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Corn as trap crop to control *Helicoverpa zea* in tomato fields: importance of phenological synchronization and choice of cultivar

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Trap cropping is an environmentally friendly "alternative" pest management strategy. To maximize the efficiency of corn, *Zea mays* L. (Poaceae), as a trap crop for *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), we (i) tested the trap crop potential of corn varieties that are not a source of infestation, and (ii) determined the best corn planting time so as to concentrate *H. zea* in this trap crop and divert the pest from tomato, *Solanum lycopersicum* L. (Solanaceae). When corn silk emergence was synchronized with tomato flowering and fresh corn silk was present during the tomato flowering stage, *H. zea* infestation was lower in the tomato field with a corn border than in those without a corn border. Sugar Jean and Java corn varieties were good trap crops because few larvae persisted on the silks and their growth was low. These two varieties could reduce the risk of *H. zea* development and dispersion from corn borders.

Keywords: corn earworm; cultural pest control; tomato fruitworm; trap cropping; West Indies; *Zea mays*

1. Introduction

"Alternative" environmentally friendly pest management methods are being developed to reduce pesticide usage, and control methods to improve habitat diversification have received considerable attention (Poveda et al. 2008). Among these methods, a trap cropping strategy associates a trap crop with a main crop within a cropping system. Pests are diverted away from the main crop by plant species that are more attractive to pests than the main crop (Hokkanen 1991; Zehnder et al. 2007).

One way to enhance trap cropping effectiveness is to ensure that the attractive phenological stage for pest oviposition starts earlier and lasts longer in the trap crop than in the main crop. Badenes-Perez et al. (2005) found that the yellow rocket trap crop, *Barbarea vulgaris* (Brassicaceae), planted 2–3 weeks before cabbage can reduce infestations of diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). When a turnip rape trap crop, *Brassica rapa* (Brassicaceae), flowered earlier than oilseed rape, *Brassica napus* (Brassicaceae), the latter was less infested by the pollen beetle, *Meligethes aeneus* (Coleoptera: Nitidulidae), whereas there was no preference when they were flowering simultaneously (Cook et al. 2006, 2007). In a study with four trap crop species to control *Crocidolomia pavonana* (Lepidoptera: Crambidae), Smyth et al. (2003) showed that the periods of highest preference of *C. pavonana* for all the tested plants were ephemeral and that trap crops would have to be planted sequentially in order to be present throughout the time of highest cabbage susceptibility.

Another way to enhance trap cropping effectiveness is to prevent the pests from surviving and proliferating on the trap crop, with the risk that subsequent generations could infest the main crop. Trap crops are generally sprayed with insecticides to kill the pests (Buntin 1998; Shelton and Badenes-Perez 2006; Cavanagh et al. 2009). However, insecticide treatments may reduce the attractiveness of the trap crop, reduce populations of beneficial insects, and increase pesticide resistance in pests. The ideal trap crop should thus be both highly attractive for pest oviposition and detrimental to larval survival and/or development. For example, Napier grass, *Pennisetum purpureum* (Poaceae), is an effective trap crop because it is preferred by borer moths, *Chilo partellus* (Lepidoptera: Pyralidae), and *Busseola fusca* (Lepidoptera: Noctuidae) for oviposition, and larval survival is low (Van Den Berg 2006; Khan et al. 2007). Similarly, Shelton and Nault (2004) used *B. vulgaris* to protect cabbage crops from *P. xylostella* in a "dead-end" trap cropping strategy whereby the trap crop was highly attractive for oviposition, but pest larvae did not survive. In addition, according to Van Emden (2003), a trap crop could increase enemy populations and activity.

The tomato fruitworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), is a major pest of tomato, *Solanum lycopersicum* L. (Solanaceae), in the West Indies and North and South America (Hardwick 1965; Capinera 2001). Larvae of this pest are responsible for significant economic losses through reductions in crop yield and fruit marketability. The moths lay eggs on tomato plants and then the larvae burrow into the fruits and feed them. The larvae may attack one fruit after another. The flowering stage is the most attractive phenological stage for ovipositing females (Zalom et al. 1983; Torres-Vila et al. 2003).

