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RESEARCH ARTICLE

PEST SCENARIO IN LONG-TERM ORGANIC AND CONVENTIONAL SUGARCANE PRODUCTION SYSTEMS

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Abstract

Pest data from the main sugarcane and rotational cotton crops in the third cycle of a long-term comparative study comprising organic and conventional farming systems are presented. Shoot borer incidence level in sugarcane at 60 days age was significantly lower in organic plot than in conventional plot in the plant crop (2009-10) but did not differ significantly between the two plots in the ratoon crop (2010-11). In the plant crop (20012-13), the non-significantly different incidence level at 45 days age became significantly higher in organic plot at 100 days age. Internode borer incidence in 135–300 d old crop and at harvest (360 d) was lower in organic plot in the few observations that showed significant differences. In multiple observations within a single crop, non-significant differences between the two plots remained constant (2009-10), significant differences became non-significant (2010-11) and non-significant differences became significant (2012-13) with crop age. The incidence levels generally increased with age reaching the maximum at harvest. The intensity and the infestation index of the borer followed a trend similar to incidence. Woolly aphid attack was observed only in plant (2012-13) crop at about 270 DAP in small patches of both plots. Higher activity of the parasitoid *Encarsia flavoscutellum* Zehntner (Hymenoptera: Aphelenidae) was observed in organic plot (50.8%) than in conventional plot (24.0%). In the rotational cotton (2008-09), severe attack of the papaya mealybug *Paracoccus marginatus* Williams and Granara de Willink (Homoptera: Pseudococcidae) in young plants led to wilting, stunted growth and death of plants. In the next rotational cotton (2011-12), mealybug was not observed; stem weevil galls were significantly less numerous in organic plot than in conventional plot. Sex pheromone traps deployed to monitor boll worms caught maximum numbers of *Spodoptera* moths followed by *Pectinophora, Earias* and *Helicoverpa* with no clear-cut trend between organic and conventional plots. Sex pheromone traps setup @ 25 per ha to mass trap sugarcane borers showed higher catches of shoot borer than internode borer in ratoon (2010-2011); smaller numbers of trap catches of the two borers were observed in plant (2012-13). Cumulative catches per trap differed marginally between conventional and organic plots. In the rotational cotton (2008-09), while insecticides controlled papaya mealybug in the conventional plot, the azadirachtin compound neemazol gave only minimal control in the organic plot. As a result, organic crop recorded considerably lower kapas yield than conventional plot. Insecticides in the conventional plot, and neem oil and neemazol in the organic plot were used to control sucking pests.

Key words: Sugarcane, organic farming, borers, sex pheromones, woolly aphid, *Ceratovacuna lanigera, Encarsia flavoscutellum,* rotational cotton, boll worms.

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Introduction

Sugarcane, the second most important cash crop in India, is cultivated as a monocrop in large tracts under the supervision of sugar industry. The spatial and temporal continuity of the crop accords it the status of what can be termed as semi-perennial habitat (Srikanth and Salin 2003). The impact of such continuous cultivation on soil and crop health can be mitigated to some extent by organic cultivation methods. Studies conducted in research and growers' farms provide evidence in this direction. For example, cane and sugar yield improved to a significantly greater degree when organic and inorganic components were integrated in nutrient management than when used alone in experimental farming (Durai and Devaraj 2003). Comparative economics of sugarcane grown in both organic and conventional systems in farmers' fields led to the conclusion that a combination of fertilizers and organic manures is essential for the crop (Gawade et al. 2005). Improvement in soil physical properties, and enhancement of carbon content and available N, P, K and S were observed under organic farming (Prashanth et al. 2009). A combination of inorganic, organic and biofertilzers, biopesticides (neem cake), trash mulching and green manuring with green gram was found suitable for sustaining productivity, maintaining soil fertility and obtaining higher monetary returns in sugarcane plant and ratoon (Thakur et al. 2012). Our long-term comparative study established the sustainability of organic production system vis-à-vis conventional production system (Sivaraman et al. 2012) despite the transient effect of invasive pests in the main and rotational crops. From the point of view of insect pests as an important biotic stress in organic sugarcane, the observations of Gawade et al. (2005) and Kshirsagar (2008) indicated marginal differences in the cost of plant protection between organic and inorganic farming systems. However, pest scenario in these systems has not been documented earlier with the exception of the extensive observations of pest dynamics and management tactics from the first two crop cycles of our long-term study on organic and conventional production systems (Srikanth et al. 2009a). In continuation of our earlier observations, we present here pest status in sugarcane and rotational cotton in the last leg of our study. We discuss the impact of regular and invasive pests on the performance and prospects of organic sugarcane which may become temporarily vulnerable to attacks by immigrant pests for which effective and immediate organic control measures are not available.

