TRIALS OF MATING DISRUPTION AGAINST THE MILLET STEM BORER, *Coniesta ignefusalis* HAMPSON (LEPIDOPTERA: PYRALIDAE) IN NIGER, 1996-1998

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Abstract. The millet stemborer, *Coniesta ignefusalis* Hampson (Lepidoptera: Pyralidae) is a major pest of pearl millet in the Sahelian region of Africa. The female sex pheromone has been identified and synthesised, and previous work showed the synthetic pheromone could cause high levels of communication disruption in small plots when released at rates of 640 mg/ha/day. The latter trials used a PVC resin formulation that had to be renewed every seven days. During trials in farmers' fields in 1996, 86.8 ± 2.6% communication disruption was obtained with polyethylene vials loaded with 0.5 mg pheromone at 400 dispensers/ha replaced every 21 days. Polyethylene vials loaded with 80 mg pheromone gave uniform, zero-order release at approximately 0.05 mg/day at 27°C. Trials were carried on replicated, 0.5 ha plots in farmers' fields in Niger using a single application of these dispensers at 400 dispensers/ha. At least 99% suppression of pheromone trap catches of male *C. ignefusalis* moths in treated plots relative to catches in untreated plots was achieved for up to 3 months. However, sampling the central portions of these plots before and after harvest showed no significant differences in infestation, damage or yield loss between plots treated with pheromone and untreated plots. Comparisons of catches of male *C. ignefusalis* moths in traps baited with the standard 0.5 mg monitoring lures and those baited with the 80 mg disruption dispensers showed catches in the latter were only 10-20% of those in the former.

INTRODUCTION

The millet stemborer, *Coniesta ignefusalis* Hampson (Lepidoptera: Noctuidae), is one of the two main insect pests of millet throughout the West African Sahelian and Soudanian zones (Harris, 1962; N'doye *et al*., 1984; N'doye and Gahukar, 1987, Youm *et al*., 1996). First generation larvae cause dead heart and stand loss, while the second and third generations cause lodging, disruption of the vascular system and inhibition of grain formation (Harris, 1962). In the sub-Saharan Africa region where pearl millet is the major staple crop grown by subsistence farmers, yield losses due to attack by *C. ignefusalis* range from 15% to total crop failure (Harris, 1962; Ajayi, 1990), and in Niger over 90% of stem borer infestation and damage on millet is caused by *C. ignefusalis* (Youm and Gilstrap, 1993, 1994).

Control by chemical means is not very effective and repeated applications are not possible in subsistence agriculture (Youm, 1990). Destruction of alternative hosts and crop residues is difficult to enforce because of the importance of these materials for construction, decoration and animal bedding in the Region (Harris, 1962). Manipulation of planting dates Vercambre, 1978; Guevremont, 1983; Youm, 1990), field sanitation (Nwanze and Muller, 1989) and burning of stalks (Guevremont, 1983; Maiga 1984) have given inconsistent results. Although

some tolerance has been reported in varieties producing a sticky secretion (N'doye, 1977) or increased tillering (Nwanze, 1985), there are no varieties showing useful levels of resistance. Natural enemies of *C. ignefusalis* have been described (see Youm *et al*., 1996), but significant parasitism develops too late in the growing season (Youm, 1990).

Female *C. ignefusalis* moths were shown to produce a sex pheromone that attracts the male moths (Bako, 1977; ICRISAT, 1989) and this was isolated, identified and synthesised by Beevor *et al*. (1999). Synthetic lures were optimised and an effective, locally-made trap developed (Youm *et al*., 1993; Youm & Beevor, 1995; Youm *et al*., 1995). The traps have been used extensively for monitoring the pest in the Region as part of the West and Central African Millet Research Network (Dakouo *et al.*, 1997; Youm *et al.*, 1997). Some reduction in damage by *C. ignefusalis* was reported for mass trapping around village granaries with 25 traps/ha (ICRISAT 1994; 1995), and initial results on use of the synthetic pheromone for control of *C. ignefusalis* by mating disruption were reported by Beevor *et al*. (1996). Using a PVC resin formulation of the pheromone components, it was shown that the attractive pheromone blend was more effective at disruption than two "inhibitor" compounds which reduce the attractiveness of the attractive blend, and essentially complete communication disruption was achieved with release rates of 0.64 gm/ha/day. The main limiting factor was lack of a suitable formulation as the PVC resin had a half life of only a few days under field conditions, making frequent replacement necessary.

This paper describes further work on mating disruption of *C. ignefusalis* and development of a longer-lived formulation.

MATERIALS AND METHODS

Experimental sites.

Experiments were carried out on-station at ICRISAT Sahelian Centre, Sadore, Niger, or in nearby farmers' fields.

Pheromone traps.
Pheromone traps were locally-constructed water-oil traps with a lid, positioned 0.5 m above ground level (Youm and Beevor, 1995). Catches of male *C. ignefusalis* moths were recorded daily and discarded. Trap lures were renewed every 21 days.

Pheromone dispensers.

Pheromone dispensers used in field trials were either sealed polyethylene vials (32 x 15 x 2 mm thick; Agrisense, UK) impregnated with 0.5 mg of the pheromone blend or sealed polyethylene vials (20 x 9 x 1.5 mm thick; Just Plastics, UK) containing 100 µl (80 mg) of the pheromone blend. The lids on the latter were sealed by heating or with EVA hot-melt "glue-gun". The pheromone blend contained (*Z*)-7-dodecenol, (*Z*)-5-decenol and (*Z*)-7-dodecenal in 100:5:3 mixture. Compounds were prepared at NRI as described by Beevor *et al*. (1999). In general, the 0.5 mg lures were for use in monitoring traps, and the 80 mg lures were developed for use in mating disruption.

Laboratory assessment of formulations.

Release rates of various formulations of the pheromone or an analogue (1-dodecanol, 12:OH) were measured at NRI. Duplicate samples of the formulation were maintained in a laboratory windtunnel (27°C, 8 kph windspeed) and release measured as weight loss by weighing the dispensers at regular intervals. Dispensers included the above small polyethylene vials and polyethylene sachets (2.5 cm x 2.5 cm x 120 µ thick; containing 120 µl approx 100 mg pheromone).

Analysis of dispensers from field.

During the 1997 mating disruption trial, two dispensers were collected each week, wrapped in aluminium foil and returned to NRI at the end of the season. The pheromone remaining in the individual dispensers was extracted with hexane (5 ml) containing dodecyl acetate (12:Ac, 5 mg) overnight at room temperature. The resulting solution was analysed by gas chromatography (GC) using a fused silica capillary column (25 m x 0.32 mm i.d.) coated with CPWax 57CB (Carbowax equivalent; Chrompack, UK), temperature programmed from 60°C for 2 min, then at 6°C/min to 230°C. Amounts of pheromone components were calculated by comparison of peak areas with those of the 12:Ac internal standard.

Damage assessment.

Typically at 40 and 70 days after sowing (DAS) the percentage of infested hills and number of dead hearts was recorded from the central portion of each plot (10 m x 10 m). After harvest the number of entry and exit holes and number of larvae were recorded from 10-50 randomly selected stems from the central portion of each plot. Percentage data was transformed to arcsin and counts to the square root and then subjected to analysis of variance.

EXPERIMENTS AND RESULTS

1996 Trials

Spacing experiment

The experiment was conducted at Sadore station. Plots (20 m x 20 m) were sown with millet variety ICMV-IS-92222 on 6 June 1996 (0.75 m spacing between hills). Plots were kept weed-free by two weeding operations with hand hoes.

Plots were treated with standard monitoring lures (0.5 mg loading) attached to metal stakes at 0.5 m above ground level at spacings of 1 m, 5 m or 10 m (equivalent to 10,000, 400 or 100 dispensers per ha, and 5 gm, 0.2 gm or 0.05 gm a.i. per ha). There were six replicates of the three treatments and an untreated control in a randomised block design with 20 m between plots. Lures were renewed every 21 days.

