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Effect of crop association on insect pest diversity in northern Côte d'Ivoire

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Abstract
Maize is one of the most important crops for human and animal consumption. However, it faces enormous damage caused by insect pests reducing its production. This study was carried out in Korhogo (high maize production area) in order to contribute to the knowledge and control of maize insect pests. The experiments were carried out in three different plots contained in the same field matrix. The first plot (control) contained only maize. The other two plots were composed of an association of maize and groundnut. The difference between these last two plots was based on maize and groundnut plants arrangement (parallel system or alternated system). The collected insects were keep in the flasks containing ethanol (70%), convoyed to the laboratory and, identified under a binocular magnifier using an insect identification key. In total, 31 species of insects belonging to 6 orders and 20 families were identified. No significant differences were observed between the specific richness of insects in the three crop systems. Regarding the abundance of insects, 4663 specimens were collected during all the study of which 1303 specimens were pests. The highest average abundance of insect pests was recorded in the monoculture (238.67±17.23) and the lowest was recorded in the alternated polyculture (57.00±7.41). Our findings are very relevant because they make it possible to classify crop association among the innovative farming strategies that can boost crop production in a region where the small farmers are increasingly numerous.

Keywords: Maize, groundnut, monoculture, polyculture, Korhogo.

1. Introduction

Maize is an annual tropical herbaceous plant widely cultivated for its starch-rich kernels as well as for its quality as a fodder crop. It's cultivated in various agricultural systems and in several agro-ecological areas. African populations, although having varied preferences and living in a different socio-economic context, mostly consume maize [1]. In Côte d'Ivoire, maize is a staple food for many populations and constitute the most cultivated cereal after rice, with an estimated yield of 654,738 tons per year, for a total area of 327,800 ha [2]. In human consumption food, maize is consumed in several forms (cooked grilled, in soup). It can be processed to obtain a wide range of products such as flour and cornmeal. In addition, it is used to make biodegradable plastics, biofuels and even alcohol [3]. Despite the great importance and the potentialities of this cereal, its cultivation experiencing enormous agronomic constraints such as, the decline of soil fertility, the damage caused by diseases and pests that reduce production [4]. To overcome these problems, farmers resort to the excessive use of pesticides leading to a loss of biodiversity, a decline of soil fertility, a resistance of pests and a health risk [5]. So, the crop association seems an alternative to the pesticide use. The models of crop association are essentially based by the binomial "cereal-legume" [6]. In the north of Côte d'Ivoire, the effect of the association groundnut, soybeans and maize on the soils, was evaluated [7]. The findings showed that groundnut was the best nitrogen provider. Its association with other crops increased maize yield by 18% [8]. In addition, this crop association promotes the development of many beneficial insects communities. In fact, "sorghum-cowpea" and "sorghum-groundnut" associations highly favored the development of predatory (Hemiptera and Coleoptera) and some parasitoids [9]. It could be that the crops association, in particular maize-groundnut, strongly affects the abundance of insect pests. This study aims to assess the impact of crops association in the communities of insect pests.

Specifically, it involves (i) to determine the diversity of insect pests in three crop systems, (ii) to compare the taxonomic composition of insects on different crop systems and (iii) to analyze the trophic groups' distribution according to the phenological conditions.

2. Materials and Methods

2.1 Study areas and design

This study was carried out in Korhogo city (9° 26' 47.06" LN; 5° 38' 40.74" LW) in northern Cote d'Ivoire (Figure 1). The climate is characterized by two seasons including a wet season of four months and a dry season of eight months. The annual rainfall varies between 1200 mm and 1400 mm. The vegetation consists of a tree savannas composed by trees and shrubs. However, there are some gallery forests along the rivers. The soils are ferralitics and belong to the group of more or less denatured soils, and of constant mineralogical composition. Most of the population derives its incomes from the main agricultural, perennial, food and market garden crops. The experimental plots located in the botanical garden of the University Peleforo Gon Coulibaly, were included in a matrix of fields composed by a monoculture (maize) and a polyculture (maize-groundnut).

