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Causal relationship between biodiversity of insect population and agro-management in organic and conventional apple orchard

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Abstract Organic management of fruit orchards may increase biodiversity and therefore contributes to achieving an ecologically balanced and productive agroecosystem. In 2013–2015, using a standard methodology for field monitoring, our study investigated and described dynamics of selected insect indicator taxa in the soil, on orchard surface and apple trees in an organic apple orchard and a reference conventional orchard in the region of Plovdiv, Bulgaria. Aiming to determine the impact of agro-management on biodiversity, our study revealed statistically significant correlations between biodiversity (i.e., as indices of the diversity of Shannon (entropy) and Simpson (1-D)) and agro-management practices (i.e., as an agricultural intensification index (AI index)). We found that density and diversity of insect indicator taxa were high in organic soil and in the conventional soil, which was attributed to above-the-norms rainfall in 2014 and 2015 and agro-management practices such as mulching and organic fertilization. The cubic regression models showed positive correlations between the AI index and biodiversity indices of indicator taxa in organic soil ($R^2 = 0.489$ to 0.497) and on orchard surface (grassed inter-rows) ($R^2 = 0.399$ to 0.419). On organic trees, changes in population dynamics of beneficial insect taxa followed the changes of pest insect taxa and were related to food availability and climate conditions. Here, the best-fit linear regression models signified that ecological intensification through organic practices here expressed as high-AI index leads to a high diversity (i.e., high indices of Shannon and Simpson) of key beneficial insect taxa such as *Coccinellidae*, *Chrysopidae*, and *Cantharidae* which keeps the pest population below economic threshold levels. Farmers, therefore, should target practices leading to higher density and diversity of beneficial added by measures such as pheromone mating-disruption dispensers and selective bio-pesticides. Our study presents an example of how can biodiversity be assessed in such complex agro-ecological system as orchards are. However, we suggest re-designing the AI index to reflect important factors such as agroecological conditions (e.g., variable climate, soil fertility) and agro-management practices (e.g., time of mowing, irrigation regime, and type of pesticides and their application).

Keywords Apple · Biodiversity · Ecosystem · Agro-management · Organic farming · Agricultural intensification

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Introduction

Major challenges to modern organic fruit production in Europe are to establish ecologically balanced and productive ecosystems. In the last decade, the concept of eco-functional intensification, based on efficient use of renewable resources, recycling of organic matter, and use of enhanced biodiversity, is taking increasing importance (Niggli et al. 2008). The central place of functional biodiversity in this concept is determined by the provision of important ecosystem services at farm level such as integrated pest management, recycled soil organic matter, achieved better water-holding capacity, etc. In recent two decades, some authors report an impact of agro-management practices on invertebrates in fruit orchards (Kromp and Meindl 1997; Melnychuk et al. 2003; Clough et al. 2007; Simon et al. 2010). Orchards managed intensively show lower overall species biodiversity (Reidsma et al. 2006; Hendrickx et al. 2007). In apple orchards, application of broad-spectrum insecticides leads to lower diversity and density of predator arthropods on land surface (Bogya et al. 2000; Markó and Kádár 2005). In contrast, diversity and abundance of invertebrates in organic orchards are higher than those in conventional (Pfiffner and Niggli 1996); species are more evenly distributed, and authors report higher abundance and diversity of arthropods on land surface (Thorbek and Bilde 2004; Hole et al. 2005; Zoppolo et al. 2011), and up to 62% more spider species (Schmidt et al. 2005) and butterflies (Rundlöf and Smith 2006). Wyss (1997) reports that grassed intra-rows in apple orchards and increased aphidophagous species lead to significant reduction of the density of aphids such as *Dysaphis plantaginea* and *Aphis pomi*. Research by the institute of biological agriculture (FiBL) in Switzerland (i.e., Weibel et al. 2010) shows that in the second and third leaf of the self-regulating orchard (2008 and 2009), the abundance of beneficial arthropods such as *C. carnea*, forficulidae, and *H. axyridis* was already significantly higher than in the reference orchards with cv. Gala, which leads to suppressing the damages caused by aphids (in particular of *D. plantaginea*) under the threshold value. A total of 159 research investigations shows a positive effect of organic farming on biodiversity (Niggli 2010), as 30% of these show higher diversity and 50% higher abundance of invertebrates (insects, etc.), especially predators and parasitoids. However, at the level of EU-28, there are no unified and widely accepted standards for monitoring and assessment of biodiversity in agricultural (incl. Organic) ecosystems or methodology for assessing the level of their eco-functionality.

Several studies in the EU-28 (Bockstaller et al. 1997; Herzog and Steiner 2006; Flohre et al. 2011; Armengot et al. 2011) attempted to investigate and show statistically (e.g., by regression and correlation analysis) causal relationships between biodiversity of insect indicator-species and agro-management practices (e.g., by using land intensity indices) in a regional (including climate) context. Flohre et al. (2011) used a pre-defined agro-management practices, i.e., number of plant protection treatments against pests, diseases, and weeds; number of treatments with fertilizers (organic and mineral); and number of soil cultivation practices and irrigation, as major factors in the land intensity index. Given the complexity of orchard ecosystem functioning, research investigations should consider other important factors *inter allia* maintenance of intra-rows surface plant cover, fluctuations in climate, or timing of irrigation and plant protection measures. Also, the choice of biodiversity indicator species is important (Simon et al. 2010) in regard to their sensitivity to agro-management practices, but also in regard to their economic value for farmers, e.g., damages to harvest (i.e., by pest taxa) or ecological significance (i.e., by beneficial taxa). Dynamics of such indicator taxa must be studied in their (possible) interconnection, e.g., in the soil, on the land surface, and at the tree canopy, to identify the human influence (e.g., agro-management) in farming systems as much as their biophysical components (Niggli et al. 2017).

Therefore, the research aimed (i) to describe dynamics of insect indicator taxa in soil, on the soil surface, and at the tree canopy, through a complex monitoring of biodiversity in an organic apple orchard and a reference conventional orchard and (ii) to determine causal relationships between biodiversity of insect population and complex organic and traditional agro-management strategies in a regional (agroecological) context.

