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Evidence of the role of predatory ants in natural pest control in banana-sugarcane rotation systems

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In Guadeloupe (French West Indies), sugarcane banana rotation is an alternative to intensive monoculture and increases vegetation diversity. Based on agroecology principles, this paper describes the structuration of the arthropod community at different stages of crop rotation with particular focus on two key pests: the banana weevil *Cosmopolites sordidus* (Coleoptera: Curculionidae) and the pyralid moth of the genus *Diatraea* (Lepidoptera: Pyralidae), known as stemborers. The functional inventory of the potential antagonists of these insect pests was mainly focused on ants which were the majority group collected in the trapping systems. The sugarcane agrosystem is less susceptible to attacks by pests than the banana agrosystem. In the context of crop rotation, sugarcane tends to limit infestation by the banana weevil to the first year of banana cropping, whereas banana does not help protect the sugarcane crop. Key information on targeted predators and their abundance and role in different agrosystems are given.
Keywords: vegetation diversity, arthropod community, *Diatraea* spp., *Cosmopolites sordidus*, antagonists.

Importance de la prédation par les fourmis en rotation canne/banane. En Guadeloupe, l'introduction de la canne à sucre dans la monoculture de banane a contribué à une alternative aux agrosystèmes intensifs et favorise la diversité végétale. S'appuyant sur les principes de l'agroécologie, il a été étudié la structuration des groupes d'arthropodes à divers stades de la rotation culturale autour de deux bioagresseurs clés: le charançon du bananier *Cosmopolites sordidus* (Coleoptera: Curculionidae) et les pyrales de la canne à sucre du genre *Diatraea* (Lepidoptera: Pyralidae). L'inventaire fonctionnel des antagonistes potentiels de ces deux bioagresseurs établi au moyen de divers types de pièges se focalise dans cet article sur les fourmis qui occupent une part importante des captures. La canne à sucre est moins exposée aux attaques de la pyrale qui se situent en dessous du seuil de nuisibilité, alors que la bananeraie nécessite des traitements dès sa plantation. Dans le cadre de la rotation, la canne à sucre limite les infestations du charançon en première année de culture de la banane, alors que la banane ne favorise pas la protection de la canne. Ces résultats montrent qu'il est nécessaire d'approfondir les connaissances sur la prédation ciblée (pour les espèces à forte affinité avec la canne, dont le genre *Solenopsis*) dans un système banane-canne à sucre et les relations fonctionnelles entre les antagonistes identifiés.
Mots clés: diversité fonctionnelle, communauté d'arthropodes, *Diatraea* spp., *Cosmopolites sordidus*, antagonistes.

1. INTRODUCTION

Artificialization and biological simplification of intensive agrosystems such as monocultures could explain their vulnerability to pest infestation (Tilman *et al.*, 2002).

In Guadeloupe (French West Indies), banana is traditionally grown as a monocrop with high levels of inputs (fertilizers, insecticides) to improve yield. In addition to degrading the soil and causing progressive loss of soil biodiversity and chemical richness (Hulugalle *et al.*, 1997), monocropping increases pest pressure and hence the use of pesticides to control them (Ganry, 2004). Monocropping thus has a negative impact on the environment including pollution of soils and phreatic groundwater systems, persistence of insecticides, one example being the persistence of chlordecone in Guadeloupe after many years of chemical treatments.

Growing sugarcane in rotation with banana in the Capesterre-Belle Eau region in Guadeloupe, led to a more diversified ecosystem as recommended by agroecology principles (Bianchi *et al.,* 2006). Even though it is driven by economic considerations, this alternative to a monoculture has many advantages in terms of both agricultural practices (Risède, 2003) and environmental aspects (Ganry, 2004).

In the French West Indies, Jaffé *et al.* (1990) studied the predation of ants on the larvae of banana weevil *Diaprepes abbreviatus* L. Germar 1824 (Coleoptera: Curculionidae), but only in lime orchards. Sirjusinghi *et al.* (1992) published a global inventory of natural enemies (fungi, grubs, insects, vertebrates) of insect pests of sugarcane and banana in the West Indies.

These two crops are subject to high infestation by borer pests. The banana weevil *Cosmopolites sordidus,* which is also a Curculionid, is a major pest and causes serious damage to banana bulbs and pseudotrunks. If not controlled, this oligophagous pest can cause yields losses of up to 40 % (Ganry, 2004) and also reduce the plant life cycle. A detailed study of the biology and control strategies of this pest was made by Gold *et al.* (2001). The main insect pests of sugarcane in the West Indies are moth stemborers of the genus *Diatraea* (Lepidoptera: Pyralidae) including two species that are well known in South America, *Diatraea saccharalis* Fabricius (1794) and *Diatraea impersonatella* Walker (1863) present in Guadeloupe. Batches of eggs are laid on the top of sugarcane leaves and after hatching, the young larvae feed on green leaves for a week or so before penetrating the stalk to bore internodes and then leaving through an exit hole to pupate. Damage caused by borers leads to losses in terms of sugar yield and quality and cane biomass (Goebel & Way, 2009).

The banana-sugarcane rotation system has already been studied to compare the diversity of arthropod fauna at different growth periods of the rotation system (Caray, *in lit.*), the presence of fauna often being used as biological indicators (Duelli & Obrist, 1998; Missa *et al.,* 2008). Caray (unpublished data*)* showed that arthropod diversity in the rotation system is lower than that observed in sugarcane monoculture. Another study by Vercambre (unpublished data) showed that after a banana crop, young sugarcane fields were subject to increase the number of attacks during the first year followed by a decrease in pest infestation in the second year of cultivation. It was then hypothesized that the difference in infestation levels could be due to lack of predator diversity and thus of natural control. This is in line with the conclusions of Fuller & Reagan (1988), who pointed out that a reduction in predator abundance due to insecticide application in sugarcane and sorghum increased populations of moth borers and hence in the damage they cause.

