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Management of *Helicoverpa armigera* (Lepidoptera: Noctuidae) on chickpea in southern India: thresholds and the economics of host plant resistance and insecticide application

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A study of the influence of the density of larval *Helicoverpa armigera* (instars 4–6) on the seed yield of chickpea plants growing in large cages indicated that one larva per plant was a critical density as far as economic injury levels are concerned. The results indicated that larval feeding activity during the first 2 weeks of flowering had no effect on yield. There was also no evidence of compensatory growth following insect attack during the flowering stage. These data were adopted to set action thresholds in a large (0.8 ha) field experiment that was designed to investigate the economics of insecticide application in the context of an on-farm chickpea enterprise. The field was managed with bullock-drawn implements and hand labour. Insecticides were applied to three varieties – Annigeri (an insect-susceptible landrace), ICCC 37 (a recently released variety) and ICC 506 (an insect-resistant landrace) – weekly, not at all (controls) and when the larval density exceeded 0.5 or 2.0 per plant. Economic parameters were assembled from village and local market records. *Helicoverpa* had a marked effect on the yield of the two pest-susceptible varieties, both of which would have made a loss in the context of a chickpea enterprise unless protected by insecticides. *Helicoverpa*-resistant ICC 506 did not achieve as high a yield as the other two varieties when treated with insecticides but did 'make a profit' when no insecticide was applied. The relationship between yield and insect days was virtually identical for Annigeri and ICCC 37. The latter needed five insecticide applications to maximize yield and the former four. The relationships between insect day summations (integrals of population curves) for eggs, and small and large larvae, suggested that eggs were undersampled and were not suitable as an indicator for insecticide applications. The density of small larvae, although probably undersampled, was a suitable indication of the damage likely to be caused by the large larvae they would develop into. A set of insect day summations indicates when insecticides in the current price range (Rs300, 400 or 850 ha^{-1}) need to be applied. The thresholds were verified in neighbouring fields. Three insecticide applications during the following season resulted in a greater than threefold increase in yield (from 0.65 to 2.2 t ha^{-1}).

Keywords: *Helicoverpa armigera, Cicer arietinum,* integrated pest management

Chickpea (*Cicer arietinum* L.) is a grain legume adapted to dry, cool environments. It is grown as a winter or spring crop in South and West Asia, North and East Africa and the Mediterranean basin. More than 69% of the world crop is harvested from India and Pakistan. There are large gaps between the average productivity of 0.6 t ha^{-1} in farmers' fields in southern India, the attainable yield of about 2 t ha^{-1} and a maximum yield potential of >5 t ha^{-1} recorded in international trials in the Mediterranean region (Singh, 1987).

Insect pests as a whole do not contribute much to this lost potential in core growing areas (Reed *et al.*, 1987). This is because chickpea has evolved a form of host plant resistance that is unique among grain legume crops. Hairs on the leaves and pods exude organic acids of low to very low pH (4–2) that produce an environment that is not conducive to the well-being of most animals that enter it (Rembold *et al.*, 1990). Other than the agromyzid leaf miner, *Liriomyza cicera*, which is restricted to the Mediterranean area, only the ubiquitous *Helicoverpa* spp., especially *H. armigera*, are able to feed on this plant with apparent ease. *Helicoverpa* feeds preferentially on the flowers and pods of this species but will eat leaves during the vegetative stage and when the reproductive structures have been destroyed. Data reviewed by Sehgal (1990) and Sehgal, Rameshwar Rao and Wightman (1990) indicate that yield loss in southern India is closely and linearly related to pod damage alone.

Farmers normally avoid *Helicoverpa* attack by sowing chickpea at the end of the cool season when larval densities are low. Unfortunately, this kind of cultural control is not possible in the south of India (latitudes below 20 degrees S) (Reed *et al.*, 1987) because winter temperatures are sufficiently high to promote plant and

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*To whom correspondence should be addressed insect growth. This insect is regarded as a major contributor to the large yield gap in this agroecological region (Faris and Gowda, 1990).

Pimbert (1990) suggested that contemporary approaches to research on the management of chickpea pests should be replaced with concepts that focus more clearly on the needs of farmers especially the resource-poor farmers who form the majority of chickpea growers. He indicated that the 'pest managers' tool box' is fairly full and that it includes host plant resistance (Lateef and Sachan, 1990), methods of enhancing natural control (by other insects and diseases), cultural controls and insecticides. This paper is a response to Pimbert's call for a rational approach to the management of *Helicoverpa* on chickpea. It describes experiments carried out to generate information about integrating insecticide application with host plant resistance within the context of integrated pest management (IPM) and sustainable agriculture. Definitions pertinent to this paper are as follows:

1. A *sustainable* farming system is managed in such a way that:
   (a) its long-term productivity and quality and that of its environment are maintained at the status quo or are improved with time;
   (b) annual productivity and/or profit are optimized; and,
   (c) seasonal variation in productivity and/or profit is minimized.
2. IPM:
   One or more management activities that are carried out by farmers that result in the density of potential pest populations being maintained below levels at which they become pests, without endangering the productivity and profitability of the farming system as a whole, the health of the farm family and its livestock, and the quality of the adjacent and downstream environments.

Neither of these definitions excludes the possibility of insecticide application being included in IPM schemes. However, what is lacking for chickpea is guidance about when insecticides should be applied (Dent, 1991). There are two sets of criteria that should guide farmers and pest managers when making such decisions – those that relate to crop and farm economics (including the risk of pest resurgences and insecticide resistance) and those that are concerned with the farm environment quality. The latter topic is beyond the scope of this paper and is discussed by Tait and Banpot Napompeth (1987).