We hypothesized that corn, *Zea mays* L. (Poaceae), would be a successful trap crop for *H. zea* management in tomato crop fields because corn, especially sweetcorn, is a highly preferred plant for ovipositing *Helicoverpa* sp. females (Fitt 1989; Guo et al. 2001). Furthermore, Wiseman and Isenhour (1990) found that maize silk reduces *H. zea* larval growth and egg production of their offspring, and Jallow and Zalucki (2003) observed reduced larval performance and offspring fitness on maize leaves for *Helicoverpa armigera* (Lepidoptera: Noctuidae), a closely related species (Behere et al. 2007). The factors of antibiosis resistance of corn to *H. zea* are widely known and depend on the variety. The C-glycosyl flavones maysin and apimaysin in the silk reduce the larval growth and increase larval mortality (Wiseman et al. 1992; Lee et al. 1998). In addition, ear husk tightness acts as a physical barrier to larval entry into the kernel (Rector et al. 2002). Larvae thus remain longer on the silks, where they are exposed to predators. Corn has already been used successfully to reduce infestation of several crops by noctuid moths. Castro et al. (1988) showed that when corn and sorghum, *Sorghum bicolor* L. (Poaceae), were planted at the same time, there was a higher *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larval infestation on corn than on sorghum. Abate (1988) showed that there were more *H. armigera* eggs and larvae on corn planted on both sides of a haricot bean field than on the haricot bean crop, and Javaid et al. (2005) showed that using corn as a peripheral trap crop distracts *H. zea* from soybean. Furthermore, Roltsch and Mayse (1984) observed that the presence of corn with fresh silk near a tomato field reduced the density of *H. zea* eggs on tomato.

With the aim of maximizing the effectiveness of corn as a trap crop for *H. zea* management, the main objectives of this study were (i) to test the effectiveness of corn varieties that do not switch from trap crops into sources of infestation, and (ii) to determine the best time for planting corn in order to concentrate *H. zea* on the corn trap crop and divert it from the tomato crop.

2.   Materials and methods

We carried out four trials. First, we assessed naturally occurring *H. zea* infestations on the three corn varieties in relation to their phenological stage. Second, we assessed the gap between the attractive stage of the three corn varieties and the attractive stage of tomato. Third, we assessed the *H. zea* host preference between a tomato crop field and a border of corn planted with effective varieties at the best time. Finally, we compared *H. zea* infestations on a tomato crop field with a corn border to a tomato field without a corn border.

2.1.   Study site

The study was conducted at the CIRAD French West Indies research site in Rivière-Lézarde, Martinique (14°39′N, 60°58′W), over a 2-year period. The area has a humid tropical climate with 1958 mm mean annual rainfall, a July to October rainy period, and a 22–28°C mean daily temperature. Four experiments were conducted under field conditions and during the tomato growing season (i.e. not in the rainy period). The plots were infested by natural *H. zea* populations and they were not sprayed with pesticides. In this study, we used one tomato variety, Heatmaster (Petossed), that is commonly planted in Martinique and three sweet corn varieties, that is, one semi-late variety, Java (Technisem), and two semi-early varieties, Challenger F1 (Seminis) and Sugar Jean (Agrinova).

2.2.   Insect infestation in relation to corn phenology and variety

Over a period of two months we set up three corn plots overall, one for each corn variety. Plots occupied an area of 88 m^2 and consisted of 11 rows of 40 plants each. Rows were 8 m long, with 1 m inter-row spacing and 0.20 m plant spacing within each row.

For each variety, we randomly sampled 20 plants on which we collected all the ears twice a week for 3 weeks, starting 1 week after tassel emergence. The corn ears were collected individually. We recorded their position on the plant (primary ear or other ears) and their stage: (i) silking (ears have ≥ 25% fresh silks), (ii) silk senescence (ears have > 75% dry silks), (iii) early milk (kernels have some milk), and (iv) ripening (kernels are yellowish to yellow and have a doughy consistency). For each ear, we counted only the number of *H. zea* larvae because larva counts on the silks were easier to perform than egg counts, and this parameter is a good indicator of *H. zea* infestation (Burkness et al. 2001; Storer et al. 2001). Each larval instar was recorded as early instar (L1-L2), medium instar (L3-L4) or late instar (L5-L6) according to body length (Anonymous 2005), and its location was recorded as on the silk or within the cob. The late instars were weighed individually.

2.3.   Gap between the attractive phenological stage of tomato and corn

Over 3 months, we set up one tomato plot and three corn plots overall, one for each corn variety. The area of each plot was 40 m^2. Corn plots consisted of 11 rows of 20 plants and tomato plots consisted of 11 rows of 10 plants. Rows were 4 m long, with 1 m inter-row spacing, and 0.20 m plant spacing within each row for corn and 0.40 m for tomato. Corn and tomato were planted at the same time. Corn was directly planted in the experimental plots, whereas tomato was planted in a nursery and transplanted in the plot 20 d later.