Materials and methods

Crop system

The present entomological notes are in continuation of our earlier observations (2003-2008) (Srikanth et al. 2009a) from a long-term study on the feasibility of organic production system vis-à-vis conventional system (Sivaraman et al. 2012). The production systems spanned three crop cycles, each comprising one plant and one ratoon of sugarcane, and one rotational cotton. After the harvest of cotton, *Sesbania aculeata* (Willd.) Pers. was raised and incorporated into the soil before beginning the next cycle. At the end of the three cycles, a final sugarcane plant crop was taken up. The production systems were maintained in two adjoining experimental plots, each comprising 300 rows of 6 m length laid out in six blocks of 50 rows (0.2 ha). The main crop sugarcane (cv Co 86032) was planted or ratooned during March/April using the recommended seed rate. In the conventional system, regular cultivation practices such as recommended basal application of farmyard manure/compost, chemical fertilizers and biofertilizers, and need-based pesticide applications were followed. In the organic system, recommended nutrients through organic / bio-sources and biofertilizers, weeding by mechanical and manual methods, application of organic/ biopesticides as and when required, and raising green manure intercrop (*S. aculeata*) to be incorporated in to the soil 40 days later were followed. The sequential cotton (cv Suraj; Culture No. CCH 510-4) was sown in August at a spacing of 90 cm x 60 cm with each 6 m row accommodating 11-12 plants.

The agronomic practices followed for cotton in both systems included manual weeding without herbicide application, gap filling, regular irrigation and need-based control measures against insect pests.

Data collection

Data on incidence and intensity of pests of sugarcane and cotton were recorded at different stages or whenever noticed in the course of the following five crop seasons covered in the present study: rotational cotton (2008-09) of cycle-II; plant (2009-10) and ratoon (2010-11) sugarcane, and rotational cotton (2011-12) of cycle-III; final plant (2012-13) sugarcane crop.

Pest status in sugarcane

The incidence of shoot borer (SB) *Chilo infuscatellus* Snellen (Lepidoptera: Crambidae), and incidence and intensity of internode borer (INB) *Chilo sacchariphagus indicus* (Kapur) (Lepidoptera: Crambidae) were recorded at appropriate age in the two production systems. In each plot, borer data were recorded in 30 rows representing 10% of the total population. In the first of the six blocks, a row was selected randomly among the first 10 rows and thereafter every 10th row was selected systematically taking a turn to the right or left at the end of the block. For assessing SB incidence, total number of shoots and number of deadhearts were recorded in each of the 30 rows selected and percent deadhearts computed. For INB in the standing crop, total number of millable canes and number of canes with deadhearts, fresh bore holes on top internodes and/or old bore holes on lower internodes were recorded and percent incidence computed. Further, from each of the 30 rows, 10 canes were selected using random and systematic sampling procedures; the total number of internodes and number of bored internodes were recorded in these 10 canes to compute percent intensity of the borer. At harvest in two crops, i.e. ratoon (2010-11) and plant (2012-13), 10 spots in each plot were randomly selected and INB incidence was recorded from 10 or 50 randomly selected harvested canes at each of these spots. Further, six or 10 spots were randomly located and INB intensity was recorded from five or 10 randomly selected harvested canes at each spot. An infestation index for INB was computed to account for the variation in incidence and intensity.

$$\text{Infestation index} = \frac{\text{\% incidence x \% intensity}}{100}$$

The crop in both systems was monitored regularly for the recurrence of woolly aphid and the occurrence of other occasional pests.

Pest scenario in cotton

During 2011-2012, observations were recorded on two sucking pests, namely aphid *Aphis gossypii* Glover (Homoptera: Aphididae) and leafhopper *Empoasca* sp. (Homoptera: Cicadellidae) at 75 DAP. A systematic sampling procedure, as followed for sugarcane borers, was adopted to locate six quadrats each comprising five continuous rows. From the middle of each row, two plants were selected and in each plant two leaves each from the upper, middle and lower strata were selected. Counts of different stages of sucking pests present on individual leaves were recorded and the number was expressed in the composite sample of 60 leaves or 10 plants per quadrat. Besides, counts of stem weevil, *Pempherulus affinis* (Faust) (Coleoptera: Curculionidae), in terms of galls present in all the plants of five rows from each of the six quadrats, were recorded at 100 DAP and expressed as number per quadrat.

To monitor the activity of boll worms, commercial sex pheromone traps of *Spodoptera*, *Pectinophora*, *Earias* and *Helicoverpa* were set up @ one trap each (H” 5 traps/ha) in organic and conventional plots (Fig. 1) at 90 DAP; lures were changed every 30 days. Daily catches recorded for about 70 days were pooled to work out weekly totals which were compared between the two plots. Boll worms were not enumerated due to low incidence.