It is logical to base IPM in tropical crops of less-developed countries on insect-resistant varieties where they are available. Cultural control methods can enhance host plant resistance, especially those that favour natural control processes. Pesticides should be needed only when pest densities exceed threshold levels that are likely to result in yield losses that will cost more than the insecticide and its application. It is our experience that the short-term, economic basis for such thresholds should be tempered by the likelihood of pest resurgences induced by the negative effects of pesticides, especially insecticides, on natural control processes. Ideally, there should also be a means of giving farmers advance warning about when a pesticide *may* be needed (Zadoks, 1987). Irrespective of the need for setting thresholds, pest managers need to understand the relationship between injury to a crop and the pest density(s) involved before they can be in a position to make relevant recommendations.

It is not often possible for researchers to furnish a complete set of parameters in totally realistic (= farm) conditions. In the current context the ideal was replaced by a sequence of research station simulations designed to lead to the development of guidelines for subsequent testing in farmers' fields. The sequence of events was (1) for cage experiments to be carried out to 'get a feel' of the relationship between *Helicoverpa* density and chickpea pod yield (Sehgal *et al.*, 1990); (2) to test two action thresholds derived from the initial cage experiment(s); and (3) to evaluate the threshold further in quasi-farm conditions.

As insecticide resistance in *Helicoverpa* is a threat to grain legume production in Asia (King and Sawicki, 1990) insecticides applied in stages 2 and 3 were applied in a rotation by chemical class. This is an important component of insecticide resistance management.

Materials and methods

Cage experiment: determination of the relationship between larval density and yield

Seed was sown on 20 October 1989 with rows 20 cm apart and 10 cm between seeds in a high-fertility Vertisol field on the ICRISAT Center farm, 30 km from Hyderabad in peninsular India. The variety was Annigeri, a *Helicoverpa*-susceptible, but Fusarium wilt-resistant, exotic landrace that is popular among local farmers. Fish-net cages, 3 × 3 × 2 m high, were placed 2 m apart over sectors of the field. A 30 cm wide strip of rolled aluminium alloy was slotted into the soil inside the net of each cage so that it protruded by 15–20 cm. This procedure has been adopted at ICRISAT for retaining the larvae of *Spodoptera litura* in research plots (Wightman *et al.*, 1990) and in the experiment described here prevented *Helicoverpa* larvae moving in and out of the cages.

Plants were thinned to 50 in the central 2 × 2 m sector of the cage. Third- or fourth-stage *Helicoverpa* larvae were introduced to the cages on 22 December 1990 at rates ranging from 0.5 to four larvae per plant (*Table 1*) during the first stage of flowering or, 2 weeks later, at the initiation of pod swelling. The larvae were collected from chickpea fields in the close vicinity. The 'plots' (= cages) were distributed in a randomized block design with four replicates (single cages) per treatment. The cages in which larvae were released in the flowering period were treated as a discrete experiment and were situated in an adjacent part of the field to the remaining cages.

Three days before the experimental larvae were introduced, small resident larvae were killed by applying dichlorvos to the plants at a rate equivalent to 1 l ha^{-1}. Each plant was then searched and the surviving (large) larvae removed by hand. This process was repeated 2 weeks after the larvae had been introduced, i.e. by the time that larval development was complete, so that no further damage was caused by larvae that had managed to enter the cage.

Flowers were removed from half the plants in each cage after this time to determine whether there was significant compensatory growth immediately following the cessation of insect attack. All plants were hand-harvested on 30 January 1990 and the grain yield determined.

Field trial: establishment of economic threshold levels for *Helicoverpa*-resistant and susceptible genotypes in farmers' field conditions

The experimental area, which was on a gently sloping Vertisol field on the ICRISAT Center farm, occupied 0.8 ha. The soil was opened with a tractor-drawn plough. Secondary land preparation and sowing were carried out with bullock-drawn implements; weeding was by hand. The land was formed into broad beds 1 m wide with 0.5 m between each bed. Four rows of seed were sown 20 cm apart in each bed on 13 September 1990.

Plots were 7.5 m (= five beds) × ~20 m long (~150 m^2). Edge effects were avoided by restricting plant-sampling activities to the central 70 m^2 (three beds by 15 m) of each plot. The genotypes were Annigeri, ICCC 37 (an improved variety with high yield potential in this agroecological zone, Fusarium wilt resistance but no pod borer resistance) and ICC 506 (a landrace with medium yield potential, *Helicoverpa* resistance but Fusarium wilt susceptibility). A split-plot design with four replicates was sown. The three genotypes were main plots and the sub-plots were four insect management treatments, as follows:

T1 – insecticide applied at approximately weekly intervals from when flowering started;
T2 – insecticide application when there were >0.5 larvae per plant;
T3 – insecticide application when there were >2.0 larvae per plant;
T4 – no insecticide application (control).

Insect density was assessed weekly from flower initiation by counting the number of eggs, and small (instars 1–3) and large (instars 4–6) larvae on 20 randomly selected plants per plot. Insecticide was applied on the day after the insect count to T1 plots and according to the stated threshold for T2 and T3 from the initiation of pod development. The decision to spray was based on the treatment mean of the larval count (small + large).