Corn and tomato phenological stages were recorded weekly on 16 randomly tagged plants per plot. The phenological stages of corn recorded were silk emergence (silk tips visible above the husks) and silk senescence (ears have > 75% dry silks). We selected these phenological stages on the basis of the findings of the first trial. For each corn plant, we calculated the duration of the silking

stage (i.e. the stage during which the plant had fresh silks), expressed as the cumulative degree-days from silk emergence to silk senescence. The phenological stages of tomato recorded were bud emergence (first bud erect), flowering initiation (first flower open), and ripening initiation (first fruit is red ripe). For each tomato plant, we calculated the duration of the flowering stage (i.e. the stage during which the plant had open flowers), expressed as the cumulative degree-days from flowering initiation to ripening initiation. The dates of silk emergence and flowering initiation were expressed in cumulative degree days since the sowing date. For these phenological stages, the degree-days were calculated by the following formula: $[(Tmax. °C + Tmin. °C)/2] - Tbase]$. $Tbase$ is the lower threshold temperature for development of the crop, $Tmin$ is the minimum daily temperature and $Tmax$ is the maximum daily temperature. $Tmax$ was set at the upper threshold temperature for development of the crop if it exceeded this limit. According to Cross and Zuber (1972), the lower and the upper threshold temperatures for development of corn are 10°C and 30°C, respectively. According to Scholberg et al. (2000), the lower and upper threshold temperatures for development of tomato are 10°C and 28°C, respectively.

2.4. Host preference between the tomato crop and the corn border

A field of tomato with an upwind corn border, based on prevailing wind direction, was set up over a 3-month period. The area of the tomato plot was 1200 m^2 and consisted of 25 rows of 150 plants each. Rows were 60 m long, with 0.80 m inter-row spacing and 0.50 m plant spacing within each row. Tomato plants were planted in a nursery and transplanted in the plot 17 d later. The corn border area was 120 m^2, that is, 10% of the tomato crop area. The corn border consisted of 6 rows of 200 plants each. Rows were 40 m long, with 0.60 m inter-row spacing and 0.20 m plant spacing within each row. The corn border was planted on three dates, at 2-week intervals starting 1 month before tomato planting. We planted two corn rows per date, being one row of Java and one row of Sugar Jean. We collected ears with fresh silk on 10 corn plants per row, randomly sampled at 7-d intervals, from silk emergence and for 5 weeks. We recorded the number of early *H. zea* instars (L1–L2) per ear. In the tomato field, 96 plants were tagged. They were distributed at eight different distances from the border crop (i.e. 2, 5, 10, 15, 20, 30, 40 and 50 m) at a rate of 12 plants per distance. We recorded the number of early *H. zea* instars (L1–L2) and eggs on these plants *in situ* weekly, from flowering initiation over a 4-week period.

2.5. Impact of the corn border on Helicoverpa zea populations in the tomato field

Three tomato fields were set up over a 3-month period; one with an upwind corn border and the others without a corn border were located 70 m and 100 m from the corn border. The area of the tomato plot was 70 m^2 and consisted of 10 rows of 22 plants each. Rows were 9 m long, with 0.80 m inter-row spacing and 0.40 m plant spacing within each row. Tomato plants were planted in a nursery and transplanted in the plot 21 d later. The corn border area was 16 m^2 and consisted of four rows of 50 plants each. Rows were 10 m long, with 0.40 m inter-row spacing and 0.20 m plant spacing within each row. To ensure that fresh corn silks were present during the tomato flowering stage, the corn border was planted sequentially on three dates, at 2-week intervals starting 1 month before tomato planting. In each tomato plot, 50 plants were sampled weekly from flowering initiation for 6 weeks. At the beginning of the study, we did not know the density of the *H. zea* population and we adopted this large number of sampled plants because, according to Dawson et al. (2006), it is necessary to have a large sample size in order to ensure high precision of the mean, and the number of samples increased with decreasing *Helicoverpa* sp. population densities. For each plant, the first leaf below the highest flower cluster was removed (Alvarado-Rodriguez et al. 1982; Hoffmann et al. 1991) and we recorded the number of *H. zea* eggs.

