



## Research Article

Dispersal pattern of *Trichogramma chilonis* Ishii in sugarcane fieldN. GEETHA<sup>1\*</sup> and R. BALAKRISHNAN<sup>2</sup><sup>1</sup>Division of Crop Protection, <sup>2</sup>Section of Statistics, Sugarcane Breeding Institute, Coimbatore 641007, Tamil Nadu, India.

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**ABSTRACT:** The ability of the laboratory-reared egg parasitoid, *Trichogramma chilonis* Ishii to disperse and locate sentinel egg cards in sugarcane field was evaluated. The dispersal behaviour was monitored at different crop ages of 45 days, 3 months, 5 months, 7 months and 9 months through egg-parasitism in sentinel cards with *Corcyra cephalonica* (Stainton) eggs in 24 h time. The sentinel cards were placed at distances of 1, 3, 5, 7, 10, 12, 15, 20, 25 and 30 m in eight cardinal directions from the release point of the parasitoid. The effects of distance from the release point, wind direction and crop age on the host location were evaluated. Distance had a clear proportional impact on the dispersal probability but this association was complicated by the fact that distance effects changed with crop age. The dispersal of the parasitoid was found to be the highest in 45 days old crop and the lowest in 7 months old crop. The parasitoid was found to move up to 10m effectively up to 5 months of crop age which declined thereafter. Although dispersal was found up to 30m, more uniform parasitism was observed in 10m circle surrounding the release point. The direction of wind was not associated with the rate of dispersal. The influence of distance, direction and age of the crop on adult emergence was not found to vary distinctly. The inference of differential ability of the parasitoid to move in the sugarcane field in securing uniform dispersal and in fixing adequate number of release points for inundative releases are discussed.

**KEY WORDS:** *Trichogramma chilonis*, dispersal, sugarcane, crop age, parasitism, emergence

(Article chronicle – Received: 02.02.2010; Sent for revision: 07.02.2010; Accepted: 10.02.2010)

## INTRODUCTION

Trichogrammatids are the most widely used egg parasitoids against lepidopterous pests on a wide range of agricultural and forest crops across the world for more than 70 years (Li, 1994) as inundative releases. Although in glasshouse crops augmentative biological control has proved commercially viable, success in the open field has been indefinable (Elzen and King, 1999). One of the main factors affecting the field performance of *Trichogramma* spp. is limited dispersal. It is well known that movement activity of *Trichogramma* species may depend on environmental conditions, primarily temperature (Fournier and Boivin, 2000), host density, release rates (Singh and Jalali, 1992), host plant density, physiological state (Reznik and Klyueva, 2006), wing size (Kölliker-Ott *et al.*, 2004) and sex (Canto-Silva *et al.*, 2006). Since *Trichogramma* species are very small in size ranging from 0.2 to 1.5mm they are believed to have a low capacity for active flights. Of more than 25 species reported in India, *Trichogramma chilonis* Ishii occurs widely all over the country throughout the year. The parasitoid is produced on a commercial scale and sold in India for the management of many lepidopterous pests and in sugarcane

against the tissue borers (Singh, 1996) occurring from germination to harvest. Despite the accepted practice of inundative release of *Trichogramma* @1-2 cc/acre for internode borer management, the degree of success obtained against the pest often varies for which the dispersing ability of the parasitoid may also be a contributing factor.

This study was conducted to understand how *T. chilonis* disperses from a single point through sugarcane crop, focusing on the influence of crop canopy and wind direction on movement pattern and the distance covered in short range dispersal. These results would provide an ingredient for the standardization of release points in an inundative release strategy using *T. chilonis* against internode borer (INB) in sugarcane.

