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Project

Mainstreaming Ecological Organic Agriculture (EOA) intoNational Policies, Strategies and Programmes in Africa

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Influence of the cultivated plant diversity on the abundance of arthropod trophic groups and *Helicoverpa armigera* biological control in tomato cropping systems in Benin

STUDY REPORT

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Summary

Intercropping generally increases cultivated plant biodiversity and influences the related arthropod communities. This plant diversity improves pest's natural regulations. With the aim of optimizing pest management, a study was carried out to determine the effect of cultivated plant diversity on arthropod communities and *Helicoverpa armigera* regulation in tomato cropping systems. Therefore, the diversity of cultivated plants and arthropod communities were assessed within and around tomato fields from 30 farmer's fields randomly selected in South of Benin. In each tomato field, all crops grown within 0 to 100 m on each side of the tomato field were identified. After identifying these crops on each side of the field, an experimental plot (or elementary plot) (20x20m) in the center of each tomato field was delimited. Each experimental plot was subdivided into a 4 m by 4 m quadrats in which all cropped plants were identified and counted. In the center of each quadrat, one Pitfall trap with soapy water leading to 25 Pitfall traps per field was placed and uplifted after 72 hours to capture the soil and litter macrofauna. The study showed that at the field scale, the abundances of omnivore predators, generalist predators and herbivores were greater in mixed cropping systems than in monocropping systems while the abundance of *Helicoverpa armigera* was lower in the mixed cropping systems than in monocropping systems. The cultivated plant diversity in the neighborhood of cultivated fields increased the abundance of omnivore and generalist predators and reduced the herbivore abundance. Multiple intercropped plant species increased the abundance of generalist and omnivore predators on which respectively *Solanum macrocarpon* and *Carica papaya* had the highest effects. This study allowed better understanding how plant diversity associated to tomato fields and in its neighborhood structure arthropods food web to finally enhance the ecological management of *H. armigera*.

Perspectives: i) Study of biological and ecological pest management on others pests of cropping systems, ii) Sensitization and training of farmers on innovative strategies of biological pest management.

1. Introduction

Cultivating plant mixtures is expected to provide a higher overall productivity, a better control of pests and diseases (Ratnadass et al. 2012), and enhanced ecological services (Vandermeer 1989, Gurr et al. 2003, Malézieux et al. 2009). Mixed cropping systems are often seen as a strategy to reduce the risk of pest incidence through ecological processes as diverse as barrier, dilution and trophic effects (Ratnadass et al., 2012). Increasing natural regulations constitutes an important component of more sustainable cropping systems. The management of animals and plants communities in the agroecosystems represents one of most important levers to improve these regulations. Understanding trophic interactions between different species in agroecosystems is essential to develop more efficient pest control strategies based on ecological regulation processes.

In Benin, tomatoes are grown in cropping systems ranging from monoculture to intercropping with diverse food crops including maize, roots, tubers and vegetables. These un-mechanized cropping systems rely on family labor and receive very little chemical inputs. The cultivation of tomato is very important for the economy of many countries and contributes to the food security of populations (Simeni et al. 2009). The tomato fruit is involved in several daily dishes and is a source of minerals and vitamins that can help reduce micronutrient and vitamin deficiencies (Beecher 1998).

Pests and diseases greatly reduce the yield and the market value of the tomato fruits. The main tomato pest is *Helicoverpa armigera*(Elégbédé et al. 2014) which feed on tomato fruits. *Helicoverpa armigera* is polyphagous and also causes massive damages to the tomato fruit, thus greatly reducing tomato yield. Several studies showed that the generalist predators are important predator groups and can improve pest control in cropping systems (Philpott et al. 2008, Tadu et al. 2014). Generally, arthropod biodiversity declines with cropping intensification, yet little is known about the mechanisms for predator declines and how the fall in diversity may affect the role of the generalist predators. Few studies showed the role of associated crops on generalist predator abundance increases and on pest regulations. The crop diversity is expected to change the structure of arthropod trophic groups in tomato cropping systems and *in fine* should modify the control of *H. armigera* by predators.