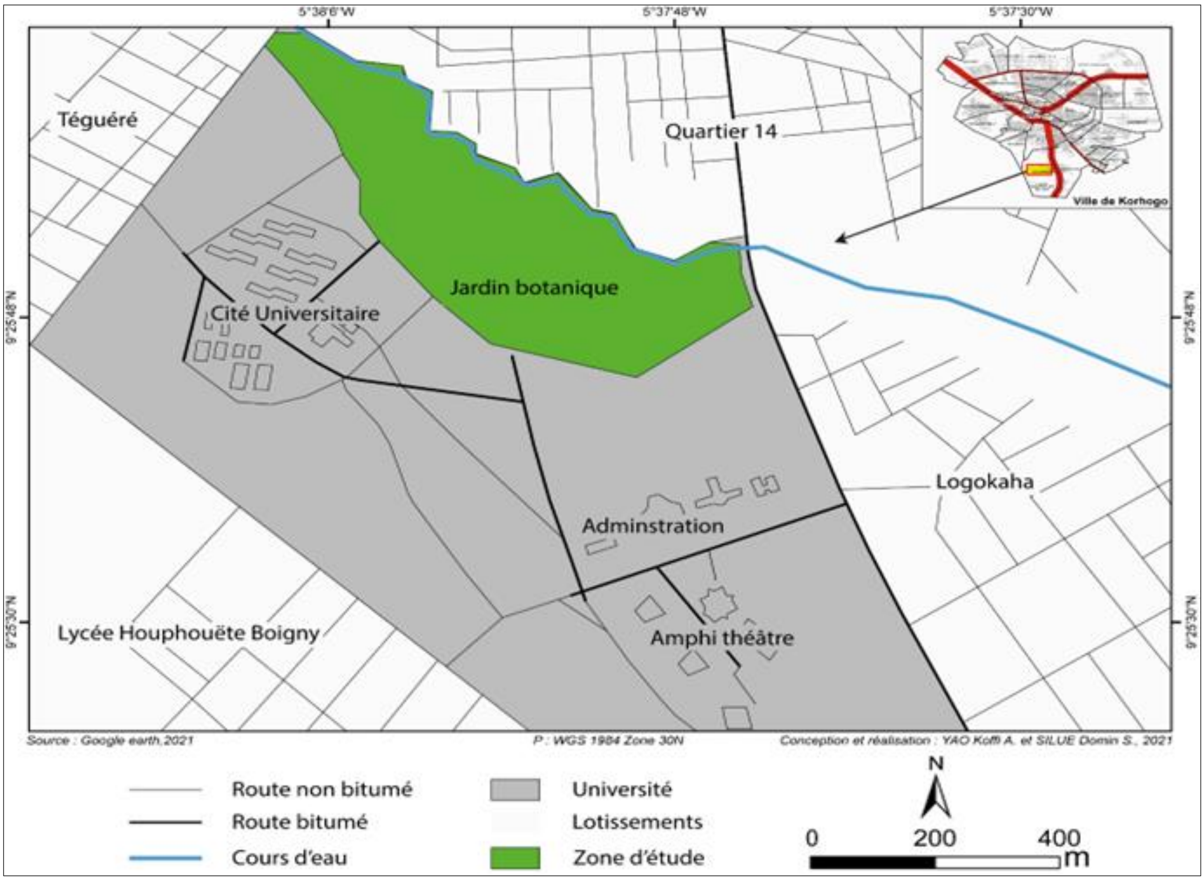

Fig 1: Location of the study site

2.2. Data collection

2.2.1 Field design

The experiments were carried out in three plots contained in the same field matrix. On the first plot, only maize was cultivated. The other two plots were composed of maize and groundnut association. However, plant arrangement in the two plots was different. In the second plot, each row containing either only maize or only groundnut was placed consecutively (parallel polyculture) while, in the third plot, maize and groundnut plots were alternated on the same row (alternated polyculture). Maize and groundnut were grown after weeding and ridge preparation. Each plot was made up of six ridges. Two seeds were placed per pocket, respecting a spacing of 40 cm for maize and 10 cm for groundnut between the pockets. After sowing, all the plots were watered continuously.

2.2.2 Capture of insects

Insects were collected using sweep net and pan trap (yellow) during different stages of maize development. Thirty pan traps were placed in each plot. The different traps were fill with salt (NaCl) saturated water and a small drop of detergent (soap). The traps were left activated for 48 hr during each sampling turn. In addition, insects were collected manually on the different plants. All captured insects were stored in the labeled flasks containing ethanol (70%), and convoyed to the laboratory for identification using a binocular magnifier (MOTIC X 4 magnifications) and a key of identification.