It was necessary to correct for the difference in the duration of the three life stages that were sampled before their interrelationships could be compared. This was done by referring to their development rates at constant temperature. N. J. Armes and D. R. Jadav (personal communication) indicated that the larval stage of *H. armigera* lasts for 31 days at 20°C. As the duration of each stadium is not known, they were assumed to be of proportional length to those of another noctuid (that is adapted to this environment), *Spodoptera litura*, at the same temperature (Ranga Rao, Wightman and Ranga Rao, 1989). The estimated development periods were 10 days for instars 1–3 and 21 days for instars 4–6. The egg stage lasts for 4–5 days in these conditions.

Insecticides were applied with a motorized knapsack sprayer fitted with a two-nozzle boom in the following sequence and at these rates: endosulfan (700 g a.i. ha^{-1}), fenvalerate (200 g a.i. ha^{-1}), monocrotophos (400 g a.i. ha^{-1}), and lannate (400 g a.i. ha^{-1}), all in 400 l water ha^{-1}. Spray drift between plots was avoided by moving a 3 × 2 m high plastic sheet along plot boundaries parallel with, and downwind to, the sprayman.

Plots were harvested on 16 January 1991. Seed was collected by hand from 12 m^2 plots located randomly within the central 70 m^2 of each plot. The same team of experienced technical staff collected all the data reported here.

Prices for representative 1 kg lots of each variety (taken from each treatment) were obtained from traders at the Hyderabad grain market.

Further verification of threshold

A spray threshold of two larvae per plant was adopted for the management of *Helicoverpa* on chickpea growing as part of long-term cropping experiments in a 25 ha section of a watershed on the ICRISAT farm during the 1991–1992 and 1992–1993 seasons. Each 0.1 ha field represented a treatment (not discussed here) that was replicated three times.

Insect density on 20 plants per field was assessed each week. Insecticide was applied when the insect density exceeded a mean of two per plant. The 'no-spray' (control) condition was simulated by placing a 12 m^2 plastic sheet over the same sectors of these fields each time insecticide was applied. Seed weight in the unsprayed areas and in a representative 12 m^2 sector of the entire field was assessed at harvest time.

Results and discussion

Cage experiment

Seed yield was not influenced by larval density when the insects were introduced at the commencement of flowering (*Table 1*). Furthermore, the removal of flowers when larval activity was finished (i.e. after ~2 weeks, when they had pupated) did not influence seed mass per plant:

With flower removal: $y = 15.07 - 0.48x; r^2 = 0.13$ (1)
Without flower removal: $y = 15.14 + 0.18x; r^2 = 0.01$ (2)

where x = number of larvae per plant and y = mean seed mass per plant (g). *Table 1* and Equations (1) and (2) suggest that plants did not produce further flowers after the larvae had finished feeding. Thus, there was no evidence of compensatory flower production, within the limits of this experiment following insect attack. Furthermore, the feeding activity of the single cohorts of insects we introduced had little impact on yield. There was a similar pattern of results in a preliminary experiment (Sehgal *et al.*, 1990), in which the pod damage in the 'no larvae' treatments was slightly lower than in all other treatments (0.1–10 larvae per plant).

Some damage occurred because the exclusion of insects was not complete. However, there was no significant relationship between larval density and grain mass per plant where insects were introduced at the flowering stage.

In contrast, caterpillar feeding did influence seed

Table 1. Influence of the density of large (4–6-instar) *Helicoverpa armigera* larvae on the per plant yield of chickpea (cv. Annigeri) introduced to cages at the start of flowering or pod formation, with and without post-treatment flower removal

Density (*n* per plant)	Per plant seed yield (g)^a	
	Flowers removed	Flowers not removed
Flowering stage		
0	16.8 ± 1.6	18.4 ± 0.7
0.1	14.4 ± 0.3	12.2 ± 1.2
0.2	13.3 ± 3.8	14.7 ± 2.5
1.0	14.7 ± 1.6	15.3 ± 2.2
2.4	14.2 ± 3.3	15.8 ± 0.6
Pod formation		
0	9.5 ± 1.6	9.9 ± 2.2
0.2	8.5 ± 2.6	8.7 ± 2.1
0.5	8.8 ± 0.7	10.8 ± 0.4
1.0	7.4 ± 0.9	8.4 ± 1.9
2.0	7.2 ± 0.9	7.7 ± 1.2
4.0	6.5 ± 1.7	6.8 ± 1.6

^{a}Values are means ± s.e.

mass when introduced at the start of pod formation [*x* and *y* as in Equations (1) and (2)]:

With flower removal: $y = 8.83 - 0.66x; r^2=0.79$ (3)

Without flower removal: $y = 9.73 - 0.79x; r^2=0.67$ (4)

but again the removal of flowers after the larvae had pupated showed that pod destruction did not induce a compensatory action. These data indicate that during the time that a single larva developed from the third instar to pupation during pod swelling and the seed-hardening period, it reduced seed yield by ~0.8 g per plant.

We cannot explain satisfactorily the differences in yield in the two phases of the cage experiment. Although the experiments were set up in a large contiguous stand, there may have been soil fertility differences. The influence of the cage on the microclimate of the plants may also have had an effect (the lowest-yielding plants were caged for a shorter period than the high-yielding plants). We cannot exclude the possibility that larval activity during the flowering period of the plants in the second part of the experiment reduced yield. However, the experimental evidence here and in Sehgal *et al.* (1990) leads us away from this conclusion.