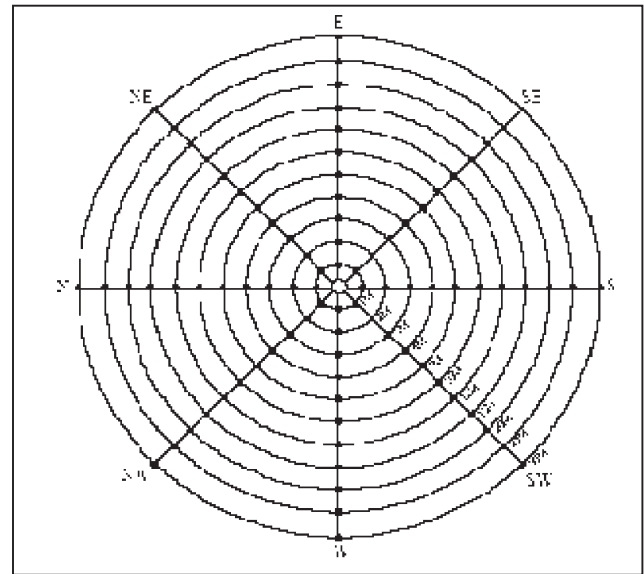
## MATERIALS AND METHODS

Since the idea was to reflect the actual dispersal during inundative releases in the field, the experiment was undertaken to compare the dispersal and parasitism of host eggs by *T. chilonis* in sugarcane fields with the crop ages of 45 days (crop height 1.5 m), 3 months, 5 months, 7 months and 9 months during 2004–2005 in Coimbatore, Tamil Nadu. In this study, *Corcyra cephalonica* (Stainton)

eggs were used in sentinel cards to observe the parasitism by the dispersing parasitoids instead of the target host, *Chilo sacchariphagus indicus* (Kapur) (INB) eggs since obtaining adequate numbers of INB eggs proved to be difficult. The less than 24 hrs old and mated *T. chilonis* parasitoids derived from the culture maintained in the insectary ( $28 \pm 2^\circ\text{C}$ ,  $50 \pm 3\%$  RH) at Sugarcane Breeding Institute (Coimbatore, Tamil Nadu), were used for this experiment.

The parasitoids were used at the rate of ca. 4000 for each of the six replicates (the dose per unit area derived –30 m radius circle of 2825 m<sup>2</sup> area, which corresponds to field dosages of ca. 40000 ha<sup>-1</sup> of wasps), in accordance with the recommendations prevailing during the period of the study. The sentinel cards were thick chart paper sheets of 8 x 1 cm size which carried at least 100 UV inactivated and unparasitised eggs of *C. cephalonica*, the factitious host used for mass production of *T. chilonis*. The fresh sentinel cards were positioned at 1, 2, 3, 5, 7, 10, 12, 15, 20, 25 and 30 m from the point of release of parasitoids at eight cardinal directions along the straight radius lines forming a ring around the release point at every distance studied (Fig. 1). The Tricho cards (with fresh mated *T. chilonis* adults) used for the study were held in glass vials till release and the cards were placed in the sugarcane field in a small circle with the central point of the circle serving as the release site of the parasitoid. Both the parasitoid cards and sentinel cards were stapled onto the ventral side of leaf lamina. The weather conditions were optimal for *Trichogramma* activity with a sunny climate and light winds. Weather parameters were later accessed from the nearest Meteorological Laboratory located at Sugarcane Breeding Institute, Coimbatore, which is ca. 3 km away from the test fields since the facilities to assess the microclimate were unavailable. Sentinel cards were placed in the top third of the plant canopy whereas *T. chilonis* cards were placed about half-way down the canopy. An interval of 24 hr was allowed to elapse following the release of the parasitoid after which the sentinel cards were collected for determination of incidence of parasitism. The cards were maintained at the ambient temperature of 28-30°C for 3 days to observe the percentage of parasitised eggs. When there was complete destruction of a sample by predators, the data was construed as missing. The natural population of *T. chilonis* at the trial site was assessed by placing sentinel cards alone, a week prior to experimentation as well as during the experiments at 200 m distance, to estimate if there is any huge interference with the data collected.

The data were transformed using arcsine square root transformation. Treatment means of per cent parasitism and emergence were analyzed using ANOVA. When



● WHERE SENTINEL CARDS WERE LOCATED

**Fig. 1. Placement of the parasitoid cards and sentinel cards in sugarcane**

significant differences among treatment means were found by ANOVA, the means were separated using Student–Newman–Keuls (SNK) multiple range test (SAS Institute, 1990). Interaction effects of distance and crop age with percentage parasitism were analysed by following general linear model (univariate) of SPSS program version 11.5.

**RESULTS AND DISCUSSION**

When the sentinel cards were collected for assessment of parasitism after 24 h of field exposure, the distance and direction from the release points were noted. Dispersal can most effectively be measured through eggmass parasitism since this shows how far the wasps traveled and reproduced successfully (Caughley, 1977). The natural parasitism rates in sentinel cards prior to and during the experiments were below 0.5% and thus were considered to be insignificant. The field temperature was 30-32°C during the day and 16-22°C during night. RH was 84-90% in the morning and 38-48% in the afternoon. Wind velocity was 1.5-2.7 km/h and wind direction was generally northeast and northwest.

