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Host plant selection by *Helicoverpa* spp. in chickpea-companion cropping systems

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Abstract

The potential of companion crops to serve as diversionary hosts for ovipositing *Helicoverpa* spp. moths in chickpea cropping systems was evaluated in a field experiment. Patterns of egg distribution by *Helicoverpa* spp. within paired combinations of chickpea and each of six companion crop species were documented in a split-plot design sampled four times during the 1999 winter growing season. Chickpea was attractive to ovipositing *Helicoverpa* moths from as early as 14 days after planting and throughout the experimental period. The companion crop species varied in relative attractiveness to ovipositing moths but none was able to effectively divert *Helicoverpa* egg pressure away from chickpea for the duration of the experiment. Of all *Helicoverpa* spp. larvae recorded from all samples and crop combinations, 98.3% were found on chickpea. A marked aggregative oviposition behaviour of *Helicoverpa* spp. on tall weeds growing through the chickpea canopy was recorded. The relevance of observed patterns of host selection and inferred moth behaviour to management of *Helicoverpa* populations on chickpea are discussed.

Introduction

The noctuids *Helicoverpa armigera* (Hübner) and *H. punctigera* (Wallengren) are among the most damaging pests of field crops in Australia (Common, 1953; Zalucki et al., 1986, 1994; Fitt, 1989). The pest status of these species has increased steadily over the last 50 years (Broadley, 1977; Passlow, 1986) due, in part, to agro-ecosystem diversification by the introduction of winter host crops such as chickpea, *Cicer arietinum* (L.) (Knights et al., 1980; Fitt, 1989). Commercial chickpea crops are important sources of *Helicoverpa* spp. founding populations on field crops in spring (Titmarsh, 1992; White et al., 1995; Sequeira, 2001).

The use of chemical insecticides has traditionally been the primary management option for *Helicoverpa* control on chickpea (Lateef, 1985; Reed et al., 1987). In recent years, however, the development of insecticide resistance in *H. armigera* (Gunning et al., 1984; Daly & Murray, 1988; Forrester et al., 1993) and renewed emphasis on sustainable, environment-friendly crop protection practices has highlighted the need to develop alternative pest management strategies.

Cultural control by way of habitat diversification has received considerable attention as an alternative pest management strategy (Bohlen & Barrett, 1990; Abate, 1991; Tonahasca & Stinner, 1991; Emeasor & Ezueh, 1997; Balasubramanian et al., 1998; Wang & Yue, 1998; Banks & Ekbom, 1999; Ekesi et al., 1999; Mensah, 1999; Parajulee & Slosser, 1999). Habitat diversification by way of companion or strip cropping aims to reduce the pest population on the target crop by diverting pressure away from the main crop or increasing the abundance of beneficial insects.

Here we report on a field assessment of experimental companion cropping systems for management of *Helicoverpa* spp. on chickpea in central Queensland. The objective of the assessment was to identify crop species that could serve as diversionary hosts for ovipositing *Helicoverpa* moths when grown as companion crops. Patterns of host selection by *Helicoverpa* spp. in chickpea-companion crop combinations were determined. A serendipitous and little known pattern of host selection in weedy chickpea was documented. The relevance of observed patterns of host selection to management of *Helicoverpa* populations on chickpea is discussed.

Materials and methods

Experimental design and field layout

The field assessment was done on cracking black clay soil under furrow irrigation in Emerald (23°34′ S, 148°10′ E), Queensland. The field layout followed a split-plot design (Cochran & Cox, 1957; Steel & Torrie, 1980) with 4 blocks, 6 plots within blocks and 2 subplots within plots. Plots were randomised within blocks. Each plot was assigned to one of six, paired crop combinations. Within each plot, one of the paired subplots was randomly assigned to chickpea (cv 'Amethyst'), the other to one of six companion crops.

Winter tolerant crop species suited to the semi-arid subtropical environment of central Queensland were chosen for companion planting. The paired crop combinations with chickpea were as follows: (1) *Brassica juncea* (L.) (indian mustard, cv 'CSIRO 997-1-1'); (2) *Brassica napus* L. var. *napus* (canola, cv 'Hylite 200 IT'); (3) *Vicia faba* L. var. *faba* (faba bean, cv 'Fiesta'); (4) *Pisum sativum* L. var. *arvense* (field pea, cv 'Dunn'); (5) *Linum usitatissumum* L. (linseed, cv local); (6) *Lupinus albus* L. (lupin, cv 'Mutant Kiev').