2.6. Statistical analysis

To assess the effect of the ear position (two levels: primary ears and other ears) and corn variety (three levels: Sugar Jean, Java, and Challenger) on the basis of the number of *H. zea* larvae per ear, we used a generalized linear mixed model (GLMM) with Poisson error distribution followed by an analysis of deviance, with sampling plant and date as random effects. We used similar methods to assess the *H. zea* preference for corn and tomato crops over time based on the number of *H. zea* individuals (early instars or eggs) counted per plant and to compare *H. zea* populations between the three tomato crops based on the number of *H. zea* eggs counted per tomato leaf and per plant. For each *H. zea* larval stage, we used a GLMM with a binomial distribution followed by an analysis of deviance with a χ^2-test to compare the three corn varieties: (i) frequency of *H. zea* larvae collected on the different phenological stages of ears (silking, silk senescence, and early milk) and (ii) proportion of *H. zea* larvae collected on ear silks relative to ear kernels. To compare the starting date and duration of the attractive crop stages for *H. zea* (i.e. silking for corn and flowering for tomato) of the different crop species and varieties, expressed in cumulative degree-days since crop sowing, we used the generalized linear model (GLM) with a gamma error distribution followed by an analysis of deviance. To assess the effect of the corn variety on the weight of late larval instars, we used the generalized linear mixed model (GLMM) with a Gaussian error distribution followed by an analysis of deviance, with sampling plant as random effect. All statistical tests were performed with R software (version 2.13.0).
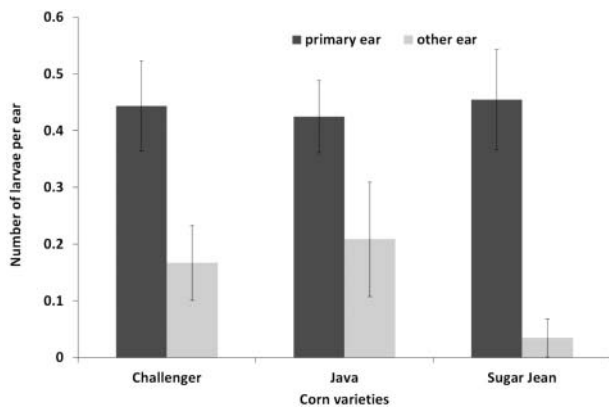
Figure 1. Mean total number of *Helicoverpa zea* larvae per ear collected on corn silks and within cobs (± standard error) for the primary ears and other ears according to corn varieties.
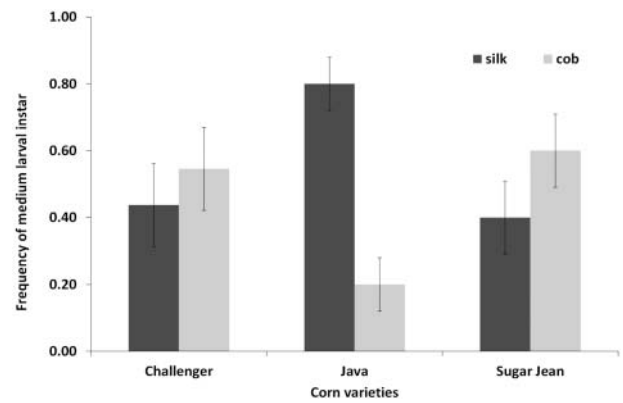

Figure 2. Mean frequency of occurrence of *Helicoverpa zea* medium larval instars (± standard error) on corn silks and within cobs according to corn varieties.

3. Results

3.1. *Insect infestation in relation to corn phenology and variety*

For all varieties, one third of the plants had several ears and the number of larvae was significantly higher on primary ears than other ears (GLMM Poisson: $\chi^2 = 17.84$, df = 1, $P < 0.001$); the number of larvae per primary ear was nine-fold higher for Sugar Jean and two-fold higher for Challenger and Java than the number of larvae per other ears (Figure 1). There was no significant effect of the corn variety (GLMM Poisson: $\chi^2 = 0.028$, df = 2, $P > 0.05$).

We found larvae in the first three corn ear phenological stages (i.e. silking, silk senescence and early milk) but none in the last ripening stage (Table 1). Early instars were found only on the silk and most of them were collected on fresh silks; at this stage, their frequency of occurrence was similar for the three varieties (GLMM

Binomial: $\chi^2 = 5.93$, df = 2, $P > 0.05$) with a mean of above 0.55. Medium instars were found at both ear locations and on corn plants at all three phenological stages; most medium instars were collected on fresh silks and at this stage their frequency of occurrence was similar for the three varieties (GLMM Binomial: $\chi^2 = 3.12$, df = 2, $P > 0.05$), with a mean of above 0.56. However, the location of medium instars on the ears differed significantly between varieties (GLMM Binomial: $\chi^2 = 6.61$, df = 2, $P < 0.05$); most medium instars collected on Java (80%) were on the ear silks, as compared with only 44% and 40% of those collected on Challenger and Sugar Jean, respectively (Figure 2). Late instars were found only within the kernels and on corn plants at the silk senescence and early milk stages. Their frequency of occurrence at the early milky stage differed significantly between varieties (GLMM Binomial: $\chi^2 = 8.33$, df = 2, < 0.05). There were fewer larvae on Sugar Jean than on the other varieties (Table 1).