Material and methods

Orchard characteristics

Aiming to assure comparable agroecological conditions, the investigations were performed in the 3-year period from 2013 to 2015 on organic and conventional apple orchards of the approximately comparable size of 0.5 ha that are situated in the vicinity of the town of Plovdiv (42°08′60.00″ N 24°45′0.00″ E), South Bulgaria. The organic orchard is maintained at the premises of the organic demonstration farm of the Agroecological Center of Agricultural University of Plovdiv and is fully certified according to EC Regulation 834/2007 and Regulation 889/2008. The conventional orchard is situated in the village of Kalekovetz (approx. 10 km from Plovdiv). Both orchards were planted in the spring 2010 and comprised i.a. three cultivars, i.e., Florina, Rewena, and Melodie, grafted on rootstocks M9 of (Table 1). The organic orchard trees were planted at 3.5 m × 1.2 m spacing (inter-row × inter-tree) at 131 trees in a row and those in the conventional orchard at 4.0 m × 1.5 m at 100 trees in a row. In both orchards, the tree canopy was pruned to maintain a "slender spindle" form. In 2013, only Florina and Melodie cultivars were selected for this investigation mainly in regard to their relative tolerance to major apple diseases, i.e., apple-scab (*Venturia inaequalis*) and powdery mildew (*Podosphaera leucotricha* (Ell. and Ev.) Salm.) and their known robustness against rosy apple aphid *Dysaphis plantaginea*. Simultaneously with the orchard establishment in spring 2010, the alley ways of the organic orchard were sown with a grass-clover mixture. In the conventional orchard, the alley ways were sown with the grassed mixture in the spring of 2013, but the intra-rows between trees were treated with a herbicide (Tables 1 and 4 below).

Agroecological conditions

Soil agrochemical parameters

The Laboratory complex of the Agricultural University of Plovdiv has analyzed soil samples from two depths 0–20 and 20–50-cm taken twice from eight experimental plots randomly placed in the intra-rows of the two apple cultivars at the beginning of each vegetation of season (in Table 2, the average values of the 3 years of investigation are shown). Major soil parameters were determined, i.e., digestible forms of nitrogen ($N–NH_4$ and $N–NO_3$, mg 100 g, ISO/TS 14256-1:03), available phosphorus (P_2O_5 mg 100 g) and potassium (K_2O mg 100 g) by the Al-method of Egner–Riehm (Enger and Riehm 1958), pH (in water extract 1:5, ISO 10390:05), humus content (in %, ISO 14235:02) as well as mechanical composition of the alluavial soils of the two orchards (Table 2). Statistical differences between parameter values at the two soil depths of the organic and conventional orchards were proven at $p < 0.05$.

The soil in the organic orchard is classified as *Gleysols* having light sandy-loam in the 0–20-cm and light alkaline pH (according to FAO 2016), a relatively high-humus content (according to Gurov and Artinova 2015), a very low ammonium and nitrate N content, an average P content, and a good K content. The 20–50-cm soil layer has the loam-sandy mechanical composition, light alkaline pH, a low humus content, a very low ammonium and nitrate N content, low P content, and an average K content. The soil in the conventional orchard is alluvial (*Mollic Fluvisols*) type with the loam-sandy mechanical composition in the 0–20-cm soil layer and sandy in the 20–50-cm soil layer. In the upper layer, the pH is neutral, and the humus content is low; the ammonium and nitrate N content is very low, the P content is average, and the K content is low. In the

Table 1 Distribution of apple cultivars in the organic and conventional orchard

Organic orchard		Conventional orchard	
Number of planted rows	Apple cultivar/grassed mixture in intra-row	Number of planted rows	Apple cultivar/grass mixture in inter-row
	Grass-clover mixture		Grass mixture
2	FLORINA	6	PINOVA
	Grass-clover mixture		Grass mixture
5	REWENA	5	GOLDEN DELICIOUS
	Grass-clover mixture		Grass mixture
2	MELODIE	3	MELODIE
	Grass-clover mixture		Grass mixture
		6	FLORINA
			Grass mixture
		14	GOLDEN DELICIOUS
			Grass mixture

Table 2 Soil agrochemical parameters in organic and conventional orchards, as an average of 2013, 2014, and 2015*

	Parameters (mean + SD)				
Soil depth (cm)	Humus (%)	pH	$NH_4^+ + NO_3^-$ (mg 100 g)	P_2O_5 (mg 100 g)	K_2O (mg 100 g)
	Organic orchard				
0–20	3.07 ± 0.058 [a]	7.38 ± 0.006 [c]	0.83 ± 0.035[a]	11.57 ± 0.058 [ab]	67.14 ± 3.602[a]
20–50	0.75 ± 0.006[d]	7.71 ± 0.010[a]	0.64 ± 0.010[b]	7.30 ± 0.100[b]	37.92 ± 4.474[b]
	Conventional orchard				
0–20	1.46 ± 0.027[c]	6.74 ± 0.006[d]	0.83 ± 0.025[a]	10.9 ± 1.448[ab]	23.80 ± 3.434[c]
20–50	1.70 ± 0.006[b]	7.42 ± 0.006[b]	0.78 ± 0.020[a]	14.62 ± 6.830[a]	25.55 ± 3.001[c]

*Duncan's Multiply Range Test, different letters show statistically significant difference at $p < 0.05$

0–20-cm soil layer, the differences between two orchards regarding N content and P content are insignificant (at $p < 0.05$), while higher values of humus and N and P content were shown in the 20–50-cm layer of the conventional soil. These results were taken into account when fertilization strategies were implemented in both orchards (see Table 4 below).

Climate characteristics

Climate data comprise the two major meteorological parameters such as the average monthly rainfall and the average monthly temperature (Table 3). The data show the norms of the two parameters for the region of Plovdiv, based on long-term average values for the period from the year 1961 to 1990 taken by the National Institute of Hydrology and Meteorology (NIMH) of Bulgarian Academy of Science (NIMH 2017). The observed values for each month of the year 2013 to 2015 period were downloaded from the local meteorological station of Plovdiv that is also under the NIMH operation.

In 2013, average annual temperature of 13.2 °C was close to the norm, and the average annual rainfall of 478.1 mm was lower than the norm. It was warm and dry in May, but above the norms, rainfall was reported in April and June. In 2014, the average annual temperature 13.4 °C was close to the norm, and the average annual rainfall of 993.9 mm was much higher than the norm. Above the norms, rainfall was detected in March, April, June, July, August, September, and October. In 2015, the average annual temperature of 13.8 °C was close to the norm, and the average annual rainfall of 761.7 mm was higher than the norm. Above the norms, rainfall was detected in March, May, June, August, September, and October.