All crop species were planted on 7 May 1999 on raised beds at recommended commercial planting rates. Subplots measuring 15 m × 5.4 m (12 rows × 45-cm spacing) within plots were adjacent to each other within plots. Blocks and plots within blocks were separated by 5.4 m wide (12 rows × 45-cm spacing) strips of *Triticum aestivum* L. (wheat) as a buffer crop to isolate the crop combinations. *H. armigera* is occasionally found on wheat but at very low densities and is not considered to be an economic pest of this crop in central Queensland. *H. punctigera* is restricted to dicotyledonous hosts.

Sampling protocols

Paired crop combinations. Sampling was done at key phenological stages of the plants, viz., vegetative, early flowering, peak flowering and grain filling. Accordingly, plant samples were collected within a 6-h period at 46, 67, 80 and 112 days after planting (DAP) respectively. At each of the four sampling dates, egg and larvae counts were obtained by using the following procedure. Within plots, two 1-m row of crops were selected at random from each subplot and the plants cut at ground level. These plants were enclosed individually in large brown paper bags and transferred to the laboratory where the number of *Helicoverpa* eggs and larvae on each plant was recorded.

In-crop weeds and wheat buffer. As part of the routine maintenance of the trial area, the plots were hand-weeded on 11 August 1999. During this operation, *Helicoverpa* eggs were observed on weeds growing within chickpea rows but not on weeds in the companion crops. Of the 24 chickpea subplots, 14 had been weeded before this phenomenon was observed. Therefore, quantification of *Helicoverpa* eggs and larvae was done on the remaining 10 chickpea subplots. The height of each weed plant and its surrounding chickpea canopy was recorded. Canopy height was determined by recording the average height of five chickpea plants within a radius of 30 cm around each weed. The total number of *Helicoverpa* eggs and larvae on each weed plant in the subplot and 10 chickpea plants surrounding each weed plant was quantified.

For each of the 10 chickpea subplots in which oviposition on weeds had been quantified, eggs and larval counts were obtained for 10 randomly selected wheat plants from buffer rows closest to and third away from chickpea. The objective of this assessment was to determine whether or not moths had discriminated between wheat plants growing in the buffer strips and as weeds in chickpea.

Data analysis

Data from the paired crop combinations were log transformed (count + 1) and analysed as a split-plot design across space and time (Steel & Torrie, 1980) with Sample-date (or DAP) as the time factor. Egg and larval data were analysed separately. The error term for plots was used to examine the significance of overall differences in egg distribution among crop combinations. The significance of differences in the distribution of eggs between chickpea and the paired companion crop were tested at the subplot level. Inclusion of Sample-date in the design facilitated the detection of temporal changes in the pattern of egg distribution.

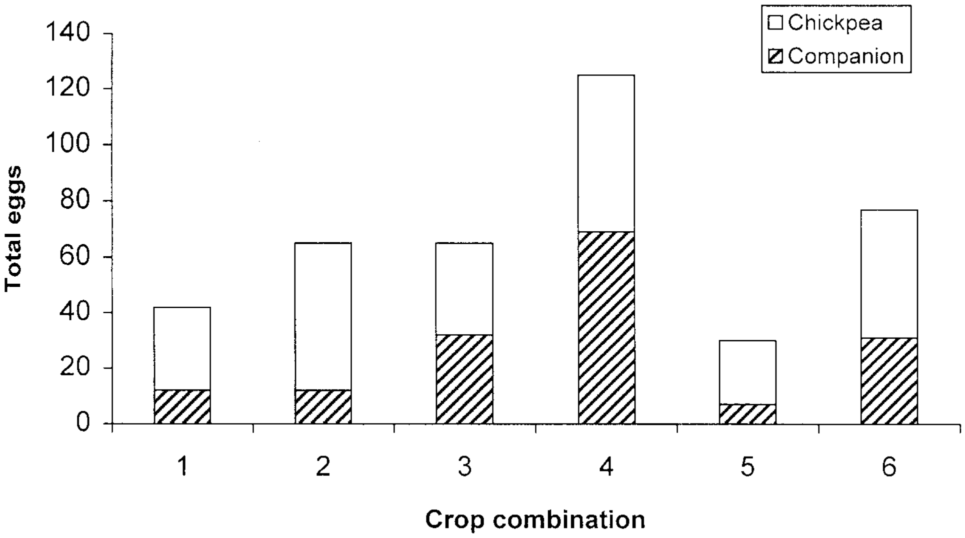

Figure 1. Distribution of total egg counts on chickpea and companion crop across paired crop combinations, pooled over Sample dates and blocks. Paired crop combinations with chickpea: (1) *Brassica juncea* (2) *Brassica napus* (3) *Vicia faba* (4) *Pisum sativum* (5) *Linum usitatissumum* (6) *Lupinus albus.*