To determine the economic implication of these data we took the *y*-intercept in Equation (4) (9.7 g) to represent plant yield with no insect damage. This was multiplied by 130 000 (= plants ha^{-1}), to obtain a seed yield of 1.26 t ha^{-1}. The market price in mid-1990 was ~Rs6500 t ^{1} so that the potential crop value was Rs8190 ha^{-1}. One larva per plant reduced 'grain yield' to 8.9 g per plant [Equation (4)] or 1.16 t ha ^{1} (value Rs7540), a cost equivalent of Rs650. This is close to the cost of two normal insecticide treatments (or one lannate application, see below). We considered that such an investment is feasible within the rather stringent boundaries set by the economics of low-input agriculture in South Asia. Thus, from these estimates we developed our first working hypothesis: 'if a farmer finds more than one larva per plant (the action threshold) during the pod swelling stage and applies an insecticide he should recover more than his cost from saved pods'. This hypothesis was tested by straddling the notional threshold and adopting strategies of 'spray when there are 0.5 or 2.0 larvae per plant' as the treatments in the field experiment.

It should be noted that thus far we have been dealing with the stage of insect that causes the damage (instars 4–6). It is, however, necessary to apply an insecticide before this density is reached (i.e. during flowering) to prevent crop injury. Furthermore, in real terms, the direction of insecticides at small larvae is essential: insecticides do not usually kill large larvae because they are to a large extent protected from contact with the toxin by the pod that they have bored. Attacking neonate larvae is in any case considered to be a viable IPM strategy because lower doses can be applied, which are less damaging to populations of arthropod predators and parasites.

Field experiment

Yield parameters. There was no difference between the number of pods m ^{2} in T1 and T2 (*Table 2*). This is in marked contrast to the unprotected plots (T4) of Annigeri and ICCC 37, where the number of pods m^{-2} was considerably reduced and the percentage of insect-damaged pods was much higher than in ICC 506. The grain yield of ICCC 37 was clearly higher than that of the other two varieties when protected by weekly insecticide applications, but fell off to low levels when supported by less-intensive or no-insecticide regimes (T3 and T4) (*Table 2*).

There were marked differences in seed yield in the four treatments, especially with Annigeri and ICCC 37. The insect resistance factor in ICC 506 appears to have given it some buffering.

There was a strong negative relationship (r = −0.944) between percentage pod damage and yield. Although severe defoliation was evident in all varieties where no insecticide was applied, it is evident that pod damage (as opposed to defoliation) was the main determinant of grain yield. This is in agreement with the conclusions of Sehgal *et al.* (1990) and Sehgal (1990).

Insect densities. The densities of small and large larvae on the three varieties (*Figures 1–3*) show the course of the infestation and the effectiveness of the insecticide regimes. Standard errors of the mean population densities are 15% of the mean or less, when $n > 1$ per plant and increase to 40% as n approaches 0 per plant.

The first application of insecticide should have been made several days earlier to reduce the larval population before pod initiation. In contrast to previous experience, endosulfan had little or no effect on larval density. Armes *et al.* (1992) have subsequently reported endosulfan resistance in *Helicoverpa* larvae taken from the ICRISAT farm during the 1990–1991 growing season: this material was not applied again in this experiment.

The relatively high larval density 56 and 67 days after sowing (DAS) (*Figures 1–3*), explains in part, the high pod damage in T1 and the difference between actual yield and potential yield. There was a build-up of small larvae 30 days into the podding stage (~80 DAS) that probably accounted for much of the pod damage in

Table 2. Plant density, pod damage and yield[a] in the field experiment

Variety	Treatment[b]	Plant density (n 10^3 ha^{-1})	Mean yield (t ha^{-1})	Total pods (n m^{-2})	Damaged pods (n m^{-2})	Damaged pods (%)
Annigeri	T1	140 ± 11	0.962 ± 0.071	515.6 ± 48.6	115.8 ± 17.8	22.5
	T2	134 ± 9	1.112 ± 0.099	601.6 ± 43.4	138.5 ± 23.0	22.7
	T3	137 ± 10	0.919 ± 0.091	583.8 ± 58.6	188.8 ± 8.2	32.4
	T4	137 ± 7	0.144 ± 0.050	125.2 ± 38.7	84.7 ± 25.4	67.6
ICCC 37	T1	127 ± 7	1.306 ± 0.101	635.8 ± 55.2	95.3 ± 18.2	15.0
	T2	120 ± 5	1.191 ± 0.017	590.9 ± 10.6	111.7 ± 15.8	18.9
	T3	121 ± 6	0.526 ± 0.115	347.9 ± 38.1	178.0 ± 38.8	51.2
	T4	132 ± 17	0.071 ± 0.020	76.1 ± 18.5	60.3 ± 14.2	79.3
ICC 506	T1	155 ± 16	1.089 ± 0.046	613.9 ± 18.4	47.8 ± 6.5	7.8
	T2	152 ± 3	0.939 ± 0.020	577.9 ± 45.4	77.6 ± 11.2	13.4
	T3	151 ± 18	0.496 ± 0.169	341.9 ± 65.1	148.7 ± 40.6	43.5
	T4	139 ± 10	0.349 ± 0.071	303.7 ± 51.3	145.4 ± 17.5	47.9

[a]Values are means ± s.e.; [b]T1, insecticide applied at approximately weekly intervals from the flowering stage; T2, insecticide applied when there were >0.5 larvae per plant; T3, insecticide applied when there were >2 larvae per plant; T4, no insecticide applied