*Dispersal as influenced by crop age and distance*

The average percentage parasitism rates were 70.83, 63.5, 77.58, 44.15 and 69.33, respectively, on the crop age of 45 days, 3 months, 5 months and 9 months at 1 m distance (Table 1) from the release point. Beyond 10 m

from the release point the dispersal was remarkably low in any given crop age tested. Within a particular crop age, the dispersal response varied in proportion to distance. On 45 days old crop, up to 3 m the rate of parasitism was higher (> 70%), which decreased to 51.0% at 5m distance and ca. 30.0% up to 12 m beyond which it declined further. *T. chilonis* could disperse up to 30 m but the level of parasitism observed was 2.88% (Table 1). As the crop canopy became dense, this trend was further affected. Except on 5 months old crop, the dispersal was below 5% at 12m and beyond. The likely reason for higher dispersal in 5 months old crop is that the crop had less of canopy compared to 3<sup>rd</sup> or 7<sup>th</sup> month crop with air flow to aid the movement.

Studies on *T. chilonis* dispersal in sugarcane are meager. Some other studies have revealed that *Trichogramma* spp. dispersal is quite limited (Andow and Prokrym, 1991; McDougall and Mills, 1997; Yu *et al.*, 1984) and decreases with distance from the release point (Bigler *et al.*, 1988; Yu *et al.*, 1984) which is seen in the present study too. However, long distance dispersal ability of different *Trichogramma* spp. has also been reported (Bigler *et al.*, 1990; Stern *et al.*, 1965; Wright *et al.*, 2001).

One possibility for lesser dispersal to longer distance could be due to lower movement ability of *Trichogramma*

to move between plants than within a single plant (Kanour and Burbutis, 1984). Further support for this theory has been found in dispersal investigations using sentinel eggs, where the newly emerged parasitoids oviposited near the colony in which they developed (Weisser and Völki, 1997). The decrease in parasitism in sentinel cards in proportion to distance (Table 1) was also due to the fact that few organisms will travel very far as a result of a tendency to settle and due to dilution of individual numbers in a larger area at increased distances from the center (Turchin, 1998).

*Dispersal as influenced by wind direction*

Wind oriented dispersal was not found in this study. Probably wind flow is required for parasitoid movement but the direction does not have any influence. There were no significant differences among parasitism rates in different directions for a given distance from the release point across the crop age (Table 2) or within a given crop age. For example, irrespective of the crop age, at 1m distance from the release point, the per cent parasitism in the sentinel cards in different directions was found to be 60 to 73 which were not significantly different. Therefore, distance and the crop age were keys to percentage parasitism with no effect of wind direction.