Agro-management practices

Agro-management practices differed in the two orchards (Table 4). The conventional orchard was intensively irrigated and treated with chemical pesticides and mineral fertilizers. The organic orchard relied on beneficial insect population (e.g., ladybirds, lacewings, etc.) to put pressure on pest population. The beneficial population was supported by installment of pheromone dispensers and treatments with biological pesticides (against fungal diseases and insect pests, Table 4) in conformity to the EC Regulation 889/2008.

Biodiversity monitoring

Monitoring of biodiversity of indicator entomofauna considered some major factors in the apple growing (Scheme 1): (i) distribution and dynamics of a preselected major indicator entomofauna (pest and beneficial insect taxa (in the soil, on the land surface, and at the tree canopy) and (ii) agro-management practices (different under organic and conventional management).

Selection of insect indicator-taxa

To investigate the level of functional biodiversity in the two orchards, groups of insect indicator taxa and species were selected. This was done on the basis of preliminary research data from the organic orchard of Agricultural University of Plovdiv as well as on suggested indicator taxa by international projects, i.e., Bio-Bio (Herzog et al. 2012) and international research on potential of invertebrates (insects and spiders) to indicate changes in biodiversity caused by agricultural practices (Wyss 1997; Hole et al. 2005; Schmidt et al. 2005; Rundlöf and

Table 3 Climate parameters (rainfall and temperature) measured during the period of 2013–2015 and their average norms for the region of Plovdiv

Month	Norm		2013		2014		2015	
	Average monthly rainfall (mm)	Average monthly temperature (°C)	Average monthly rainfall (mm)	Average monthly temperature (°C)	Average monthly rainfall (mm)	Average monthly temperature (°C)	Average monthly rainfall (mm)	Average monthly temperature (°C)
I	40	0.3	37	1.8	25	3.4	17	3.1
II	34	2.8	45	4.6	9	5.8	76	3.7
III	40	6.8	33	7.4	88	9.8	138	6.7
IV	42	12.2	84	14.0	123	12.7	14	12.4
V	65	17.1	3	20.0	66	16.9	69	19.3
VI	54	20.9	109	20.8	98	21.2	76	21.1
VII	50	22.9	63	23.4	70	23.5	4	25.3
VIII	38	22.0	7	25.2	53	23.9	150	24.3
IX	32	18.4	10	19.7	195	18.1	100	21.0
X	31	12.4	28	11.6	121	12.8	70	12.8
XI	44	7.0	47	9.1	49	7.9	39	11.3
XII	44	2.4	7	1.3	93	5.1	3	5.1

Smith 2006; Weibel et al. 2010. Previous research (Andreev 2012; Harizanov et al. 2010) on the region of Plovdiv suggests that there is an impact of climate conditions on soil macrofauna and tree-entomofauna in fruit orchards. On this basis, the following indicator taxa were selected:

i) in soil—beneficial taxa of *Lumbricidae and Geophilidae* and pest taxa of *Porcellionidae*, *Elateridae (click beetles)*, *Carabidae* ((*Zabrus*, *Harpalus*, *Amara* (ground beetles)) and *Limacidae* (keelback slugs),
ii) on soil surface—beneficial taxa of *Carabidae* (*Calosoma*, *Carabus* (ground beetles)), *Staphylinidae* rove beetles)) and pest taxa of *Gryllidae* (crickets) and *Cetoniidae* (scarab beetles),
iii) on apple trees—beneficial taxa of *Coccinellidae* (ladybugs), *Cantharidae* (leatherwings), *Syrphidae* (hoverflies), *Chrysopidae* (lacewings) and pest taxa of *Chrysomelidae* (leaf beetles) and *Tortricidae* (apple codling moth).

Biodiversity of soil organisms in soil depth was monitored by single sampling (using methodology of Guilyarov (1987) at spring, summer, and autumn in both agrocenoses. Two plots of 0.50 m^{-3} each were placed in four apple orchards' intra-rows. The soil was sampled in depth of 40 cm in each plot and then normalized per 1 m^3. Density and diversity of harmful and beneficial entomofauna were calculated. Using a pitfall-trap method (Greenslade 1964), individuals of indicator taxa living on the land surface were caught and then collected once a month from the traps. The traps were in three replicates situated at 39 cm inside the apple inter-rows.

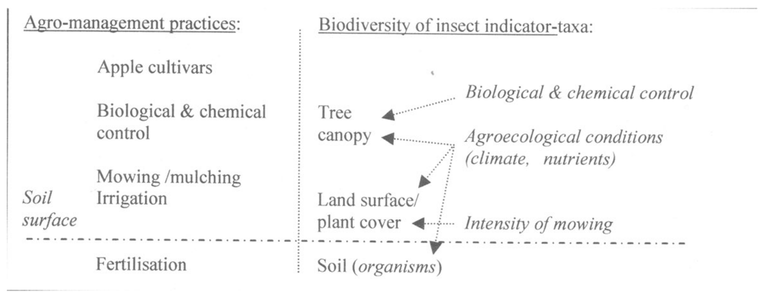
For determining the biodiversity of indicator taxa on apple trees, a "shaking branches" method was used in both contrasting orchards, i.e., shaking of about 100 branches from the four sides of a tree, taking at least ten trees per unit of land. Individuals caught in a hand-sack were then collected and counted, and their density was normalized per 100 tree branches. These observations were done from March till November in each of the study years, three times a month (at decades) aimed to consider the impact of climate and soil conditions. Diversity and abundance were determined down to taxa (family) according to Fauna Europea (2013) and by using following ecological parameters:

a) Density: the total number of individuals of taxa relative to 1 m^3 of soil (Magurran 1988) or on 1 m^2 land surface.