A standard pheromone trap was placed at the centre of each plot and catches of male *C. ignefusalis* moths were counted each day and discarded from 9 July to 26 September 1996. At 40 and 70 DAS the percentage of infested hills and number of dead hearts were recorded from the central portion of each plot (10 m x 10 m). After harvest the number of entry and

exit holes and number of larvae were recorded from 10 randomly selected stems from each plot.

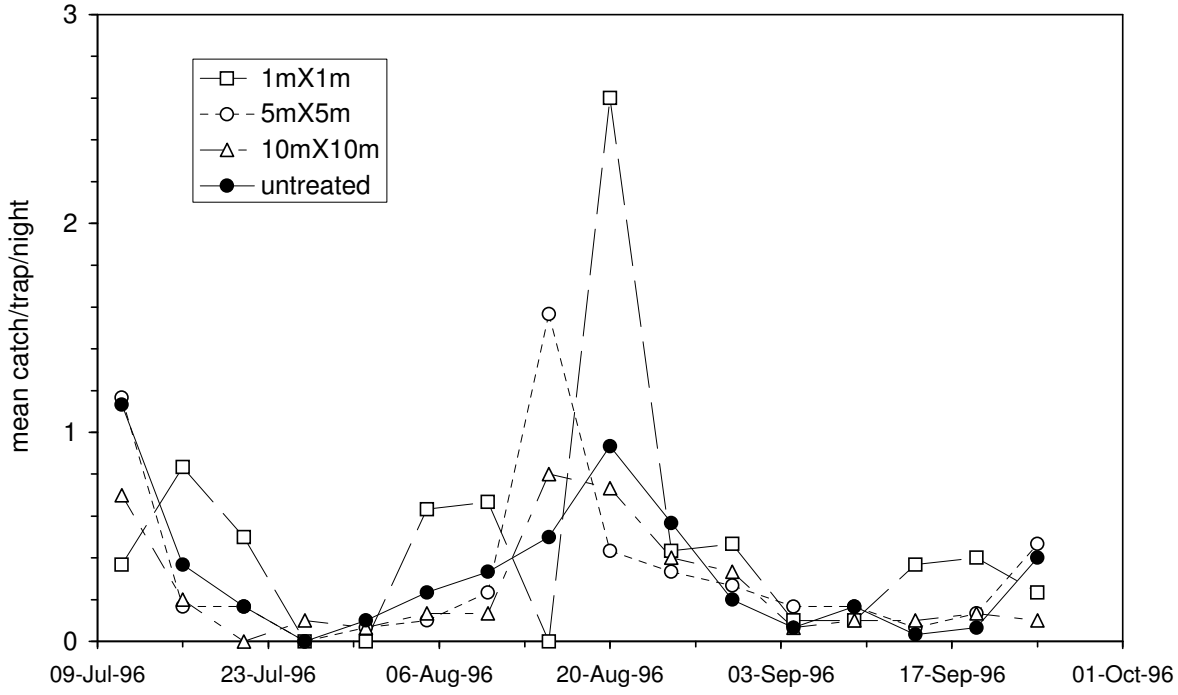

FIG. 1 Mean catches of male *C. ignefusalis* moths in traps in plots treated with pheromone dispensers at different spacings (six replicates; mean catches over five day periods; 1996).

Pheromone trap catches in all plots were low and there was no evidence of reduction in catches in any of the treated plots relative to the catches in the untreated plots (Fig. 1). Furthermore there was no evidence for any reductions in infestations before (Table 1) or after (Table 2) harvest.

TABLE 1. Mean numbers of dead hearts and percentage infested hills (± standard error) at 40 and 70 DAS in dispenser spacing experiment (central 10 m x 10 m).

	Dead heart count		% Infested hill	
Treatment	40 DAS	70 DAS	40 DAS	70 DAS
1 m x 1 m	0.00 ± 0.0	1.83 ± 1.04	0.00 ± 0.00	0.76 ± 0.39
5 m x 5 m	0.33 ± 0.21	4.16 ± 1.42	0.22 ± 0.13	1.43 ± 0.30
10 m x 10 m	1.66 ± 1.11	3.00 ± 1.50	0.43 ± 0.21	1.30 ± 0.69
Untreated	0.83 ± 0.83	2.00 ± 1.29	0.32 ± 0.32	0.86 ± 0.61
Trial mean	0.70	2.74	0.24	1.08

TABLE 2. Mean numbers of larvae, entry and exit holes (± standard error) in dispenser spacing experiment after harvest (10 plants)

Treatment	Larvae	Entry holes	Exit holes
1 m x 1 m	3.50 ± 1.36	54.66 ± 19.27	17.50 ± 8.29
5 m x 5 m	8.16 ± 1.85	76.33 ± 14.31	16.83 ± 4.45
10 m x 10 m	4.50 ± 0.80	57.16 ± 8.78	15.33 ± 2.89
Untreated	4.33 ± 1.81	68.33 ± 24.43	16.50 ± 6.57
Trial mean	5.12	64.12	16.54

Mating disruption

The experiment was conducted at Sadore station. Plots (40 m x 40 m) were sown with millet varieties Sadore Local and ICMV-IS-89305 on 6 June 1996 (1 m spacing between rows and 0.75 m spacing within rows). Plots were kept weed-free by two weeding operations with hand hoes.

There were three treatments - pheromone, insecticide and untreated - replicated with each variety in four randomised blocks. The pheromone plots were treated with standard monitoring lures (0.5 mg loading) attached to metal stakes at 0.5 m above ground level at 5 m spacing (equivalent to 400 per ha, 200 mg a.i. per ha). The treatment began 21 DAS, and dispensers were renewed every 21 days. The insecticide plots were treated with Decis at 21 DAS, flag leaf stage and at one third panicle exertion.

A standard pheromone trap was placed at the centre of each plot and catches of male *C. ignefusalis* moths were counted each day and discarded from 21 June to 26 September 1996. At 40 and 75 DAS the percentage of infested hills and number of dead hearts was recorded from the central portion of each plot (10 m x 10 m). After harvest the number of entry and exit holes and number of larvae were recorded from 10 randomly selected stems from each plot.

In this trial, the pheromone dispensers caused a significant reduction in catches in the pheromone trap in the treated plots relative to those in the untreated plots (Fig. 2). The mean percentage reduction in catch over the season across the eight replicates (four blocks with two varieties) was 86.8 ± 2.6% (untransformed data).

However, damage assessments showed no consistent or significant ($P < 0.05$) differences between dead heart counts, percent infestation, entry and exit holes or larval counts in pheromone, insecticide or untreated plots (Tables 3 and 4).

There were also few differences between the performances of the two varieties (Tables 5, 6)