**Table 1. Percentage sentinel egg parasitism based on plant age and distance (irrespective of direction)**

| Distance (m)<br>(m)           | Age of the crop (months)     |                             |                              |                             |                             | Pooled data<br>(in a single<br>distance) |
|-------------------------------|------------------------------|-----------------------------|------------------------------|-----------------------------|-----------------------------|--|
|                               | 45days                       | 3 months                    | 5months                      | 7 months                    | 9 months                    |  |
|                               | Mean ± S.E                   | Mean ± S.E                  | Mean ± S.E                   | Mean ± S.E                  | Mean ± S.E                  |  |
| 1                             | 70.83 ± 2.73 <sup>f</sup> B  | 63.5 ± 2.73 <sup>f</sup> B  | 77.58 ± 2.73 <sup>d</sup> B  | 44.15 ± 3.30 <sup>a</sup> A | 69.33 ± 2.73 <sup>a</sup> B | 66.48 ± 1.28 <sup>e</sup>                |
| 2                             | 82.19 ± 2.73 <sup>c</sup> C  | 59.94 ± 2.73 <sup>f</sup> B | 71.63 ± 2.73 <sup>d</sup> B  | 36.49 ± 3.03 <sup>a</sup> A | 68.02 ± 2.73 <sup>a</sup> B | 64.71 ± 1.25 <sup>e</sup>                |
| 3                             | 71.77 ± 2.76 <sup>c</sup> C  | 41.15 ± .73 <sup>c</sup> B  | 40.77 ± 2.86 <sup>c</sup> B  | 20.83 ± 2.92 <sup>b</sup> A | 31.49 ± 2.76 <sup>d</sup> B | 41.65 ± 1.26 <sup>f</sup>                |
| 5                             | 51.29 ± 2.76 <sup>c</sup> C  | 31.44 ± 2.73 <sup>d</sup> B | 37.39 ± 2.96 <sup>c</sup> B  | 18.23 ± 3.03 <sup>b</sup> A | 17.29 ± 2.73 <sup>c</sup> A | 31.36 ± 1.27 <sup>c</sup>                |
| 7                             | 29.42 ± 2.73 <sup>cd</sup> D | 24.52 ± 2.73 <sup>c</sup> B | 31.67 ± 2.92 <sup>c</sup> A  | 6.15 ± 3.30 <sup>a</sup> A  | 6.59 ± 3.52 <sup>b</sup> A  | 17.64 ± 1.37 <sup>d</sup>                |
| 10                            | 28.96 ± 2.82 <sup>cd</sup> D | 11.79 ± 2.73 <sup>b</sup> C | 20.89 ± 3.30 <sup>b</sup> D  | 1.76 ± 3.03 <sup>a</sup> A  | 4.92 ± 3.16 <sup>b</sup> B  | 15.52 ± 1.35 <sup>d</sup>                |
| 12                            | 30.94 ± 3.16 <sup>d</sup> B  | 1.36 ± 2.92 <sup>a</sup> A  | 14.72 ± 3.03 <sup>ab</sup> B | 1.47 ± 2.82 <sup>a</sup> A  | 1.13 ± 3.11 <sup>a</sup> A  | 10.22 ± 1.39 <sup>c</sup>                |
| 15                            | 16.2 ± 2.82 <sup>bc</sup> A  | 0.62 ± 2.86 <sup>a</sup> A  | 12.95 ± 2.89 <sup>b</sup> B  | 0.45 ± 2.92 <sup>a</sup> A  | 0.60 ± 3.95 <sup>a</sup> A  | 7.45 ± 1.35 <sup>c</sup>                 |
| 20                            | 15.68 ± 2.96 <sup>bc</sup> C | 0.20 ± 3.2 <sup>a</sup> A   | 12.68 ± 3.03 <sup>ab</sup> B | 0.72 ± 3.03 <sup>a</sup> A  | 0.35 ± 3.46 <sup>a</sup> AB | 4.39 ± 1.39 <sup>b</sup>                 |
| 25                            | 6.30 ± 3.29 <sup>b</sup> B   | 0.69 ± 3.03 <sup>a</sup> A  | 4.21 ± 2.96 <sup>a</sup> B   | 0.07 ± 2.92 <sup>a</sup> A  | 0.67 ± 3.46 <sup>a</sup> A  | 4.58 ± 1.4 <sup>b</sup>                  |
| 30                            | 2.88 ± 2.73 <sup>a</sup> AB  | 0.75 ± 2.86 <sup>a</sup> AB | 4.10 ± .03 <sup>a</sup> B    | 0.09 ± 4.13 <sup>a</sup> A  | 0.43 ± 3.20 <sup>a</sup> A  | 1.86 ± 1.44 <sup>a</sup>                 |
| Pooled data (in a single age) | 38.43 ± 0.87 <sup>d</sup>    | 22.98 ± 0.86 <sup>b</sup>   | 31.44 ± 0.89 <sup>c</sup>    | 11.57 ± 0.95 <sup>a</sup>   | 22.78 ± 0.96 <sup>b</sup>   |  |

Mean values in a column (lower case) and in a row (upper case) followed by the same letters are not significantly different (Student–Newman–Keuls (SNK) multiple range test, *Alpha* = 0.05). Based on Type III Sum of Squares; analysis conducted on arcsine–transformed data; Age x Distance interaction was significant (*Alpha* = 0.05). Pooled data in the last column (distance) and in the last row (age) showed significant differences within themselves, indicated by different alphabets

In open field conditions, researchers found that wind has a substantial influence on dispersal direction and distance traveled by *Trichogramma* spp. (Hendricks, 1967; Yu *et al.*, 1984). On the contrary, upwind movement of *T. chilonis* by orienting themselves to wind-borne chemical cues and flying in that direction when wind conditions are conducive to flight has been reported (Boo and Young, 2000).