Table 4 Agro-management practices in organic and conventional orchards during 2013, 2014, and 2015

Organic			Conventional		
Year			Year		
2013	2014	2015	2013	2014	2015
Number of soil irrigations *(total per month)*					
5-	*3-*	*8-*	*24-*	*22-*	*21-*
Maintaining plant cover of inter-rows *(number of treatments per season)*					
7- mowings	*3-* mowings	*3-* mowings	*3-* mowings + 360 g l Glyphosate (on intra-rows)	*3-* mowings + 360 g l Glyphosate (on intra-rows)	*3-* mowings + 360 g l Glyphosate (on intra-rows)
Maintaining soil fertility *(number and type of fertilizer treatments per season)*					
2- N-common + N organical + C	*2-* Composted manure (13 t ha^{-1}); N-common + N organic + C	*2-* N-common + N organic + C	*4-* MgSO4, Multi-K	*1-* Multi-K	*5-* NPK, Ca-chloride, carbamate
Plant protection *(number and type of treatments per season)*					
6- Zn + Cu	*16-* Zn + Cu, Mineral oil, 50% Cu, Pheromone (mating disruption) dispensers, A retrieval from the Tree Neem, Natural extract of *Chrysanthemum cinerariefolium*, Granulous virus with a 6 × 10 titer, 1% azadirachtin A + 0.5% azadirachatin B, C, D, E and 2.5% nonsubstance	*13-* Zn + Cu, Mineral oil, 50% Cu, Pheromone (mating disruption) dispensers, A retrieval from the Tree Neem, Natural extract of *Chrysanthemum cinerariefolium*, Granulous virus with a 6 × 10 titer, 1% azadirachatin A + 0.5% azadirachatin B, C, D, E and 2.5% nonsubstance	*18-* 50% Cu, Tetra copper gluconate (II) and zinc (Zn), Cyprodinyl, 80% Thiram, 50 g l lambda cyhalo-thrin, 250 g l difenoconazol, 480 g l thiaclopride, N-P-K, 500 g kg^{-1} tebuconazole; 250 g kg^{-1} trifloxy-strobin B, Dithianone, Deltamethrin 25 g l, 480 g l chlorpy-rifostil, 400 g l flusilazole, 400 g l chlorpyrifos-methyl, etc.	*18-* 50% Cu, Tetra copper gluconate (II) and zinc (Zn), Cyprodinyl, 80% Thiram, 50 g l lambda cyhalo-thrin, 250 g l difenoconazol, 480 g l thiaclopride, N-P-K, 500 g kg^{-1} tebuconazole; 250 g kg^{-1} trifloxy-strobin B, Dithianone, Deltamethrin 25 g l, 480 g l chlorpy-rifostil, 400 g l flusilazole, 400 g l chlorpyrifos-methyl, etc.	*25-* 50% Cu, Tetra copper gluconate (II) and zinc (Zn), Cyprodinyl, 80% Thiram, 50 g l lambda cyhalo-thrin, 250 g l difenoconazol, 480 g l thiaclopride, N-P-K, 500 g kg^{-1} tebuconazole; 250 g kg^{-1} trifloxy-strobin B, Dithianone, Deltamethrin 25 g l, 480 g l chlorpy-rifostil, 400 g l flusilazole, 400 g l chlorpyrifos-methyl, etc.

Scheme 1 Factors impacting apple growing dynamics and biodiversity of insect indicator taxa



b) *Shannon index (entropy):* A diversity index, which reflects the number of individuals and number of taxa. It varies from zero for communities with only a single taxon with high values for communities with many taxa, each with few individuals.

$$H_i = -\sum_{i=1}^{R} p_i ln\, p_i$$

where R is the total number of types in the dataset, p_i is the proportion of individuals belonging to the ith species in the dataset of interest.

Then the Shannon entropy quantifies the uncertainty in predicting the species identity of an individual that is taken at random from the dataset.

c) *Simpson index 1-D:* The value ranges between 0 and 1. The greater the value, the greater the sample diversity. The index represents the probability that two individuals randomly selected from a sample will belong to different species.

$$1{-}D = 1{-}\frac{\sum_{i=1}^{R} n_i(n_i{-}1)}{N\ (N{-}1)}$$

where n_i is the total number of organisms of a particular species and N is the total number of organisms of all species.

Data processing and statistical analysis

The two indices of biodiversity were calculated by using the PAST (Hammer 2001) program. Comparison between means was done using Duncan multiply range test (Duncan 1955). To assess the complex impact of agroecological (year, season, and climate) factors and agro-management (organic and conventional) factors on biodiversity parameters, the study employed a factorial ANOVA-model using STATISTICA 9.0 (StatSoft Inc. 2004) program. Considering the impossibility of replications of both conventional and organic orchards, as they were established 3 years before the study, i.e., in 2010, the study opted for testing the impact of major factors (independent variables) per each type of land use, i.e., organic and conventional management. The independent variables were *years* of investigation, i.e., 2013, 2014, and 2015, *season*, i.e., spring (March, April, and May), summer (June, July, and August), and autumn (September, October, and November) that were chosen because of the different dynamics of indicator taxa and insect taxa selected for indication of changes (as each taxon has a specific response to climate and agro-management). The dependent variables were the density of taxa and the biodiversity indices of Shannon (entropy) and Simpson (1-D).

The Agricultural Intensification (AI) index (Herzog and Steiner 2006; Flohre et al. 2011) for both orchards was calculated on the basis of monitoring and reporting the applied agro-practices, i.e., number of pesticide treatments per season, amount of fertilizers (kg N year da^{-1}) and number of mechanical tillage (number of operations per season including mowing):

$$AI = \frac{\sum_{i=1}^{n} (y_i{-}y_{imin})/(y_{imax}{-}y_{imin})}{n} \times 100$$

where AI is the agricultural intensification index, y_i is the observed value (number of pesticide applications, amount of fertilizer applied or number of tillage operations), y_{min} is the minimum observed value in all regions, y_{max} is the maximum observed value in all regions, n is the number of individual indicators, and i is the identifier for the three indicators.

Then, using regression analysis, the study investigated correlations between AI index and biodiversity at three levels, i.e., in the soil, on the land surface, and

Table 5 Density and diversity of indicator taxa in soil and AI index, an average of the year 2013, 2014, and 2015*

Season	Organic orchard				Conventional orchard			
	Density	Simpson index (1-D)	Shannon index (entropy)	AI index	Density	Simpson index (1-D)	Shannon index (entropy)	AI index
				2013				
Spring	55.63 [a]	0.07 [a]	0.17 [a]	54.35 [a]	99.90 [a]	0.00 [a]	0.00 [a]	54.40 [a]
Summer	5.30 [b]	0.46 [b]	0.78 [c]	44.40 [b]	15.95 [b]	0.63 [b]	1.03 [b]	42.61 [b]
Autumn	0.00 [c]	0.00 [a]	0.00 [b]	33.30 [c]	31.95 [c]	0.50 [c]	0.69 [c]	33.30 [c]
				2014				
Spring	21.70 [a]	0.45 [a]	0.78 [a]	36.43 [a]	11.70 [a]	0.45 [a]	0.87 [a]	73.46 [a]
Summer	21.00 [a]	0.60 [b]	1.12 [b]	56.61 [b]	21.20 [b]	0.58 [b]	1.02 [b]	64.57 [b]
Autumn	41.62 [b]	0.56 [b]	1.13 [b]	0.00 [c]	16.95 [c]	0.26 [c]	0.56 [c]	33.30 [c]
				2015				
Spring	7.95 [a]	0.50 [a]	0.98 [a]	54.94 [a]	27.70 [a]	0.18 [a]	0.43 [a]	59.05 [a]
Summer	8.95 [b]	0.44 [a]	0.91 [a]	63.39 [b]	17.20 [b]	0.57 [b]	1.01 [b]	57.15 [a]
Autumn	8.28 [b]	0.32 [b]	0.66 [b]	33.30 [c]	18.20 [b]	0.51 [b]	0.94 [b]	0.00 [b]