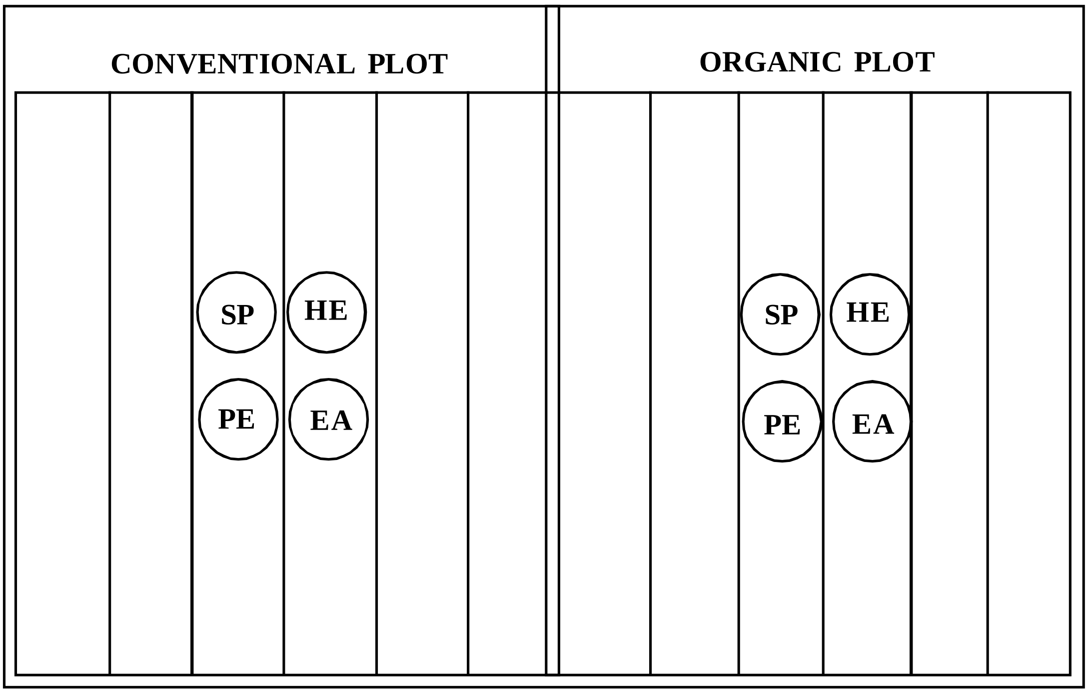

Fig. 1. Layout of sex pheromone traps of boll worms in cotton. SP : *Spodoptera;* HE : *Helicoverpa;* PE : *Pectinophora;* EA : *Earias*

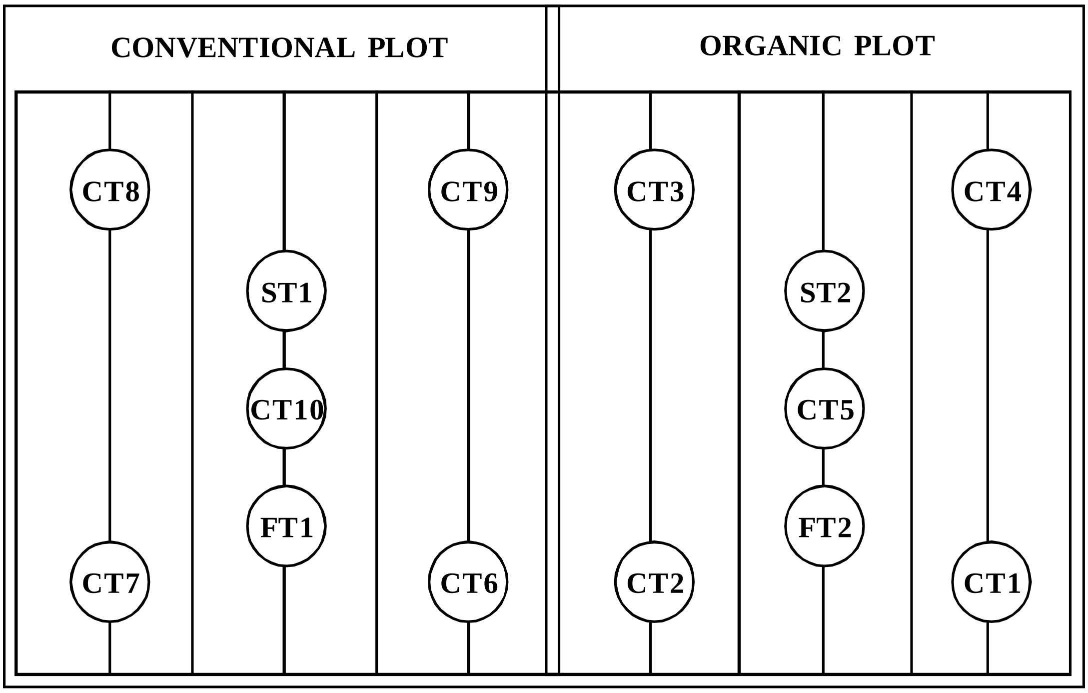

Fig. 2. Layout of sex pheromone traps of shoot borer and internode borer in sugarcane. CT 1-10: commercial water-traps; ST 1-2: SBI water-traps; FT 1-2: commercial funnel traps

Pest management in sugarcane

Management tactics were adopted in accordance with the principles of the production system. In an effort to mass trap borer moths, commercial sex pheromone lures of SB and INB were deployed in five stake-mounted plastic conical water traps (H" 25 traps/ha) (Fig. 2) at a height of 75 and 150 cm height from the ground, respectively. In ratoon (2010-2011), SB lures were deployed late in the season (120-150 days age) and INB lures during 150-300 days age. In plant (2012-13) crop, SB pheromone traps were set up early (45-110 DAP) and INB lures during 150-330 days age. Besides the commercial water traps, one each of SBI water trap and commercial funnel trap were set up in each plot (Fig. 2). Water was changed every week and about 5 ml of kerosene was spread on the surface of the water with every water change; lures were changed every 30 days. Trap catches were recorded every day and cumulative weekly or monthly totals were worked out and compared between the plots.

Pest management in cotton

Control measures were adopted in both organic and conventional plots during 2008-09 and 2011-2012. Recommended insecticides in conventional plot and organic products in organic plot were applied for the control of sucking pests.

Data analysis

SB and INB counts from sample rows of sugarcane, and sucking pests and stem weevil data from quadrat samples of cotton were compared between organic and conventional plots using Student's *t* test. Pooled pheromone trap catches were analyzed using repeated measures ANOVA and means compared for plot and period of observation with Newman-Keuls post-hoc test.