*Pooled data analysis on parasitism influenced by separate effects of crop age, distance, direction*

The individual effects of crop age, distance from release point and wind direction were analysed by pooling data on parasitism (category wise) over all distances, in all directions and at all ages tested (Table 1, 2). It was observed that parasitism rates ranged from 11.57 to 31.44 per cent among the different crop ages tested (Table 1) showing significant effect of crop canopy on the parasitism levels. In the crop age of 45 days the parasitism was  $\leq 30\%$  up to 12 m while in three and five months this was reduced to 7m and reduced to 3 m in the crop age of 9 months. With reference to the distances from the release points the per cent parasitism varied from 66.48 at 1m to 1.86 at 30m with significant differences among them (Table 1). No significant differences were found in the parasitism rates (24.23 to 27.94%) among

different cardinal directions irrespective of the age or distance (Table 2).

*Parasitoid emergence*

The parasitoid emergence was not influenced by crop age, distance or directions in the present study. Within a given crop age, the per cent emergence did not vary with distance in 45 days and seven months old crop. On three, five and nine month old crops there were differences but not necessarily in correspondence to distance from release point (Table 3). There were non-significant differences in parasitoid emergence pattern with respect to directions in any crop age or distance tested. Pooling the data on per cent emergence the differences were overlapping with respect to crop age as well as distance from releases points tested. No effect of directions on the emergence of the parasitoids was observed (Table 3).

*Probable reasons for lower levels of dispersal*

The factors that may have led to lower levels of dispersal by *T. chilonis* in the present study could be many. One of them may be the innate disability of the parasitoid to disperse rapidly and to longer distances since species to species differences in dispersal ability of *Trichogramma* have been reported. Other factors influencing the dispersal pattern besides the parasitoid behavior are the time after