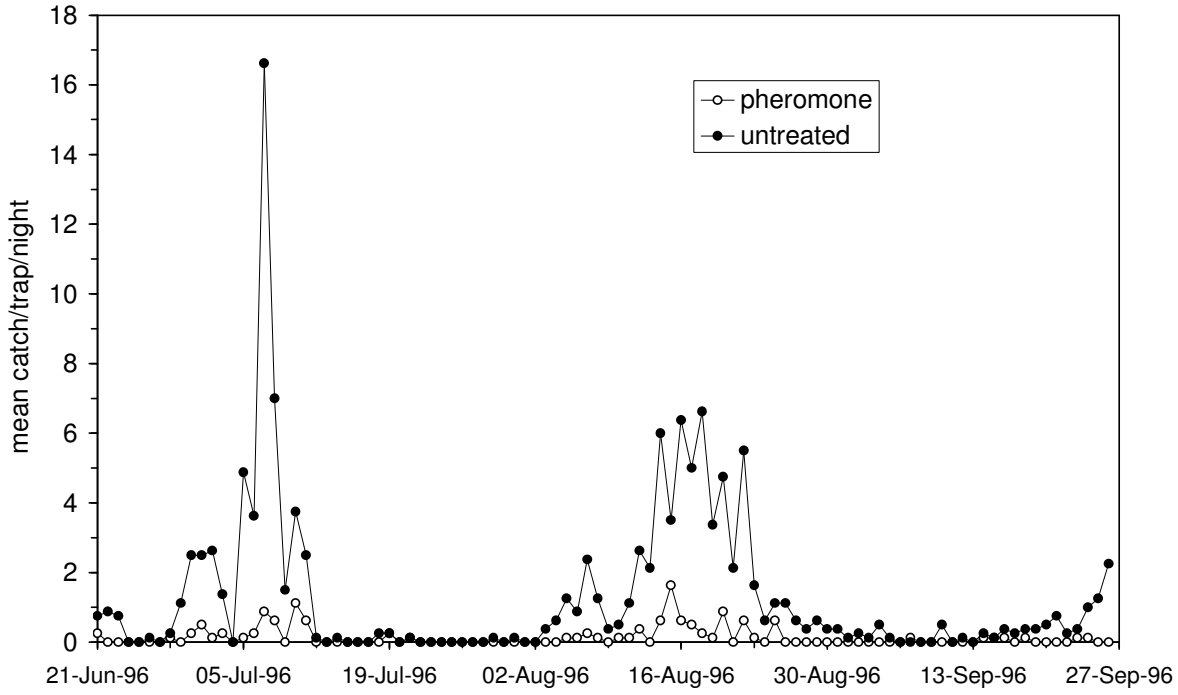

FIG. 2. Mean catches of male *C. ignefusalis* moths in traps in 1996 mating disruption trial (four replicates on each of two varieties).

TABLE 3. Mean numbers of dead hearts and percentage infested hills (± standard error) at 40 and 70 DAS in 1996 mating disruption trial (four replicates for two varieties; results from central 10 m x 10 m).

Treatment	Dead heart count		% Infested hill	
	40 DAS	75 DAS	40 DAS	75 DAS
Pheromone	1.62 ± 0.94	2.87 ± 1.24	0.65 ± 0.24	1.23 ± 0.34
Insecticide	0.87 ± 0.51	2.12 ± 1.00	0.56 ± 0.33	0.81 ± 0.36
Untreated	1.25 ± 0.67	2.25 ± 0.83	0.49 ± 0.23	1.07 ± 0.35

TABLE 4. Mean numbers of larvae, entry and exit holes (± standard error) in 1996 mating disruption trial after harvest (four replicates for two varieties; results from 10 stems).

Treatment	Larvae	Entry holes	Exit holes
Pheromone	0.01 ± 0.00	0.15 ± 0.04	0.01 ± 0.01
Insecticide	0.08 ± 0.07	0.53 ± 0.32	0.09 ± 0.06
Untreated	0.03 ± 0.01	0.16 ± 0.06	0.03 ± 0.01

TABLE 5. Mean numbers of dead hearts and percentage infested hills (± standard error) at 40 and 70 DAS in 1996 mating disruption trial on the two varieties (four replicates for three treatments; results from central 10 m x 10 m).

Variety	Dead heart count		% Infested hill	
	40 DAS	75 DAS	40 DAS	75 DAS
ICMV-IS-92222	1.75 ± 0.32	1.08 ± 0.89	0.43 ± 0.20	0.54 ± 0.24
Sadore Local	0.75 ± 0.39	3.75 ± 0.52	0.70 ± 0.23	1.50 ± 0.23

TABLE 6. Mean numbers of larvae, entry and exit holes (± standard error) in 1996 mating disruption trial after harvest (four replicates for three treatments; results from 10 stems).

Treatment	Larvae	Entry holes	Exit holes
ICMV-IS-92222	0.06 ± 0.04	0.39 ± 0.21	0.07 ± 0.04
Sadore Local	0.02 ± 0.00	0.17 ± 0.05	0.02 ± 0.01

1997 Trials

Dispenser evaluation.

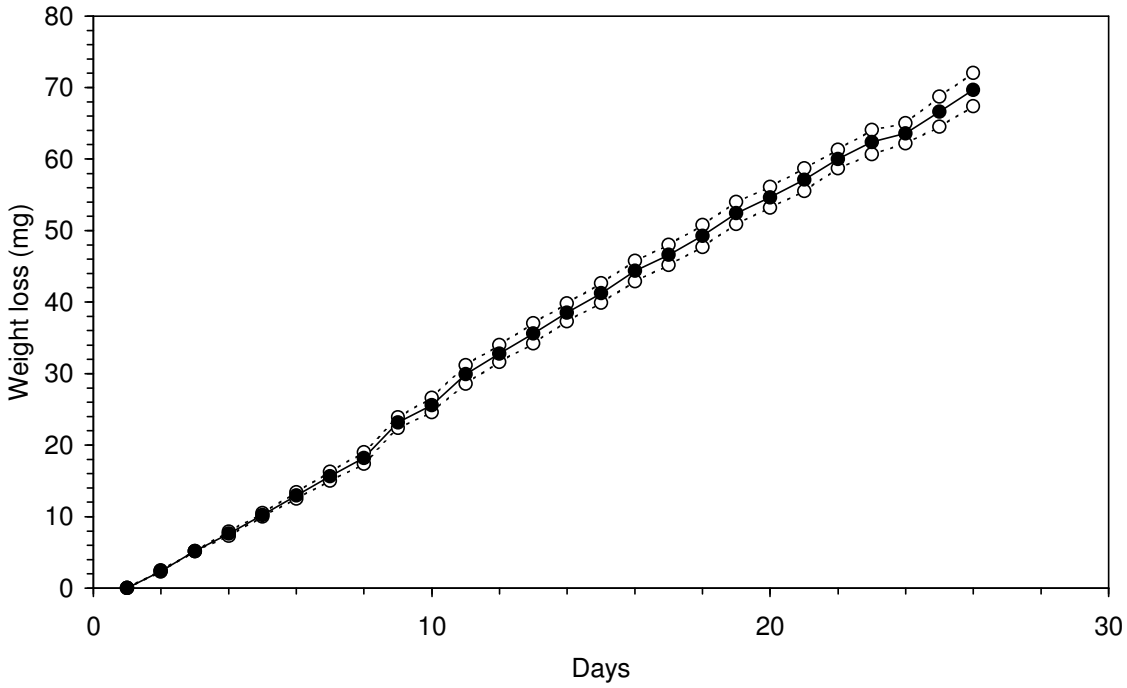

FIG. 3. Release of 1-dodecanol from polyethylene sachet (25 mm x 25 mm x 0.12 mm thick; 100 mg; 27°C, 8 kph windspeed; ● mean of two replicates ❍).