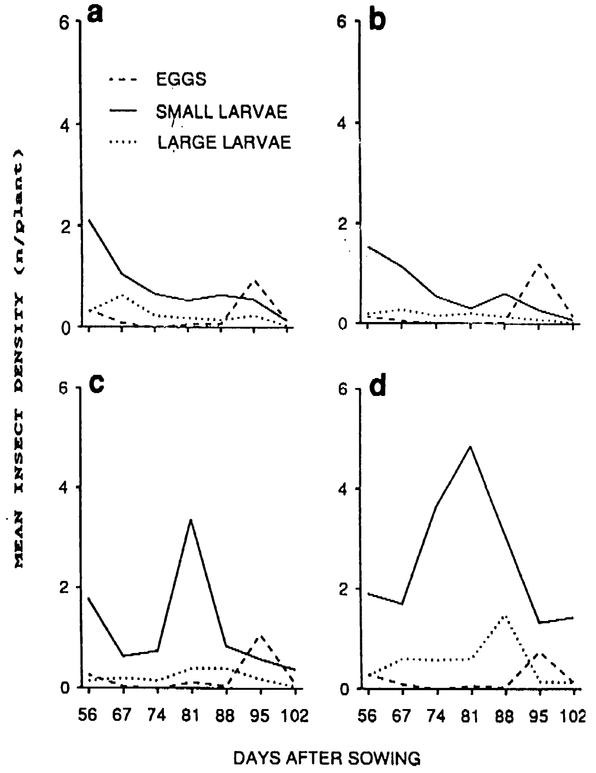

Figure 1. Density of *H. armigera* eggs (– – –) and small (———) and large (· · · ·) larvae on Annigeri in treatments 1 (a), 2 (b), 3 (c) and 4 (d) during the pod formation stage; field experiment in 1991

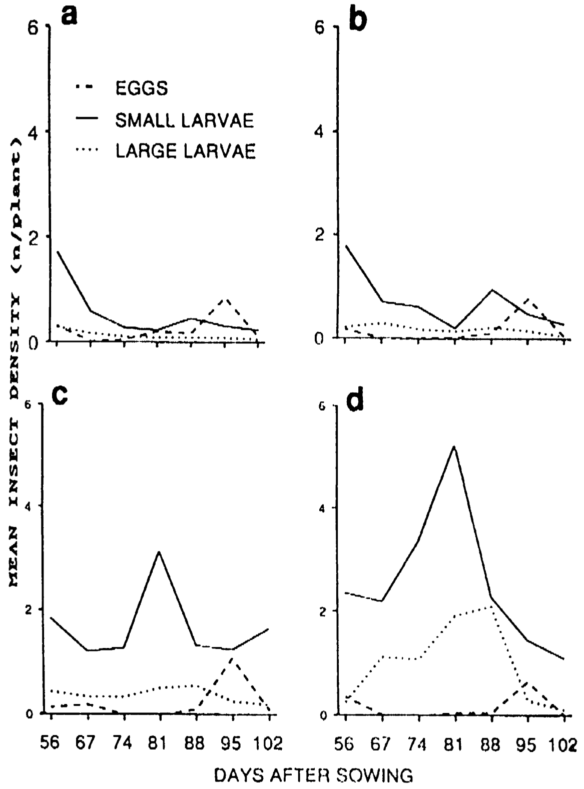

Figure 2. Density of *H. armigera* eggs (– – –) and small (———) and large (· · · ·) larvae on ICCC 37 in treatments 1 (a), 2 (b), 3 (c) and 4 (d) during the pod formation stage; field experiment in 1991

Annigeri and ICCC 37 (T3 and T4). It should be noted that the host plant resistance factor in ICC 506 suppressed a density build-up in this variety (*Figure 3*).

Insect intensity and yield. Relationships between insect density and yield are clearest when the former are converted to cumulative units (insect days = the area under the curves in *Figures 1–3*), an index of *insect intensity* (*Table 3*). This procedure is justified for this particular crop because we are dealing with a single pest which apparently causes damage during only one stage – the development of the harvested product.

The insect day data for the egg stage and small larvae were corrected to the duration of larvae 4–6 (*Table 3*). There was little difference in insect intensity on Annigeri and ICCC 37 (in T3 and T4) indicating similar levels of susceptibility. Resistant ICC 506 carried considerably fewer insects.

Life table analysis of *Helicoverpa* spp. reveals that most mortality (>90%) takes place during the egg and

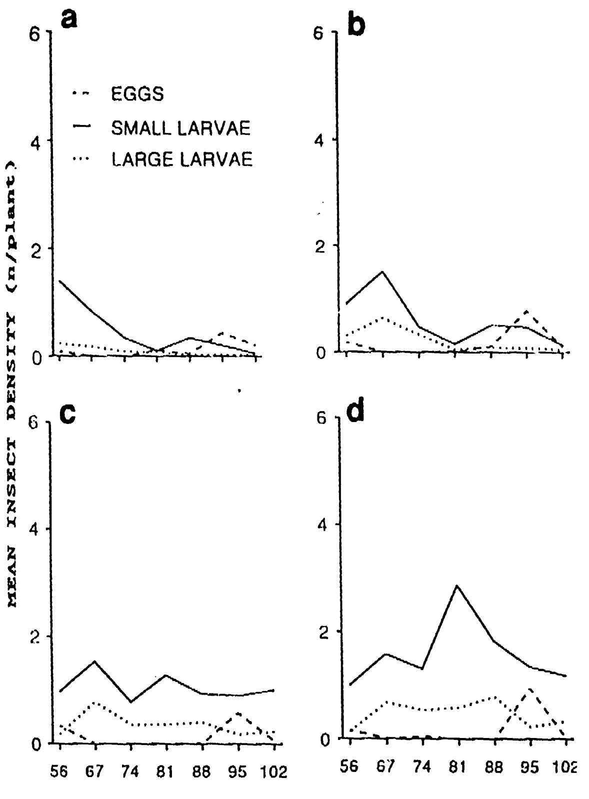

Figure 3. Density of *H. armigera* eggs (– – –) and small (———) and large (· · · ·) larvae on ICC 506 in treatments 1 to 4 during the pod formation stage; field experiment in 1991

first instar (Fitt, 1989; Zalucki *et al.* 1986; Kyi, Zalucki and Titmarsh, 1991). Therefore, if the sampling of a *Helicoverpa* population is absolute there would be at least ten (probably closer to 100) times as many eggs as there are large larvae, among which there is little mortality. Our data (*Table 3*) thus indicate that the density of eggs (and probably of first- and second-instar larvae, which are also difficult to locate) was underestimated, compared with that of the larger larvae.