The management of plant diversity in tomato fields is the primary pest management practice that farmers can do. It is thus important to understand how cultivated plant diversity in these systems influences the structure of arthropod food webs and the control of *H. armigera*. In this study, we studied 30 tomato fields (in monocropping or in mixcropping) to investigate how the cultivated plants mixed with tomato plants and in the field neighborhoods affect the abundance of generalist predators and of *H. armigera*. Our goal was to identify the plants intercropped with tomatoes that participate to improve the control of *H. armigera* and to reduce the postharvest damages.

2. Materials and Methods

2.1. Study sites

The study was realized at the southern part of Benin in the regions of Atlantic, Mono and Couffo. The tomato fields were located in the small villages of Allada, Kpomassè, Sèhouè, Ouègbo, Grand-popo, Azovè, Djakotomey and Aplahoué, in areas where tomato is a major production. The climate is humid tropical with, an average temperature of 28 ° C and rainfall up to 1400 mm per year. The soil is sandy clay soil. All fields contained the tomato plants and a diverse array of other annual (e.g. maize, groundnut and vegetable crops) and perennial crops (e.g. palms and pineapples).

2.2. Measurements of plant diversity and arthropod communities in tomato cropping systems

The effect of the diversity of cultivated plants bordering tomato fields on the food web structure of arthropods has been measured in 30 fields covering a gradient of situations ranging from 1 to 10 associated crops. We characterized vegetation structure (species composition) at the field and the neighboring scales. In each tomato field, all crops grown within 0 to 100 m on each side of the tomato field were identified. After identifying these crops on each side of the field, an experimental plot (or elementary plot) (20x20m) in the center of each tomato field was delimited. Each experimental plot was subdivided into a 4 m by 4 m quadrats in which all cropped plants were identified and counted. In the center of each quadrat, one Pitfall trap with soapy water leading to 25 Pitfall traps per field was placed and uplifted after 72 hours to capture the soil and litter macrofauna. At total 25 pitfall traps were used per field in order to maximize the trapping. Additionally, all flying insects were captured with an entomological net and the others were collected directly on the plants using a mouth aspirator. All arthropod individuals collected with the traps, nets and aspirator were identified up to the genus or to the species and counted. The same measurements were realized between 8 to 12 AM in two periods: 3 months in the long rainy season (May, June and July) and 3 months in the short rainy season (August, September and October). The identification of arthropod taxa collected in the fields was completed at Entomological Museum of IITA – Benin. Each taxon was associated to a trophic group (herbivore, predator…) according to the literature.

2.3. Data analysis

The abundance of both taxa and trophic groups were calculated by summing the abundance of arthropods of the same order or trophic group. The cultivated plant diversity was evaluated with Shannon Index which was calculated with the diversity function of the vegan package version 2.2-1 (Oksanen and O'Hara 2013). Poisson Generalized Linear Models (GLMs) was used to analyze the effect of cultivated plant diversity on the abundance of arthropod trophic groups. The effect of cultivated plant diversity was tested against a null model using a Likelihood Ratio Test (LRT) (Bolker et al. 2009). The student test was used to test the difference between pluricrops and monocrops of tomato with respect to the abundance of each arthropod trophic group. All GLMs were estimated using the 'lme4' package (Bates et al.

2012), in which the maximum likelihood of parameters is approximated by the Laplace method (Bolker et al. 2009). Statistical analyses were performed with R 2.15.0 (R Development Core Team 2014) at a significant level of 5% (alpha=0.05).

3. Results

As a whole, 3349 individual arthropods from 12 orders were collected inside tomatoes fields. The most abundant orders were Hymenoptera with 1937 individuals followed by Orthoptera with 391 individuals, Araneae with 382 individuals, Coleoptera with 353 individuals. On the literature basis, 5 arthropod trophic groups were constituted as follows: omnivore predators (1905 individuals), herbivores (940 individuals), generalist predators (467 individuals), detritivores (30 individuals) and parasitoids (7 individuals). We retained for further analyses the arthropods for which the trophic group abundances were > 400 individuals.

3.1. Difference of *Helicoverpa armigera* abundance between monocrop and multi-crops in tomato agro-ecosystems

The cultivated plant diversity had a negative significant effect on the abundance of *Helicoverpa armigera* ($P < 0.0001$; Estimates = -3.31; Z-value = -5.89). The abundance of *Helicoverpa armigera* was lower in a mixed cropping than in monocropping systems (**Figure 1**), but the test of Student did not show a significant effect ($t = -0.72$; Df = 5,22 ; $P = 0.49$).

