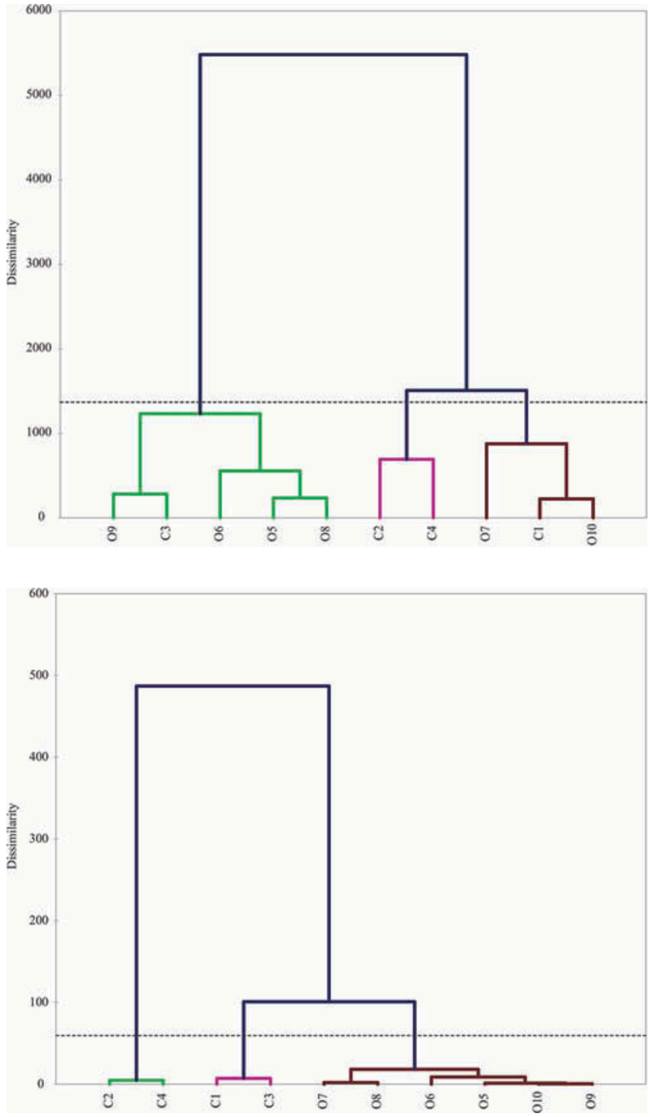


**Figure 2.** Dendrograms representing orchard groups based on dissimilarity distances in the (a) biodiversity and (b) management assemblage. The dotted line represents the truncation of these groups, and the numbers below show the intraclass variance of each group. Each analysis shows three groups. The initial in each orchard recognizes the type of management: conventional (C) and organic (O).

## 4. Discussion

Our results from different tests showed that biodiversity and management practices were highly related in the avocado orchards studied but also that biodiversity was not straightforward associated to either the conventional or organic management types. This suggests that the most common

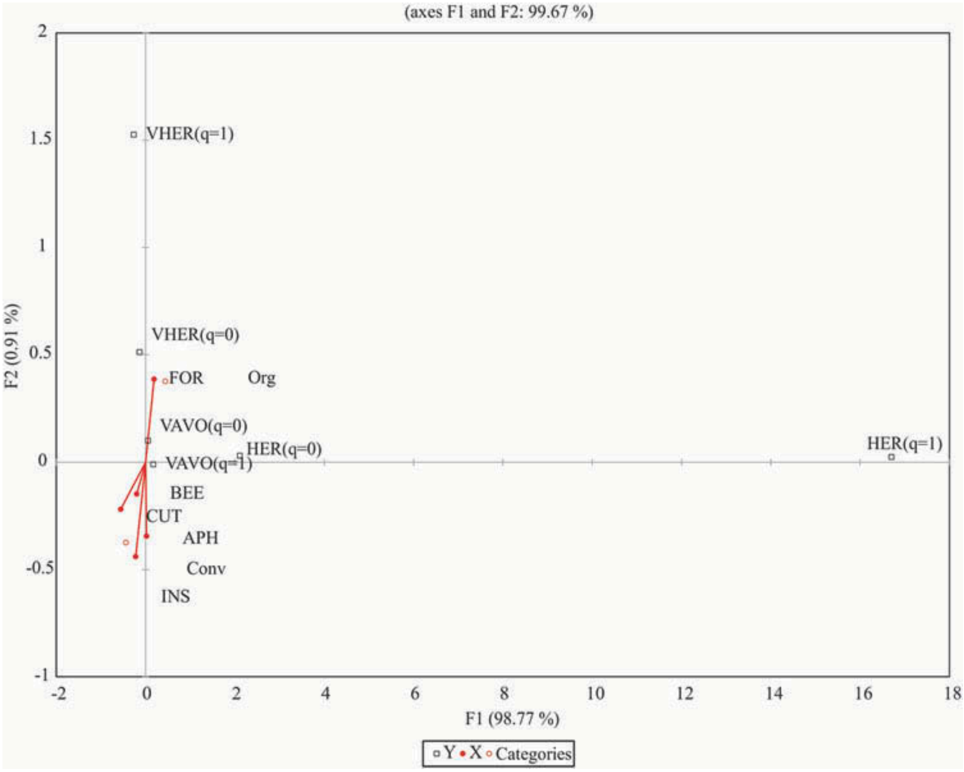


Figure 3. Redundancy analysis of biodiversity and management indicators.

management-type labels used not only for marketing but for environmental policy and decision making, conventional and organic, may be too broad to reflect important environmental impacts and sustainability in production.