Table 1. Mean frequency of occurrence (± standard error) of *Helicoverpa zea* larvae on the three phenological stages of corn ears according to the larval stage and corn variety.

| Early *H. zea* instars (L1–L2)				
Corn variety	N	Ears with fresh silks	Ears with dry silks	Early milk ears
Challenger	9	0.78 ± 0.14	0.22 ± 0.14	0
Java	11	0.55 ± 0.15	0.45±0.15	0
Sugar Jean	14	0.93 ± 0.07	0.07±0.07	0
Medium *H. zea* instars (L3–L4)				
Corn variety	N	Ears with fresh silks	Ears with dry silks	Early milk ears
Challenger	16	0.56 ± 0.12	0.31 ± 0.12	0.13 ± 0.08
Java	25	0.80 ± 0.08	0.16 ± 0.12	0.04 ± 0.08
Sugar Jean	20	0.80 ± 0.09	0.20 ± 0.09	0
Late *H. zea* instars (L5–L6)				
Corn variety	N	Ears with fresh silks	Ears with dry silks	Early milk ears
Challenger	18	0	0.22± 0.10	0.78 ± 0.10
Java	16	0	0.12 ± 0.08	0.88 ± 0.08
Sugar Jean	9	0	0.67± 0.17	0.33 ± 0.17

N = the total number of larvae collected on all ears.
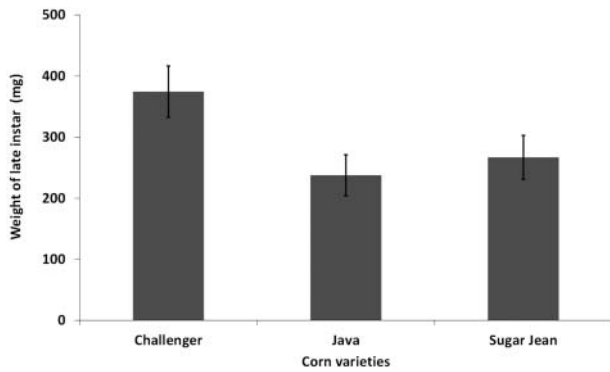
Figure 3. Mean weight of *Helicoverpa zea* late larval instars (±standard error) according to corn varieties.

The late instar weights differed significantly between varieties (GLMM Gaussian: $F = 4.41$, df $= 2$, $P < 0.05$) and the late instar weight on Challenger was higher than on the other varieties (Figure 3).

3.2. Gap between the attractive phenological stage of tomato and corn

The number of degree-days since sowing for the crops to reach their attractive stages (i.e. flowering for tomato and silking for corn) differed significantly among the species/variety combinations (GLM Gamma: $F = 112.58$, df $= 3$, $P < 0.001$). Tomato flowering initiation occurred at a lower mean thermal sum than silk emergence of the semi-early corn varieties (Challenger and Sugar Jean), with the latter occurring at a lower thermal sum than the semi-late (Java) one (Table 2). At a constant temperature of 25°C, flowering initiation occurred 46 d after sowing and silk emergence occurred 55 d and 72 d after sowing, for the semi-early and semi-late corn varieties, respectively. The duration of the attractive crop stages differed significantly among the species/variety combinations (GLM Gamma: $F = 32.03$, df $= 3$, $P < 0.001$). Tomato flowering was about two- to three-fold longer than corn silking, when expressed in sum of degree-days (Table 2). At a constant

Table 2. Starting date and duration of corn silking stage and tomato flowering stage for three corn varieties and one tomato variety (mean values ± standard error).