The main aim of agricultural practices is not to favor biodiversity but to optimize it while increasing crop productivity. The aim of the present study was to identify and understand the functional component of the diversity of arthropod fauna and the role of predators in the natural control of two major pests *D. saccharalis* and *C. sordidus* in banana-sugarcane rotation systems. Particular attention was paid to the ant community (Formicidae), which is frequently used as a bioindicator of the level of diversity and environmental changes in the ecosystem, in comparison with other invertebrates (Lawton *et al.,* 1998; Underwood & Fisher, 2006). In fact the Formicid family is the most commonly cited family in publications on the topic due to its diversity and functional importance (Mc Geoch, 2007) but also to its abundance in the ecosystem and to its ubiquity (Abera-Kalibata *et al.,* 2007). Even though many studies mention the importance of these generalist predators in controlling pest populations (Symondson *et al.,* 2002) particularly in agrosystems (Negm & Hensley, 1969; Roche & Abreu, 1983; Way & Khoo, 1992; Rossi & Fowler, 2000 & 2004), there is a paucity of information on the agricultural importance and role of ants in Guadeloupe, and their ability to maintain pest damage under economic thresholds.

2. MATERIAL AND METHODS

2.1. Experimental plots

Five agrosystems ("plots") representing different sugarcane-banana rotation systems were studied in the Capesterre-Belle-Eau region (16°09'53N 61°28'02W), Guadeloupe:

- CC: "Continuous" sugarcane cropping (Control 1), single-crop farming;

- BB: "Continuous" banana cropping (Control 2), single-crop farming;
- CB1: First year of banana after sugarcane (plantation);
- CB3: Third year of banana after sugarcane (2nd ratoon);
- BC1: First year of sugarcane after banana (plantation).

Another plot, BC3, (third year of sugarcane after banana) could have been tested; however as this situation is rare in Guadeloupe, it was decided not to include it in the experiment. Each plot had three replicates (Table 1). Hereafter all arthropods identified as predators and parasitoids of the banana weevil borer and of the sugarcane stemborer are referred to as antagonists.

2.2. Trapping systems

A method was implemented using ground and flight interception traps (data obtained from the aerial traps are informative), according to Duelli *et al.* (1999) and taking into account the conclusions of Missa *et al.* (2008).

Traps used for data analysis

a/ Pitfall traps are open containers placed on the soil surface (can box type, height 157 mm, diameter 77 mm) in plastic cylindrical boxes for easy handling. The container is filled with a detergent solution (100 ml) to prevent insects from escaping and ensure their preservation. Each trap was removed at day 4 and day 7 to avoid additional water due to rainfall. Data were collated weekly and represent a sample unit. Pitfall traps are widely used to study insect fauna (Bestelmeyer *et al.*, 2000).

b/ Sticky traps catch individuals present in the agrosystems. "Pelton type" sticky mesh green bands (BANDF-9917, Scotts France SAS; width 14 cm, including 12 cm of glued surface) were placed in the field at a height of 80 to 120 cm from the ground and attached to the banana tree trunks and to three sugarcane stalks in the same stool, in order to compare samples.

c/ In addition, two other sticky traps were used in the plots but the data were not used for statistical analysis. These were sticky yellow traps (height 334 mm, Adolive SARL) and/or double sticky face blue traps (dimensions 23x10 cm, Profertyl). These traps were attached to two sugarcane stalks or banana trunks 180 cm from the ground with 2 mm diameter nylon strings. Each plot had 5 trap locations and 2 types of trap were used at each location. The spacing is shown in Figure 1.

Identification

Glue was removed from the trapped insects by immersing them in a petrol solution for 30 minutes. The insects were then preserved in vials filled with 70 % ethanol. Individuals bigger than 1 mm were identified under a microscope (x 50). Ants were identified using the Bolton classification (1994) and confirmed by a specialist in taxonomy of Formicidae.

Damage assessment in banana agrosystem

The assessment technique was adapted from Vilardebo (1973). Samples of 60 banana bulbs were randomly chosen and dug up to a depth of 1-2 cm using a shovel. To avoid compromising the following harvest, the bulb should only be sampled on three-quarters of its periphery due to the presence of the young shoot in the last quarter.

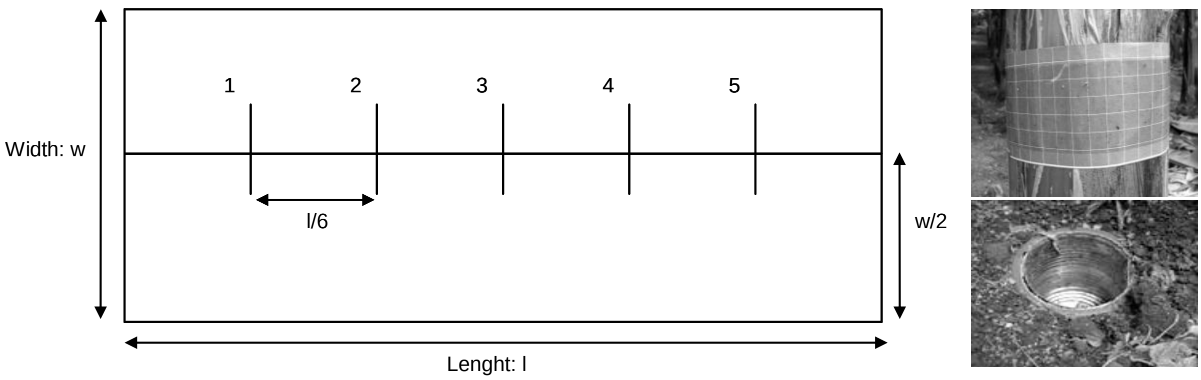

Figure 1: Location of a trap in a plot. The spacing between sites is one sixth of the length of the plot. On the right hand side a sticky trap (upper photo) and a pitfall trap (lower photo).