**Table 2. Percentage sentinel egg parasitism based on direction and distance (irrespective of plant age)**

| Distance (m) | Direction (Mean $\pm$ S.E.)*   |                                |                               |                                 |                                |                                |                                |                               |
|--------------|--------------------------------|--------------------------------|-------------------------------|---------------------------------|--------------------------------|--------------------------------|--------------------------------|-------------------------------|
|              | North                          | Northeast                      | East                          | Southeast                       | South                          | Southwest                      | West                           | Northwest                     |
| 1            | 64.87 $\pm$ 3.98 <sup>c</sup>  | 70.78 $\pm$ 4.20 <sup>d</sup>  | 61.63 $\pm$ 3.98 <sup>e</sup> | 67.13 $\pm$ 4.45 <sup>d</sup>   | 60.41 $\pm$ 4.20 <sup>d</sup>  | 73.08 $\pm$ 4.45 <sup>f</sup>  | 68.67 $\pm$ 4.45 <sup>c</sup>  | 66.37 $\pm$ 4.05 <sup>d</sup> |
| 2            | 70.50 $\pm$ 3.98 <sup>c</sup>  | 69.37 $\pm$ 4.20 <sup>d</sup>  | 65.00 $\pm$ 3.98 <sup>e</sup> | 66.07 $\pm$ 4.88 <sup>d</sup>   | 61.19 $\pm$ 4.36 <sup>d</sup>  | 60.57 $\pm$ 4.36 <sup>f</sup>  | 63.33 $\pm$ 4.28 <sup>c</sup>  | 61.90 $\pm$ 4.20 <sup>d</sup> |
| 3            | 50.83 $\pm$ 3.98 <sup>d</sup>  | 40.41 $\pm$ 3.98 <sup>c</sup>  | 45.57 $\pm$ 3.98 <sup>f</sup> | 35.41 $\pm$ 4.28 <sup>c</sup>   | 42.96 $\pm$ 4.05 <sup>c</sup>  | 39.97 $\pm$ 4.05 <sup>c</sup>  | 44.34 $\pm$ 4.76 <sup>d</sup>  | 32.86 $\pm$ 4.12 <sup>c</sup> |
| 5            | 27.32 $\pm$ 4.36 <sup>c</sup>  | 40.40 $\pm$ 4.36 <sup>c</sup>  | 39.38 $\pm$ 4.05 <sup>c</sup> | 29.17 $\pm$ 4.20 <sup>bc</sup>  | 26.59 $\pm$ 4.45 <sup>b</sup>  | 26.13 $\pm$ 4.28 <sup>d</sup>  | 28.20 $\pm$ 4.45 <sup>c</sup>  | 32.41 $\pm$ 4.36 <sup>c</sup> |
| 7            | 23.78 $\pm$ 5.14 <sup>c</sup>  | 16.16 $\pm$ 4.28 <sup>b</sup>  | 14.40 $\pm$ 4.36 <sup>d</sup> | 16.83 $\pm$ 5.14 <sup>abc</sup> | 24.00 $\pm$ 4.45 <sup>b</sup>  | 20.71 $\pm$ 4.88 <sup>cd</sup> | 18.43 $\pm$ 4.28 <sup>bc</sup> | 19.75 $\pm$ 4.28 <sup>b</sup> |
| 10           | 13.48 $\pm$ 4.36 <sup>bc</sup> | 14.54 $\pm$ 4.28 <sup>b</sup>  | 8.91 $\pm$ 4.65 <sup>d</sup>  | 21.15 $\pm$ 5.14 <sup>ab</sup>  | 19.17 $\pm$ 4.36 <sup>ab</sup> | 13.75 $\pm$ 4.55 <sup>bc</sup> | 17.60 $\pm$ 3.98 <sup>bc</sup> | 14.84 $\pm$ 4.36 <sup>b</sup> |
| 12           | 9.88 $\pm$ 4.45 <sup>ab</sup>  | 13.04 $\pm$ 4.55 <sup>ab</sup> | 9.86 $\pm$ 4.65 <sup>c</sup>  | 15.29 $\pm$ 4.45 <sup>ab</sup>  | 7.71 $\pm$ 4.55 <sup>a</sup>   | 5.62 $\pm$ 3.98 <sup>ab</sup>  | 8.12 $\pm$ 3.98 <sup>ab</sup>  | 9.88 $\pm$ 4.76 <sup>ab</sup> |
| 15           | 10.63 $\pm$ 4.45 <sup>ab</sup> | 8.58 $\pm$ 4.20 <sup>ab</sup>  | 3.57 $\pm$ 4.55 <sup>bc</sup> | 11.11 $\pm$ 3.98 <sup>a</sup>   | 5.75 $\pm$ 4.76 <sup>a</sup>   | 4.68 $\pm$ 3.98 <sup>ab</sup>  | 6.21 $\pm$ 3.98 <sup>ab</sup>  | 7.08 $\pm$ 4.20 <sup>ab</sup> |
| 20           | 4.27 $\pm$ 4.28 <sup>ab</sup>  | 4.38 $\pm$ 4.36 <sup>ab</sup>  | 5.04 $\pm$ 4.28 <sup>ab</sup> | 8.89 $\pm$ 4.05 <sup>a</sup>    | 5.88 $\pm$ 3.98 <sup>a</sup>   | 5.58 $\pm$ 4.05 <sup>ab</sup>  | 2.19 $\pm$ 4.05 <sup>a</sup>   | 2.59 $\pm$ 5.14 <sup>a</sup>  |
| 25           | 3.88 $\pm$ 4.45 <sup>ab</sup>  | 2.12 $\pm$ 4.20 <sup>ab</sup>  | 3.96 $\pm$ 4.45 <sup>ab</sup> | 5.96 $\pm$ 4.55 <sup>a</sup>    | 5.78 $\pm$ 4.20 <sup>a</sup>   | 4.15 $\pm$ 4.36 <sup>ab</sup>  | 1.92 $\pm$ 4.36 <sup>a</sup>   | 3.62 $\pm$ 4.20 <sup>a</sup>  |
| 30           | 0.43 $\pm$ 4.76 <sup>a</sup>   | 0.91 $\pm$ 4.05 <sup>a</sup>   | 1.17 $\pm$ 3.98 <sup>a</sup>  | 4.09 $\pm$ 3.98 <sup>a</sup>    | 3.52 $\pm$ 4.20 <sup>a</sup>   | 0.96 $\pm$ 4.12 <sup>a</sup>   | 1.50 $\pm$ 4.65 <sup>a</sup>   | 1.22 $\pm$ 4.20 <sup>a</sup>  |
| Pooled data* | 26.18 $\pm$ 1.95               | 25.07 $\pm$ 1.82               | 25.51 $\pm$ 1.85              | 24.23 $\pm$ 1.80                | 24.74 $\pm$ 1.81               | 25.55 $\pm$ 1.88               | 27.94 $\pm$ 1.96               | 27.69 $\pm$ 2.01              |