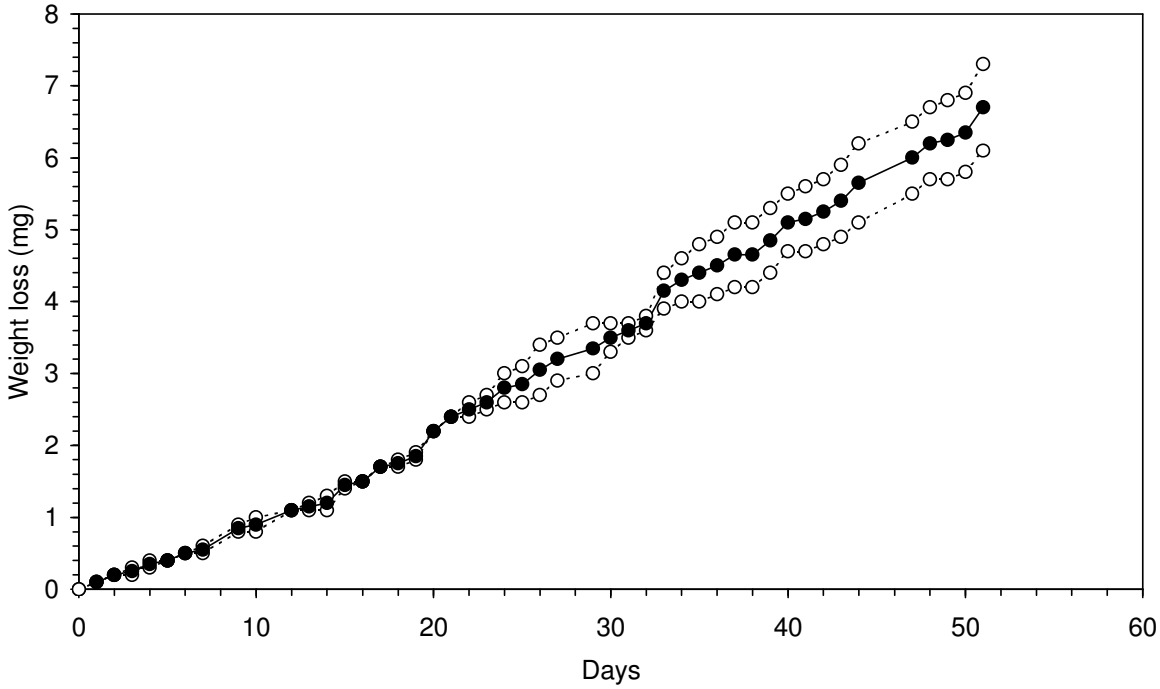

FIG. 4. Release of 1-dodecanol from polyethylene vials (27°C, 8 kph windspeed; ; ● mean of two replicates ❍))

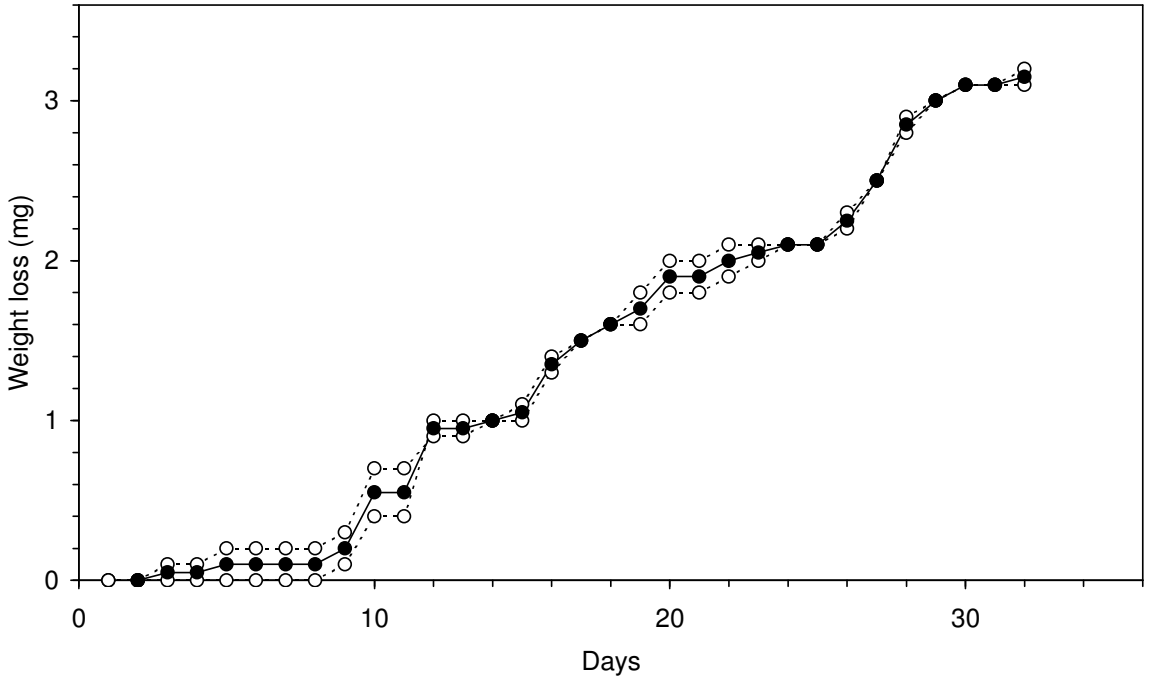

FIG. 5. Release of *C. ignefusalis* pheromone blend from polyethylene vials (27°C, 8 kph windspeed; ● mean of two replicates ❍).

The release rate of 1-dodecanol from a polyethylene sachet was constant (zero-order) over the period of measurement (Fig. 3).

Similarly, release of 1-dodecanol (Fig. 4) or the *C. ignefusalis* pheromone blend (Fig. 5) from sealed polyethylene vials loaded with 100 µl of material was constant.

TABLE 7. Release rates of pheromone components from dispensers under laboratory conditions measured by weight loss (27°C, 8 kph windspeed)

Dispenser	Compound	Rate (mg/day)	
		1 dispenser	400 dispensers
Polyethylene sachet	12:OH	2.58	1,032
Polyethylene vial	12:OH	0.13	52
Polyethylene vial	*C. ignefusalis* blend	0.11	44

Actual release rates at 27°C are shown in Table 7 giving the observed rate for each type of dispenser and the rate calculated per ha for an application of 400 dispensers per ha as had been used previously in the field. Previous results had shown that a mean rate of 640 mg/ha/day gave effective communication disruption (Beevor *et al.*, 1996). Typical shade temperatures for Sadore (1996 data) are shown in Fig 6. These show mean maximum of 35.1°C, mean minimum 23.7°C and overall average 29.4°C.

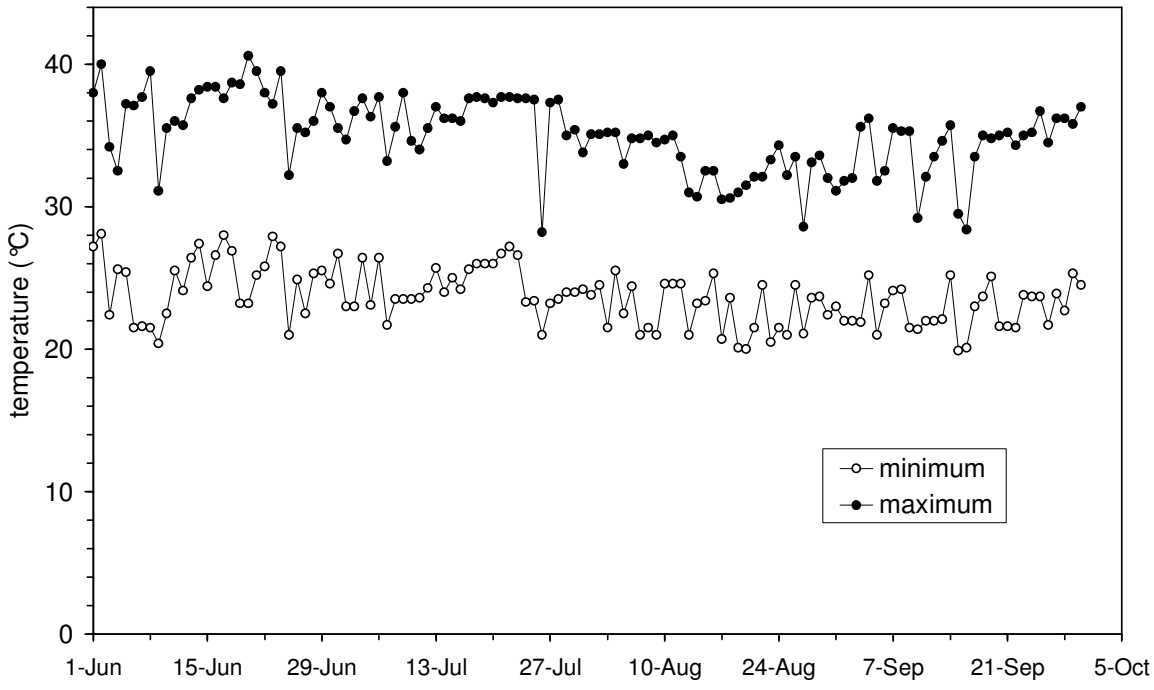

FIG 6. Maximum and minimum temperatures at Sadore, 1996 (Mean max 35.1 °C, mean min 23.7 °C, overall average 29.4 °C).