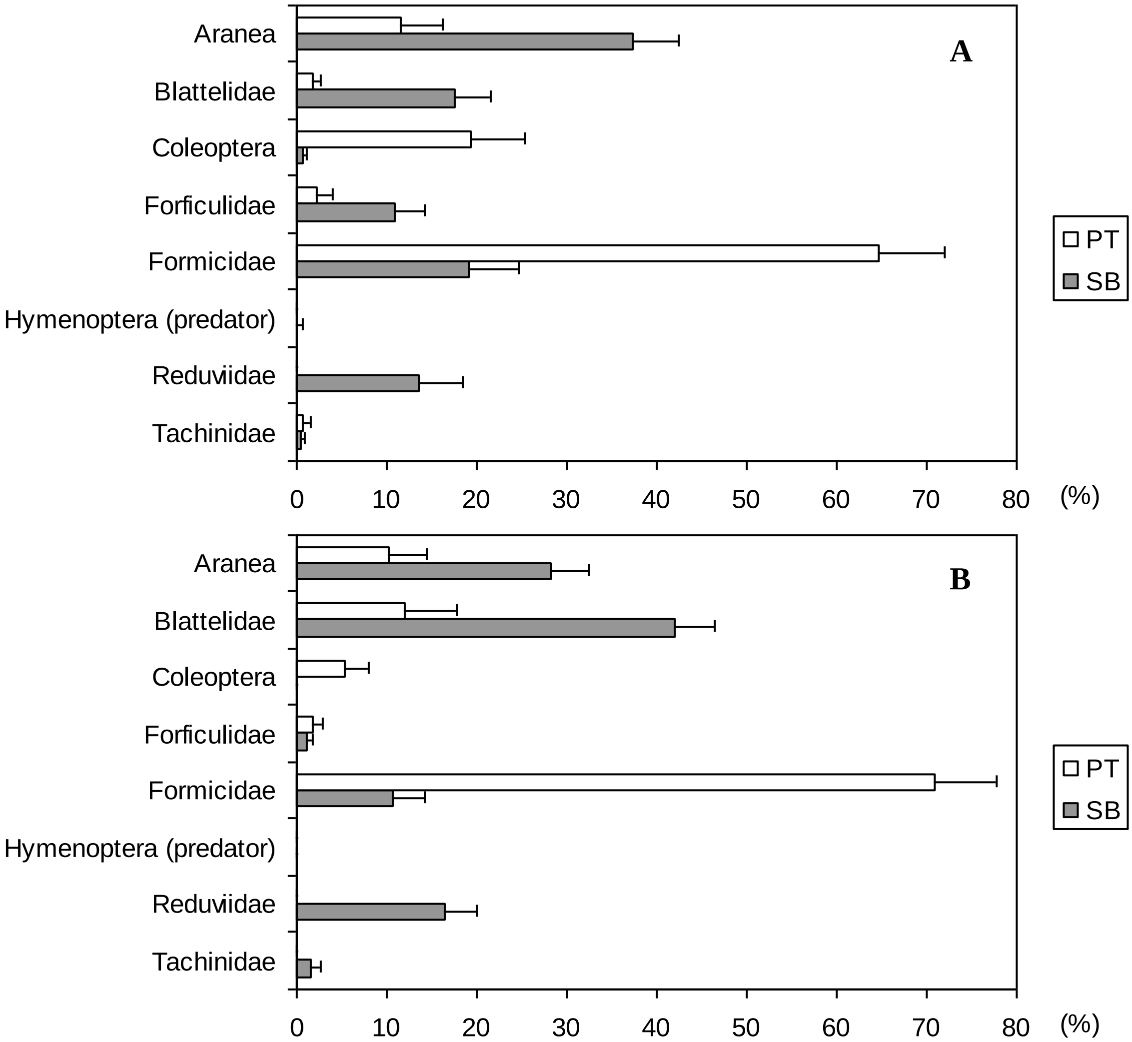

Figure 2: Importance of taxa (order and family) defined as antagonists with respect to all the antagonists trapped in the banana (A) and sugarcane (B) systems. Data for CB3 are not presented here but did not strongly affect the results for banana. For instance, respectively in SB and PT, ants represent 19.19 % (+/-5.38) and 64.58 % (+/-7.48) of all antagonists when CB3 data are excluded, and 21.90 % (+/-4.50) and 63.10 % (+/-6.67) when CB3 data are included. The standard error is included within the graph.
BB: "continuous" banana cropping (Control 2), single-crop farming; CB1: first year of banana after sugarcane (plantation); CB3: third year of banana after sugarcane (2^{nd} ratoon); CC: "continuous" sugarcane cropping (Control 1), single-crop farming; BC1: first year of sugarcane after banana (plantation); banana (BB and CB1); sugarcane (CC and BC1); PT: catches in pitfall traps; SB: catches in sticky traps.

The level of pest damage should be assessed soon after the harvest, as infestation by the weevil borer occurs on crop residues. The coefficient of infestation (CIb) shows the extent of damage to the banana stool (damage intensity index). The sum of the tunnels/boreholes found in the peripheral zone of the bulbs (from 0 to 100 %) shows the extent of damage in the study area: 5 (small boreholes), 20 (1/5 of the area infested), and then as the damage increases, 40, 60, 80, etc. According to Vilardebo (1973), different studies have shown that infestation levels above 10 % often lead to significant yield losses.

Sampling for damage was conducted from June 23, 2008 to August 4, 2008. Fewer samples were collected from plot CB1 than from the other plots because this plot was harvested earlier by the grower.

Damage assessment in the sugarcane agrosystem

The method used was the one described by Cochereau (1981). Each plot was divided into four sub-plots of equal size, and then two sampling sites were randomly selected in each sub-plot. From a selected location, 25 consecutive stalks in the field (200 stalks per plot) were sampled and inspected for borer damage. Stalks were carefully checked for the presence of holes and damaged and undamaged internodes were counted starting from the bottom of the stalk.

All bored internodes were sliced with a knife and the damage intensity was rated on the basis of the size (length) of internal tunnels in the whole internode. A coefficient of infestation in sugarcane (CIc) is also used starting from 0 (no infestation) to 5 (serious internal damage with presence of external side shooting resulting from plant stress).

Field identification of the pest was based on the larvae and pupae collected. All samples were kept in the laboratory to check for parasitism. Similarly, all stages of parasitoids found were collected and kept for further identification.
The level of pest damage to the two crops was determined not only on the basis of the percentage of infested plants (or stalks) but also on the intensity of infestation given by two indices CIb and CIc. Damage and pest sampling was conducted from June 9 to June 19, 2008, and a total of 1 200 stalks (20 622 internodes) were inspected.

Statistical analysis of data

The samples from each week were combined to obtain a pooled sample of fauna per trap for each sampling site. Due to the high variability of data collected, comparisons based on the fauna diversity between plots focused on the relative abundance (proportion) of taxa/individuals out of the whole catches. Instead of using statistical analysis comparing means, the Khi² test appeared to be the most relevant for this study whose aim was to highlight structural differences in the composition of the arthropod community.
For each plot/agrosystem, all damage assessment data were considered as non-parametric and were therefore subjected to non-parametric methods. The Kruskall-Wallis test was used to compare numbers while testing for the presence of a plot/treatment effect (= agrosystem). Independent means were also compared using the Wilcoxon Mann-Whitney test to test the extent of damage in relation with the agrosystem. A Khi² test was used to compare qualitative data such as whether the plant was damaged or not.