*Different letters show statistically significant differences between means (Duncan multiple range tests at $p < 0.05$) reported for spring, summer, and autumn

apple trees in both orchards. To select the most suited regression model, the study used an analytical method based on criteria "coefficient of determination" (R^2). The R^2 is used as a relative measure of how well the regression line fits the data. The latter shows the relative share of variation of the dependent variable, explained

Table 6 Correlations between biodiversity of indicator species in soil and AI index and best-fit regression models for organic and conventional orchard

Regression model	Correlation coefficient	Coefficient of determination (R^2)	Standard error of estimate (regression)	F ratio	Level of significance
Organic orchard					
Dependent variable density of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.752	0.565	66.960	2.169	0.021
Dependent variable Simpson index (1-D) of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.699	0.489	0.232	4.534	0.005
Dependent variable Shannon index (entropy) of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.705	0.497	0.415	4.778	0.049
Conventional orchard					
Dependent variable density of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.812	0.660	16.738	6.232	0.045
Dependent variable Simpson index (1-D) of indicator-species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.282	0.080	0.260	5.144	0.042
Dependent variable Shannon index (entropy) of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.359	0.129	0.411	5.247	0.048

by the regression equation and is a good indicator of regression effectiveness (Rancheva 2010). Thus correlations were showing the relative impact of the factors chosen in the AI on biodiversity parameters.

Results

Biodiversity

In the soil

In the organic orchard soil (Table 5), the highest density of indicator-taxa was shown in the spring of 2013 when the AI index was also highest. In 2014, density was higher in autumn with an AI index was 0.00. Overall, the indices of Simpson and Shannon were higher in 2014 and 2015 compared to 2013. In the conventional orchard, the density was significantly higher in 2013 compared to 2014 and 2015. Overall, the highest indices of Simpson and Shannon were reported in the summer of 2013, 2014, and 2015.

The best-fit regression models for explaining the relationship between biodiversity parameters in soil and the AI index are shown in Table 6.

The best-fit regression models that adequately describe relationships are the cubic models (Table 6). Considering the calculated coefficient of determination, the independent variable AI index could explain about 56.5% of the changes in density and only about 48.9 and 49.7% of changes in the diversity of indicator taxa in the organic orchard. However, the independent variable AI index could explain about 66.0% of the changes in density, but only about 8.0 and 12.9% of changes in the diversity of indicator taxa in the conventional orchard.

On the soil surface

In the organic orchard (Table 7), the lowest density of indicator taxa on soil surface was shown in 2013 compared to the other 2 years of investigation, i.e., the highest density in summer of 2014 and summer and autumn of 2015. The AI was lowest in autumn of 2014 where density kept relatively high (close to the one in spring of this year). Overall, the Simpson (1-D) index and the Shannon (entropy) index of diversity were higher in 2014 and 2015 compared to 2013. In the conventional orchard, the density was also lowest in 2013 compared to 2014 and 2015. Overall, the highest indices of Simpson and Shannon were reported in the summer of 2014.

The ANOVA showed a significant impact ($p < 0.05$) of main factors land use, season, and insect taxa on the indicator taxa living on the land surface in the two contrasting orchards. The impact was more profound in summer on the organic soil surface where the density of indicator taxa (dominated by *Carabidae* and *Gryllidae* taxa) was higher than the density in conventional soil surface (dominated by *Carabidae taxa* (*Calosoma*, *Carabus*).

The best-fit regression models for explaining the relationship between biodiversity parameters on the soil surface and the AI index are shown in Table 8.

The polynomial function (cubic) is the best fit for the data points (Table 8). The coefficient of determination signifies that about 20.3% of the changes in density and about 39.9 and 41.9% of changes in the diversity of indicator taxa in the organic orchard can be explained by changes in independent variable AI index. In contrast, about 60.7% of the changes in density and about 94.4 and 91.2% of changes in the diversity of indicator taxa in the conventional orchard can be explained by changes in the independent variable AI index.

On the apple trees

In the organic orchard (Table 9), high density of indicator taxa was reported in the summer and autumn of 2014 when the AI was 56.61 and 0.00, respectively. Similarly, the density was high in spring and summer of 2015 and AI index was also high. Overall, the indices of Simpson and Shannon were high in 2013, 2014, and 2015, except the autumn of 2015. In the conventional orchard, the density was highest in summer of 2015 compared to 2013 and 2014. Overall, the indices of Simpson and Shannon were higher in 2013, 2014, and 2015, except in the autumn of 2014. The AI index was 0.00 in the autumn of 2015 with higher indices of biodiversity indices of Simpson and Shannon (0.64 and 1.06, respectively) compared to previous two seasons.