Release through polyethylene devices is known to be affected exponentially by temperature and double for a 6°C rise in temperature (Torr *et al*., 1996), and so it was considered that release of pheromone from the polyethylene sachets would be much more rapid than was required. Release from the vials was probably on the slow side, but, allowing for the fact that the above temperatures are shade temperatures, overall release rates might well reach 1 mg/day/dispenser (400 mg/ha/day) which was approaching the target value. Furthermore, dispensers containing 80 mg pheromone would then be predicted to last for up to three months in the field, as required for *C. ignefusalis*. A lower estimate would be 0.3 mg/day/dispenser corresponding to only 30% released during the season.

Field trial

The 1997 trial was carried out in farmers' fields at Sadore with four plots (0.5 ha) treated with pheromone and four (0.25 ha) untreated. Treated and untreated plots were separated by at least 500 m. All plots were planted with millet variety ICVM-IS-92222 with 1 m x 1 m spacing between hills. After emergence hills were thinned to three plants and two weeding operations were carried out.

Pheromone dispensers for mating disruption were sealed polyethylene vials (22 x 9 x 1.5 mm, Just Plastics Ltd.) containing 100 µl (80 mg) of the *C. ignefusalis* pheromone blend (Z7-12:OH + Z5-10:OH + Z7-12:Ald 100:5:3). In the treated plots, dispensers were placed on wire stakes at 0.5 m above ground level; and 5 m spacing to give an application rate of 400 sources/ha (32 gm a.i./ha). The sources were not replaced during the season from 4 July - 14 October 1997.

A standard pheromone trap was placed at the centre of each plot and catches of male *C. ignefusalis* moths were counted each day and discarded. In the treated plots, traps were baited with the 80 mg dispensers used for mating disruption. In the untreated plots, standard monitoring lures (polyethylene vials 32 x 15 x 2 mm, impregnated with 0.5 mg pheromone blend) were used 4 July - 4 August 1997, but these were then replaced by the 80 mg dispensers for the remainder of the trial. All trap lures were renewed every 21 days.

At 40 and 75 DAS the percentage of infested hills and number of dead hearts was recorded from the central portion of each plot (10 m x 10 m). After harvest the number of exit holes and number of larvae were recorded from 50 stems randomly selected from the central portion of each plot (5 from each row). Percentage infested hills data was transformed to arcsin, and percentage dead hearts and exit hole and larval counts data to the square root and then subjected to analysis of variance.

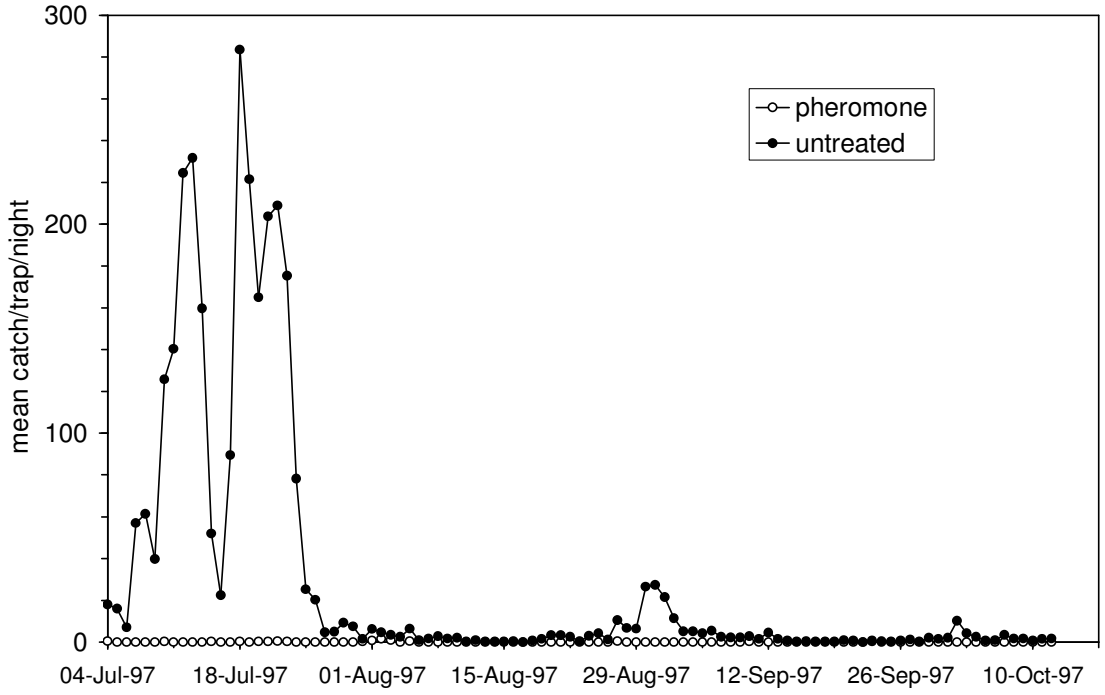

FIG. 7. Trap catches of male *C. ignefusalis* moths in treated and untreated areas during mating disruption 1997 trial (mean of four replicates)

TABLE 8. Pheromone trap catch data for 1997 mating disruption trial (across four replicates pheromone-treated and untreated for period indicated; % disruption untransformed)

Dates	No. Nights	Mean catch/trap/night ± SE		% Disruption ± SE
		Pheromone	Untreated	
4 Jul - 4 Aug	31	0.19 ± 0.04	79.47 ± 20.51	99.7 ± 0.1
4 Aug - 14 Oct	70	0.02 ± 0.01	3.26 ± 0.87	99.0 ± 0.5
4 Jul - 14 Oct	101	0.07 ± 0.02	26.65 ± 6.67	99.7 ± 0.1

Trap catch data in Fig. 7 indicates a high level of trap catch shut down in the treated plots relative to catches in the untreated plots, and the results are summarised in Table 8.

However, it should be noted that traps in the treated plots were baited with the 80 mg lures throughout, whereas those in the untreated plots were baited with 0.5 mg lures from 4 July - 4 August 1997 and the 80 mg lures thereafter. As is shown later, catches with the 80 mg lures are much lower than with the 0.5 mg lures, so that catches in treated and untreated plots during 4 July - 4 August cannot really be compared. However, it should be noted that during the subsequent period when traps in treated and untreated plots were baited with identical 80 mg lures, trap catches in the treated plots remained at zero when catches in the untreated plots increased significantly at the end of August. This was more than 8 weeks after the mating disruption dispensers were first deployed.

The mating disruption dispensers were sampled at weekly intervals and the amount of pheromone remaining determined by GC analysis at NRI. The results were very variable, probably due to leakage of pheromone from some of the dispensers during handling. However, lures that had not leaked still contained 70% of the initial loading of pheromone after 10 weeks in the field. Fig. 8 shows the proportions of the minor pheromone components, Z7-12:Ald and Z5-10:OH, relative to the major component, Z7-12:OH, remaining in the dispensers. The proportion of the relatively more volatile Z5-10:OH remained remarkably constant although that of the Z7-12:Ald declined. This was probably due to both a higher release rate and degradation of the more labile aldehyde.