### 4.1. *Relationship between orchards according to management type*

Our analysis identified specific management practices and ecological structure data that relate positively to biodiversity conservation in the orchards and could be encouraged in any form of management. Clustering in large groups according to the presence of forest areas, application of synthetic or organic products for pest control, and, to a lesser extent, the cutting frequency of herbaceous plants, was noteworthy. The orchards differed more in management practices and ecological contexts than in inputs, which explains why there was no consistent pattern in the groupings of orchards, especially among organic orchards. It is possible that technical practices and ecological structure of orchards compensate for one another: the lack of food resources for flower visitors (pollen and nectar) resulting from the frequent cutting of herbaceous plants may be compensated for by the presence of a large wooded area. For that reason, the matrices appeared to be correlated despite the differences in forested area among related orchards of both indicators, showing that a relationship exists in orchards between species richness and agronomic practices. This finding might even be highlighting agroecosystem management models influencing biodiversity.

### 4.2. Relationship between agronomic management practices and biodiversity of floral and plant visitors

Many studies have demonstrated that organic orchards or orchards with less intensive management (Hudewenz et al. 2012) have greater species richness and greater abundance of herbaceous plants (Hald 1999; Hole et al. 2005) and pollinators than conventional orchards (Gabriel and Tscharntke 2007; Holzschuh, Steffan-Dewenter, and Tscharntke 2008; Kehinde and Samways 2012; Kremen et al. 2007; Kremen, Williams, and Thorp 2002; Rundlo, Nilsson, and Smith 2008). Also, a greater number of plant–animal interactions exists whenever there is a greater diversity of herbaceous plants due to lower frequency of weeding or browsing (Batary et al. 2010). Accordingly, the results of our work supported a relationship between management and biodiversity but mostly at the level of specific management practices applied to each orchard. This became evident in the similitude we observed between some orchards categorized as conventional and organic. For example, the similitude of the agronomical practices can be seen in the lack of difference found between groups of organic and conventional orchards when the richness of avocado flower visitors was analyzed because in all cases weeding must be done before the fruit is harvested, which occurs before flowering of avocado trees. However, when analyzing richness of herbaceous plants and their flower visitors, some organic orchards presented similarities with conventional orchards. This may be explained by technical characteristics and ecological structure because the organic orchards with small forest areas were weeded twice per year whereas the organic orchards with large forest areas were weeded up to six times. This is, to our knowledge, the first study of avocado cultivation to show that orchard management practices applied are related with biodiversity of pollinators and of herbaceous plants.

Most orchards use inputs to control pests and the frequency of application of these inputs may have been similar in organic and conventional orchards; however, organic orchards tend to use products with a lower toxicological risk. Organic orchards were managed with organically synthesized products of low toxicological categories, and they had the lowest values of the non-sustainable use of insecticides, low frequency of weeding, and presence of forested areas, which resulted in the highest richness in the three diversity assessments we made. On the contrary, conventional orchards presented the lowest richness possibly as a result of intensive weeding, application of chemically synthesized herbicides and insecticides of intermediate and high toxicological categories, and lack of forest areas.

The establishment of plant–animal interactions is another important aspect of biodiversity maintenance. Maintenance of the functionality of biodiversity – which is affected by management practices – has to be analyzed at the community level taking plant–animal interactions into account. Although we found no evidence of the directionality of the plant–flower visitor relationships, we found that the communities present in organic orchards exhibited high biodiversity of herbaceous plants, their flower visitors, and VAVO. This could indicate that a higher diversity of herbaceous plants increases the quantity of resources available for the sustenance of their flower visitors in the absence of avocado flowers and, in turn, it also increases the diversity of avocado flower visitors. However, although it has been established that a high number of flowering plant species are associated to a high richness of pollinators (Biesmeijer et al. 2006; Hudewenz et al. 2012), there is also evidence that the persistence of a plant community may be affected by loss of pollinator biodiversity (Fontaine et al. 2006). Hence, application of insecticides with high toxicological risk or of management practices that decrease any of these biological groups in a drastic way (such as intensive weeding or application of herbicides) could have a cascading effect that may eventually affect the biodiversity of the interacting groups of organisms.