3. RESULTS

No significant differences in monthly means of meteorological data were observed between the plots during the study period.

Global diversity and diversity within the antagonist community

All sugarcane plots were surveyed at the end of the crop cycle. Trap catches collected between June 10 and July 17, 2008 totaled 5 229 arthropods, representing 12 orders and 35 families (Table 2).
The following analyses focused on the comparison of the two crops to characterize three situations: sugarcane (CC and BC1); banana (BB and CB1); and CB3.

Importance of the trapping system

The classification of the individuals according to their functional activity in the agrosystem was adapted from different studies targeting arthropod families found to be generalist and/or specific predators of weevil borer and stem borer. Regarding global diversity, 21 families representing 1 675 individuals were considered active in the control of these pests (Table 2).
The number of families (15) and the structure of the antagonist community were very similar in the two agrosystems. If plots CB3 are included, two new families, Ichneumonidae and Tenebrionidae, were added to the taxonomic richness previously observed in the banana agrosystem.

Both crops showed similar results in terms of insect catches due to the trap efficiency. The Formicidae family was strongly represented in pitfall trap catches (65 to 71 % depending on the agrosystem) while the sticky band traps caught a wider taxonomical range which was also more balanced in the number of catches. On the soil surface, the Coleoptera order was more frequently found in the banana than in sugarcane agrosystem, while the number of blattoptera (Blattaria) was higher in sugarcane. Forficula insects considered as predators were more frequently found in sticky traps in banana than in sugarcane as opposed to tachinid flies. The proportion of ants collected in sticky traps was higher in banana than in

sugarcane (p=0.034, Khi²=4.50), and results from CB3 confirmed this difference p<0.0001, Khi²=17.72). The difference was not significant on the surface of the soil (p=0.32, Khi²=0.98).
Figure 2 shows the taxonomic distribution of the antagonists (orders and/or families) that had an impact on the pest population for each trap and each agrosystem.

Given their predominance in the traps, Formicidae were the subject of more detailed determination. Generalist in their predatory activities, these ants are abundant and ubiquistic whatever the disturbance level of the habitat surveyed. They have been particularly well studied in tropical environments, including agricultural habitats (Way & Khoo, 1992; Power, 1996).

The proportion of ants in the antagonist community varied depending on the agrosystem and the trap considered (Figure 3). On the soil surface (pitfall traps) ants were dominant, particularly in sugarcane. On the plants themselves (sticky traps) their number was lower.
Comparisons within the same crop showed that the proportion of ants differed significantly only on sticky bands between BB-CB1 (p=0.0008, Khi²=11.09) and CC-BC1 (p=0.0014, Khi²=10.23). The same comparisons were not significant on the soil surface. Other analyses between plots revealed differences between CC and BB both on the soil surface (p=0.033, Khi²=4.57) and in the vegetation (p=0.015, Khi²=5.95). In the banana crop, the proportion of ants in traps in CB3 differed significantly from that in BB both in pitfall traps (p=0.046, Khi²=3.98) and sticky traps (p<0.0001, Khi²=18.48).

Species inventory

The inventory of the 855 individuals collected (Table 3), which were distributed in four sub-families, 15 geniuses and 19 species, provided information on the distribution per plot (31.9 % in CC, 9.8 % in BC1, 9.2 % in BB, 21.0 % in CB1 and 28.1 % in CB3). Catches were biggest in the pitfall traps (80.9 %) and these also had the highest species richness (six more species than in the sticky traps). Most of the species were particularly mobile and were caught in different types of traps. Species *Azteca sp.* (Dolichoderinae) and *Pheidole sp1* (Myrmicinae) were only represented by reproductive (presence of wings) individuals which were not counted in this study.

In Guadeloupe, 59 species distributed in five sub-families species have already been described (Jaffé & Lattke, 1994). Our inventory added eight

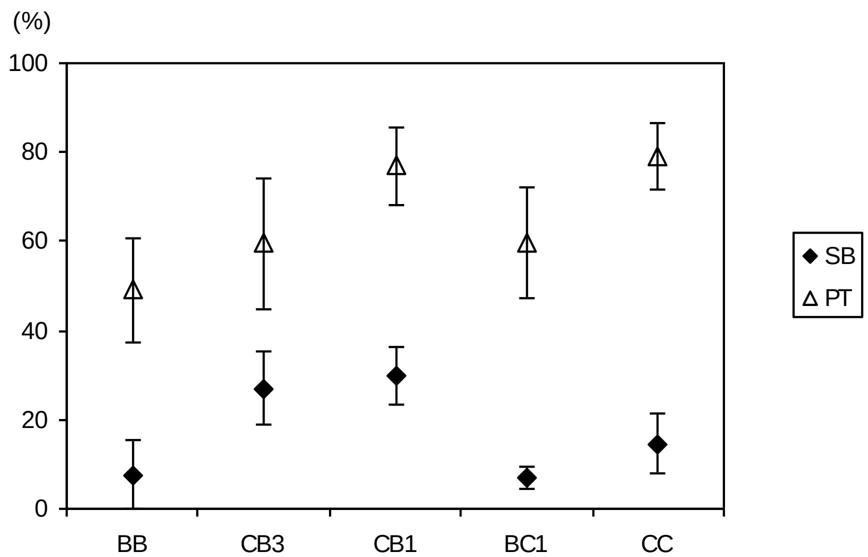

Figure 3: Average proportion of ants per trapping system and agrosystem among all the arthropods trapped. The standard error is included within the graph.
BB: "continuous" banana cropping (Control 2), single-crop farming; CB1: first year of banana after sugarcane (plantation); CB3: third year of banana after sugarcane (2nd ratoon); CC: "continuous" sugarcane cropping (Control 1), single-crop farming; BC1: first year of sugarcane after banana (plantation); PT: catches in pitfall traps; SB: catches in sticky traps.

new species to the previous lists: *Nylanderia pubens* (Plate 1), *Monomorium ebeninum* (Plate 2), *Solenopsis invicta* (Plate 2), *Pheidole vallifica* (Plate 1), *Cardiocondyla minutior*, *Cardiocondyla obscurior* (photo of the genus *Cardiocondyla*, Plate 3), *Hypoponera opaciceps*, *Odontomachus brunneus* (Plate 1).
The genus and species richness was higher in the sugarcane agrosystem than in banana including plots CB3. Only five species (*S. invicta*, *S. geminata* (Plate 1), *M. ebeninum*, *P. vallifica*, *T. bicarinatum*) were found in both agrosystems including *N. pubens* observed in the additional traps placed in banana (CB3 plots).