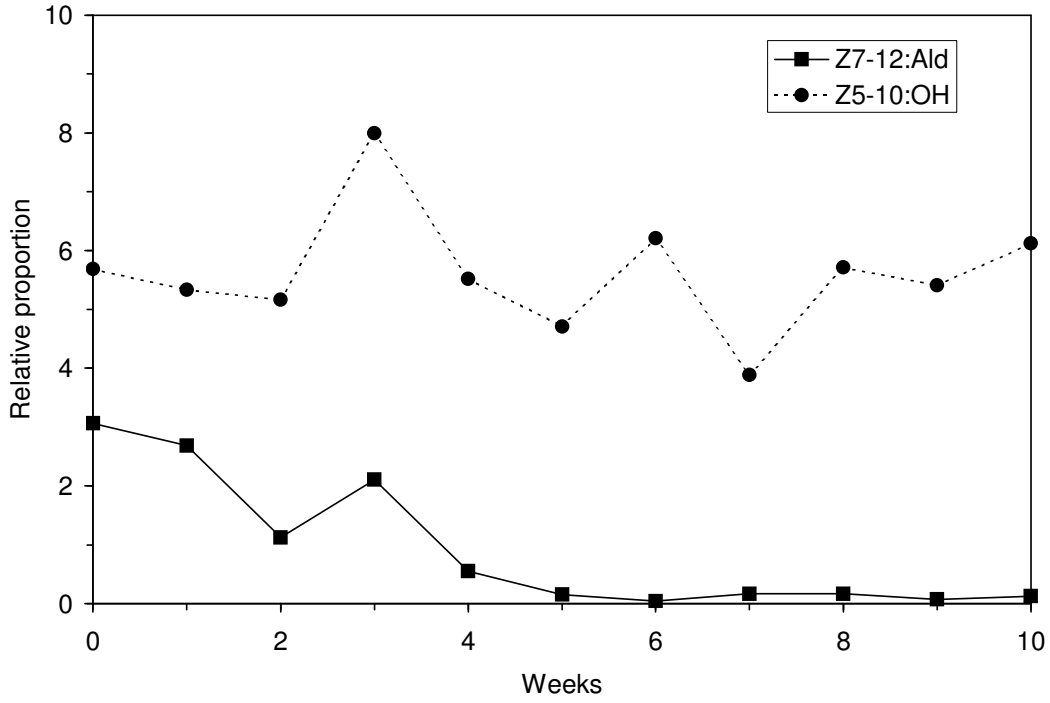

FIG. 8. Relative proportions (Z7-12:OH = 100) of Z5-10:OH and Z7-12:Ald remaining in dispensers used in 1997 mating disruption trial.

Estimates of damage by *C. ignefusalis* showed lower numbers of dead hearts and infested hills in the plots treated with pheromone relative to those in the untreated plots, although these differences were not significant at the 5% level (Table 9). After harvest, counts of larvae and exit holes were significantly lower ($P<0.05$) in the pheromone-treated plots than in the untreated plots, although damage levels were low throughout (Table 10).

TABLE 9. Mean percent dead hearts and infested hills (± standard error) at 40 and 70 DAS in 1997 mating disruption trial (four replicates; results from central 10 m x 10 m).

Treatment	% Dead heart		% Infested hill	
	40 DAS	70 DAS	40 DAS	70 DAS
Pheromone	0.45 ± 0.30	5.37 ± 4.51	1.35 ± 0.90	13.91 ± 10.91
Untreated	0.93 ± 0.32	7.08 ± 2.34	2.04 ± 0.84	18.81 ± 7.40

TABLE 10. Mean numbers of larvae and exit holes (± standard error) in 1997 mating disruption trial (four replicates; results from 50 stems; means followed by different letter in a column are significantly different at 5% level by DMRT)).

Treatment	Larvae	Exit holes
Pheromone treated	2.28 ± 0.22 a	1.79 ± 0.15 a
Untreated	2.88 ± 0.02 b	2.30 ± 0.13 b

Trapping experiments

Three experiments were carried out to compare catches in water traps baited with standard 0.5 mg monitoring lures with those in similar traps baited with the 80 mg dispensers used for mating disruption. In all three experiments, lures were renewed every 21 days.

In the first experiment, two traps of each type were placed at opposite corners of a 35 m square on the ICRISAT station, and catches were monitored daily from 16 July - 30 October 1997 (106 nights).

The second experiment was run over the same period using three replicates of the two traps 30-35 m apart in three different farmers' fields.

In the third experiment, two traps of each type were placed at opposite corners of a 100 m square on-station and catches were monitored from 5 September - 30 October 1997 (56 nights).

Results are shown in Figs. 9, 10 and 11 for the three experiments respectively. In all three experiments, catches in traps baited with the 0.5 mg lures were much higher than those in traps baited with the 80 mg lures, and mean catches across the replicates are summarised in Table 11. In all three trials, differences between means were highly significant ($P<0.01$) by simple *t* tests on untransformed data.

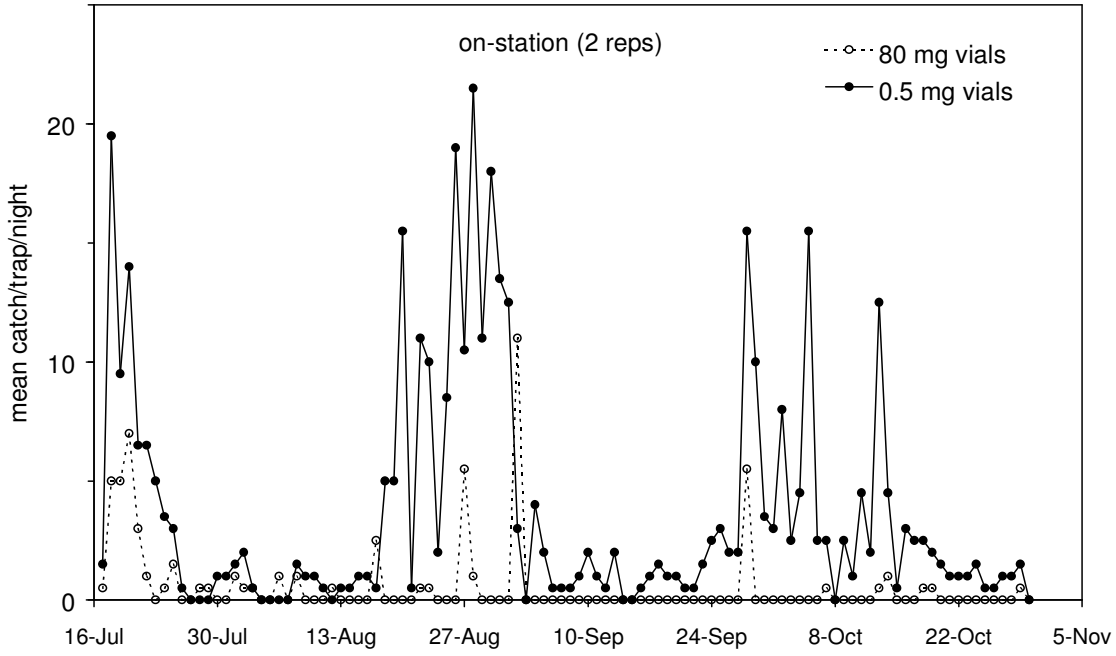

FIG. 9. Catches of *C. ignefusalis* male moths in traps baited with polyethylene vials containing 0.5 mg or 80 mg pheromone on-station (traps 30-35 m apart; 2 replicates).