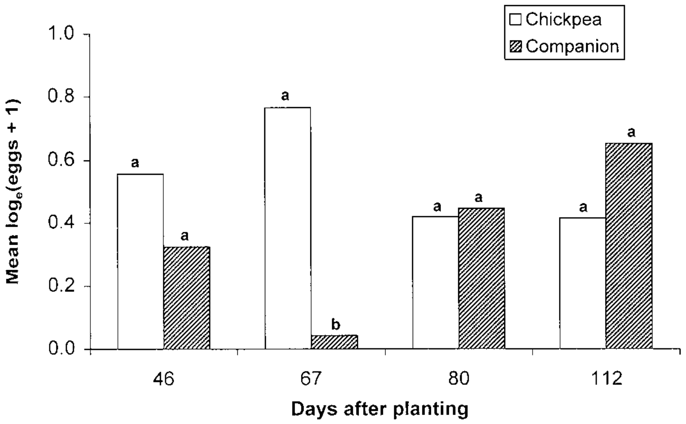

Figure 2. Mean egg density per metre on chickpea and companion crop across Sample dates, pooled over blocks and crop combinations.

Results

Crop phenology. Of the six companion crops, mustard followed by canola and faba bean, exhibited the most vigorous seedling growth. Only the Brassica species were flowering at the time of the first sample (46 DAP). *Helicoverpa* eggs and neonate larvae were found on chickpea plants within 7 days of seedling emergence (14 DAP) but not until much later on the other species. At the time of the second sample (67 DAP), all plant species were flowering, and at 80 DAP, all companion crop plants except lupin were taller than chickpea.

Analysis of egg counts – Paired crop combinations. A total of 404 eggs were recorded over all Sample-dates, Blocks and Plots. Of this total, 59.7% were found on chickpea. Egg distribution (pooled across all Sample-dates and Blocks) varied between and within crop combinations (Figure 1). Within combinations 3 (*V. faba*) and 4 (*P. sativum*), chickpea and the paired companion crop received similar numbers of eggs whereas in all the other combinations the majority of eggs was laid on chickpea. Combination 4 received the largest proportion of eggs (31%) whereas 1 (*B. juncea*) and 5 (*L. usitatissumum*) received the least.

The results of the split-plot analysis on eggs are given in Table 1. There were significant differences in overall mean egg density among crop combina-

Table 1. Analysis of variance table for the split-plot design across space and time on log transformed (count + 1) data for eggs

Source of variation	d.f.	s.s.	m.s.	v.r.	P
Block level					
Block	3	1.5	0.5	0.8	
Plot level					
Plot	5	11.531	2.306	4.17	0.014
Residual	15	8.294	0.553	0.79	
Subplot level					
Subplot	1	2.851	2.851	4.1	0.058
Plot×subplot	5	3.282	0.656	0.94	0.477
Residual	18	12.523	0.696	4.37	
Sample-date level					
Sample-date	3	0.921	0.307	1.0	0.394
Plot×sample-date	15	7.454	0.497	1.62	0.07
Subplot×sample-date	3	12.304	4.101	13.34	<0.001
Plot×subplot×sample-date	15	14.941	0.996	3.24	<0.001
Residual	252	77.483	0.308		
Total	383	160.716			

tions. Combinations 3, 4 and 6 (*L. albus*) were not significantly different from each other in mean egg density but as a group differed significantly from the others [LSD, $P < 0.05$]. The effect of Sample-date is insignificant, indicative of parity in egg distribution over time. The borderline significance level ($P = 0.06$) of the Subplot main effect, together with significant two- and three-way interaction with the other factors indicate changes in the distribution of eggs within and among crop combinations over time. The Subplot × Sample-date interaction results from the marked preference for chickpea subplots at 67 DAP (Figure 2). The Plot×Subplot×Sample-date interaction is shown in Figure 3. The companion crops *B. juncea* and *B. napus* received few or no eggs after the first Sample-date (46 DAP). In contrast, *V. faba, P. sativum, L. usitatissumum* and *L. albus* received more than 50% of the eggs laid at 80 and 112 DAP.