Results and discussion

Sugarcane pests

Borers

SB deadheart incidence recorded at 45-100 days age differed significantly between organic and conventional plots among the plant and ratoon crops of cycle III (2009-11) and final plant crop (2012-13) (Table 1). In the plant crop (2009-10), borer incidence at 60 days after planting (DAP) was significantly lower in organic plot than in conventional plot. In the ratoon crop (2010-11), however, SB incidence at the same age of 60 days did not differ significantly between the organic and conventional plots despite the general higher incidence than was observed in plant crop (2009-10). In the plant crop (20012-13), the non-significantly different deadheart incidence at 45 DAP became significantly higher in organic plot at 100 DAP. SB showed year-to-year variation

Table 1. Shoot borer incidence in two cycles of sugarcane

Crop cycle	Year	Crop type	Crop age (days)	Mean percent incidence		
				Organic plot	Conventional plot	*t*-value
III	2009-10	Plant	60	3.8 ± 2.5	7.6 ± 6.6	2.86^{**}
	2010-11	Ratoon	60	11.1 ± 2.3	11.5 ± 3.4	0.47^{ns}
Final	2012-13	Plant	45	6.5 ± 2.9	5.8 ± 2.6	0.99^{ns}
			100	7.7 ± 4.0	5.7 ± 2.4	2.39^{*}

* P<0.05; ** P<0.01; ^{ns} P>0.05

Table 2. Internode borer incidence and intensity in two cycles of sugarcane

Crop cycle	Year	Crop type	Crop age (days)	Mean percent incidence		t-value	Mean percent intensity		t-value	Infestation index	
				Organic plot	Conventional plot		Organic plot	Conventional plot		Organic plot	Conventional plot
III	2009-10	Plant	135	4.4 ± 3.0	3.5 ± 2.7	1.31[ns]	2.1 ± 1.7	2.0 ± 1.5	0.21[ns]	0.09	0.07
			250	11.2 ± 6.6	11.3 ± 6.2	0.05[ns]	2.8 ± 1.4	3.4 ± 1.3	1.97[ns]	0.31	0.38
	2010-11	Ratoon	180	2.5 ± 3.7	11.3 ± 7.8	5.60***	0.8 ± 1.6	5.8 ± 4.9	5.33***	0.02	0.66
			240	2.1 ± 2.2	4.8 ± 3.3	3.78***	0.8 ± 0.8	2.1 ± 2.1	3.41**	0.02	0.10
			360	49.0 ± 21.3	36.0 ± 21.7	1.35[ns]	8.5 ± 4.0	6.1 ± 3.4	1.16[ns]	4.17	2.20
Final	2012-13	Plant	180	2.5 ± 1.9	3.1 ± 2.3	0.96[ns]	1.3 ± 1.0	1.4 ± 1.1	0.50[ns]	0.03	0.04
			300	16.6 ± 6.0	17.0 ± 5.6	0.26[ns]	3.1 ± 1.9	3.2 ± 1.6	0.32[ns]	0.51	0.54
			360	20.2 ± 5.2	25.6 ± 5.5	2.26*	3.9 ± 1.2	3.8 ± 0.8	0.16[ns]	0.79	0.97

* P<0.05; ** P<0.01; *** P<0.001; ns P>0.05

with the mean maximum incidence of 11.5% in ratoon (2010-11).

INB incidence in 135–300 days age and at harvest (360 d) showed variable trends between organic and conventional plots in crop cycle-III and final plant crop (Table 2). The incidence was lower in organic plot in all the observations that showed significant differences. Within a single crop, multiple observations showed variable differences: some differences remained constant (2009-10); some significant differences became non-significant (2010-11); some non-significant differences became significant (2012-13). The incidence levels were generally moderate and progressively increased with age reaching higher levels in the second observation and maximum at harvest; ratoon (2010-11) was the exception in that it showed a slight decrease in the second observation, which could be partly due to sampling variation, but increased substantially to reach the overall highest incidence of the study period at harvest with no significant difference between the two plots.

The intensity of the borer followed the same trend shown by the incidence levels in that it did not differ between the plots in most observations (Table 2). However, in those observations that showed differences, it was generally lower in organic plot than in conventional plot. Although intensity generally increased with age and reached the highest at harvest just as incidence, it showed an occasional decrease within a year as in the second observation of ratoon (2010-11). However, once again as in incidence, the highest overall intensity was observed at harvest in ratoon (2010-11) with no significant differences between the two plots. Infestation index of the borer also showed a similar trend (Table 2) of marginally lower values in organic plot than in conventional plot in most observations.

SB incidence levels recorded in cycle-III (2009-11) and the final plant (2012-13) crop of the present study were slightly higher than those recorded in the first two cycles (Srikanth et al. 2009a). Yet, the highest overall incidence levels observed in ratoon (2010-11) crop were moderate and lower than the established threshold levels of 16-22% (David and Sithanantham 1986; Sardana 1998). INB incidence levels too were higher in the present cycle than those in earlier cycles (Srikanth et al. 2009a) with no definite pattern in the differences between organic and conventional plots for both the borers. However, occasional lower borer attack in organic plot indicated that organic farming has somewhat rendered the crop less attractive to pests through optimal nutrient and mineral balance as suggested by Zehnder et al. (2007), if not made it more susceptible to the attack of the borers. The comparable levels of SB incidence in this study and those in our earlier independent studies (Srikanth et al. 2002 & 2009b) indicated the general level of abundance of the borer in the study habitat. Although not examined through destructive sampling of shoots and collection of larvae, variation in natural enemy activity (Easwaramoorthy et al. 1996; Srikanth et al. 1999, 2001, 2002 & 2009b) could have partly governed borer dynamics.