Species / Variety	starting date (degree-days)[a]	duration (degree-days)[b]
Corn / Challenger	832.56 ± 17.68	191.63 ± 7.75
Corn / Java	1077.06 ± 23.45	150.70 ± 11.77
Corn / Sugar	840.81 ± 10.46	206.08 ± 21.30
Tomato / Heatmaster	692.23 ± 9.95	427.17 ± 13.81
$F_{3,59}$	112.58	32.03
P	< 0.0001	< 0.001

[a]Starting date is the date of silk emergence for corn or the date of flowering initiation for tomato and is expressed in cumulative degree-days since crop sowing.
[b]Duration of corn silking stage is the number of cumulated degree-days from silk emergence to silk senescence and duration of tomato flowering stage is the number of cumulated degree-days from flowering initiation to ripening initiation.
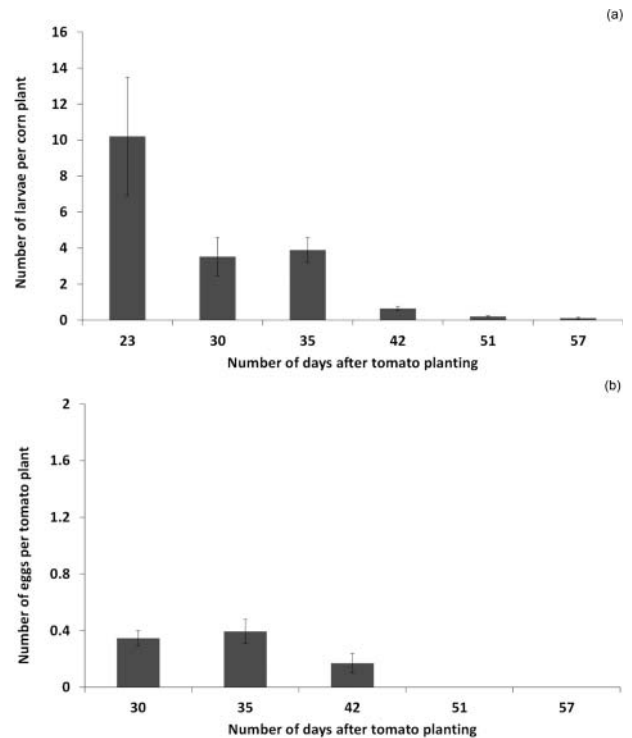

Figure 4. Mean number of *Helicoverpa zea* larvae per plant (±standard error) collected in the corn border (a) and mean number of *H. zea* eggs per plant (±standard error) collected in the tomato field (b). The larvae were counted on ears with fresh silks since silk emergence, and the eggs were counted since flowering initiation.

temperature of 25°C, tomato flowering lasted 28 days and corn silking lasted 10–14 d.

3.3. Host preference between tomato and corn border

Throughout the sampling period, we collected 358 larvae in the corn border, but only 61 eggs and no larvae in the tomato field. The number of *H. zea* individuals (larvae for corn and eggs for tomato) decreased over time and differed between tomato and corn (GLMM Poisson: $\chi^2 = 62.25$, df $= 1$, $P > 0.001$). The average number of *H. zea* larvae per sampling date in the corn border ranged from 10.2 ± 3.3 to 0.2 ± 0.0 larvae per plant, whereas in the tomato field the average number of *H. zea* eggs per sampling date was less than one egg per tomato plant (Figure 4a, b).

Corn silk emergence began with the first corn sowing at 21 d after tomato planting, whereas tomato flowering began 30 d after tomato planting. Moreover, during the tomato flowering period, there were always ears with fresh silk in the corn border, since silk emergence of the second and third corn sowings occurred at 34 d and 49 d, respectively, after tomato planting.

3.4. Impact of the corn border on Helicoverpa zea populations in the tomato field

The number of *H. zea* eggs differed significantly among the three tomato plots (GLMM Poisson: $\chi^2 = 22.91$, df $= 2$, $P < 0.001$). The average number of *H. zea* egg per
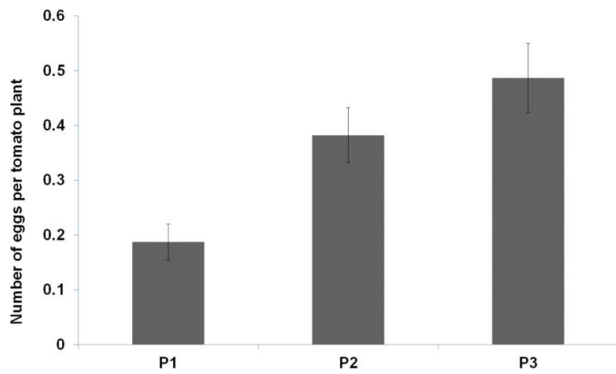
Figure 5.   Mean number of *Helicoverpa zea* eggs per tomato plant (±standard error) collected in the tomato plots. P1 is the tomato plot with an upwind corn border; P2 is the tomato plot without a corn border and situated at 70 m from the corn border; P3 is the tomato plot without a corn border and situated at 100 m from the corn border. The eggs were counted on the first leaf below the highest flower cluster since flowering initiation.

tomato plant was two- to three-fold higher for the plots without a corn border than the tomato plot with a corn border (Figure 5).