2.3. Data Analysis

Insect data were analyzed regarding their abundance, estimated species richness using Simpson diversity indices and Pielou's evenness index. The structure of insect communities was analyze using Jaccard indices. The ANOVA test was used to compare diversity (richness and abundance) of insect within the different plots. Following this analysis, pairwise test allowed to classify crop systems. In addition, insect orders were characterized using the Principal Component Analysis (PCA). This analysis allowed to establish the link between the different insect trophic groups and the plant phenological stages. All statistical analyses were performed using STATISTICA version 7.1 and PAST version 1.0.

3. Results
3.1 Global richness
A total of 31 species of insects were identified during all the study. They belong to 6 orders and 20 families. Specifically, all the 31 species of insects were found in the monoculture. We recorded 30 and 27 species of insects respectively in the parallel polyculture and alternated polyculture (Table 1). However, no significant difference was recorded between the specific richness of insects in the different crop systems (F=0.95; P=0.95).

Table 1: Taxonomic richness of all collected insects

Crop systems	Orders	Families	Species
Monoculture	6	20	31
Parallel polyculture	6	19	30
Alternated polyculture	6	17	27

3.2. Richness of insect pests
Regarding the insect pests, 16 species were identified in the monoculture and the parallel polyculture each, against 14 species in the alternated polyculture (Table 2). No significant difference was observed between the specific richness of insects in the different crop systems (F = 1.69; P = 0.21). Shannon indices and Pielou's evenness indices were approximately the same in the three crop systems: (Monoculture H' = 2.98 / E = 0.86; Parallel polyculture H' = 2.84 / E = 0.82; Alternated polyculture H' = 2.65 / E = 0.79).

Table 2: Taxonomic richness of insect pests

Indices of diversity	Monoculture	Parallel polyculture	Alternated polyculture
Specific richness	16	16	14
Shannon index (H')	2.98	2.84	2.65
Pielou's evenness index	0.86	0.82	0.79

3.3. Taxonomic composition of insects
The values of Jaccard indices showed a similarity between the taxonomic richness of insects in the different crop systems (J > 0.5) (Table 3). However, these values were higher between the monoculture and the parallel polyculture showing their similarity compared to alternated polyculture. The lowest values of Jaccard indices was recorded between the monoculture and the alternated polyculture (Table 3). Some species of insects were common to the different crop systems. Thus, the monoculture and the parallel polyculture had the highest number of the common species. On the other hand, the alternated polyculture and the parallel polyculture had the lowest number of the common species. The species *Nepa cinerea* was present only in the monoculture while the species *Serina brunnea* and *Scarites subterraneus* were present in the monoculture and the parallel polyculture.

Table 3: Indices of Jaccard

Crop systems	Monoculture	Parallel polyculture	Alternated polyculture
Monoculture	1		
Parallel polyculture	0.96	1	
Alternated polyculture	0.90	0.93	1

3.4. Global abundance of insects
In total, 4663 specimens of insects were collected. The highest abundance was recorded in the parallel polyculture (1756 specimens), followed by the monoculture (1718 specimens) and the alternated polyculture, respectively (1189 specimens) (Table 4). No significant difference was observed between the average abundance of insects in the three crop systems (F = 1.64; P = 0.22). The most abundant species was *Solenopsis invicta* (539 specimens), followed by *Phaonia subventa* (494 specimens), *Musca domestica* (437 specimens), *Pyrrhocoris apterus* (417 specimens), and *Camponotus maculatus* (408 specimens). In contrast, *Nepa cinerea* (4 specimens), *Carabus blaptoides* (10 specimens), *Neocurtilla hexadactyla* (10 specimens), *Serina brunnea* (14 specimens) and *Naupaetus cevinus* (18 specimens) were the least abundant species, respectively.