Woolly aphid

The aphid was not observed in plant (2009-10) and ratoon (2010-11) crops of cycle-III. It was, however, noticed at about 270 DAP in two different patches of four and five rows in organic plot and in a single patch of six rows in conventional plot of the final plant (2012-13) crop. The parasitoid *Encarsia flavoscutellum* Zehntner (Hymenoptera: Aphelenidae) was active in both the plots (Fig. 3) with higher levels of parasitism in organic plot (50.8%) than in conventional plot (24.0%). The lack of difference between organic and conventional fields

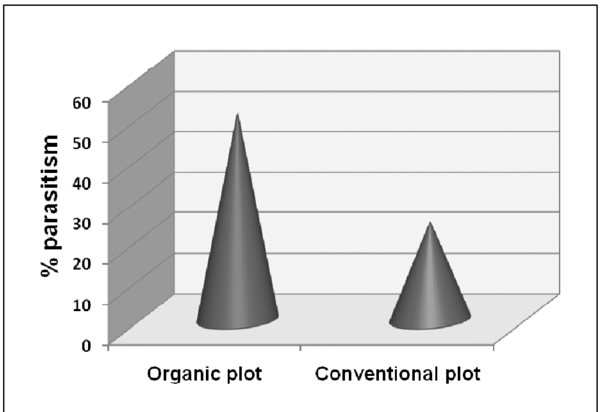

Fig. 3. *Encarsia flavoscutellum* parasitism levels in woolly aphid at 270 DAP in plant (2012-13) sugarcane

in the level of cereal aphid mortality due to parasitoids, the levels of primary parasitism, hyperparasitism and multiparasitism, or parasitoid diversity, was attributed to the heterogeneity of the region of investigation (Macfadyen et al. 2009) in the light of the suggestion that clear differences between diversity on organic and conventional farms may be more obvious in more homogeneous landscapes (Roschewitz et al. 2005). In the present study, the contiguous organic and conventional plots in a predominantly sugarcane experimental farm constituted a more or less homogenous habitat. Thus, the considerable difference observed in parasitism rates due to *E. flavoscutellum* assessed from a single composite sample, though not statistically analyzed due to the small infested area, reflected, at least partly, the true variation between the plots. Comparable aphid attack in only two patches (nine rows) in organic plot and one patch (six rows) in conventional plot but considerably higher parasitism rate in the former seemed to indicate that organic farming has rendered the crop more attractive to the parasitoid but not the aphid, probably through optimal nutrient and mineral balance (Zehnder et al. 2007) and other unknown reasons related to chemical ecology of the system that would be interesting to investigate. The adequate non-crop area in the study habitat, which is considered important for providing resources for natural enemies of pests including aphids (Macfadyen et al. 2009), may not have played a serious role in sustaining the parasitoid with a known narrow host range (Evans et al. 1995).

In view of the significant activity of the parasitoid, no chemical control was taken up in the conventional plot in tune with the guidelines formulated by us earlier (Srikanth et al. 2008). About 2,000 parasitoid adults resting on infested leaves in the organic plot and also those emerging from infested leaves maintained in the laboratory in glass chimneys were collected and released in the infested patch of the conventional plot. The aphid showed gradual decline in both the plots without any further spread. This invasive pest, observed to impact economic parameters of the crop (Mukunthan et al. 2008), responded gradually to augmentative releases of its major predator *Dipha aphidivora* Meyrick (Lepidoptera: Pyralidae) in the first phases of the study (Srikanth et al. 2009a). The subsequent introduction and establishment of *E. flavoscutellum* resulted in natural regulation of the aphid and prevention of economic loss to the attacked crop (Srikanth et al. 2012a). Currently, the aphid sporadically appears in small patches, as was observed in the final (2012-13) crop, and is followed by the parasitoid which gradually prevents its spatial spread in the attacked field which indicated that the spatio-temporal continuity of the crop in the region is supporting discrete populations of both the aphid and parasitoid (J. Srikanth et al. unpubl. data).

Other pests

In plant (2009-10), conventional plot showed sporadic rat damage at 240 DAP. Neither whitefly nor termite, which were observed in the previous crop cycles (Srikanth et al. 2009a), nor any other pest was observed in serious proportion to warrant attention or control measures during the present observation period. Absence of pests other than borers on a regular basis indicates that pests may not constitute a serious biotic stress in organic or conventional farming in identical crop habitats.

Cotton pests

In the rotational cotton of 2008-09 planted after the completion of the second cycle of sugarcane, sucking pests such as aphid, jassid and whitefly were observed in low abundance. However, an unusually heavy incidence of the papaya mealybug *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) was noticed in both plots. The mealybug colonized the petioles, midribs and leaf lamina of young plants; dense colonies gave the appearance of 'white mealy' covering on the surface of attacked plants. As a result of the severe attack of the mealybug, the foliage wilted and plant growth was seriously affected, particularly in the organic plot where control measures were less effective than in the conventional plot (discussed below).