3.2. Effect of field scale cultivated diversity on the abundance of arthropod trophic groups

The abundance of herbivores, generalist predators and omnivore predators were higher in tomato mixed cropping systems than in tomato monocropping systems (**Figure 2**). However, these differences were not significant for herbivores ($t = -0.41$; Df = 6, 83; $P = 0.69$), generalist predators ($t = -1.07$; Df = 7, 21; $P = 0.31$), nor omnivore predators ($t = -0.71$; Df = 5, 25; $P = 0.50$).

Globally, the plant diversity had a significant effect on the arthropod abundance ($P < 0.0001$; Estimates = 3.78; Z-value = 25.10). At the field scale, the cultivated plant diversity had a positive significant effect on omnivore predator abundance but this effect was not significant for the other arthropod trophic groups (**Table 1, Figure 3**). At the neighbourhood field scale, the cultivated plant diversity had a positive significant effect on both omnivore and generalist predator abundance, inversely this effect was negative for herbivores (**Table 2**).

3.3. Relationship between plant species and arthropod trophic groups in tomato agro-ecosystems

The abundances of six different associated plant species (*Manihot esculenta*, *Arachis hypogaea*, *Elaeis guineensis*, *Abelmoschus esculentus*, *Ananas comosus*, *Talinum triangulare*) had positive significant effects on both omnivore and generalist predator abundances. Inversely, three plant species (*Irvingia gabonensis*, *Citrus sinensis* and *Corchorus olitorius*) had negative significant effects on both omnivore and generalist predator abundances (**Table 3, 4**).

4. Discussion

4.1. Relationship between plant diversity and arthropod trophic groups in tomato agroecosystems

In this study, the effect of cultivated plant diversity on the abundance of arthropod trophic groups showed that the abundance of omnivore predators was positively correlated with the cultivated plant diversity. This result corroborates previous studies from biodiversity experiment or meta-analyses (Scherber et al. 2010, Letourneau et al. 2011). This could be explained by an increase in ant predator abundance due to the diversification of the plant resources as suggested by others studies (Mollot et al. 2012, Dassou et al. 2015). Plant diversity often modifies the structure of arthropod communities, increases the abundance of generalist predators (Song et al. 2010), and reduces the abundance of pests (Baliddawa 1985). In our study, the cultivated plant diversity was positively correlated to ant abundances. As mentioned in a recent meta-analysis(Dassou and Tixier 2016), this finding could be the results of two complementary processes: diversified cropping systems is expected i) to provide more favorable habitats for ants and ii) to increase the availability of plant resources for predatory ants (Vasconcelos et al. 2008). At the neighbourhood field scale, the cultivated plant diversity increased the abundance of omnivore and generalist predators and reduced the abundance of herbivores showing the importance of the neighboring fields for the ecological pest management. The neighbouring cultivated plants in tomato fields constituted favorable habitats for omnivore and generalist predators and provided them additional primary resources.

The comparison of the abundances of arthropod trophic groups between monocrops and pluricrops showed that the herbivores, omnivores and generalist predators were greater in mixed cropping systems than in monocropping systems. This could be explained by the fact that tomato is a seasonal crop in which the intercropped plants provide a favorable habitats and plant resources to the herbivores and predators. These results are in line with those obtained by Scherber (2010) who found that plant diversity increases the abundance of arthropod trophic groups without the invasive species. In plantain agro-ecosystems, Dassou et al. (2016) showed that plant diversity tend to increase the abundance of generalist predators and reduced the abundance of herbivore abundance.

4.2. Difference of *Helicoverpa armigera* abundance between monocrops and pluricrops in tomato agro-ecosystems

The results show that *Helicoverpa armigera* abundance was greater in monocropping than in mixed cropping systems. The cultivated plant diversity increased the predator abundance and in-turn probably increased the control of lower trophic levels including *H. armigera*. This is in conformity with the findings of Dassou at al. (2016) and Haddad et al. (2009) who reported that plant diversity increases the abundances of arthropods at higher trophic levels and reduces the abundances of lower trophic levels. Our results suggest the important role of ants (eg. *Pachycondyla tarsata* and *Camponotus sericeus*) on the control of *H. armigera*. These ants are the potential predators of *H. armigera* as showed by Mansfield et al (2003) on *H. armigera* eggs.