Table 4: Average abundance of insect in the three crop systems

Insects (species)	Monoculture	Parallel polyculture	Alternated polyculture	F	P
Acheta domesticus	7.00±2.43^a	5.33±2.19^a	2.00±1.77^b	4.84	0.03
Agraunus vanillae	3.33±1.13^a	1.67±0.62^b	4.33±1.78^a	4.41	0.031
Atalia rosae	14.33±3.27^b	33.33±5.29^a	11.00±3.02^b	4.86	0.03
Calliptamus italicus	3.67±1.22^a	3.00±1.05^a	1.00±0.89^b	4.82	0.03
Camponotus maculatus	32.00±4.94^c	41.67±5.37^b	62.33±7.11^a	6.21	0.015
Carabus blaptoides	2.33±0.78^a	0.67±0.18^b	0.33±0.11^b	4.87	0.03
Chrysochraon dispa	2.67±0.86^a	1.33±0.67^a	0.33±0.14^a	4.83	0.03
Chrysomia megacephala	14.67±2.44^a	9.00±2.12^b	6.67±1.49^c	5.29	0.024
Clodia interpunctella	9.67±1.71^a	5.33±1.23^b	2.00±0.95^c	5.91	0.02
Coccinella septempunctata	15.67±3.89^a	15.00±3.66^a	8.67±1.98^b	4.41	0.031
Gastrophisa polygoni	11.67±3.71^a	6.00±1.35^b	3.33±0.93^c	5.39	0.023
Grillodes sigillatus	8.33±1.66^a	5.67±1.21^a	2.67±0.92^b	4.14	0.034
Gryllus bimaculatus	5.00±1.11^a	3.33±1.03^a	0.67±0.37^b	5.75	0.022
Hermetia illucens	21.33±3.87^a	10.33±3.01^b	9.33±2.86^b	4.89	0.03
Hormonia axyridis	11.33±3.46^a	11.67±3.51^a	7.67±2.35^b	4.18	0.033
Monomorium minimum	15.33±3.78^b	30.00±5.78^a	29.67±5.22^a	3.67	0.04
Monomorium pharaonis	19.67±4.01^b	30.00±5.27^a	33.00±5.98^a	4.81	0.031
Musca domestica	41.67±6.52^b	71.00±8.89^a	33.00±5.43^b	4.82	0.03
Naupaetus cevinus	3.00±1.21^a	2.33±1.03^a	0.67±0.12^b	4.88	0.03
Neocurtilla Hexadactyla	1.67±0.14^a	1.00±0.11^a	0.67±0.09^a	1.63	0.24
Neoitamus cyanurus	28.33±4.18^a	34.33±5.66^a	14.00±3.32^b	4.91	0.03
Nepa cinerea	1.33±0.13^a	0.00±00^b	0.00±00^b	4.85	0.03

Nezara viridula	54.33±7.22^{a}	35.67±4.96^{b}	23.33±3.33^{c}	5.93	0.02
Oedipoda caerulescens	6.33±1.34^{a}	1.67±0.21^{b}	0.67±0.11^{b}	4.89	0.03
Pamponorus germanicus	11.67±3.78^{a}	16.00±3.75^{a}	10.00±3.21^{a}	1.46	0.25
Phaonia subventa	52.33±7.33^{b}	77.33±9.14^{a}	35.00±5.59^{c}	6.42	0.012
Philaenus spumarius	29.67±4.11^{a}	19.00±4.02^{b}	6.67±1.88^{c}	5.97	0.02
Pyrrhocoris apterus	84.33±9.67^{a}	42.00±6.35^{b}	12.67±3.98^{c}	6.33	0.013
Scarites subterraneus	5.67±1.87^{a}	5.00±1.54^{a}	0.00±00^{b}	5.94	0.02
Serina brunnea	3.33±0.99^{a}	1.33±0.65^{a}	0.00±00^{b}	3.65	0.04
Solenopsis invicta	43.00±6.71^{a}	65.00±8.33^{a}	71.67±9.43^{a}	1.61	0.23
Total	572.67±29.07^{a}	585.33±31.32^{a}	396.33±24.62^{a}	1.64	0.22

3.5. Abundance of insect pests

In total, 1303 specimens of insect pests were collected including 716 specimens recorded in the monoculture, 416 specimens in the parallel polyculture and 171 specimens in the alternated polyculture (Table 5). According to ANOVA test, the average abundance of insect pests in the monoculture was significantly different compared to the parallel polyculture and alternated polyculture (F = 6.52; P = 0.02). On the other hand, there was no significant difference between the average abundance of insects collected in the parallel polyculture and the alternated polyculture (F = 1.06; P = 0.37). The most abundant species in the three crop systems were *Pyrrhocori apterus* (Monoculture: 253 specimens; Parallel polyculture: 126 specimens; Alternated polyculture: 38 specimens), *Nezara viridula* (Monoculture: 163 specimens; Parallel polyculture: 107 specimens; Alternated polyculture: 70 specimens) and *Philaenus spumarius* (Monoculture: 89 specimens; Parallel polyculture: 57 specimens; Alternated polyculture: 20 specimens).