4.   Discussion

Most early *H. zea* instars (93%, 78% and 55% for Sugar Jean, Challenger and Java, respectively) were on ears at the silking stage, suggesting that fresh silks are suitable hosts for *H. zea*. Nishida and Napompeth (1974) and Lopez (1978) observed that *H. zea* females are most attracted to silking corn and its preferred oviposition site is the silks, even though they can lay their eggs on leaves before the silking stage. According to Cantelo and Jacobson (1979) and Raina et al. (1992), corn silks emit phenylacetaldehyde, which is attractive to *H. zea*, and ethylene, which in turn induces pheromone production by *H. zea* females. Harrison (1960) observed that *H. zea* laid a large number of eggs on 1- and 2-d-old silks and Matrangolo et al. (1998) also found eggs and larvae on fresh silks. We thus confirm that the most attractive phenological corn stage for oviposition of *H. zea* females is silking, that is, the stage at which ears have fresh silks.

We showed that the attractive stages of tomato and corn were not synchronized when they were planted at the same time. Corn silk emergence was later than tomato flowering initiation (about 140 degree-days later for the semi-early varieties, Challenger and Sugar Jean, and 395 degree-days later for the semi-late variety, Java). In addition, the duration of tomato flowering was about two-fold longer than that of silk emergence (about 427 degree-days for tomato, 150 degree-days for Java, and 200 degree-days for Challenger and Sugar Jean). Consequently, corn should be planted earlier than tomato and at sequential planting dates in order to synchronize the attractive stages of both crops. Several studies on other trap cropping systems with early and sequential planting led to the same conclusions, showing that synchronization between the attractive stage of the trap crop and that of the main crop enhances the effectiveness of trap crops.

Smyth et al. (2003) showed that the periods of highest preference of *Crocidolomia pavonana* for all the tested plants were ephemeral and that trap crops would have to be planted sequentially in order to be present throughout the time of highest cabbage susceptibility. Muniappan et al. (2004) showed that collard, *Brassica oleracea* var *acephala* (Brassicaceae), planted 4 weeks before cabbage was an effective trap crop for *Plutella xylostella* in cabbage fields. For pollen beetles (*Meligethes aeneus*), Tillman (2006) planted sorghum as trap crop on three dates to ensure that a sufficient supply of panicles was available for adult southern green stink bugs, *Nezara viridula* (Heteroptera: Pentatomidae). Besides these general/strategic recommendations, tactical recommendations such as the choice of optimal dates and sowing frequency would, however, depend on the corn varieties planted. The use of two corn varieties at each sowing date – one early variety and one late variety – is, in addition to increasing the number of sowing dates, another way to extend the duration of the corn silking stage. We validated these recommendations experimentally. Indeed, the planting design that we defined applying these recommendations (three sowings of early and late corn varieties at a 2-week interval from 1 month before tomato planting) ensures the presence of ears with fresh silks in the corn border throughout the tomato flowering stage.

Our study on the tomato field with a corn border showed that the number of early instar larvae per corn plant was higher than the number of both early instar larvae and eggs per tomato plant. Since the number of early instars was always lower than (or at least equal to) the number of eggs because of individual mortality over time, our results confirmed those of Roltsch and Mayse (1984), who observed an average of less than one egg per tomato plant, whereas there were up to 10 eggs per corn plant in the adjacent corn field with fresh silks. Moreover, Purcell et al. (1992) found more *H. zea* eggs on corn silks than on tomato leaflets less than 5 m from corn plants. *Helicoverpa* sp. mortality did not differ markedly between corn and tomato plants for young larvae: the percentage survival of L2 *H. zea* was 29% on corn (Vargas and Nishida 1980) and that of L2 *H. armigera*, which is closely related to *H. zea*, was 20% on tomato (Liu et al. 2004). Our results thus suggested either (i) that when both tomato and corn were at their attractive phenological stage for *H. zea* oviposition (flowering and silking, respectively), *H. zea* preferred to lay eggs on corn, or (ii) that egg mortality was much higher on tomato than on corn, or (iii) that both processes occurred at the same time. The egg-laying preference of *H. zea* for corn over tomato was also supported by the fact that the level of *H. zea* infestation was clearly lower in the tomato field with a corn border than in those without a corn border.