This comment is made to indicate that it would not be a good idea to suggest to farmers, scouts and extension workers that they should base a crop monitoring programme, within the context of IPM, on estimates of egg density.

There was a closer relationship between the intensity of small (S) and large (L) larvae (calculated data):

$$L = 1.603 + 0.314S; \quad r^2 = 0.718; \quad n = 48 \qquad (5)$$

which indicates that it is 'safe' to adopt the former estimate as an indication of larval density of the stages that cause the yield loss. The proviso is 'but only if the sampling procedure is carried out with equal or better efficiency by farmers or their advisers'.

The relationships between insect days and yield, as expressed in *Figure 4* and Equations (6)–(11), where Y = yield (t ha^{-1}), S = the intensity of small larvae, L = the intensity of large larve and n = 12 for the three varieties:

$$\text{Annigeri: } Y = 1.536 - 0.0111S; \quad r^2 = 0.967 \qquad (6)$$
$$\text{ICCC 37: } Y = 1.482 - 0.0111S; \quad r^2 = 0.958 \qquad (7)$$
$$\text{ICC 506: } Y = 1.496 - 0.155S; \quad r^2 = 0.938 \qquad (8)$$
$$\text{Annigeri: } Y = 1.545 - 0.0442L; \quad r^2 = 0.923 \qquad (9)$$
$$\text{ICCC 37: } Y = 1.308 - 0.0231L; \quad r^2 = 0.839 \qquad (10)$$
$$\text{ICC 506: } Y = 1.380 - 0.0387L; \quad r^2 = 0.906 \qquad (11)$$

These high regression coefficients indicate that the pod damage caused by the caterpillars was the major source of inter-treatment variation. The intercepts, indicating yields of ~1.5 t ha^{-1} (means of small and large larvae), are accepted as estimates of yield potential of the three varieties under the conditions of this experiment. FAO data indicate that the average chickpea yield for India is only 0.6 t ha^{-1}.

Threshold verification

There was a more than threefold increase in yield gained from applying insecticide when the larval density reached two per plant in the neighbouring chickpea fields in the study watershed (*Table 4*). Two applications were called for in 1991, three in 1992. The higher yield potential of ICCC 37 was not expressed in these results so that it is suspected that, as indicated in

Table 3. Mean 'insect days' for eggs, small and large larvae and total larvae

		Insect days						
		Eggs		Small larvae		Large larvae	All larvae	
Variety		Ca	Co	Ca	Co	Ca	Ca	Co
Annigeri	1	16.0	67.2	44.6	93.7	16.0	60.6	109.7
	2	17.6	74.1	38.4	80.6	9.4	47.8	89.4
	3	17.7	74.5	65.4	137.3	11.8	77.2	149.1
	4	13.2	55.4	123.2	258.7	30.5	153.6	289.2
ICCC 37	1	13.4	56.1	12.6	26.5	6.5	19.1	33.0
	2	10.8	45.5	38.3	80.4	10.4	48.7	90.8
	3	17.8	74.8	72.8	152.9	18.8	91.6	171.7
	4	11.0	46.3	130.6	222.6	56.8	187.4	279.4
ICC 506	1	6.8	28.6	28.1	59.0	5.6	33.7	64.6
	2	10.7	45.0	40.4	84.8	15.6	56.0	100.4
	3	9.7	40.9	53.6	112.6	21.8	75.4	134.4
	4	14.8	62.2	78.3	164.3	25.5	103.8	189.8

[a] Data as calculated (Ca) and corrected (Co) to the duration of large larvae

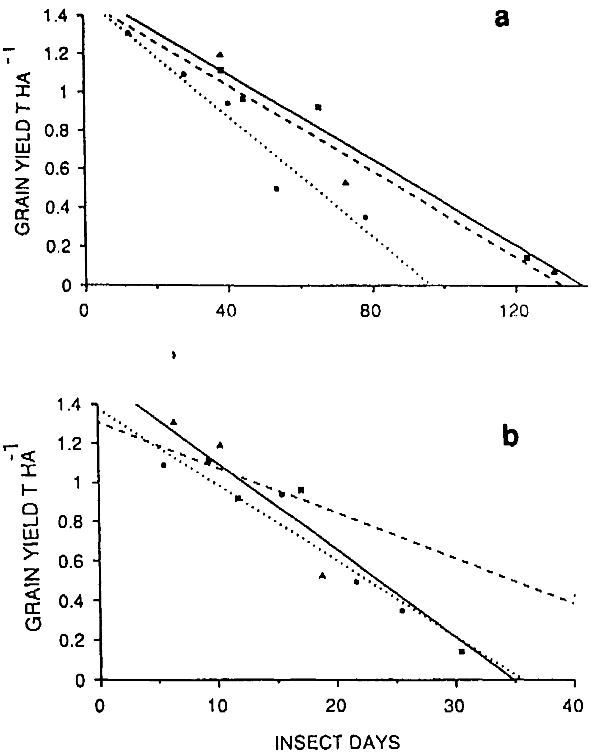

Figure 4. Relationships between corrected insect days and yield for (a) small and (b) large larvae on varieties Annigeri (x———x), ICCC 37 (▲– – –▲) and ICC 506 (■· · ·■)

the field trial, a more stringent threshold of less than two larvae per plant may be needed for this variety. Yields in the sprayed areas during the 1992–1993 season were high for southern India, even in research station conditions. They show that the potential benefits of managing *Helicoverpa* are great.