The ANOVA showed a significant impact ($p < 0.05$) of main factors land use, season, and taxa on the insect indicator taxa in the two contrasting orchards (Fig. 1). The density of all taxa was higher

Table 7 Density and diversity of indicator-taxa on soil surface and the AI index, an average of the year 2013, 2014, and 2015*

Season	Organic orchard				Conventional orchard			
	Density	Simpson index (1-D)	Shannon index (entropy)	AI index	Density	Simpson index (1-D)	Shannon index (entropy)	AI index
				2013				
Spring	144.00 [a]	0.37 [a]	0.56 [a]	54.35 [a]	4.00 [a]	0.00 [a]	0.00 [a]	54.40 [a]
Summer	108.60 [b]	0.04 [b]	0.10 [b]	44.40 [b]	7.00 [b]	0.00 [a]	0.00 [a]	42.61 [b]
Autumn	10.00 [c]	0.38 [a]	0.65 [c]	33.30 [c]	0.00 [c]	0.00 [a]	0.00 [a]	33.30 [c]
				2014				
Spring	231.60 [a]	0.42 [a]	0.69 [a]	36.43 [a]	32.00 [a]	0.12 [a]	0.23 [a]	73.46 [a]
Summer	310.00 [b]	0.32 [b]	0.54 [b]	56.61 [b]	45.00 [b]	0.08 [a]	0.18 [a]	64.57 [b]
Autumn	222.60 [a]	0.49 [a]	0.72 [a]	0.00 [c]	191.00 [c]	0.00 [b]	0.00 [b]	33.30 [c]
				2015				
Spring	160.00 [a]	0.54 [a]	0.87 [a]	54.94 [a]	194.00 [a]	0.02 [a]	0.06 [a]	59.05 [a]
Summer	328.00 [b]	0.52 [a]	0.78 [b]	63.39 [b]	164.50 [b]	0.02 [a]	0.05 [a]	57.15 [a]
Autumn	409.00 [c]	0.49 [a]	0.75 [b]	33.30 [c]	283.00 [c]	0.01 [a]	0.04 [a]	0.00 [b]

*Different letters show statistically significant differences between means (Duncan multiple range tests at $p < 0.05$) reported for spring, summer, and autumn

on organic than on conventional trees, except *Chrysopidae* taxa on conventional trees in summer. In the organic orchard, the density of beneficial insects of *Coccinellidae* was higher, the *Syrphidae*

Table 8 Correlations between biodiversity of indicator-species on soil surface and AI index, and regression models (best-fit) in organic and conventional orchard

Regression model	Correlation coefficient	Coefficient of determination (R^2)	Standard error of estimate (regression)	F ratio	Level of significance
Organic orchard					
Dependent variable density of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.450	0.203	427.580	3.424	0.045
Dependent variable Simpson index (1-D) of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.632	0.399	0.155	4.949	0.048
Dependent variable Shannon index (entropy) of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.647	0.419	0.237	4.711	0.049
Conventional orchard					
Dependent variable density of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.779	0.607	160.847	1.573	0.002
Dependent variable Simpson index (1-D) of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.971	0.944	0.013	3.945	0.001
Dependent variable Shannon index (entropy) of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3$	0.955	0.912	0.032	3.208	0.005

Table 9 Density and diversity of indicator taxa (taxa and individuals) on apple trees and AI index, as an average of 2013, 2014, and 2015*

	Organic orchard				Conventional orchard			
Season	Density	Simpson index (1-D)	Shannon index (entropy)	AI index	Density	Simpson index (1-D)	Shannon index (entropy)	AI index
				2013				
Spring	7.25 [a]	0.68 [a]	1.23 [a]	54.35 [a]	3.50 [a]	0.49 [a]	0.68 [a]	54.40 [a]
Summer	11.33 [b]	0.78 [b]	1.61 [b]	44.40 [b]	5.60 [b]	0.57 [b]	1.11 [b]	42.60 [b]
Autumn	3.66 [c]	0.60 [c]	0.99 [c]	33.30 [c]	5.50 [b]	0.30 [c]	0.47 [c]	33.30 [c]
				2014				
Spring	9.23 [a]	0.63 [a]	1.16 [a]	36.43 a	5.33 [a]	0.66 [a]	1.10 [a]	73.50 [a]
Summer	15.65 [b]	0.77 [b]	1.62 [b]	56.61 [b]	1.00 [b]	0.32 [b]	0.70 [b]	64.60 [b]
Autumn	18.95 [b]	0.00 [c]	0.00 [c]	0.00 [c]	0.00 [c]	0.00 [c]	0.00 [c]	33.30 [c]
				2015				
Spring	14.00 [a]	0.26 [a]	0.55 [a]	54.94 [a]	1.50 [a]	0.44 [a]	0.64 [a]	59.10 [a]
Summer	12.20 [a]	0.69 [b]	1.42 [b]	63.39 [b]	13.40 [b]	0.47 [a]	0.91 [b]	57.20 [a]
Autumn	7.75 [b]	0.66 [b]	1.20 [c]	33.30 [c]	1.70 [a]	0.64 [b]	1.06 [c]	0.00 [b]

*Different letters show statistically significant differences between means (Duncan multiple range tests at $p < 0.05$) reported for spring, summer, and autumn

and *Chrysopidae* population increased in 2014 and 2015, while the insect taxa of *Cantharidae* taxa decreased.

Insect population dynamics showed a higher density (Fig. 2) and biodiversity indices of Shannon and Simpson of beneficial indicator taxa (i.e., *Coccinellidae*, *Chrysopidae*, and *Cantharidae*) on the organic trees in April, May, July, August, September, and October. Pest population declined after the peaks in April and June, i.e., changes in the beneficial entomofauna followed changes of pest entomofauna.

The best-fit regression models for explaining the relationship between biodiversity parameters on organic and conventional trees and the AI index are shown in Table 10.

In the conventional orchard, the best-fit regression models that adequately describe relationships are cubic (Table 10). The calculated coefficient of

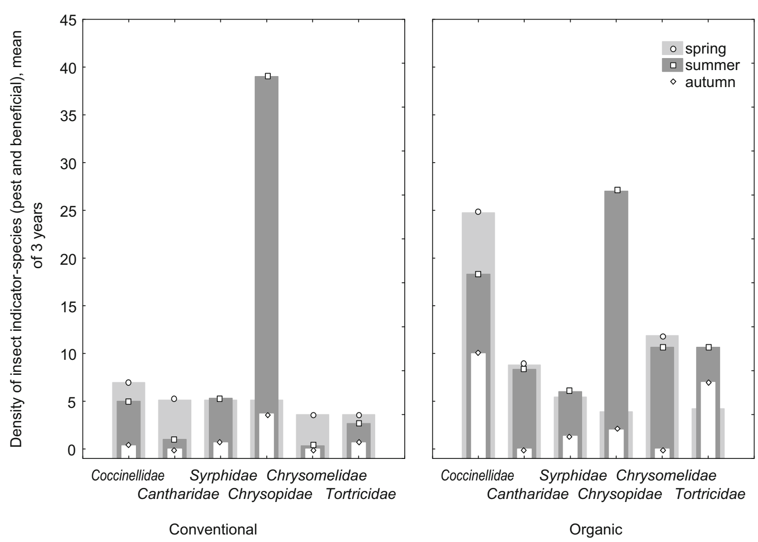


Fig. 1 Seasonal density of pest and beneficial insect indicator-taxa on organic and conventional trees (as an average of the 3 years of investigation)