\*No significant differences among directions within a distance parameter; no significant interaction of age x direction; significant interaction of distance x direction. Mean values in a column followed by the same letter(s) are not significantly different (Student–Newman–Keuls (SNK) multiple range test,  $\alpha = 0.05$ ). Based on Type III. Sum of Squares; analysis conducted on arcsine- transformed data; Pooled data on per cent parasitism in a single direction (over all the distances tested irrespective of crop age) in the last row showed significant differences within themselves, indicated by different alphabets



**Table 3. Percentage emergence from parasitised sentinel eggs based on plant age and distance (irrespective of direction)**

| Distance (m)           | Age of the crop (months)   |                            |                            |                           |                            | Pooled data (Age)          |
|------------------------|----------------------------|----------------------------|----------------------------|---------------------------|----------------------------|----------------------------|
|                        | 45days*                    | 3 months                   | 5months                    | 7 months*                 | 9 months                   |                            |
|                        | Mean ± S.E                 | Mean ± S.E                 | Mean ± S.E                 | Mean ± S.E                | Mean ± S.E                 | Mean ± S.E                 |
| 1                      | 91.86 ± 1.85               | 90.14 ± 1.81 <sup>ab</sup> | 92.83 ± 1.81 <sup>ab</sup> | 94.67 ± 2.37              | 93.95 ± 1.81 <sup>ab</sup> | 92.52 ± 0.88 <sup>b</sup>  |
| 2                      | 92.16 ± 1.81               | 91.25 ± 1.81 <sup>ab</sup> | 93.61 ± 1.81 <sup>b</sup>  | 96.43 ± 2.29              | 93.69 ± 1.81 <sup>ab</sup> | 93.19 ± 0.88 <sup>b</sup>  |
| 3                      | 91.54 ± 1.85               | 85.26 ± 1.81 <sup>ab</sup> | 89.92 ± 1.91 <sup>ab</sup> | 93.11 ± 2.55              | 86.61 ± 1.93 <sup>ab</sup> | 88.88 ± 0.92 <sup>ab</sup> |
| 5                      | 96.53 ± 1.89               | 83.88 ± 1.81 <sup>a</sup>  | 91.34 ± 2.06 <sup>ab</sup> | 95.77 ± 2.50              | 83.91 ± 2.03 <sup>a</sup>  | 89.77 ± 0.94 <sup>ab</sup> |
| 7                      | 89.06 ± 2.06               | 83.56 ± 1.91 <sup>a</sup>  | 87.34 ± 2.80 <sup>ab</sup> | 96.41 ± 3.23              | 88.18 ± 2.73 <sup>ab</sup> | 86.20 ± 1.12 <sup>a</sup>  |
| 10                     | 90.21 ± 2.00               | 85.70 ± 1.95 <sup>ab</sup> | 89.71 ± 2.21 <sup>ab</sup> | 97.92 ± 5.11              | 85.55 ± 2.50 <sup>a</sup>  | 86.56 ± 1.09 <sup>a</sup>  |
| 12                     | 75.41 ± 2.03               | 82.45 ± 2.80 <sup>ab</sup> | 83.11 ± 2.15 <sup>a</sup>  | 90.01 ± 6.26              | 92.50 ± 3.96 <sup>ab</sup> | 89.86 ± 1.27 <sup>a</sup>  |
| 15                     | 91.25 ± 2.09               | 80.13 ± 3.47 <sup>ab</sup> | 91.35 ± 2.41 <sup>ab</sup> | 97.91 ± 4.73              | 95.00 ± 5.60 <sup>b</sup>  | 90.38 ± 1.39 <sup>ab</sup> |
| 20                     | 87.64 ± 2.09               | 79.17 ± 6.26 <sup>ab</sup> | 92.52 ± 3.77 <sup>b</sup>  | 92.00 ± 8.85              | 91.02 ± 3.96 <sup>ab</sup> | 90.31 ± 1.64 <sup>ab</sup> |
| 25                     | 85.45 ± 2.18               | 88.33 ± 3.96 <sup>b</sup>  | 91.16 ± 2.87 <sup>ab</sup> | 86.11 ± 4.73              | 94.44 ± 4.17 <sup>b</sup>  | 88.31 ± 1.48 <sup>ab</sup> |
| 30                     | 86.62 ± 3.61               | 80.00 ± 3.77 <sup>ab</sup> | 92.27 ± 3.47 <sup>b</sup>  | 87.00 ± 12.51             | 91.02 ± 4.42 <sup>ab</sup> | 89.31 ± 1.95 <sup>ab</sup> |
| Pooled data (distance) | 89.09 ± 0.67 <sup>BC</sup> | 84.27 ± 0.98 <sup>AB</sup> | 90.96 ± 0.82 <sup>BC</sup> | 92.62 ± 1.96 <sup>C</sup> | 88.94 ± 1.10 <sup>BC</sup> | 92.52 ± 0.88 <sup>B</sup>  |