4.3. Relationship between plant species and arthropod trophic groups in tomato agro-ecosystems

Results showed that *Solanum macrocarpon* intercropped in the tomato field attracts strongly the generalist predator trophic group while *Carica papaya* attracts strongly the omnivore trophic group. This finding shows that *Solanum macrocarpon* and *Carica papaya* seem to be the best associated plant for the ecological management of *H. armigera* in tomato agro-ecosystems. Plant diversification depends to the type of cultivated plant species such as annual and perennial plants which improve differently the communities of omnivore predators and generalist predators. The scale of cultivated plant diversity management in fields and around of fields may be considered as an efficient ecological approach whose the farmers need for ecological pest management.

In summary, the cultivated plant diversity inside and around of tomato fields increase the arthropods trophic groups abundances, especially the omnivores predators and generalist predators for the best control of *H. armigera*. This finding should be confirmed with experiments that specifically mix *Solanum macrocarpon* and *Carica papaya* in tomato fields. For future directions of ecological research, the type of intercropped cultivated plant and the scale of implementation are two important things whose attention should be paid to the provision of multiple ecosystem services.

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Annex :

Table 1. Effect of cultivated plant diversity on arthropod trophic groups at field scale

Trophic groups	Estimates	Df	Pr (Chi)
Omnivore predator abundance	1.3810	1	<0.00001
Generalist predator abundance	0.3113	1	0.383
Herbivore abundance	0.1825	1	0.5614

Table 2. Effect of cultivated plant diversity on arthropod trophic groups at neighboring field scale

Trophic groups	Estimates	Df	Pr (Chi)
Omnivore predator abundance	0.23916	1	<0.00001
Generalist predator abundance	0.46022	1	<0.00001
Herbivore abundance	-0.15007	1	<0.00001

Table 3. Effect of cultivated plant abundances on the generalist predator abundance

No.	Taxon	Estimates	Df	LRT	Pr (Chi)
1	African mango	-11.1038	1	4.4548	0.0348
2	Cassava	0.014079	1	49.311	<0.00001
3	Cowpea	-0.03386	1	1.2993	0.2543 (ns)
4	Crin-crin	-0.001489	1	0.0019195	0.9651 (ns)
5	Garden egg	0.36416	1	35.786	<0.00001
6	Groundnut	0.029831	1	42.784	<0.00001
7	Hot pepper	0.028397	1	107.92	<0.00001
8	Maize	-0.00542	1	2.1335	0.1441 (ns)
9	Oil palm	0.02541	1	4.93	0.02639
10	Okra (gombo)	0.04830	1	0.71495	0.3978 (ns)
11	Orange	-13.1154	1	26.773	<0.00001
12	Papaya	-12.1044	1	8.9126	0.002832
13	Pigeon pea	-12.1136	1	13.373	0.0002552
14	Pineapple	0.0090556	1	141.23	<0.00001
15	Talinum	0.06132	1	1.4536	0.2279 (ns)
16	Tomato	0.0017896	1	20.035	<0.00001
17	Triumphetta	0.042229	1	22.392	<0.00001

Table 4. Effect of cultivated plant abundances on the omnivore predator abundance

No.	Taxon	Estimates	Df	LRT	Pr (Chi)
1	African mango	-11.648258	1	20.873	<0.00001
2	Cassava	0.0203834	1	605.46	<0.00001
3	Cowpea	0.064684	1	40.055	<0.00001
4	Crin-crin	-0.449811	1	73.015	<0.00001
5	Garden egg	-1.005788	1	71.557	<0.00001
6	Groundnut	0.014255	1	31.968	<0.00001
7	Hot pepper	-0.000147	1	0.0043061	0.9477 (ns)
8	Maize	0.047362	1	1703.4	<0.00001
9	Oil palm	0.121929	1	849.87	<0.00001
10	Okra (gombo)	0.040569	1	2.3091	0.1286 (ns)
11	Orange	-13.003007	1	125.45	<0.00001
12	Papaya	0.363629	1	3.5213	0.06058
13	Pigeon pea	-0.224603	1	2.4742	0.1157 (ns)
14	Pineapple	0.0094729	1	749.42	<0.00001
15	Talinum	0.096995	1	20.426	<0.00001
16	Tomato	-0.001417	1	44.324	<0.00001
17	Triumphetta	-0.027705	1	21.121	<0.00001