Table 5: Average abundance of insect pests in the crop systems

Pests (species)	Monoculture	Parallel polyculture	Alternated polyculture	F	P
Serina brunnea	3.33±1.35^{a}	1.33±0.18^{b}	0.00±0.00^{c}	5.77	0.03
Gastrophisa polygoni	11.67±3.17^{a}	6.00±2.01^{b}	3.33±1.13^{c}	6.22	0.023
Naupaetus cervinus	3.00±1.23^{a}	2.33±0.23^{a}	0.67±0.51^{b}	4.37	0.043
Scarites subterraneus	5.67±1.91^{a}	5.00±1.22^{a}	0.00±0.00^{b}	5.02	0.037
Carabus blaptoides	2.33±0.65^{a}	0.67±0.20^{b}	0.33±0.13^{b}	5.09	0.036
Plodia interpunctella	9.67±3.03^{a}	5.33±1.39^{b}	2.00±0.91^{c}	6.54	0.02
Oedipoda caerulescens	6.33±2.12^{a}	1.67±0.34^{b}	0.67±0.51^{b}	5.49	0.03
Chrysochraon dispa	2.67±0.77^{a}	1.33±0.17^{b}	0.33±0.13^{c}	6.57	0.02
Calliptamus italicus	3.67±1.88^{a}	3.00±0.99^{a}	1.00±0.76^{b}	5.11	0.034
Grillodes sigillatus	8.33±2.97^{a}	5.67±1.45^{b}	2.67±0.98^{c}	6.61	0.02
Gryllus bimaculatus	5.00±1.22^{a}	3.33±1.01^{a}	0.67±0.51^{b}	5.82	0.03
Acheta domesticus	7.00±2.81^{a}	5.33±1.39^{a}	2.00±0.91^{b}	5.71	0.03
Neocurtilla Hexadactyla	1.67±0.11^{a}	1.00±0.10^{a}	0.67±0.51^{a}	4.88	0.41
Philaenus spumarius	29.67±5.62^{a}	19.00±4.32^{b}	6.67±1.98^{c}	7.34	0.01
Nezara viridula	54.33±7.01^{a}	35.67±6.21^{b}	23.33±4.14^{c}	7.21	0.01
Pyrrhocoris apterus	84.33±9.34^{a}	42.00±6.71^{b}	12.67±3.36^{c}	8.15	0.013
Total	238.67±17.23^{a}	138.67±11.09^{b}	57.00±7.41^{b}	6.52	0.02

Values on the same line containing different letters are significantly different at $p<0.05$

3.5. Principal Component Analysis (PCA)

Principal component analysis (PCA) highlighted the correlations between the different trophic groups of insects collected in this study and the plant phenological stages (Figure 2). It revealed the presence of detritivores, predators and omnivores during the emergence and tillering phase. We therefore note a strong correlation between these different trophic groups and these phenological stages of plants. This PCA also showed a high abundance of defoliators, pollinators and sucking biters during the heading phase of the plant. There was therefore a strong correlation between the presence of these trophic groups and the heading phase of the plant.

4. Discussion

The sampling coverage rate was well above 95% showing that the collected samples were fairly representative. The lowest abundance of insect pests was recorded in the polycultures and mainly in the parallel polyculture. Indeed, the crop association disrupts the development cycle of several insect groups which are generally subservient to a single plant species. According to Kone *et al*. [10], the polycultures provide shelter insects dependent on each crop and their predators. Thus, the presence of an unusual plant for an insect could take it out of its natural habitat. Furthermore, although polyculture, in general, leads to a reduction of insect pests, the alternated polyculture has shown an even more considerable reduction of insect pests. The low abundance of insect pests in the alternated polyculture would be due to the proximity of maize and groundnut plots compared to the parallel polyculture. Bringing maize and groundnut plots closer together certainly creates less space for insect pests which prefer more airy environments. In a study carried out by Kone *et al.* [10], the higher abundance of insects in parallel polyculture could be explained by the presence of several predators and auxiliaries in this type of crop system. These results are also consistent with those of Corre-Hellou *et al.* [11] who assert that the crop association complicates the cover structure, increases botanical diversity and can thus induce both visual and olfactory confusion in certain pests. This complexity will alter their ability to find the host plant and therefore to develop in these mixtures. This result is also in agreement with that of Kone *et al.* [10] who assert that mixed farming reduces the number of certain pests by increasing the abundance of their natural enemies.