The insecticide regime and its rupee cost; gross and net returns for the chickpea enterprise

The retail prices of the insecticides applied in the experiment are provided for Hyderabad and for a study village where chickpea is grown (*Table 5*). The materials listed for the village are the ones that are available to the local farmers for application to their chickpea crops. Hyderabad prices were adopted to compile *Table 6*, which shows the costs of the insecticide regimes adopted in the field trial. Costs are high because lannate was included in the regime. If monocrotophos (the cheapest material) had been applied throughout, the maximum cost (six applications) would have been Rs1764 ha^{-1}. The pest-resistant variety ICC 506 required considerably less insecticide than Annigeri and consequently approaches the needs of a farmer unable, or unwilling, to invest in insecticide application.

Market prices for the grain were in a narrow band and indicated that the traders had a small preference for the improved variety ICCC 37 – but only if it had been protected with insecticides (*Table 7*). Annigeri, with its larger seeds, was preferred, marginally, to ICC 506, which was, nevertheless, apparently acceptable.

The net return data indicate that the action threshold of one larva per two plants is applicable for ICCC 37 and ICC 506, whereas the more relaxed threshold of two larvae per plant is marginally more applicable to Annigeri (*Table 7*). The high-yielding variety ICCC 37 needed an intensive threshold of 0.5 larvae per plant to maximize returns. This differed little from the weekly application. The insect-resistant line ICC 506 also seemed to need a higher threshold to maximize yield. However, (a) larval density is less likely to reach this

Table 4. Chickpea grain yield in 0.1 ha fields to which insecticide was applied when the density of *Helicoverpa* larvae exceeded two per plant

Year	Applications (n per season)	Field no.	Genotype	Grain yield ($t\ ha^{-1}$)[a] With insecticide	 No insecticide[b]
1991–1992	2	1	ICCC 37	1.46 ± 0.09 1.63 ± 0.11	0.88 ± 0.29 0.62 ± (NA)
	2	2	ICCC 37	1.75 ± 0.08	0.54 ± 0.04
1992–1993	3	1	Annigeri	2.04 ± 0.04 2.28 ± 0.12	0.66 ± 0.04 0.55 ± 0.06
			ICCC 37	1.91 ± 0.10 2.18 ± 0.10	0.78 ± 0.08 0.72 ± 0.07
	3	2	Annigeri	2.26 + 0.08 2.31 ± 0.03	0.67 ± 0.11 0.58 ± 0.09
			ICCC 37	2.16 ± 0.04 2.22 ± 0.04	0.59 ± 0.03 0.71 ± 0.33
	3	3	Annigeri	2.11 ± 0.08 2.27 ± 0.05	0.84 ± 0.15 0.86 + 0.22
			ICCC 37	2.01 ± 0.51 2.21 + 0.04	0.85 ± 0.08 0.69 + 0.07

[a] Values are means ± s.e.; [b] control (no insecticide) data were collected from 12 m^2 areas of all fields that were covered in plastic sheet when the remainder of the field was sprayed

Table 5. Rates and costs of insecticide treatments[a]

Insecticide	Site	Product rate (l ha^{-1})	Product price (Rs l^{-1})	Product cost (Rs ha^{-1})	Labour cost (Rs ha^{-1})	Total (Rs ha^{-1})
Endosulfan (35 EC)	Kanzara[b] village	3.75	96	360	60	420
	IC[c]	2.0	124	248	60	308
Fenvalerate (20 EC)	IC	1.0	235	235	60	295
Monocrotophos (40 EC)	IC	1.0	234	234	60	294
Lannate (24 EC)	IC	1.65	482	795	60	855
Quinalphos (25 EC)	Kanzara village	2.5	140	350	60	410

[a] Prices paid by ICRISAT and by farmers in a study village, total cost assuming village wages (three people day^{-1} ha^{-1} at Rs20 per person day^{-1}); [b] prices paid by farmers in 1990–1991 for the only materials available in the shop nearest to their village and the rates they applied to their chickpea fields; [c] prices paid by ICRISAT (IC) on the Hyderabad retail market in 1990, rates applied, in the experiment and adopted in subsequent analysis

Table 6. Materials applied in the field experiment and the date of application with costs

		Treatment price (rupees)								
		Annigeri			ICCC 37			ICC 506		
Date (1991)	Insecticide	T1	T2	T3	T1	T2	T3	T1	T2	T3
9 Nov	Endosulfan	308	308	308	308	308	308	308	0	0
20 Nov	Fenvalerate	295	295	0	295	295	0	295	295	295
27 Nov	Lannate	855	855	0	855	855	0	855	855	0
4 Dec	Monocrotophos	294	294	294	294	0	294	294	0	0
11 Dec	Fenvalerate	295	295	0	295	295	0	295	295	0
19 Dec	Lannate	855	0	0	855	0	0	855	0	0
Number of applications		6	5	2	6	4	2	6	3	1
Total cost (Rs ha^{-1}) of insecticides		2902	2047	602	2902	1753	602	2902	1445	295