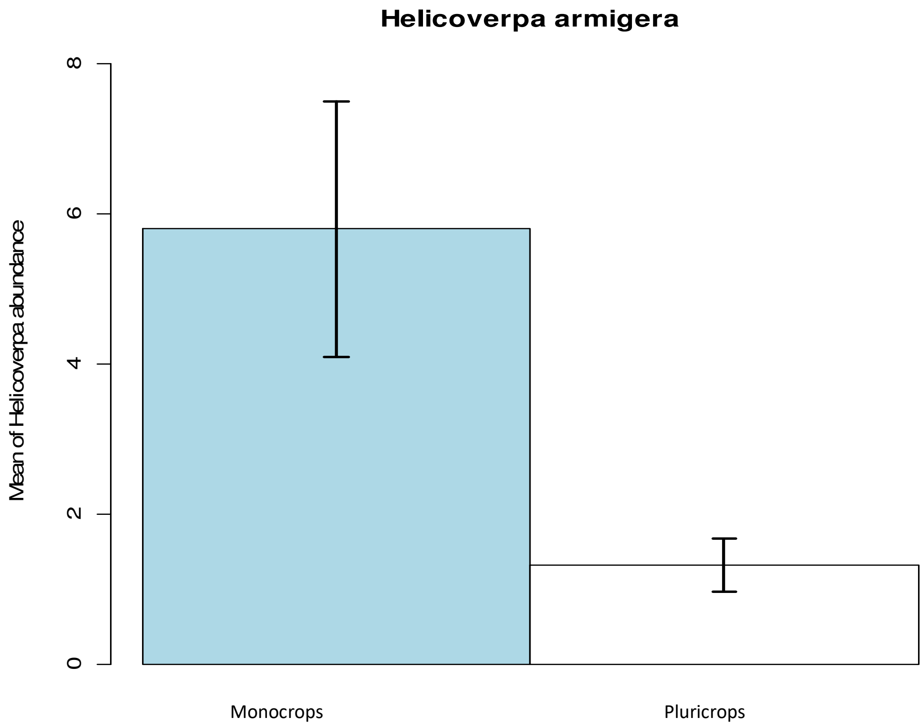

Figure 1. Mean abundances of *H. armigera* in mixed cropping systems and monocropping systems