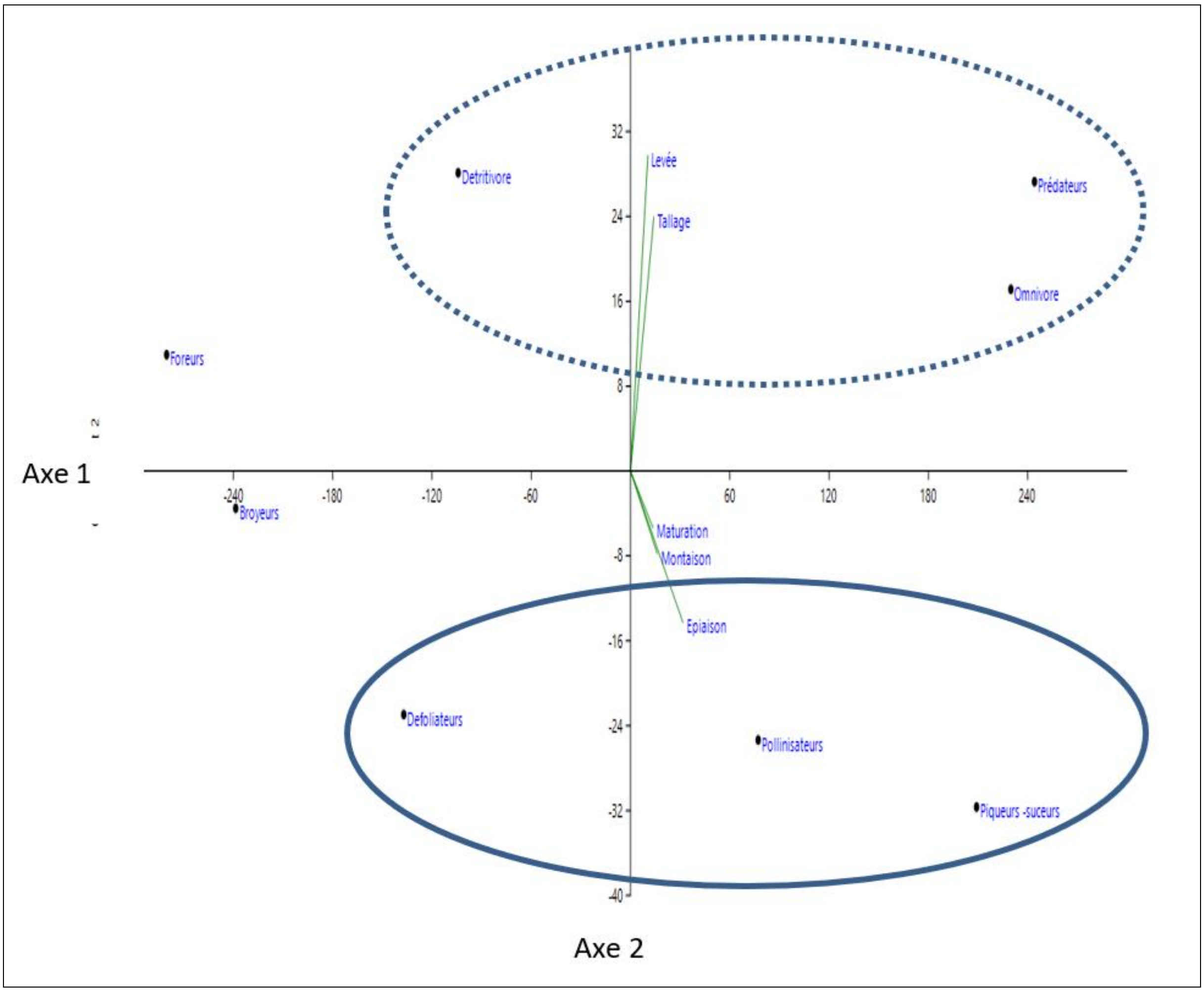

Fig 2: PCA of trophic groups according to the stages of plant evolution

Furthermore, the high abundance of insect pests in the monoculture could be explained by the lack of competition between insect pests unlike polyculture which shelters certain predators due to the environment diversity.