The response to land-use change by individuals, populations, and communities of flower visitors mainly depends on the spatial and temporal distribution of flower resources, whereas the vulnerability of plant reproduction depends on the degree of dependence of external pollinators. Hence, it can be considered that pollinator diversity and processes are sensitive to landscape changes and habitat loss (Kremen 2007; Winfree et al. 2009), and to the presence and size of a forest area (Jha and Vandermeer 2010; Kremen, Williams, and Thorp 2002; Le Feon et al. 2010; Lentini et al. 2012). In the case of the avocado orchards in Michoacán, we observed a change over time in avocado and herbaceous plant flower resources due to management and seasonal climatic changes. Geographical location and micro environmental variables were, however, not considered because they had no impact on biodiversity, and in all orchards they met the recommended standards for the production of "Hass" variety avocadoes (Gutiérrez et al. 2010). At present, the importance of the maintenance of herbaceous plant diversity and presence of other plants in the orchards or in their surroundings has acquired importance for the preservation of biodiversity and the provision of ecosystem services, specifically the services of pest control and pollination (Brown 1999; Gurr, Wratten, and Luna 2003; Macfadyen et al. 2009). Also the presence of forests in the orchards gains recognition because it generates a greater richness of nearby flower visitors and pollinators (Kremen, Williams, and Thorp 2002). Our study did not analyze in depth the direct effect of forest areas on biodiversity. However, presence of forest areas was considered as part of the ecological structure of orchards and was one of the variables of management indicators that generated two groups within the organic orchards, therefore deserving further study.

There are numerous factors influencing the biological diversity of each agroecosystem, such as agronomical practices, agricultural products, and the frequency of their application (Altieri 1999). Nevertheless, defining a model for each orchard would be unrealistic due to the limitations of developing as many models as there are orchards (Köbrich, Rehman, and Khan 2003). The methodology of grouping orchards by identifying generalities and regularities is useful because it enables the formulation of a generic management (Blazy et al. 2009; Jackson and Piper 1989; Morales 2003). The identification of agronomical practices that determine the ecological dynamics allows for adjusting management practices in order to increase the delivery of ecosystem services in the agricultural system. For example, reducing the frequency of weeding when avocado trees are not in flower and reducing the frequency of the application of insecticides could increase the richness of herbaceous plants and of flower visitors in the avocado orchards.

Our study avoids the discussion about which type of management (organic or conventional) is the most adequate for ecosystem's productivity, a subject that is widely revised in numerous works (Bradley et al. 2002; Brumfield, Rimal, and Reiners 2010; Castellini et al. 2006; De Ponti, Rijk, and Van Ittersum 2012; Drinkwater et al. 1995; Gibson et al. 2007; Kremen, Williams, and Thorp 2002; Macfadyen et al. 2009; Van Diepeningen et al. 2006), but focuses on the implications of each form of management for biodiversity. Although the suppression of agrochemicals in food production unarguably brings numerous environmental benefits over conventional management, current efforts to revert global biodiversity loss, and the specially relevant global pollinator decline for this particular case, urge us to foster the implementation of alternative management classification types that reflect better the maintenance of natural resources and ecosystem functions and services.

Previous studies have hypothesized that there is an association between orchard management and biodiversity (Altieri 1999; Giller et al. 1997), and subsequent studies demonstrated the existence of this association in the field (Bradley et al. 2002; Firbank et al. 2008), both at the orchard and the landscape levels. Here we provide further evidence suggesting that management practices associated to an intensification process reduce the biodiversity of groups important for the maintenance of natural pollination and other services. It seems little useful to keep classifying productive systems simply as organic or conventional within the frameworks of sustainable agriculture and integrated orchard management because agricultural activity is practiced under different natural and social conditions leading to different modes of production (Morales 2003).

Our results support the hypothesis of the decrease in the specific richness as a result of the intensification of the agricultural management, specifically because of the kinds of agricultural products and the application frequency of certain practices. In this way, our study highlights the need to generate a more integrated management for orchards – clearly differing from annual or short-cycle crops – and to combine the benefits of agricultural products, practices, and total biodiversity (Altieri 1999; Bradley et al. 2002; Dixon, Gibbon, and Gulliver 2001; Tscharntke et al. 2005). Adequate management of the relationship between agronomic practices and their total biodiversity may lead to an increase in their sustainability.



## 5. Conclusion

The results of our research suggest that classification of agronomical management should go beyond the origin or kind of products applied. We have confirmed the existence of an association between management and biodiversity of pollinators and herbaceous plants in avocado orchards but this association was not straightforward related to conventional or organic management labels. We report evidence supporting the use of indicators of management intensity (consisting of derivate indexes of the kind and frequency of use of the agricultural products), and indicators of ecological structure and biodiversity (compensating factors such as the presence in the orchard of other species and forested areas, and indexes derived from measurements of biodiversity) to design an improved classification system that reflects better more sustainable management. The selection of the best indicators could be reinforced in future studies involving a larger and more representative sampling of orchard management. The response of total biodiversity to the different management practices must be evaluated with the goals of maintaining the ecological processes of the productive system and of generating a greater ecological sustainability.

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