Emergence among different directions was not found to be significantly different (range: 88.20 – 91.56). Mean values in a column followed by the same lower case letter(s) (and upper case letters in pooled data on distance in the same row) are not significantly different (Student–Newman–Keuls (SNK) multiple range test,  $\alpha = 0.05$ ). Based on Type III Sum of Squares; analysis conducted on arcsine-transformed data; Age x Distance interaction was significant ( $\alpha = 0.05$ ); \* The per cent emergence was not significantly different.

release and the size of experimental area (Canto-Silva *et al.*, 2006). The lower levels of parasitism found in the current study could be due to lesser time (24 h) allowed for dispersal. This view is supported by Wright *et al.* (2001) who found increased levels of parasitism by *T. ostrinae* over time (14 days).

The low level of parasitism as distance increased could also be due to lack of sufficient number of parasitoids required to cover the area. In such a case, the number of release points as well as the number of parasitoids used per inundative release has to be increased to have good dispersal. Density-dependent and independent dispersal has been observed in other crops and other *Trichogramma* spp. (Fournier and Boivin, 2000; McDougall and Mills, 1997; Singh and Jalali, 1992; Wright *et al.*, 2001).

Besides the reasons cited above, the effect of crop architecture may have been an important factor influencing the dispersal rate considering the results. However, it is not clear why the dense crop canopy (3 and 9 months) which is complex yet due to the continuum of foliage could have aided but actually did not support dispersal and why the simple crop design at 45 days and 5 months where there is a lot of open field, had allowed parasitoid

dispersal. Role of plant cues in the location of host habitat and eggs in *Trichogramma* (Bjorksten and Hoffmann, 1998) has been established and for *T. chilonis* too, crop age specific cues may have been strategic to search and parasitise.

#### *Impact of dispersal ability on inundative releases*

For augmentation to be effective, we need to understand the factors limiting the field performance of *T. chilonis* and crop age influencing the dispersal rate is a factor as proven in this study. The number of release sites for inundative introductions should ensure that the parasitoid is uniformly distributed throughout the crop to achieve maximum control effect (Wang and Shipp, 2004).

Parasitoids are biocontrol agents which have specialized to be good searchers of hosts for their survival. However, given the low level of dispersal ability of *T. chilonis* varying with crop age, and the arbitrary, uneven and isolated pattern of lepidopterous borer infestations, optimization of spacing and thus number of release points per unit area is required for sufficient pest management. In other crops and other species of *Trichogramma*, work in such an aspect has been found in abundance but neither in sugarcane nor on *T. chilonis*. In Switzerland,

*Trichogramma* wasps are released at 50 points per ha for the wasps to parasitise host eggs efficiently within an 8m radius (Bigler, 1983). Increasing the number of release points resulted in greater parasitism levels by *T. pretiosum* (Wang and Shipp, 2004). A single release point per hectare had been adequate to ensure uniform dispersal of *T. ostrinae* into sweet corn fields (Wright *et al.*, 2001). However, in most of these studies quoting higher dispersal, the release rates of parasitoids used had been higher, time allowed for dispersal longer and plant architecture simpler compared to those in the present study.

Before drawing conclusions from the present study on the number of release points required for efficient dispersal in sugarcane, the effect of increased density of the parasitoid on the dispersal range and time allowed for dispersal need to be considered. Analyzing such factors would give a true picture so as to decide the number of dispersal points.

#### ACKNOWLEDGEMENTS

We thank Dr. N. Balasundaram, the Director during the period of study and Dr. N. Vijayan Nair, the Director, Sugarcane Breeding Institute for the facilities and encouragement. Support by Shri. R. Palanisamy (SBI) and Dr. V. Geethalakshmi, Professor (Meteorology, TNAU) is gratefully acknowledged for the provision of weather data and for interpretation of weather data, respectively.

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