Table 3. Pest activity in rotational (2011-2012) cotton

Pest	Mean number per quadrat	
	Organic plot	Conventional plot
Aphid (*Aphis gossypii*)	20.3	24.5^{ns}
Leafhopper (*Empoasca* sp.)	62.5	76.5^{ns}
Stem weevil galls (*Pempherulus affinis*)	54.3	76.5^{**}

** $P<0.01$; *** $P<0.001$; ^{ns} $P>0.05$

In the rotational cotton crop of 2011-12, mealybug was not observed in both plots. Observations of sucking pests recorded at about 75 DAP showed similar aphid and leafhopper numbers per quadrat in both organic and conventional plots (Table 3). However, stem weevil galls per quadrat were significantly less numerous in organic plot than in conventional plot. Monitoring the daily catches of boll worms using funnel traps with sex pheromone lures of *Spodoptera*, *Pectinophora*, *Earias* and *Helicoverpa* during 2011-12 indicated that the four species were active in the same order of decreasing magnitude (Table 4). The moth catches did not show a clear-cut trend between organic and conventional plots. The cumulative weekly counts of *Spodoptera* moths trapped for about 10 weeks from 90 DAP indicated a gradual increase in the third week, a sharp peak in the fourth week and a decline from the fifth week onwards in both organic and conventional plots (Fig. 4).

Pest management

Sugarcane

In ratoon (2010-2011), pheromone traps with SB lures set up @ 25 per ha late in the season (120-150

Table 4. Sex pheromone trap catches of boll worm moths in funnel traps in rotational (2011-12) cotton

Trap parameter	*Spodoptera*	*Helicoverpa*	*Pectinophora*	*Earias*
		Organic plot		
Minimum / trap / day	0	0	0	0
Maximum / trap / day	570	1	8	0
Total in the season*	1112	3	21	0
		Conventional plot		
Minimum / trap / day	0	0	0	0
Maximum / trap / day	346	1	18	7
Total in the season*	893	4	137	27

* 10 weeks collection (Dec 2011-Feb 2012) in one trap for each species

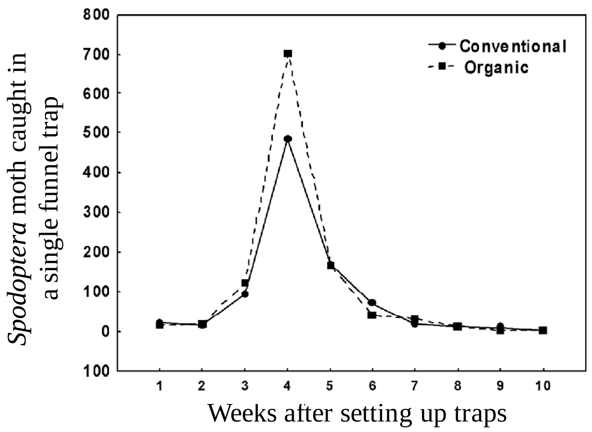

Fig. 4. Cumulative *Spodoptera* moth catches in sex pheromone traps in 90-day old rotational (2011-12) cotton

days age) collected greater number of moths in 1 month duration than the traps with INB lures (150-300 days age) collected in 5 months when the number of moths per month was considered (Table 5). In the entire season, while SB moths were captured in greater numbers in organic plot, INB moths were more numerous in conventional plot. Cumulative collections per trap of both borers showed a progressive decline within the observation period (Fig. 5). In SB, repeated measures ANOVA and Newman-Keuls post-hoc comparison test of cumulative weekly collections per trap showed non-significant differences ($F_{1,8}$=1.62; *P*=0.238) between the overall means of organic (7.65) and conventional

Table 5. Sex pheromone trap catches of moths in commercial water traps in ratoon (2010-11) sugarcane

Parameter	Shoot borer[1]		Internode borer[2]	
	Organic plot	Conventional plot	Organic plot	Conventional plot
Minimum / trap / day	0	0	0	0
Maximum / trap / day	8	3	6	5
Total in the season*	153	86	43	125

[1] 1-month (4-week) collection (Jul-Aug 2010); [2] 5-month collection (Aug 2010-Feb 2011)
* Five traps per plot

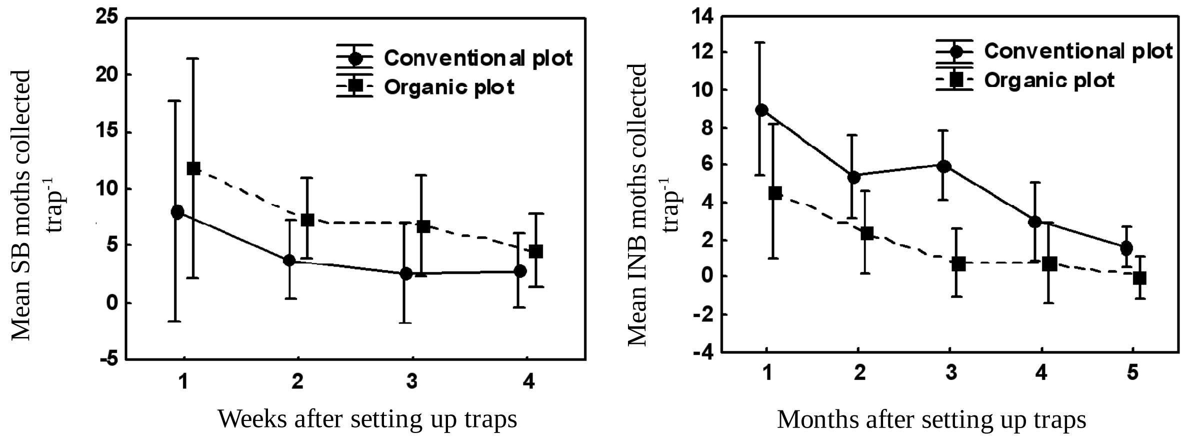

Fig. 5. Cumulative shoot borer (SB) and internode borer (INB) moth catches in sex pheromone traps in ratoon (2010-2011) sugarcane