The sub-family Myrmicinae was most abundant and represented 76 % of the trap catches. The composition of the arthropod community differed in the two crops. Myrmicinae were more abundant in banana (100 % of the captures, and 95.6 % in CB3) than in sugarcane (45.5 %), which hosted Ponerinae and Dolichorinae families. Similarly, the genus *Tetramorium* represented 39.2 % and was particularly abundant in banana at 55.8 % of the catches (75.9 % in CB3) in comparison with sugarcane (2.4 %). At the species level, *N. pubens* was the most frequent species found in sugarcane (28.2 %) followed by *E. ruidum* (16.3 %, Plate 3). In banana, two ant species *T. bicarinatum* (49.1 %) and *M. ebeninum* (22.8 %) were very abundant in CB3 plots (respectively 69.5 % and 8.0 %). Although the species richness remained stable in banana (5-6 species), the structure of the ant community differed between the different plots.

Delabie *et al.* (2000) proposed an original method to group species: the notion of insect guilds that organizes taxons based on their role and biological preferences in the ecosystem. For example, guilds 1, 3, 7 and 8 (Delabie *et al.*, 2000) are represented in our study. By grouping the generalist predators, true omnivores and omnivorous arboreal nesting dominants, guilds 7 and 8 include individuals that prospect on soil, litter and plant debris for feeding. At least 87.8 % of the individuals identified belonged to these guilds and species such as *P. pubens*, *M. ebeninum* and *T. bicarinatum* totaled 71.7 %. Guilds 7 and 8 tended to be more widely represented in the sugarcane agrosystem (87.5 %) than in banana (83.9 % of all ants, and 92.4 % in CB3).

Damage assessment in the banana agrosystem

Data on *C. sordidus* infestation are listed in Table 4. Damage levels differed significantly between the experimental plots in terms of the number of plants infested by the pest (df: 2, Khi^2=91.69, p<0.0001) as well as the intensity of damage (df: 2, H=67.02, p<0.0001). In this sense, the comparisons 2x2 of plots BB-CB3 (Khi^2=25.47), BB-CB1 (90.71) and CB3-CB1 (38.12) were all significant (df: 1, p<0.0001) in terms of the percentage of infested plants. The least damaged plots (in terms of the intensity of the infestation) were CB1 in comparison with plots BB and CB3 (p<0.0001 in the 2 cases) while plot BB tended to differ from plot CB3 (p=0.058).

Damage assessment in the sugarcane agrosystem

Results are summarized in Table 5. The damage threshold was defined as 5 % of bored internodes. Despite a higher infestation of the plot (BC1), the level of infestation remained below this threshold. This result is not in agreement with previous work in the same region (in 2005) when BC1 plots had more than 5 % bored internodes while other CC plots had damage levels of between 0.1 and 1.3 %.

The percentage of stalk damage differed significantly between both sugarcane agrosystems (df: 23, Khi^2=147.5, p<0.0001), whereas the percentage of bored internodes (df: 23, Khi^2= 18.13, p=0.75) and the intensity of the infestation CIc (z=-1.89, p=0.058) did not.
Both pest species were well established in the sugarcane single-crop system whereas *D. saccharalis* appeared to be predominant in the first year of sugarcane after banana.

4. DISCUSSION

The work presented here provides new key information on the importance of ant diversity in community of antagonists present in the banana-sugarcane rotation system. The study of arthropods (Duelli & Obrist 1998) using different trapping systems (Missa *et al.*, 2008) is a common method to identify the arthropod diversity of agronomic interest, i.e. plays a functional role in insect control. Referring to the criteria listed by Missa *et al.* (2008) (cost, maintenance and easy setup, low impact on populations, etc.), the combination of pitfall traps and sticky traps was particularly suitable for our study that focused on individuals moving in and around the plant, and that were assumed to be involved in the predation or parasitism of the targeted pest. The use of non-selective traps also allowed us to unravel the taxonomic diversity in the different agrosystems, species richness, and the presence of rare species in comparison with other trapping systems such as lure traps (Abera-Kalibata, 2007; Souza *et al.*, 2010). The functional activity of the samples of insect collected, provided useful information on the composition of antagonist species which was more diversified in the vegetation than on the surface of the soil, and this was valid for both crops. For example, the catches revealed the importance of Formicidae.

These findings are in agreement with the results obtained by Underwood & Fisher (2006), who collected ants using different sampling methods and identified them as key factors for conservation purposes. In this regard, the taxonomy of ants is actually well advanced compared to other invertebrate groups (Matlock & Cruz, 2003).

Even if statistical analyses were not always significant, many trends were highlighted in this study. On the soil surface, ants tend to be predominant when sugarcane is grown for several consecutive years (situations CC and CB1), as opposed to banana where their presence is lower, this result being similar to that observed when a new sugarcane plantation is established after banana (BC1). Known for its major role in different habitats (dominance and ecological abundance, eusocial behavior and diversified food regime) and its use in pest control programs (Hölldobler & Wilson, 1990; Way & Khoo, 1992), the Formicidae family is cited as efficient natural predators of weevil borers and pyralid moth borers. Our results underlined their affinity for the crop and their susceptibility to disturbances caused by crop rotation systems.

Many authors have pointed to the efficacy of ants in the suppression of *C. sordidus* (Gold *et al.*, 2001; Abera-Kalibata *et al.*, 2007) and stalk borers such as *D. saccharalis* and *C. sacchariphagus*, particularly at the egg stage and first instar larva (Negm & Hensley, 1972; Adams *et al.*, 1981; Ali & Reagan, 1985; Goebel, 1999; Rossi & Fowler, 2000).

For example, *S. invicta*, which are considered to be extremely voracious (Eubanks *et al.*, 2002), have been shown to play a major role in the control of borer populations, particularly in the USA (Negm & Hensley, 1969; Ali & Reagan, 1985). The species feeds on *D. saccharalis* eggs and larvae (Adams *et al.*, 1981; Rossi & Fowler, 2000; Rossi & Fowler, 2004). In Guadeloupe, unlike the above mentioned results, *S. invicta* is not the predominant species in the sugarcane agrosystem. In this region, the species *W. auropunctata* (Plate 2) is cited as a potential natural enemy of *C. sordidus* while *E. ruidum* and *O. brunneus* have been identified as active predators of eggs and larvae of the sugarcane weevil borer *D. abbreviatus* (Sirjusinghi *et al.*, 1992).