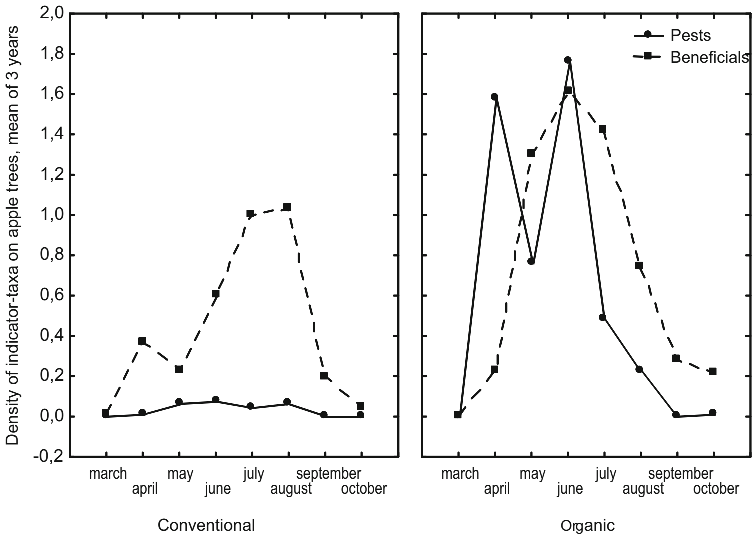


Fig. 2 Population dynamics of pest and beneficial indicator-taxa on apple trees of organic and conventional orchard (mean of 2013, 2014, and 2015)

determination shows that the independent variable AI index could explain only about 28.6% of the changes in density and about 59.6 and 54.5% of changes in the diversity of indicator taxa.

In the organic orchard, the relationships can be explained by a linear regression model, i.e., an increase of the AI index leads to increase in density of insect indicator taxa. The coefficient of determination shows that the independent variable AI index could explain about 46.9% of the changes in density. Similarly, the linear regression model adequately explains the relationship between the AI index and the dependent variable

Table 10 Correlations between biodiversity of insect indicator-species on organic and conventional trees and AI index and regression models (best-fit)

Regression model	Correlation coefficient	Coefficient of determination (R^2)	Standard error of estimate (regression)	*F* ratio	Level of significance
Organic orchard					
Dependent variable density of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1 X_i$	0.685	0.469	2.493	6.192	0.042
Dependent variable Simpson index (1-D) of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1 X_i + b_2 X_i^2 + b_3 X_i^3$	0.817	0.668	0.190	3.356	0.113
Dependent variable Shannon index (entropy) of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1 X_i$	0.699	0.489	0.400	5.697	0.036
Conventional orchard					
Dependent variable density of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1 X_i + b_2 X_i^2 + b_3 X_i^3$	0.534	0.286	27.838	1.666	0.005
Dependent variable Simpson index (1-D) of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1 X_i + b_2 X_i^2 + b_3 X_i^3$	0.772	0.596	0.192	2.369	0.003
Dependent variable Shannon index (entropy) of indicator species, independent variable—AI index					
$\hat{Y}_i = b_0 + b_1 X_i + b_2 X_i^2 + b_3 X_i^3$	0.738	0.545	0.350	2.146	0.004

Shannon index (entropy), i.e., about 48.9% of changes in the diversity of indicator taxa can be explained with agro-management factors included in the AI index.

Discussion

Agroecological conditions

Although sufficient efforts were made to provide the necessary amount of nutrients for feeding the apple trees (i.e., through the application of composted organic manure in the beginning of 2014 in the organic orchard and mineral fertilizers in conventional orchard), the total N content in both orchard soils was very low compared to the indicative national requirements for good total N-content in soil (Table 2). The study found that the addition of composted manure and liquid fertilizers in organic orchard soil not only compensated the low N- and P-levels, but also increased long-term microbiological activity thus confirming Niggli (2010).

Biodiversity of insect indicator taxa

The study added new insights to uncovering causal relationships between biodiversity of insect indicator taxa and agro-management practices in a regional (agroecological) context (Bockstaller et al. 1997; Kromp and Meindl 1997; Melnychuk et al. 2003; Clough et al. 2007; Flohre et al. 2011; Herzog et al. 2012). It showed that the complex relationships between taxa in orchard ecosystems might be addressed by a complex monitoring of biodiversity, i.e., by determining dynamics of insect indicator taxa in the soil, on the soil surface, and at the tree canopy. By using the existing methodology, the study not only investigated and proves statistically (e.g., by regression and correlation analysis) causal relationships between biodiversity of insect indicator taxa and agro-management practices but provided a critical look onto applicability of land intensity indices (Herzog and Steiner 2006; Flohre et al. 2011).

In the soil

Organic orchard soil showed diverse indicator taxa, i.e., family *Lumbricidae* and *Geophilidae* (beneficial) and *Porcellionidae* (pests) which could be attributed to the application of organic composted manure in the spring of 2014 and above-the-norms temperature in May 2013 and rainfall in April 2013. Climate conditions, i.e., above-the-norms average rainfall in 2014 and 2015, lead to the higher density of indicator taxa in conventional soil and higher indices of Shannon and Simpson. It indicates a uniformity of representativeness of taxa, i.e., the *Lumbricidae* taxa were not the dominant in the soil, but also individuals from *Geophilidae* and *Limacidae* taxa. This trend could be attributed to the significant combined effect of major factors land use, season, and taxa (ANOVA, $p < 0.05$) as the more frequent irrigation and mowing of intra-rows stimulated the activity of various soil organisms. Higher values of indices of Simpson and Shannon cannot be associated with relatively high AI index in the organic orchard or relatively low-AI index in the conventional orchard (Table 6). Relatively low coefficients of determination (R^2) both in organic and conventional orchards signify that only insignificant share of the changes in the dependent variables, i.e., indices Simpson and Shannon, can be explained with changes in the independent variable AI index. The land-use practices included in the AI index formulae cannot fully determine dynamics of biodiversity (indicator insect taxa). Rather, other factors should be taken into account, e.g., organic matter dynamics, soil water content, irrigation intensity, or/and susceptibility of certain groups of soil macrofauna to herbicides.