In this study, three species of insect pests were more abundant in the monoculture compared to the polycultures. These species (*Philaenus spumarius*; *Nezara viridula*; *Pyrrhocoriapterus*) belonging to the order Hemiptera are very invasive. They have a preference for monospecific crops, hence their strong presence in pure maize monoculture.

Monoculture was the most diverse crop system with the highest indices of diversity. This reveals the impact of polycultures on the diversity of insect pests. The results are consistent with that of Bianchi *et al.*, Chaplin-Kramer *et al.* [13] and Chaplin-Kramer and Kremen [14] cited by Kone *et al.* [10], who assert that the most diverse landscapes hold more of potential for the biodiversity conservation and the maintenance of the pest control function.

The specific composition of insects in the different plots did not differ significantly. The species found in the monoculture could be found easily in the polycultures even if the alternated polyculture recorded the fewer species. This similarity was verified through Jaccard index values. These results are in agreement with those of Sacchi *et al*. [15] and Salmela [16]. Indeed, they showed that the ecological factors which appear within the populations and which influence their demography have an influence on the distribution of different individuals. The insect groups with the same ecological requirements will group together in the same environment. However, the similarity between the polycultures and the monoculture could be explained by the presence of groundnut in the both systems.

The correlation between the different trophic groups of insects and the stages of plant evolution is highlighted by the Principal Component Analysis (PCA). This PCA showed a strong correlation between the presence of predators, omnivores and detritivores during the emergence and tillering phase. It also showed a strong correlation between the heading phase and the presence of biters, pollinators and defoliators. Indeed, during the emergence and tillering phase, the presence of detritivores and omnivores is due to the appearance of leaves because detritivores and omnivores feed on plants. The presence of omnivores and detritivores also attracts their predators, hence the observation of these different trophic groups at these evolutionary phases. According to Livory [17], the specie *Pamponorus germanicus* being a predator, feeds on the specie *Monomorium pharaonis* which is a scavenger; the specie *Neoitamus cyanurus* feeds also on the specie *Pyrrhocoris apterus* which is an omnivore. The trophic groups present at these stages therefore find elements necessary for their development.

The heading phase characterizes the phase of biological cycle during which the ear completes its extraction of the last leaves. The ear is the female organ of the maize plant. Simultaneously, with the development of female flowers (ear), we observe the appearance of silks (pollen receptors) [18]. It's during this period that pollination by species such as *Agraunus vanillae* and *Atalia rosae* takes place. The pollination observed at this stage of maize development explains the strong presence of pollinators. The defoliators such as Acrididae attack maize leaves which are more developed at this stage. Sucking biters feed on the sap of maize leaves by biting them. As an example of sucking biters, we have *Nezara viridula*, which develops by absorbing plant liquids by suction, in the leaf axils and on growing ears [19].

5. Conclusion
This study aimed to contribute to the knowledge and monitoring of pest communities in maize fields. It was carried out in two crop systems (monoculture and polyculture). It revealed that the monocultures are likely to maintain strong communities of insect pests compared to the polycultures. However, within a crop association, when maize and groundnut are grown alternately, the number of pests, drops considerably. The crop association thus presents itself as an alternative to fight against insect pests. This study is of great benefit to farmers and consumers because it could help reduce the use of pesticides in the fields. It will also help to protect and conserve the biodiversity of beneficial insects such as pollinators. It would be interesting to associate other crops and if possible, to extend the same study to other climatic zones while taking data from all seasons.

6. Author contributions
MK and DC designed the study. DC and WKS collected data in the field. MK and DC determined insect specimens and their traits. DC, FD and MK analyzed and plotted output data. MK and DC wrote the first draft of the manuscript. YT contributed to improve the draft. All authors contributed substantially to revisions.

7. Acknowledgments
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