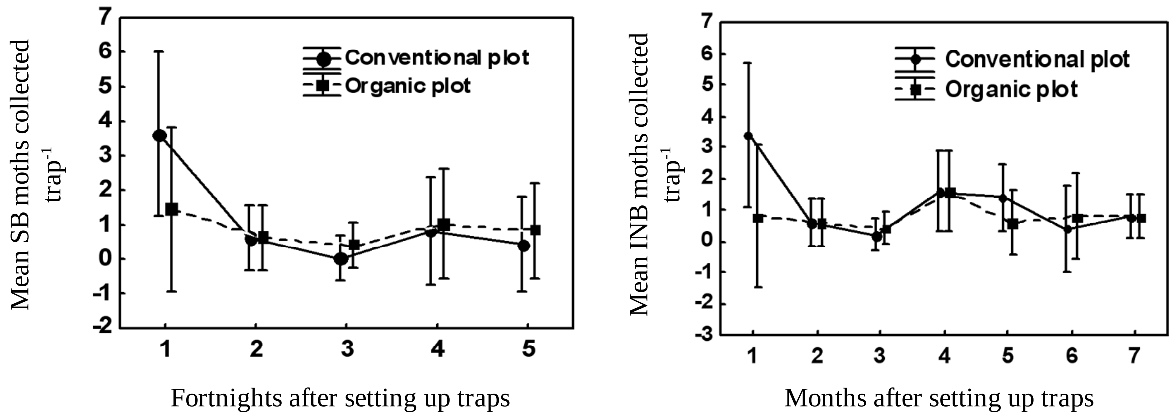

Fig. 6. Cumulative shoot borer (SB) and internode borer (INB) moth catches in sex pheromone traps in plant (2012-2013) sugarcane

(4.30) plots. In contrast, the cumulative collections in the plots were significantly ($F_{3,24}$=3.94; *P*=0.020) highest in the first week and remained on par within the subsequent three weeks. In INB, cumulative monthly collections per trap were significantly ($F_{1,8}$=12.03; *P*=0.008) lower in organic (1.72) than in conventional (5.00) plot. As in the case of SB, trap catches of INB were significantly ($F_{4, 32}$=15.01; *P*<0.0001) highest in the first month, on par in the next three months and lowest in the last month with a minor overlap. This season recorded the highest overall incidence of both borers among different years. Also, the differential moth catches of the two borers reflected in differences in their incidence levels (Tables 1 & 2).

Trap catches of the two borers in plant (2012-13) crop (Table 6) were lower than those collected in ratoon (2010-11) despite the fact that the traps were set up earlier and maintained for longer duration. This indicated lower activity of the borers than in the previous crop which was confirmed by the lower levels of incidence and intensity of the borers recorded in the two seasons (Tables 1 & 2). Cumulative trap catches progressively decreased and fluctuated with the season (Fig. 6) in a manner more or less similar to the trend observed in the previous season. In SB, as in the previous season, repeated measures ANOVA and Newman-Keuls post-hoc comparison test of cumulative fortnightly collections per trap showed non-significant

Table 6. Sex pheromone trap catches of moths in commercial water traps in plant (2012-13) sugarcane

Parameter	Shoot borer[1]		Internode borer[2]	
	Organic plot	Conventional plot	Organic plot	Conventional plot
Minimum / trap / day	0	0	0	0
Maximum / trap / day	3	4	2	2
Total in the season*	21	27	42	28

[1] 2.5-month (5-fortnight) collection (May-Jul 2012); [2] 7-month collection (Aug 2012-Mar 2013)
* Five traps per plot

differences ($F_{1, 8}$=0.72; P=0.421) between the overall means of organic (0.84) and conventional (1.08) plots. Also, the cumulative collections in the plots were significantly ($F_{4, 32}$=3.35; P=0.021) highest in the first fortnight and remained on par within the subsequent four fortnights. In INB, overall mean monthly collections per trap were non-significantly ($F_{1, 8}$=1.04; P=0.337) different between organic (0.80) and conventional (1.20) plots. Trap catches were significantly ($F_{6, 48}$=3.06; P=0.013) higher in the first month but showed lower values in the following months with overlapping differences. In the single SBI water trap and commercial funnel trap evaluated concurrently for the same duration in the season, total SB catches in the season adjusted to single trap were slightly lower than those in the commercial water trap (Table 7). For INB, while the total catches per trap in SBI water trap were comparable, funnel trap catches were slightly higher than those in the commercial water trap.