In our study, damage assessment revealed different levels of infestation. In the sugarcane fields surveyed, damage was below the economic injury level of 5 % internodes bored, indicating effective control of the sugarcane borer by its natural enemies, which was not the case for the banana weevil borer. Already shown in the first and second sugarcane ratoons (White,1980), this natural control intensifies when the sugarcane is grown for several consecutive years after banana, while the opposite effect is observed in the banana agrosystem. In the light of these observations, we can conclude that sugarcane is not favored by succeeding banana in the rotation system; the first year of sugarcane after banana (BC1) led to highest infestation levels compared to CC plots. Conversely, the banana crop appears to benefit from succeeding sugarcane, as is the case for nematodes (Risède, 2003) at least in the first year, as from the third year on, this benefit appears to decrease. Many observations suggest a major role of ants in pest regulation: abundance in the antagonist community at the ground level, mobility in and around the plants, the preference of Ponerinae and Dolichoderinae for sugarcane, observation of predation activities of the ant *S. invicta* and their presence in the boreholes caused by stemborers (Sirjusinghi *et al.*, 1992; Rossi & Fowler, 2004).

These results will be confirmed by further experiments, particularly on the role and importance of ants and other predators such as the spiders in the control of populations of major pests. Other aspects such as intra and interspecific interactions (Sirjusinghi *et al.*, 1992; Wing, 1983; Gillespie & Reimer, 1993) require additional investigation as does the agronomic interest of *S. invicta*, which has sometimes been cited as an agricultural pest even though its action has led to pesticide reduction (Long *et al.*, 1987; Way & Khoo, 1992; Eubanks, 2001; Eubanks, 2002; Symondson *et al.*, 2002).

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Plates and tables

Plate 1: (from top to bottom)**:** *Odontomachus bruneus* (Patton 1894) (Ponerinae): full-face and profile - *Nylanderia pubens* (Forel 1893) (Formicinae): full-face and profile - *Pheidole villifica* (Formicinae): full-face and profile - *Solenopsis geminata* (Fabricius 1804) (Myrmicinae): full-face and profile (scale: full-face 0.25 mm; profile 1 mm).

Plate 2: (from top to bottom)**:** *Solenopsis invicta* (Buren 1972) (Myrmicinae): full-face and profile - *Monomorium ebeninum* (Forel 1891) (Myrmicinae): full-face and profile - *Wasmannia auropunctata* (Roger 1863) (Myrmicinae): full-face and profile - (scale: full-face 0.25 mm; profile: 1 mm).

Plate 3: (from top to bottom)**:** *Camponotus sexguttatu* (Fabricius 1793) (Formicinae): full-face and profile - *Cardiocondyla* sp (Myrmicinae): full-face and profile - *Cyphomyrmex* sp (Myrmicinae): full-face and profile - *Ectatomma ruidum* (Roger 1860) (Ectatomminae): full-face and profile (scale: full-face 0.25 mm; profile 1 mm).

Table 1: Attributes of selected agrosystems

Agrosystems (plots)	Name of field (replicates)	Area (ha)	Crop variety	Planting date	Geographical coordinates	Average altitude (m)
BC1	Dinde5	1.77	B 69566	3.x.2007	16°00’59N 61°35’06W	47
BC1	Cressonniere3	1.63	B 69566	3.x.2007	16°01’12N 61°35’09W	64
BC1	Case à Nègre	1.21	B 69566	3.x.2007	16°01’25N 61°35’16W	86
CB3	Riz1	1.66	ZELIG + GAL	26.v.2005	16°01’25N 61°35’28W	95
CB3	Marquise1	1.26	GAL + JAFFA	23.vi.2005	16°01’39N 61°35’47W	139
CB3	Marquise2	1.26	JAFFA	23. vi .2005	16°01’36N 61°35’49W	138
BB	Gaegaba2	1.68	Traditional	14.x.1999	16°01’41N 61°35’08W	98
BB	Digue	3.08	Traditional	1.iii.2002	16°01’37N 61°35’27W	108
BB	Monbin3	1.91	MA 13 + GAL	25. vi .2004	16°01’37N 61°35’39W	126
CB1	Helise2	1.18	MA 13	14. vi .2007	16°01’08N 61°35’21W	68
CB1	Helise3	1.30	MA 13	1. vi .2007	16°01’13N 61°35’25W	78
CB1	Helise4	0.87	MA 13	1. vi .2007	16°01’14N 61°35’23W	74
CC	Solanne1	3.34	B 69566	2001	16°05’06N 61°34’12W	57
CC	Solanne2	2.56	B 69566	2001	16°05’11N 61°34’11W	58
CC	Anonyme	3.56	B 69566	2000	16°05’07N 61°33’59W	43

BB: "continuous" banana cropping (Control 2), single-crop farming; CB1: first year of banana after sugarcane (plantation); CB3: third year of banana after sugarcane (2nd ratoon); CC: "continuous" sugarcane cropping (Control 1), single-crop farming; BC1: first year of sugarcane after banana (plantation).

Table 2: Distribution of arthropods sampled in the banana-sugarcane rotation system according to order and family