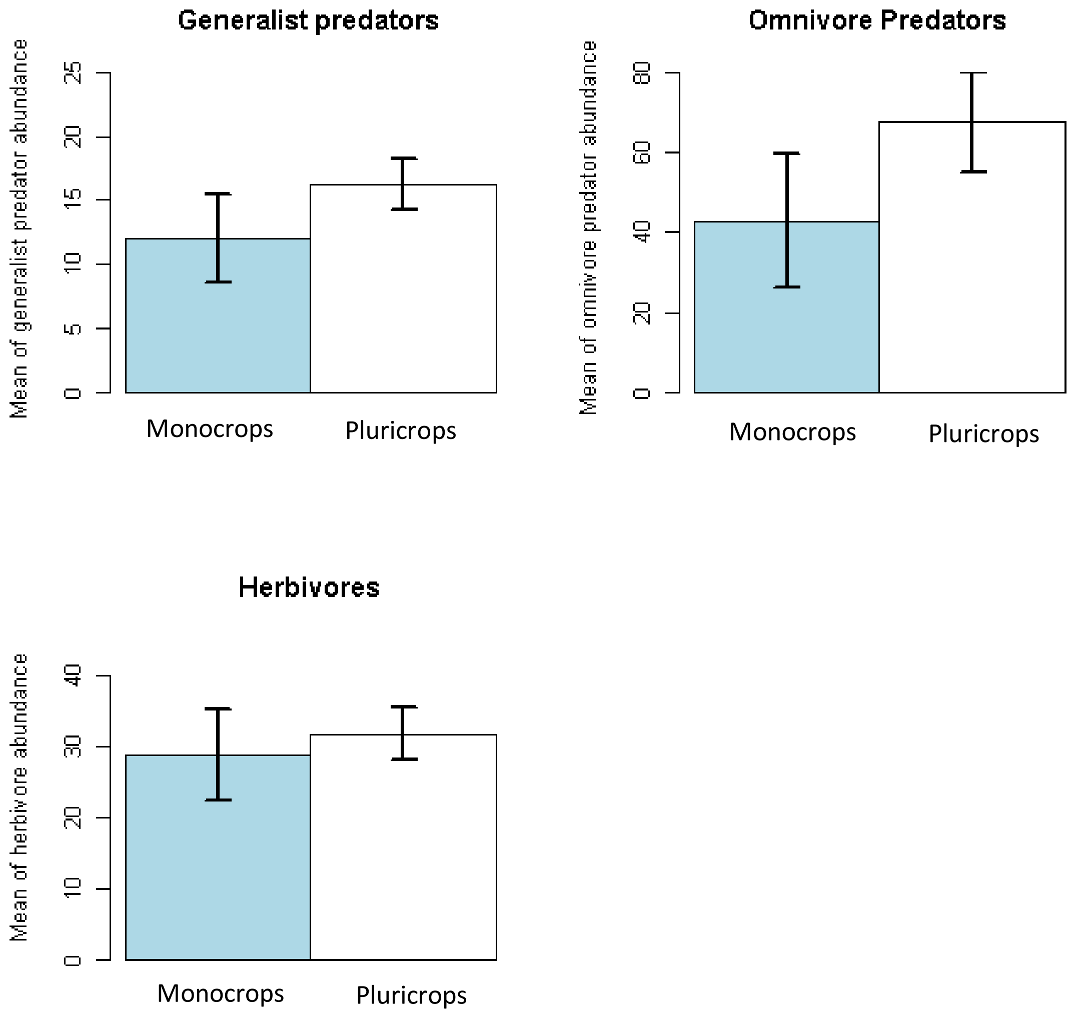

Figure 2. Mean abundances of arthropod trophic groups in diversified tomato systems and monocrop tomato systems