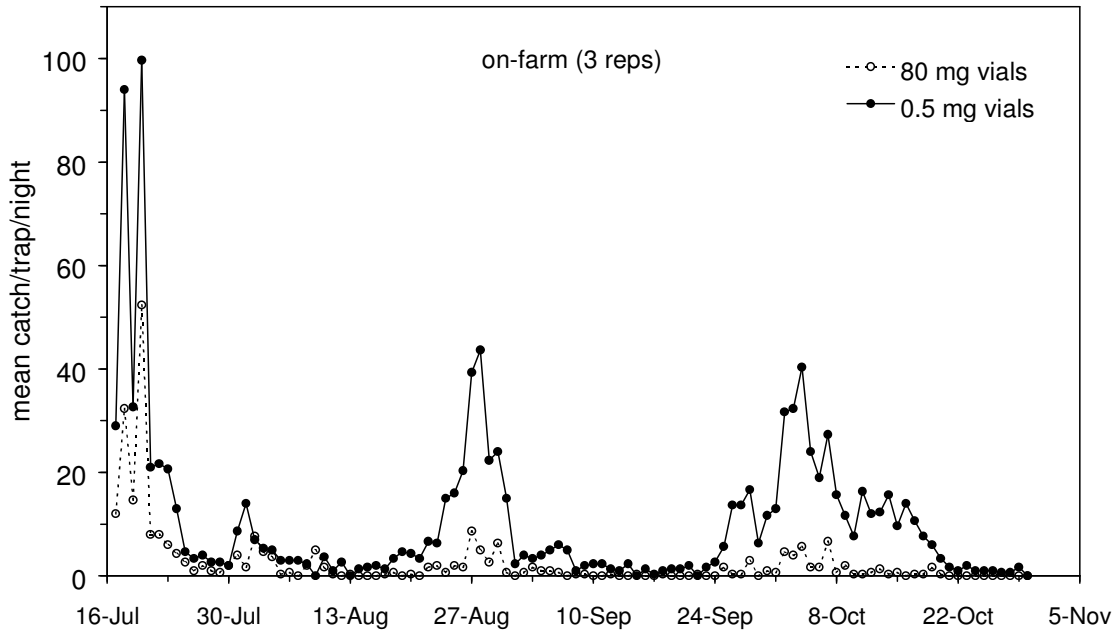

FIG. 10. Catches of *C. ignefusalis* male moths in traps baited with polyethylene vials containing 0.5 mg or 80 mg pheromone in farmers' fields (traps 30-35 m apart; 3 replicates)

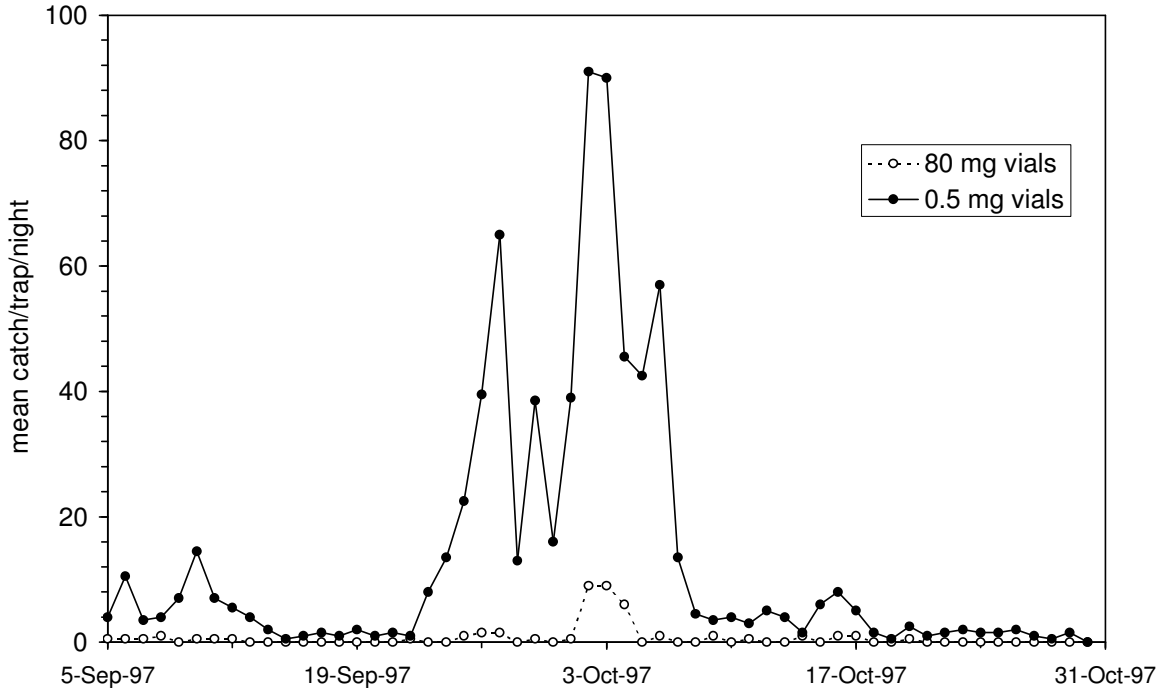

FIG. 11. Catches of *C. ignefusalis* male moths in water traps baited with polyethylene vials containing 80 mg or 0.5 mg pheromone (trap spacing 100 m; 2 replicates)

TABLE 11. Mean catches of *C. ignefusalis* male moths in traps baited with 0.5 mg or 80 mg lures.

Location	Spacing (m)	No. nights	No. reps	Mean catch/trap/night ± SE	
				0.5 mg lure	80 mg lure
On-station	30-35	106	2	3.74 ± 0.04	0.56 ± 0.03
On-farm	30-35	106	3	10.25 ± 1.86	2.42 ± 0.19
On-station	100	56	2	12.99 ± 0.35	0.71 ± 0.17

1998

Mating disruption trial

The trial was carried out in farmers' fields at Sadore with five plots (0.5 ha) treated with pheromone and five (0.25 ha) untreated. Treated and untreated plots were separated by at least 500 m.

Pheromone dispensers for mating disruption were sealed polyethylene vials (22 x 9 x 1.5 mm, Just Plastics Ltd.) containing 100 µl (80 mg) of the *C. ignefusalis* pheromone blend (Z7-12:OH + Z5-10:OH + Z7-12:Ald 100:5:3). In the treated plots, dispensers were placed on wire stakes at 0.5 m above ground level; and 5 m spacing to give an application rate of

400 sources/ha (32 gm a.i./ha). The sources were not replaced during the season from 4 July - 1 October 1998.

A standard pheromone trap was placed at the centre of each plot and catches of male *C. ignefusalis* moths were counted each day and discarded. All traps were baited with the same 80 mg dispensers as used for mating disruption throughout, and were renewed every 21 days. At 70 and 90 DAS the numbers of hills, tillers, infested hills and dead hearts were recorded from the central portion of each plot (10 m x 10 m). At harvest the number of exit holes and number of larvae were recorded from one stem randomly selected from each hill in the central portion of each plot.

The number of infested hills was expressed as a percentage of the number of hills and the number of dead hearts as a percentage of the number of tillers, and these data were transformed to arcsin. Counts of larvae and exit holes were transformed to the square root and data were then subjected to analysis of variance.

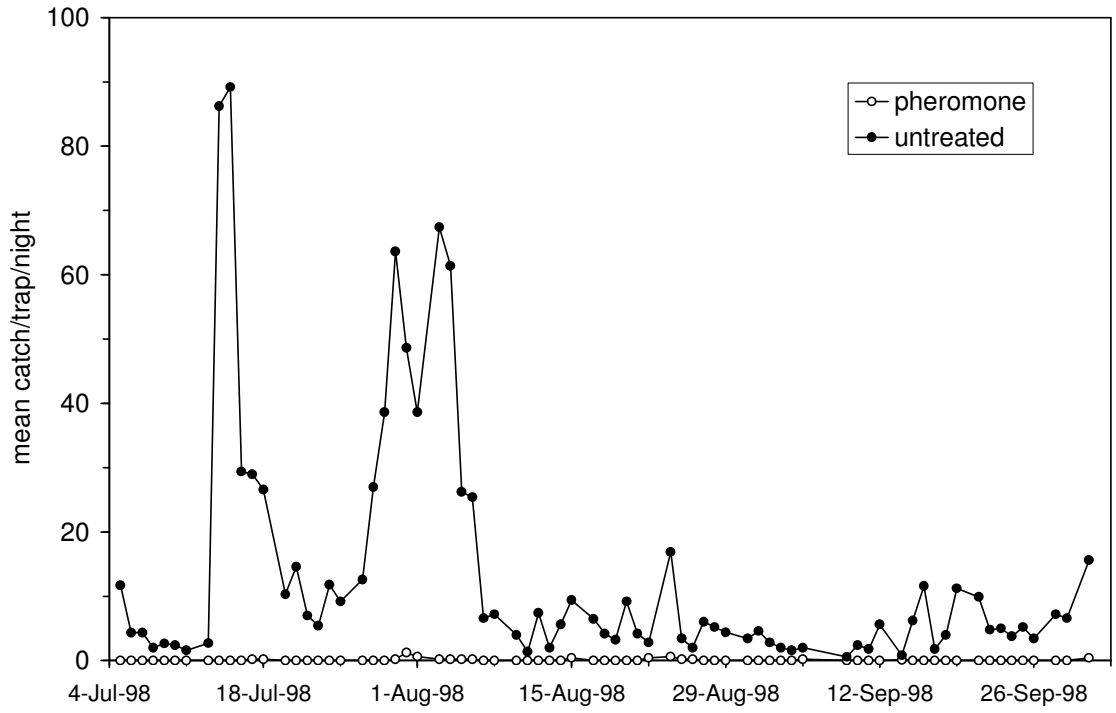

FIG. 12. Trap catches of male *C. ignefusalis* moths in treated and untreated areas during 1998 mating disruption trial (mean of five replicates)