Order	Family	BB	CB3	CB1	BC1	CC	Banana	Sugarcane	Pests targeted
Blattaria*	Blattellidae* Karny 1908	x	x	x	x	x	x	x	Sugarcane pest in Reunion Island (Goebel 1999)
Dermaptera*	Forficulidae* Stephens 1829	x	x	x	x	x	x	x	*C. sordidus* (Gold *et al.*, 2001) and the sugarcane borer in Reunion Island (Goebel, 1999)
Neuroptera	Chrysopidae Schneider 1851	o	o	o	x		o	x	
Diptera*	Tachinidae*	o		x	x	x	x	x	Three species introduced in the French West Indies between 1938 and 1954 (Astabie *in lit.*) to compete against the genus *Diatraea*: *Metagonistylum minense* Townsend 1927, *Lixophaga diatraeae* Townsend 1916 and *Paratheresia claripalpis* van der Wulp.
	Conopidae	x	x				x		
	Culicidae Meigen 1818			x	x		x	x	
	Syrphidae		o						
Araneae*	Lycosidae* Sundevall 1833	x	x	x	o		x	o	
	Tetragnathidae* Menge 1866	x	x		x	x	x	x	
	Anyphaenidae* Bertkau 1878	x	x	x	x	x	x	x	
	Linyphiidae* Blackwall 1859	x	x	x	x	o	x	x	Control of plant-eating insects and major actor in agrosystems (Cocquempot & Chambon, 1989), notably in sugarcane (Negm & Hensley, 1969). Omnivorous, they are mentioned as predators of the genus *Diatraea* (Negm & Hensley, 1972).
	Theridiidae* Sundevall 1833	o	x	x	x	x	x	x	
	Salticidae* Blackwall 1841	x	x	x	x	x	x	x	
	Oonopidae* Simon 1890		o		x	o		x	
	Araneidae* Clerck 1757				o	o		o	
Hymenoptera*	Formicidae* Latreille 1809	x	x	x	x	x	x	x	More explanations below.
	Sphecidae* Latreille 1802	o					o		Carnivorous larva feed on paralyzed insects carried to the nest by adults (Roth, 1968).
	Halictidae Thomson 1869	o	o	x			x		
	Ichneumonidae* Latreille 1802		x		o			o	Attacks mainly targeted on true and false caterpillars as well as on Lepidoptera chrysalis (Roth, 1968).
	Apidae Latreille 1802			o	o		o	o	
	Vespidae* Latreille 1802					o		o	Feed on chewed larva (Roth, 1968).
	Scoliidae Latreille 1802			o			o		
Coleoptera*	Carabidae* Latreille 1802	x	x	x	x	x	x	x	Natural enemy of *C. sordidus* (Gold *et al.*, 2001) and *D. saccharalis* (Negm & Hensley, 1972)
	Anobiidae Fleming 1821	o	o	o	o		o	o	
	Bostrichidae Latreille 1804	o	o				o		
	Elateridae Leach 1815	o	o				o		
	Scolytinae (Ipsidae) Latreille 1804	o	x	x	o	o	x	o	
	Scarabeidae* Latreille 1802	x	x	x	x	x	x	x	*C. sordidus* (Gold *et al.*, 2001).

Order	Family	BB	CB3	CB1	BC1	CC	Banana	Sugarcane	Pests targeted
	Coccinellidae Latreille 1807	o	x	o	x	x	o	x	
	Curculionidae* Latreille 1802	x	x	x	o	x	x	x	*C. sordidus* (Gold *et al.*, 2001)
	Nitidulidae Latreille 1802			o			o		
	Phytophagonidae	x	x	x	x	x	x	x	
	Staphylinidae* Latreille 1802	x	x	x	o		x	o	*C. sordidus* (Gold *et al.*, 2001)
	Tenebrionidae* Latreille 1802		x		x	x		x	*C. sordidus* (Gold *et al.*, 2001)
Hemiptera*	Cercopidae Leach 1815					x		x	
	Cicadellidae Latreille 1802	o			o	x	o	x	
	Coreidae Leach 1815	x	x	x	o		x	o	
	Pentatomidae Leach 1815	x	x	x		x	x	x	
	Reduviidae* Latreille 1807	x	x	x	x	x	x	x	Natural enemy of *C. sordidus* (Sirjusinghi *et al.*, 1992; Gold *et al.*, 2001).
Isoptera	Termitidae Sands 1972	o	x	x	x		x	x	
Lepidoptera	Undefined	x	x	o		x	x	x	
Orthoptera	Caelifera Ander 1936	x	x	x	x	x	x	x	
	Gryllidae Bolivar 1878	x	x	x	x	x	x	x	
	Tettigoniidae Krauss 1902				x			x	
Iulida	Iulidae Leach 1814	x	x	x	x	x	x	x	
	Undefined Sp 1	x	x	x	x	x	x	x	
Total Order/Family	**12/36**	**10/22**	**11/28**	**10/25**	**11/24**	**10/23**	**11/28**	**12/29**	

*****: families described in the literature as predators of one or both pests; x: informs on catches in pitfall traps (PT) and sticky traps (SB); o: species caught by a trapping system not used in this study.
BB: "continuous" banana cropping (Control 2), single-crop farming; CB1: first year of banana after sugarcane (plantation); CB3: third year of banana after sugarcane (2nd ratoon); CC: "continuous" sugarcane cropping (Control 1), single-crop farming; BC1: first year of sugarcane after banana (plantation); banana (BB and CB1); sugarcane (CC and BC1).

Table 3: Distribution of ants as a function of the agrosystem and crop, and their diet.

Species	Proportion (%)	BB	CB3	CB1	BC1	CC	Banana	Sugarcane	Trapping system	Foraging characteristics	Involvement of the genus in pest control
Formicinae	**13**										
Nylanderia pubens Forel 1893	12.4	o	x		x	x		x	+PT / SB	Omnivore	This genius was originally named Paratrechina. An undefined species is attracted by *C. sordidus* larvae (Abera-Kalibata *et al.* 2007).
Camponotus sexguttatus Fabricius 1793	0.6		x						+PT / SB	Omnivore	Cited in the larval stage predation of the sugarcane weevil *Diaprepes abbreviatus* Linnaeus (1758) (Sirjusinghi *et al.* 1992)
Myrmicinae	**76.1**										
Solenopsis geminata Fabricius 1804	5.8	x	x		x	x	x	x	PT	Omnivore or graminivore	Potentially involved in the control of *C. sordidus* in Guadeloupe (Sirjusinghi *et al.* 1992) and *D. saccharalis* (Fowler *et al.* 1991)
Solenopsis invicta Buren 1972	3.4	x		x	x	x	x	x	+PT / SB		
Brachymyrmex sp.	0.1					x		x	PT	Omnivore (nectarivore)	*B. obscurior* is mentioned as a predator of *D. abbreviatus* (Sirjusinghi *et al.* 1992)
Cyphomyrmex sp.	0.8				x	x		x	+PT / SB		
Monomorium ebeninum Forel 1891	15.1	x	x	x	x	x	x	x	+PT / SB	Omnivore	
Wasmannia auropunctata Roger 1863	2.7				x	x		x	+PT / SB	Omnivore and nectarivore	Potential natural enemy of *C. sordidus* (Sirjusinghi *et al.* 1992)
Pheidole vallifica Forel 1901	7.7	x	x	x	x	x	x	x	+PT / SB	Omnivore (maybe few graminivorous species)	Many species known as natural enemies of *C. sordidus* (Sirjusinghi *et al.* 1992; Abera-Kalibata *et al.* 2007) and *D. saccharalis* (Adams *et al.* 1981, Rossi & Fowler 2004), or of the African sugarcane borer *Eldana saccharina* Walker in Africa (Girling 1978) and *Chilo sacchariphagus* Bojer in Reunion Island (Goebel 1999).
Pheidole sp1	-	o		x			x		PT / SB		
Tetramorium undefined	3.8		x						+PT / SB	Omnivore (nectarivore)	Predator of *C. sordidus* in Cuba (Roche & Abreu 1983) and in South America, *de D. abbreviatus* in Florida (Sirjusinghi *et al.* 1992) and also of *E. saccharina*'s eggs (Girling 1978).
Tetramorium bicarinatum Nylander 1846	35.4	x	x	x		x	x	x	+PT / SB		
Cardiocondyla minutior Forel,	0.7	x	x				x		PT	Omnivore rather	Predation of larvae and eggs of *D.*