The results we obtained suggest that Sugar Jean and Java are the most promising sweet corn varieties for use as trap crops. The late instars collected on Sugar Jean and Java weighed less than those collected on Challenger. This suggests that Java and Sugar Jean could have an antibiosis effect on *H. zea*. Before entering the kernels, *H. zea*

larvae feed on silks that contain allelochemical compounds such as maysin. This compound reduces larval growth or contributes to larval mortality. The maysin concentration depends on corn varieties, and Snook et al. (1993) reported that it ranges from 0 to 0.9% fresh weight in corn silks. They showed that silks with a maysin level of over 0.2% have an antibiosis effect. Wiseman et al. (1981) also observed reduced growth and increased mortality (up to 32%) of *H. zea* larvae when they fed on silks for 6 d or more. In addition, the infestation level was higher on the primary ears than on the other ears, especially for Sugar Jean, which had a nine-fold higher number of larvae per primary ear relative to other ears. This could be due to their position within the corn plant: *H. zea* would remain on the primary ear because it is taller than the other ears. Indeed, Firempong and Zalucki (1991) showed that *H. armigera* oviposition was greater on higher sites than lower sites. The high infestation of primary ears may increase the antibiosis effect because the maysin concentration in corn silks is higher in the silks of primary ears than in the those of other ears (Wiseman et al. 1993). Most of the medium instar larvae remained on the silks of Java and consequently fed on more silks. We suppose that its husks could be tight, which would make it difficult for the larvae to penetrate into the kernel, so they would feed more on silks. Previous studies showed a negative correlation between the tightness of husks and the presence of *H. zea* in the kernel (Archer et al. 1994; Rector et al. 2002). The longer stay on the silks could increase the level of predation of the larvae since they would be exposed to predators. We noted the presence of arthropod predators within the corn plots, mainly ants (Formicidae), ladybirds *Coleomegilla maculata* (Coleoptera: Coccinellidae)*,* and pirate bugs *Orius insidiosus* (Heteroptera: Anthocoridae), which are known to be major predators of *H. zea* eggs and first instars in corn and cotton fields (Sansone and Smith 2001; Pfannenstiel and Yeargan 2002; Seagraves and Yeargan 2009). The use of Java and Sugar Jean varieties should minimize the risk that the corn border turns into a source of *H. zea* infestation. We did not observe larvae in ears at the ripening stage and found few larvae in early milk ears of Sugar Jean. We suppose that the mature larvae would leave the ear to pupate in the soil (Capinera 2001). Hence, to optimize the use of these two varieties and prevent the emergence of first generation *H. zea* adults, we propose that ears should be destroyed after silk senescence in order to prevent mature larvae from exiting. This trap strategy would be economically acceptable to growers because sweet corn could be used as poultry or pig feed. Insecticide spraying would be useless because *H. zea* larvae are protected within the cob.

Helicoverpa zea has, however, a large dispersion potential. According to Fitt (1989), *Helicoverpa* sp. are facultative migrants and local movements within and near the crop are substantial if the local feeding and oviposition conditions are good. Our results suggested that corn is an effective trap crop at a small scale, and Roltsch and Mayse

(1984) observed similar results at a larger scale in tomato fields ranging from 0.6 to 2.4 ha and corn fields from 0.15 to 1 ha. Thus, the permanent presence of corn plants with fresh silks in close proximity to tomato crops may be an effective pest management strategy in agrosystems with vegetable crops since corn is more attractive for *H. zea*. However, the trap crop effectiveness at a large scale may partly depend on the trap crop area and its distribution relative to the major crop. Indeed, *Helicoverpa* sp. is highly polyphagous, and female moths may encounter different crop and non-crop species as oviposition sites (Fitt 1989). Female moths can change the order of host preference by learning. Their experience in finding a suitable host for oviposition enhances their ability to accept that host, and the most abundant host may become the most preferred crop (Cunningham et al. 1999, 2001). According to Jallow et al. (2004), trap cropping may be an effective control strategy for *H. armigera* if the trap crop species is a locally abundant host crop that may have to be matched to the agroecosystem in which it will be used. The presence of sweetcorn in Martinique might have improved its effectiveness as a trap crop.

In conclusion, when the trap crop planting strategy is well defined (optimal choice of planting date and varieties), trap cropping can be a valuable contribution for agroecological management of targeted pests. Our study contributed to defining this strategy for the corn–tomato cropping system (i.e. optimal choice of date, number and frequency of corn sowings and of corn varieties), thus providing a way to improve the use of corn as a trap crop to manage *H. zea* in tomato fields. Further improvements could result from optimization of the spatial arrangement of corn plants within tomato fields.

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