Catches in the pheromone treated plots (mean of five replicates 0.08 ± 0.03 moths/trap/night) were greatly reduced relative to those in the untreated plots (mean 13.15 ± 4.33 moths/trap/night), giving a mean level of communication disruption of 99.4 ± 0.2% (calculated on untransformed data) (Fig. 12).

Damage caused by *C. ignefusalis* was high. Differences in numbers of dead hearts and infested hills between pheromone-treated and untreated plots were small and inconsistent (Table 12). However, after harvest numbers of larvae and exit holes in stems from the plots

treated with pheromone were much greater than those in stems from the untreated plots (Table 13).

TABLE 12. Mean percent dead hearts and infested hills at 70 and 90 DAS in 1998 mating disruption trial (five replicates; results from central 10 m x 10 m).

Treatment	% Dead heart		% Infested hill	
	70 DAS	90 DAS	70 DAS	90 DAS
Pheromone	1.99 ± 0.76	4.74 ± 2.12	9.18 ± 3.72	34.25 ± 13.61
Untreated	3.11 ± 1.27	4.14 ± 0.92	10.87 ± 2.84	28.00 ± 6.92

TABLE 13. Mean numbers of larvae and exit holes (± standard error) in 1998 mating disruption trial (four replicates; results from 50 stems; means followed by different letter in a column are significantly different at 5% level by DMRT)).

Treatment	Larvae	Exit holes
Pheromone	14.00 ± 9.24	31.20 ± 10.49 a
Untreated	3.60 ± 2.11	12.80 ± 3.72 b

DISCUSSION

Dispensers

In previous work on mating disruption of *C. ignefusalis* (Beevor *et al.*, 1996), a PVC resin formulation developed at NRI (Cork *et al.,* 1989) and commercialised by Agrisense-BCS was used. This has been used successfully with the pheromones of several other pests, e.g. pink bollworm, *Pectinophora gossypiella* on cotton (Minks and Cardé, 1995) and yellow stemborer on rice (Cork *et al.*, 1998). However, the components of the pheromone of *C. ignefusalis* are significantly more volatile than those of these other pests, and the formulation was very short-lived, requiring replacement every seven days under field conditions in Niger. Nevertheless, as judged by depression of trap catches of male moths and suppression of mating of tethered virgin female moths in plots treated with pheromone, these dispensers gave high levels of mating disruption at a release rate of 640 mg/ha/day (Beevor *et al.*, 1996).

A main aim of this work was to develop better dispensers that had a longer field life, preferably lasting for the whole millet-growing season of approximately three months, and were practical to prepare and apply in the field. Polyethylene sachets and polyethylene vials loaded with 80-100 mg of pheromone were examined. These "reservoir" dispensers showed constant, zero-order release rates, in contrast to the "monolithic" PVC dispensers which showed first-order release rates decreasing as the pheromone content decreased. Release from polyethylene sachets was too rapid. Considering temperature data from Niger, it was

estimated that release of pheromone from the vials could approach 400 mg/ha/day at an application rate of 400 dispensers/ha in full sun, and an 80 mg loading would give a field life of at least 3 months.

The vials are commercially available, and filling could easily be automated. Sealing the filled vials gave some problems: heat-sealing or use of hot-melt EVA glue was tedious and not always totally effective. Application in the field required fastening to sticks, but was relatively straightforward.

Mating disruption trials

In initial trials of mating disruption against *C. ignefusalis* carried out at ICRISAT Sahelian Centre, Niger, in 1996, standard polyethylene vial dispensers containing 0.5 mg of pheromone for use in traps were used and replaced every 21 days. As measured by reduction of catches of male *C. ignefusalis* moths in pheromone traps in treated plots relative to those in untreated plots, significant communication disruption (86.8 ± 2.6%) was observed in 0.16 ha plots at 400 dispensers/ha equivalent to a remarkably low 200 mg pheromone/ha/application or 800 mg/ha/season.

Trials in 1997 and 1998 used the mating disruption polyethylene vials containing 80 mg pheromone at 400 dispensers/ha with a single application per season, giving an application rate of 32 g pheromone/ha/season. In replicated 0.5 ha plots in farmers' fields, very high levels of trap catch suppression ($\geq$ 99%) were observed throughout the season. However, estimates of infestation, damage and yield loss due to *C. ignefusalis* during the season and after harvest in the central portions of the experimental areas showed no significant differences between plots treated with pheromone and untreated plots.

Examination of dispensers returned from the field showed that only 30% of the initial loading of pheromone had been released, which agreed with the lower estimates from laboratory release rate data.

Lures for traps

During the 1997 mating disruption trials, monitoring traps in the plots treated with pheromone were baited with the dispensers containing 80 mg of pheromone as used for mating disruption. The traps in the untreated plots were initially baited with the standard 0.5 mg monitoring lures, but later these were replaced with the 80 mg lures. This was done because it has been reported by Minks and Cardé (1995) that monitoring traps equivalent to "super females" releasing large amounts of pheromone give a more discriminating and valid test of effectiveness in mating disruption trials. However, subsequent comparisons of catches of male *C. ignefusalis* moths in traps baited with 0.5 mg or 80 mg lures in the absence of mating disruption treatments showed that catches with the 80 mg lures were only 10-20% of the catches with the 0.5 mg lures. Unfortunately the 80 mg lures were used again in the monitoring traps for the 1998 trials, but at least they were used consistently in treated and non-treated plots throughout so a valid comparison could be made

Previous studies (Beevor *et al.*, 1996) indicated that the release rate of pheromone from a fresh 0.5 mg lure was approximately 0.01 mg/day at 27°C. Under the same conditions, release from the 80 mg dispenser was more than ten times greater at 0.13 mg/day (Table 7).

Conclusions

Following previous work in which successful mating disruption of millet stemborer, *C. ignefusalis* was demonstrated but pheromone dispensers were too short-lived for practical exploitation, suitable dispensers have been developed. These sealed polyethylene vials loaded with 80 mg of pheromone were shown to maintain $\geq$ 99% communication dispruption for up to three months in farmers' fields in Niger when applied at 400 dispensers/ha. Approximately 30% of the pheromone was released (110 mg/ha/day), and so the loading of pheromone in the dispensers could safely be reduced to 40 mg/dispenser so that 400 dispensers/ha is equivalent to an application rate of 16 gm/ha/season.

In the replicated 0.5 ha plots used in these trials, effective communication disruption did not translate into reduced infestation, damage or yield loss due to *C. ignefusalis*. This may have been because actual reduction in mating was less effective than the reduction in pheromone trap catch would indicate, or because immigration of mated female moths into the treated plots were negated any reduction of mating of females within the treated plots. The latter is considered to be more likely (Minks and Cardé, 1995), and future trials should investigate whether mating disruption in larger plots can give effective control of *C. ignefusalis.*

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