On the soil surface

The higher total density of all indicator taxa and higher abundance of indicator taxa of *Carabidae* and *Gryllidae* on the organic inter-row surface might be attributed to the maintenance of the mulching system and organic fertilization. The absence of herbicide treatments and suitable climate conditions stimulated vegetation biomass in the inter-rows thus fulfilling ecological requirements of indicator-taxa. Remarkably, the population density of indicator-taxa was superior in the autumn of 2014 (compared to the previous two season) even when the AI index was 0.00. In a long-run, population density of taxa of *Staphylinidae* (rove beetles) should be stimulated for a better natural bio-control of prey organisms such as the *Elateridae* species (spring beetles), spiders, trips, larvae of whiteflies, and eggs of aphids, from June to August. High biodiversity (i.e., indices of Simpson and Shannon) in the organic orchard and relatively low indices in the reference conventional orchard confirm the findings of Miñarro and Dapena (2003) and Popov et al. (2014).

Overall, the ecological intensification of the organic orchard (i.e., high AI index) leads to increased density and diversity of indicator taxa. The reference conventional orchard showed interesting dynamics, i.e., transition to inter-row mulching and regular irrigations lead to increased density of indicator-entomofauna, but overall diversity (i.e., indices of Simpson and Shannon) remained relatively low. In conventional orchard inter-rows, only *Carabidae* (*Calosoma*, *Carabus*) taxa dominated during the period of investigation, while *Gryllidae* and *Carabidae* (*Calosoma*, *Carabus*) taxa dominated on the organic surface but only in 2014 and 2015. These trends could be mainly attributed to agro-management practices, i.e., in conventional orchard the application of mineral fertilizers and higher soil water content in 2014 and 2015 lead to massive spread of *Poacea* sp. weeds that stimulated the abundance of *Carabidae* (*Calosoma*, *Carabus*) taxa (Hofmann and Mason 2006; Tuovinen et al. 2006; Hatten et al. 2007; Miñarro et al. 2008).

On the apple trees

The study suggests that climate conditions impacted positively beneficial indicator-taxa in the organic orchard (i.e., *Coccinelidae* taxa (Wyss 1997; Weibel et al. 2010)), while *Cantharidae* taxa decreased due to their preference to hot and dry habitats, which is not a characteristic of the study region. The *Syrphidae* taxa increased in 2014 and 2015 which could be attributed to the increased average rainfall and temperature in these 2 years that suited the ecological requirements of these taxa, i.e., the larvae hatching is most active at 10 to 18 °C and larvae predating is most dynamic at 25 to 30 °C (Harizanov et al. 2010). The density of *Chrysopidae* taxa was also higher in 2014 and 2015. The index of Simpson describes the insect population of the organic orchard as predominant in 2013 and 2014 (mainly in spring and summer) and as monodominant in 2015.

Although the study showed a high density of beneficial indicator taxa (i.e., *Coccinelidae*, *Chrysopidae*, and *Cantharidae* taxa) and a high-biodiversity indices of Shannon and Simpson on organic trees, it does not necessarily indicate an efficient control of the pest population (e.g., *Tortricidae* taxa, apple codling moth, and *Chrysomelidae* taxa, leaf beetle) below the damage threshold levels. The changes in population dynamics of beneficial entomofauna followed the changes of pest entomofauna that is related to food availability (Niggli 2010). The study suggests that the strategies for keeping pest population of below the damage threshold levels should involve measures to increase biodiversity (beneficial) and biological control (Simon et al. 2010), e.g., pheromone mating-disruption dispensers and biopesticides. These measures should target the second generation of apple codling moth, but also aphids and leafminers.

Regression analysis

In the organic orchard, there are positive correlation (as cubic model of regression) between the AI index and the density and indices of biodiversity of Simpson and Shannon of insect indicator taxa in soil (R^2 equals 0.565, 0.489, and 0.497, respectively) and on the orchard surface (R^2 equals 0.203, 0.399, and 0.419, respectively). Higher-order polynomials as quadratic regression, cubic regression, etc. are very flexible and useful, when a model must be developed empirically. On the apple trees, there is also a positive correlation (at linear regression model) between AI index and Shannon index ($R^2 = 0.489$). The latter shows that the ecological intensification may increase the diversity of indicator-taxa and, in turn, may suppress more effectively the pest population (Niggli 2010). However, at all levels of the apple tree ecosystem, such as in the soil, on the land surface and at the tree canopy, the relatively low values of coefficients of determination signify that very small percentage of changes in the response variable biodiversity can be explained with changes in the factorial variable AI index. Almost 2/3 to 1/2 of the changes in dynamics of biodiversity in organic orchard could be attributed to factors that could potentially impact it, i.e., agro-ecological (e.g., climate and soil conditions) or agro-management (e.g., time of mowing, irrigation regime, or time of pesticide applications). The AI index considers solely the number of pesticide treatments, but not their toxicity on targeted pest and beneficial taxa. To determine the impact of different toxicity for different taxa and treatments, however, is complex. All such factors should be expressed mathematically and be included in the present AI index, as pointed out by Armengot et al. (2011), to also reflect better the human impact on agro-management decision-taking (Niggli et al. 2017).

Conclusions

The study employed a complex research (interconnecting climate and soil data, insect entomofauna, and agro-technologies) on a complex apple ecosystem aiming to uncover dynamics of insect indicator-taxa as affected by agro-management practices. The data on dynamics of insect indicator taxa in the soil, on the soil surface and at the apple tree canopy suggests that their population density and diversity is high in the organic orchard and relatively low in the reference conventional orchard. It could be attributed to major factors such as regional climate conditions and type of agricultural management practices such as mulching, organic (or mineral) fertilization, and biological (or chemical) plant protection. The linear regression models suggest that ecological intensification through organic practices (i.e., higher AI index) leads to a higher diversity of key beneficial insect taxa on apple trees such as *Coccinelidae*, *Chrysopidae*, and *Cantharidae* (higher indices of Simpson and Shannon) that is crucial in attempts to keep pest populations below the economic threshold levels. Therefore, farmers should aim at intensifying practices leading to higher density and diversity of beneficial supported by measures such as pheromone mating-disruption dispensers and bio-pesticides. However, the AI index, used for measuring the intensity of agro-management practices, should be re-designed to reflect important factors such as agroecological conditions (e.g., variable climate, soil fertility) and/or agro-management practices (e.g., time of mowing, irrigation regime and time of pesticide applications), in order to explain better the variability of insect biodiversity and support better the farmers' decision-making.

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