Paired crop combinations – Larval counts. Of 2749 larvae enumerated across all Samples-dates, Blocks and crop combinations, 2703 (98.3%) were found on chickpea in comparison to 46 (1.7%) on all companion crops. Mean larval density per m^2 (± s.e.m) on chickpea increased from 15.6 (1.3) at 46 DAP to 45.8 (0.4) at 67 DAP before decreasing to 20.8 (5.3) at 112 DAP. By comparison, the corresponding estimates on the companion crops did not exceed 1.7 m^{-2}. In view of the highly asymmetric distribution of larvae (98.3% on chickpea), tests of differences in mean density among groups could not be assigned any biological significance and hence are not presented here.

Oviposition on in-crop weeds and wheat buffer. Deposition of eggs on the weeds in chickpea subplots became apparent only after the weed plants grew noticeably above the height of the chickpea canopy. Although weeds were found in companion-crop subplots, none were taller than the surrounding crop canopy or had *Helicoverpa* eggs on them. The weed population in chickpea comprised *T. aestivum, Sonchus oleraceus* L. (common sowthistle) and all companion-crop plants except *L. albus*.

A total of 1866 eggs were recorded on 102 weed plants. The mean number of eggs per plant on the weed species ranged from 5.8 (*B. juncea*) to 28.7 (*P. sativum*), whereas the corresponding mean of eggs found on 10 chickpea plants surrounding each weed plant (nearest neighbour) ranged from 0.3 to 1.7 (Table 2). A total of 90 eggs were recorded on all the nearest-neighbour chickpea plants from all plots. In contrast to egg density, mean larval density was similar on both groups of plants, ranging from 0 (*P. sativum*) to 2.8 (*S. oleraceus*) on individual weed

Table 2. Mean number of eggs and larvae observed on individual weed plants and 10 chickpea plants surrounding each weed plant. Numbers in brackets are minimum and maximum counts

Weed species	*N*	Height[a] (cm)	Per Weed Plant		Per ten chickpea plants	
			Eggs	Larvae	Eggs	Larvae
B. napus	11	16.4	10.1 (0,29)	0.3 (0,1)	1.7 (0,15)	0.8 (0,3)
V. faba	8	7.4	21.3 (0,47)	1.0 (0,3)	0.3 (0,1)	1.4 (0,4)
P. sativum	3	23.0	28.7 (3,61)	0	0.3 (0,1)	0.3 (0,1)
L. usitatissumum	28	11.0	13.9 (0, 55)	0.7 (0,4)	1.2 (0,5)	1.2 (0,3)
B. juncea	8	24.3	5.8 (0,29)	0.3 (0,1)	0.3 (0,1)	0.8 (0,2)
S. oleraceus	12	14.2	23.2 (0,128)	2.8 (0,29)	1.3 (0,9)	0.5 (0,4)
T. aestivum	32	21.0	24.6 (0,64)	0.5 (0,4)	0.5 (0,7)	1.2 (0,5)
Mean		16.7	18.2	0.8	0.8	0.9

[a]Mean height of the weed plant above the chickpea canopy.

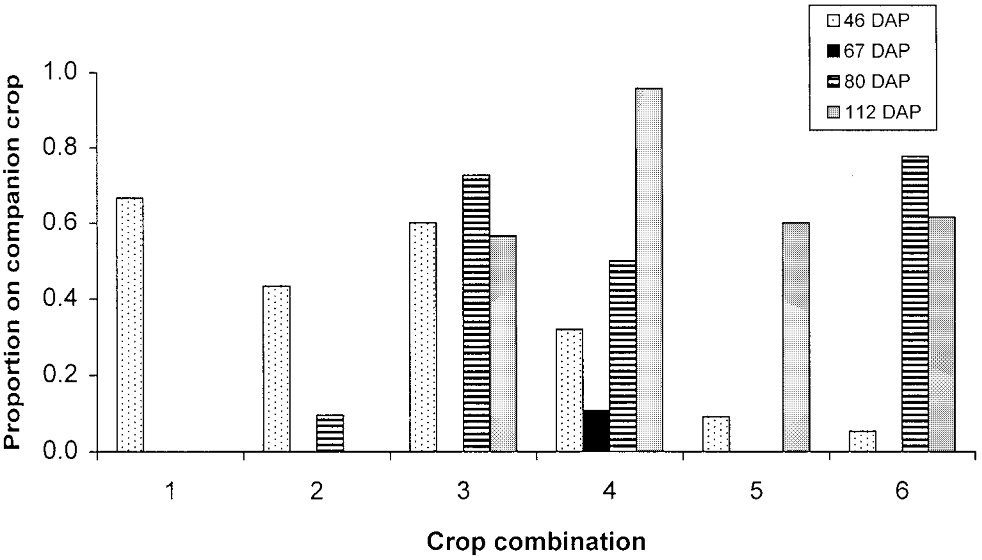

Figure 3. Distribution of total egg counts on chickpea and companion crop across paired crop combinations and Sample date, pooled over blocks. See Figure 1 legend for crop combination labels.

plants and 0.3 to 1.4 on 10 nearest neighbour chickpea plants (Table 2).