At the recommended dosage of 25 traps/ha (Mukunthan and Singaravelu 2004), SB lures captured higher number of moths than INB lures which suggested the greater efficacy of the former since both pests were active in the habitat. Further, the lack of clear-cut differences between the trap catches of the two plots, as was evident from repeated measures ANOVA and Newman-Keuls post-hoc test, pheromone traps may show greater efficacy when used on an area-wide basis than in individual contiguous plots as already suggested earlier (Srikanth et al. 2009a). A comparison between pheromone lures of sugarcane borers and

Table 7. Sex pheromone trap catches of moths in SBI water trap and funnel trap in plant (2012-13) sugarcane

Trap parameter	Shoot borer[1]				Internode borer[2]			
	SBI Water trap		Funnel trap		SBI Water trap		Funnel trap	
	Org[a]	Conv[b]	Org	Conv	Org	Conv	Org	Conv
Minimum / trap / day	0	0	0	0	0	0	0	0
Maximum / trap / day	1	2	0	2	1	1	1	4
Total in the season*	1	2	0	4	7	4	9	11

[1] 2.5-month (5-fortnight) collection (May-Jul 2012); [2] 7-month collection (Aug 2012-Mar 2013)
[a] Organic plot; [b] Conventional plot
* One trap per plot

cotton boll worms clearly indicated that at a dosage equivalent of only 5 traps/ha, *Spodoptera* lures captured far greater numbers of moths per week per trap than SB or INB lures. These results suggest a couple of points: (i) the efficacy of pheromone lures of sugarcane borers needs improvement to use them as mass trapping tools and presently they can serve only as a monitoring tool since the poor trap catches were at best related to the seasonal variations in borer incidence; (ii) SBI water trap and commercial funnel trap with SB and INB lures need to be evaluated at higher dosages to assess their field efficacy; (iii) pheromone lures of *Spodoptera* may be used for mass trapping in cotton or other crops in view of high field efficacy.

Cotton

In the rotational cotton crop of 2008-09, recommended insecticides controlled the populations of the mealybug *P. marginatus* in the conventional plot. However, application of the azadirachtin compound neemazol gave only minimal control of the pest in the organic plot. The mealybug damage led to a considerably lower kapas yield of 8.97 q/ha in organic plot than the 19.57 q/ha observed in the conventional plot (Sivaraman et al. 2012) seriously affecting the economics of the crop. In the rotational cotton crop of 2011-12, papaya mealybug incidence was not observed due to the introduction and establishment of specific and efficient natural enemies in the intervening two years (Dharajothi et al. 2011). Spray applications of imidacloprid and acephate in the conventional plot, and neem oil and neemazol in the organic plot brought down the populations of other sucking pests.

Overview and conclusions

The 10-year plot-level organic farming study in organic and conventional sugarcane plots revealed considerable variation in sugarcane pest scenario. The occasional significantly lower borer levels in organic cultivation could partly be due to the crop system, besides the crop-pest-natural enemy equilibrium sugarcane system seemed to exhibit in tropical India (Srikanth and Salin 2003). Also, organic farming did not aggravate borer problem even though it did not substantially decrease it. As discussed earlier (Srikanth et al. 2009a), selected pest management strategies adopted in our long-term study broadly agreed with those outlined in the model of Wyss et al. (2005) in both calendar- and need-based approaches. The studies suggested the role of pheromone traps in monitoring, if not mass trapping, borers. More importantly, the long –term study endorsed the usefulness of augmentative releases of biological control agents such as *D. aphidivora* and *E. flavoscutellum*, whose efficacy was established in independent studies (Srikanth et al. 2012 a & b), against woolly aphid in organic sugarcane. Validation of organic system under high pest densities and at farm or ecosystem level would allow application of the model in toto in an increasingly complex system. Comparative study of sample sugarcane farms in Maharashtra State indicated that the general low cost of plant protection (<4%) (Gawade et al. 2005; Kshirsagar 2008) was considerably reduced due to the use of biopesticides and other cultural practices in organic farming (Kshirsagar 2008). The minimal use of pheromonal, biological and organic chemicals in organic farming system of the present study indicated that the system can be economically viable from plant protection point of view. Invasive pests such as woolly aphid in the initial cycles appeared to pose a threat to organic farming since emergency insecticidal control could not be used against it and augmentative releases of the predator *D. aphidivora* gave gradual control (Srikanth et al. 2009a). As a result, the organic crop suffered substantial yield loss in plant (2006-07) crop (Sivaraman et al. 2012). However, the subsequent identification and field establishment of the potential parasitoid *E. flavoscutellum* led to natural regulation and stabilization of the aphid in the crop in a short span of 2-3 years resulting in comparable or slightly higher yield in organic plot in plant (2012-13) crop (Sivaraman et al. 2012). These developments indicate that biotic contingencies may hinder the progress of organic farming temporarily but need not undermine its prospects and practice.

In rotational cotton, pheromone traps and lures appeared to be a good tool for monitoring the activity of boll worms and the abundant catches of *Spodoptera* indicated the possibility of using its lures in the field for mass trapping. Also, organic system did not intensify routine pest problems and sucking pests could be managed with organic methods such as plant products. The invasive papaya mealybug in cotton devastated the crop and reduced the yield by half in 2008-09. However, as in the case of woolly aphid of sugarcane, successful establishment of natural enemies (Dharajothi et al. 2011) led to its control in about two years time. This proved that such threats can be tackled through organic means even in a pest- and pesticide-intensive crop like cotton.

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