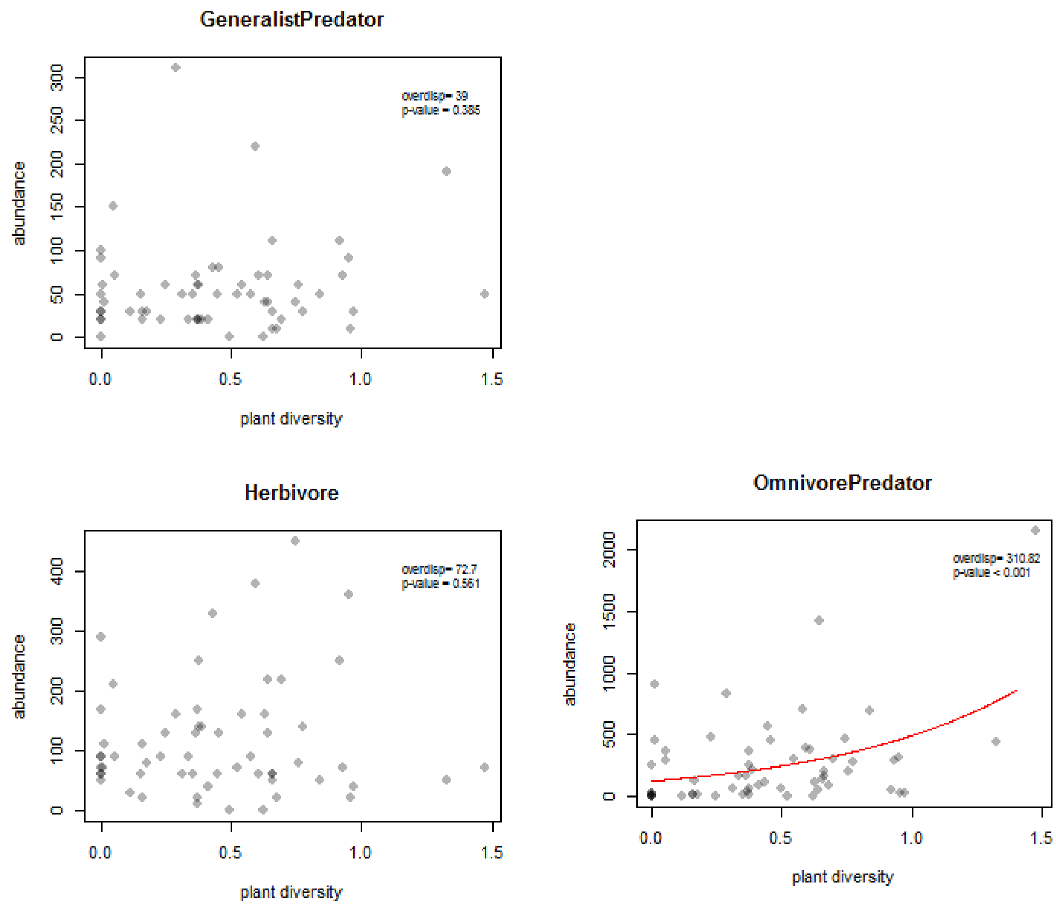

Figure 3. Relationship between cultivated intra-field plant diversity and arthropod trophic groups

Supplementary materials

Table S1. Systematic classification of the cultivated plants intercropped with the tomato

No.	Taxon	Class	Order	Family	Genus	Species
1	African mango	Magnoliopsida	Malpighiales	Irvingiaceae	*Irvingia*	*gabonensis*
2	Cassava	Magnoliopsida	Euphorbiales	Euphorbiaceae	*Manihot*	*esculenta*
3	Cowpea	Magnoliopsida	Fabales	Fabaceae	*Vigna*	*unguiculata*
4	Crin-crin	Magnoliopsida	Malvales	Malvaceae	*Corchorus*	*olitorus*
5	Garden egg	Magnoliopsida	Solanales	Solanaceae	*Solanum*	*macrocarpon*
6	Groundnut	Magnoliopsida	Fabales	Fabaceae	*Arachis*	*hypogaea*
7	Hot pepper	Magnoliopsida	Solanales	Solanaceae	*Capsicum*	*anuum*
8	Maize	Liliopsida	Cyperales	Poaceae	*Zea*	*mays*
9	Oil palm	Liliopsida	Arecales	Arecaceae	*Elaeis*	*guineensis*
10	Okra (gombo)	Magnoliopsida	Malvales	Malvaceae	*Abelmoschus*	*esculentus*
11	Orange	Magnoliopsida	Sapindales	Rutaceae	*Citrus*	*sinensis*
12	Papaya	Magnoliopsida	Violales	Caricaceae	*Carica*	*papaya*
13	Pigeon pea	Magnoliopsida	Fabales	Fabaceae	*Cajanus*	*cajan*
14	Pineapple	Liliopsida	Bromeliales	Bromeliaceae	*Ananas*	*comosus*
15	Talinum	Magnoliopsida	Caryophyllales	Talinaceae	*Talinum*	*triangulare*
16	Tomato	Magnoliopsida	Solanales	Solanaceae	*Solanum*	*lycopersicum*
17	Triumphetta	Magnoliopsida	Malvales	Malvaceae	*Triumphetta*	sp

Table S2. Systematic classification of arthropod species collected in the tomato agro ecosystems