Table 7. Insecticide costs (from *Tables 5* and *6*) within the context of the chickpea production enterprise, with an indication of net income

Variety	Treatment	Market price (Rs t^{-1})	Gross income (Rs ha^{-1})	Cost of insecticide application[a] (Rs ha^{-1})	Notional variable costs[b] (Rs ha^{-1})	Net income (Rs ha^{-1})
Annigeri	T1	7100	6830	2902	2000	1928
	T2	7200	8006	2047	2000	3959
	T3	7300	6709	602	2000	4107
	T4	6800	979	0	2000	−1021
ICCC 37	T1	7300	9534	2902	2000	4632
	T2	7300	8694	1753	2000	4941
	T3	7300	3840	602	2000	1238
	T4	6800	483	0	2000	−1517
ICC 506	T1	6800	7405	2902	2000	2503
	T2	7100	6667	1445	2000	3222
	T3	7000	3472	295	2000	1177
	T4	7000	2443	0	2000	443

[a] These include all costs associated with the purchase and application of insecticides; [b] these include the cost of land opening, cultivation, ridge formation, sowing, weeding, pest monitoring, harvesting, threshing, bagging, transport and agent's fees. It is likely that in real life the last five items would not appear in the budget where negative net income is indicated because farmers would cut their losses by abandoning the crop

threshold on ICC 506, (b) maximum yield was achieved with only three insecticide applications (five for ICCC 37) and, (c) such a variety is likely to be sown by farmers who wish to avoid insecticide application. Despite high levels of insect attack in the unsprayed plots, this variety yielded a profit (albeit a small one), whereas the other two registered a loss.

Table 7 also demonstrates, in general terms, the economic advantage of applying insecticides according to a threshold suited to a particular variety. In all cases, net income was lower or considerably lower in treatment 1 (calendar spray) than in treatments 2 or 3, depending on the needs of a given variety.

Applying these data to the 1992–1993 threshold verification data (*Table 4*) indicates that the application of three insecticide applications to either genotype increased the net profit from Rs2550 to Rs12 350 ha^{-1}.

The economics of insecticide application

The rupee equivalents of one insect day were derived from the relationships between small larva days and yield and the maximum market price. These data were applied to determine the number of insect days that need to be accumulated to justify one application of endosulfan (if effective), fenvalerate or monocrotophos at Rs300 ha^{-1}, quinalphos (village rates) at Rs400 ha^{-1} and lannate at Rs850 ha^{-1} (*Table 8*).

ICC 506 has the lowest 'threshold'. This is presumably because larval densities will remain lower for longer on this variety, i.e. the threshold is less likely to be crossed.

Table 8. Equivalent value of 1 insect day in rupees and kg and the number of insect days (small larvae) that cause yield loss equivalent to Rs300, 400 and 850[a]

	'Value' ha^{-1} of 1 insect day		Insect days[b] needed to justify the cost of insecticide application		
Variety	Rs	kg	Rs300	Rs400	Rs850
Annigeri	79.9	11.1	3.8	5.0	10.6
ICCC 37	81.0	11.1	3.7	4.9	10.5
ICC 506	110.0	15.1	2.7	3.6	7.7

[a] Cost of insecticide treatments applied in the field experiment (*Table 6*); [b] using equations

Thresholds

Data in *Table 8* were checked by applying the formula described by Mumford and Norton (1987) and the same results were obtained, provided that the effectiveness of the insecticide treatment was set at unity. This parameter is not relevant as the ability of this species to reinvade means that more than one insecticide application may be needed in a given season and that monitoring should continue after spraying.

The formula described by Mumford and Norton (1987) is for the calculation of an economic threshold. This has become an action threshold in the current context because we apply it to the insect stage that precedes the one that injures the crop.

Crop monitoring implications

A visual search of plants for eggs and larvae is conceptually a simple and precise basis for developing a monitoring system. The apparent failure of our field staff to locate eggs and the smallest larvae during the conduct of the field experiment has indicated that we need to reconsider the sampling procedure. A simple development would be to evaluate the acceptability to farmers of a modification of the entomologists' beating tray whereby plants are shaken or beaten with a stick over a piece of cloth to dislodge insects, which can then be counted with ease. The uprooted plants can then be checked for eggs. A change in the sampling system may entail the need to set different thresholds, but this is considered to be part of the tuning process.

Conclusions

The cage experiment produced reliable information that we needed to set parameters within which the field experiment should be operated. It showed that we need not consider insect damage during the flowering stage to be of economic relevance within the limits of our experiments. However, the field experiment showed us that even though damage during the flowering stage had little effect on yield, insecticide treatment during this phase could be considered to lower the larval density to a level that would not damage the tender pods. The field experiment also showed that we should not recommend egg density to predict when an insecticide should be applied, but that the density of small larvae was suitable. A budget for the notional chickpea enterprise showed that the two susceptible varieties would not have shown a profit unless insecticides had been applied, whereas the pest-resistant variety, ICC 506, appeared to be more viable in the low-input context. The number of sprays needed to keep the larval population below the threshold of 0.5 larvae per plant was intuitively 'too high' in view of the amount of damage to other arthropods and the 'environment' that can be done by five insecticide applications in only 6 weeks. Clearly, what is needed is a variety with high yield potential *and* resistance to *Helicoverpa*, perhaps supported by the application of an insect pathogen (Rabindra, Sathiah and Jayaraj, 1992).

The field experiment provided further data indicating that pod yield is a direct function of pod damage. The thresholds, provided either as small larvae per plant or in insect days, are guidelines for starting the next phase of this research and are expected to be modified to suit specific sets of conditions.

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