Species	Proportion (%)	BB	CB3	CB1	BC1	CC	Banana	Sugarcane	Trapping system	Foraging characteristics	Involvement of the genus in pest control
1899										than nectarivore	*abbreviatus* in Porto Rico (Sirjusinghi *et al.* 1992).
Cardiocondyla obscurior Wheeler, 1929	0.6		x		x			x	PT		
Ponerinae	**8.7**										
Ectatomma ruidum Roger, 1860	6,8				x	x		x	+PT / SB	Generalist predator	This genus preys on arthropod eggs (Hölldobler & Wilson 1990) including eggs and larvae of *D. abbreviatus* (Sirjusinghi *et al.* 1992), and potentially *D. saccharalis* (Rossi & Fowler 2004).
Odontomachus brunneus Patton, 1894	1.7					x		x	PT	Generalist predator	The species *O. troglodytes* is a predator of *C. sordidus* eggs (Abera-Kalibata 2007) and *D. abbreviatus* larvae (Sirjusinghi *et al.* 1992)
Hypoponera opaciceps Mayr, 1887	0.2					x		x	PT	Generalist predator (mainly of micro-arthropods)	If a closed genus called *Plectroctena* Smith (1858) is described as an egg-parasite, the carnivorous genus *Hypoponera* seems to prefer springtails (Collembola) (Hölldobler & Wilson 1990).
Dolichoderinae	**2.2**										
Tapinoma melanocephalum Fabricius, 1793	2.2					x		x	SB	Nectarivore	Genus described as predator of *D. abbreviatus* (Sirjusinghi *et al.* 1992; Abera-Kalibata *et al.* 2006).
Azteca sp	-		x	x		x	x	x	+PT / SB	Omnivore	Predator of weevils *C. sordidus* in banana and *D. abbreviatus* in sugarcane (Sirjusinghi *et al.* 1992)
Total (sub family/genus/species)	4/14/17	1/5/6	2/7/9	1/4/4	3/8/9	4/12/13	1/5/6	4/13/14			

+: indicates the trap with the highest number of catches for the species; x: informs on catches in pitfall traps (PT) and sticky traps (SB); o: species caught by a trapping system not used in this study. The above statistics do not include flying individuals (*Azteca sp* and *Pheidole sp1*) or individuals caught by other trapping systems than pitfall traps and sticky traps. Statistics on the 'banana' agrosystem do not include data collected in the plot CB3. BB: "continuous" banana cropping (Control 2), single-crop farming; CB1: first year of banana after sugarcane (plantation); CB3: third year of banana after sugarcane (2nd ratoon); CC: "continuous" sugarcane cropping (Control 1), single-crop farming; BC1: first year of sugarcane after banana (plantation); banana (BB and CB1); sugarcane (CC and BC1).

Table 4: Summary of damage to banana agrosystem

Name of field (replicates)	Number of bulbs sampled	Damaged plants (%)	CIb	
			M	*S-E*
Gaegaba2	60	83	17.25	2.27
Digue	60	88	24.33	3.01
Monbin3	60	58	9.00	1.50
Total BB	***180***	***76.7***	***16.86***	***1.42***
Riz1	60	25	2.42	0.68
Marquise1	60	58	15.08	2.85
Marquise2	60	70	21.58	3.49
Total CB3	***180***	***51.1***	***13.03***	***1.62***
Helise2	22	0	0	
Helise3	15	0	0	
Helise4	16	13	1.56	1.09
Total CB1	***53***	***3.8***	***0.47***	***0.34***

CIb: coefficient of Infestation assessed in banana crop; M: mean; S-E: standard-error.
BB: "continuous" banana cropping (Control 2), single-crop farming; CB1: first year of banana after sugarcane (plantation); CB3: third year of banana after sugarcane (2nd ratoon).

Table 5: Main characteristics of damage and pest distribution in the sugarcane agrosystem.

Name of field (replicates)	Damaged plants (%)		Number of internodes		Damaged internodes (%)		CIc		*Diatraea* (%)	
	M	*S-E*	*M*	*S-E*	*M*	*S-E*	*M*	*S-E*	*D. s.*	*D. i*
Dinde5	13	3.68	338	7.38	1.87	0.59	0.027	0.01	83.3	16.7
Cressonniere3	15.5	1.92	351	7.10	1.8	0.27	0.026	0.006	50	50
Case à Nègre	45	5.79	375	5.78	6.8	1.37	0.113	0.024	91.7	8.3
Total BC1	***24.5***	***3.78***	***355***	***4.93***	***3.48***	***0.69***	***0.055***	***0.012***	***85***	***15***
Anonyme	22	4.66	549	5.29	1.32	0.29	0.021	0.005	100	0
Solanne 1	30	3.70	563	7.46	2.1	0.21	0.027	0.003	60	40
Solanne 2	18	3.93	401	24.09	1,6	0.33	0.027	0.005	50	50
Total CC	***23.3***	***2.49***	***504***	***17.40***	***1.67***	***0.17***	***0.025***	***0.002***	***58.3***	***41.7***

CIc: Rating of infestation in sugarcane; M: mean; *S-E*: standard error; D.s.: *Diatraea sacharralis*; D.i.: *Diatraea impersonatella*. CC: "continuous" sugarcane cropping (Control 1), single-crop farming; BC1: first year of sugarcane after banana (plantation).