Order	Class	Family	Taxon name	Trophic groups
Prostigmata	Arachnida	Tetranychidae	*Tetranychus* sp. 1	Herbivore
Araneae	Arachnida	Araneidae	*Araneus* sp. 1	Predator
	Arachnida	Linyphiidae	*Erigone* sp. 1	Predator
	Arachnida	Linyphiidae	*Araneus* sp. 2	Predator
Blattodea	insecta	Blattellidae	*Blattellidae*	Detritivore
Chilopoda	Scolopendromorpha	Scolopendridae	Undet. sp.	Predator
Coleoptera	insecta	Attelabidae	*Parapoderus* sp. 1	Herbivore
	insecta	Carabidae	*Tetragonoderus* sp.	Predator
	insecta	Cerambycidae	*Obereopsis variipes*	Herbivore
	insecta	Chrysomelidae	*Altise* sp.	Herbivore
	insecta	Chrysomelidae	*Chiridopsis aubei*	Herbivore
	insecta	Chrysomelidae	*Lema cephalotes*	Herbivore
	insecta	Chrysomelidae	*Nisotra dilecta*	Herbivore
	insecta	Coccinellidae	*Coccinella septempunctata*	Omnivore
	insecta	Elateridae	*Agriotes* sp. 1	Herbivore
	insecta	Elateridae	*Heteroderes* sp. 1	Herbivore
	insecta	Meloidae	*Hycleus* sp. 1	herbivore
	insecta	Tenebrionidae	*Gonocephalum simplex*	Herbivore
Dermaptera	insecta	Forficulae	Undet. sp.	Omnivore
Diptera	insecta	Tephritidae	*Dacus ciliatus*	Herbivore
	insecta	Agromyzidae	*Lyriomiza sativae*	Herbivore
Hemiptera	insecta	Coreidae	*Clavigralla tomentosicollis*	Herbivore
	insecta	Coreidae	*Leptoglossus* sp. 1	Herbivore
	insecta	Pentatomidae	*Caura pugillator*	Herbivore
	insecta	Pentatomidae	*Nezara viridulla*	Herbivore
	insecta	Reduviidae	*Acanthaspis vidua*	Predator
Hymenoptera	insecta	Apididae	*Apis* sp. 1	Herbivore
	insecta	Braconidae	*Aleiodes* sp. 1	Parasitoid
	insecta	Braconidae	*Apanteles* sp. 1	Parasitoid
	insecta	Encyrtidae	*Acerophagus* sp. 1	Parasitoid
	insecta	Formicidae	*Camponotus brutus*	Omnivore
	insecta	Formicidae	*Camponotus sericeus*	Omnivore
	insecta	Formicidae	*Camponotus* sp. 1	Omnivore
	insecta	Formicidae	*Camponotus* sp. 2	Omnivore
	insecta	Formicidae	*Camponotus* sp. 3	Omnivore
	insecta	Formicidae	*Crematogaster* sp. 1	Omnivore
	insecta	Formicidae	*Monomorium bicolor*	Omnivore
	insecta	Formicidae	*Monomorium* sp. 1	Omnivore
	insecta	Formicidae	*Paltothyreus tarsatus*	Predator
	insecta	Formicidae	*Paratrechina longicornis*	Omnivore

	insecta	Formicidae	*Pheidole megacephala*	Omnivore
	insecta	Formicidae	*Pheidole* sp. 1	Omnivore
	insecta	Formicidae	*Pheidole* sp. 2	Omnivore
	insecta	Formicidae	*Odontomachus troglodytes*	Predator
	insecta	Vespidae	*Belonogaster juncea*	Omnivore
Blattodea	insecta	Termitidae	*Macrotermes* sp.	Detritivore
Lepidoptera	insecta	Noctuidae	*Helicoverpa armigera*	Herbivore
	insecta	Noctuidae	*Spodoptera* sp. 1	Herbivore
	insecta	Nymphalidae	*Acraea serena*	Herbivore
	insecta	Pieridae	*Catopsilia florella*	Herbivore
	insecta	Pieridae	*Eurema brigitta*	Herbivore
	insecta	Pieridae	*Eurema* sp. 1	Herbivore
Mantodea	insecta	Mantidae	*Mantis religiosa*	Predator
Orthoptera	insecta	Acrididae	*Acrida* sp. 1	Herbivore
	insecta	Acrididae	*Aiolopus simulatrix*	Herbivore
	insecta	Acrididae	*Humbe tenuicornis*	Herbivore
	insecta	Acrididae	*Trilophidia conturbata*	Herbivore
	insecta	Gryllidae	*Modicogryllus* sp. 1	Omnivore
	insecta	Gryllidae	*Scapsipedus* sp. 1	Omnivore
	insecta	Phalangospidae	*Homeogryllus reticulatus*	Omnivore
	insecta	Acrididae	*Gastrimargus africanus*	Herbivore
	insecta	Pyrgomorphidae	*Chrotogonus senegalensis*	Herbivore
	insecta	Pyrgomorphidae	*Zonocerus variegatus*	Herbivore
	insecta	Tettigoniidae	*Anepitacta* sp. 1	Herbivore
	insecta	Tettigoniidae	*Conocephalus* sp.	Omnivore
Polydesmida	Diplopoda	Paradoxosomatidae	Undet. sp.	Detritivore
Isopoda	Malacostraca	Porcellionidae	Undet. sp.	Detritivore