Within weed species for which sample size was adequate, namely *L. usitatissumum* and *T. aestivum*, a positive, albeit weak, correlation between egg density and height of weed plants above the canopy was detected. For both species the regression of egg density on height above chickpea was significant (*L. usitatissumum*: $N = 28$, $R^2 = 0.244$, Student's $t = 2.89$, P $= 0.008$; *T. aestivum*: $N = 32$, $R^2 = 0.187$, Student's $t = 2.62$, P $= 0.014$).

Few eggs were found on *T. aestivum* plants in the buffer strips. Mean egg density per *T. aestivum* plant in buffer row 1 (closest to chickpea) ranged from 0 to 0.9 and in buffer row 3 (third away from chickpea) from 0 to 0.5. *Helicoverpa* larvae were not found on the 100 *T. aestivum* plants sampled in the buffer strips.

Discussion

Patterns of egg distribution and asymmetry of choice indicated by differential oviposition activity are end results of the host selection process (Fitt, 1991). Therefore, host selection behaviour in the field can be inferred from observed patterns of egg distribution within and among host plant species. The host selection process in *Helicoverpa* spp. is influenced by a multitude of factors, including plant species, plant height and plant physiological stage (Zalucki et al., 1986; Firempong & Zalucki, 1990; Fitt, 1991; Jallow & Zalucki, 1996).

The results presented here show that some crop combinations were more attractive to *Helicoverpa* moths than others. Crop combination 4 received the largest proportion of eggs over all Sample-dates (Figure 1), but within that combination a clear preference for *P. sativum* (96% of eggs) did not become evident until 112 DAP (Figure 3). The *Brassica* crops (combinations 1 and 2) flowered earliest and enjoyed a height advantage over the other crops which could account for some oviposition activity on these crops at 46 DAP. However, the paucity of eggs on these species at later Sample-dates (Figure 3) suggests that they were not preferred hosts relative to the other crops evaluated in our study. *Vicia faba, P. sativum, L. usitatissumum* and *L. albus* were able to divert 50% or more of eggs away from chickpea only in the later flowering stages (80, 112 DAP; Figure 3) and after a clear height differential with chickpea had become apparent.

Chickpea elicits oviposition by *Helicoverpa* spp. in all its phenological stages (Reed et al., 1987) but is particularly attractive at 67 DAP in our study (Figure 2) which corresponds to the peak flowering stage. At 67 DAP 96.5% of all eggs recorded (pooled across blocks and plots) were found on chickpea (Figure 2) whereas the remainder were found on *P. sativum* (combination 4, Figure 3). It is noteworthy that with the exception of *P. sativum* at 112 DAP, oviposition on chickpea was never reduced to insignificant levels throughout the field assessment.

From a practical pest management viewpoint, an effective diversionary crop must be markedly more attractive than the main crop for a significant duration of the crop cycle. This differential attractiveness can then be exploited by using a relatively small area of the former to draw pest pressure away from a much larger area of the latter. None of the companion crops tested in our study was sufficiently more attractive than chickpea throughout all of its phenological stages to be useful as a diversionary or trap crop.

The highly aggregative oviposition pattern on weeds within chickpea is a behavioural response possibly triggered by the vertically differentiated canopy structure made up of tall plants sparsely dispersed within a population of shorter plants. Another possible trigger for the observed oviposition response is the chickpea foliar secretions containing high concentrations of malic acid (Rembold, 1981). The amount of foliar exudate and the concentration of malic acid depend on temperature and growth stage, and have been shown to increase during the reproductive stages of the plant (Koundal & Sinha, 1981). Whilst moths are drawn to chickpea in all growth stages, there is relatively less oviposition activity and damage in resistant cultivars that secrete high concentrations of malic acid (Rembold, 1981; Rembold & Winter, 1982; Lateef, 1985; Reed et al., 1987). Moths could therefore be assessing weeds in post-flowering chickpea as oases in an increasingly hostile oviposition environment.

Subsequent to this study, the aggregative oviposition response of *Helicoverpa* spp. in weedy chickpea has been documented in experimental as well as commercial crops with results similar to those reported here (R. Sequeira, unpubl.). However, much work needs to be done to fully understand the processes underlying observed patterns of host plant selection in the field and their relevance to insect pest management.

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