INTERNATIONAL JOURNAL OF PEST MANAGEMENT, 2003, **49**(2) 155–161

Effect of weeds on insect pests of maize and their natural enemies in Southern Mexico

(*Keywords:* maize, non-crop vegetation, insect pests, natural enemies, Mexico)

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Abstract. A pilot study performed on the Pacific coastal plain of Chiapas, Mexico, focused on the prevalence of maize crop infestation by insect pests, parasitism of pests and the abundance of insect predators in maize plots with weeds compared with plots under a regime of rigorous manual weed control. Sampling was conducted on four occasions at 20, 32, 44 and 56 days post-planting. Infestation of maize by fall armyworm larvae, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), was more than twice as great in plots with strict weed control compared with weedy plots at 20 days post-planting, but declined thereafter in both treatments. The prevalence of aphid infestation and the abundance of nitidulid beetles were consistently greater in weed-controlled plots. In contrast, the density of beneficial predatory Coleoptera increased significantly in plots with weeds, and it is suggested that this probably explains the lower incidence of pests. *S. frugiperda* egg masses placed in experimental plots suffered a significantly higher incidence rate of parasitism by *Chelonus insularis* (Hymenoptera: Braconidae) in clean plots (42.0%) compared with those placed in weedy plots (3.75%); it is suspected that weeds may hinder the location of egg masses by parasitoids. Overall, the presence or absence of weeds had a marked influence on the arthropod community present in maize fields. The weeds did not affect maize plant height, the levels of plant damage or the yield of grain from plants under each type of weed regime, implying that competitive effects of weeds may be offset by greater numbers of beneficial insects in weedy plots. Our pilot study indicates that strict weed control in maize may be unnecessary.

1. Introduction

Weeds are traditionally viewed as undesirable plants that reduce yields by competing with crops or by harbouring insect pests and plant pathogens (van Emden 1965, Thresh 1981). In many agricultural systems, however, pest populations are reduced when crops are grown in the presence of weeds or interplanted with another crop. Maize grown in Colombia or the USA was more heavily attacked by larvae of the fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) when planted as a monoculture compared with when intermingled with weeds or intercropped with beans (Altieri 1980). Plant diversity increases availability of refuges, alternative prey and food sources (pollen, nectar, etc.) for natural enemies.

An alternative hypothesis, the ‘resource concentration’ hypothesis, states that the presence of non-host plants causes chemical confusion of the stimuli used by insect pests to find host plants and it also presents physical barriers to plant location. Changes in resource concentration may be more relevant than regulation by natural enemy populations for certain pests (Risch 1981). The importance of plant diversity for enhancing the impact of natural pest control is recognized as a means for reducing grower dependence on chemical measures (Altieri and Whitcomb 1979, Dent 1991, Gurr and Wratten 1999). Moreover, weeds are valuable in soil erosion control, conservation of soil moisture, promoting build-up of organic matter and nitrification of the soil (Gliessman *et al*. 1981, Weil 1982).

Habitats containing a diversity of possible food plants may also be attractive to polyphagous noctuid pests. The ability of phytophagous noctuids to discriminate between potential host plants and move between non-crop and crop plants will have important consequences for the levels of crop damage (Portillo *et al*. 1996). The feeding and oviposition preferences of such pests will also have consequences for expedient weed management practices.

The fall armyworm, *S. frugiperda*, is a polyphagous pest of many crops but shows a preference for members of the Poaceae such as sorghum and maize (Pitre *et al*. 1983). The insect is considered an important constraint on maize production throughout Latin America (Andrews 1980). Infestations of 55–100% of plants resulted in losses of 15–75% of the grain yield in Nicaragua (Hruska and Gould 1997). In Honduras, *S. frugiperda* has been observed feeding on non-crop vegetation (weeds) together with three other lepidopterous defoliators of maize (Portillo *et al*. 1996).

Control of *S. frugiperda* and other insect pests such as the stalk borer, *Diatraea lineolata* (Walker) (Lepidoptera: Pyralidae), is usually achieved by application of organophosphate insecticides in spray or granule formulations (Andrews 1988). These chemicals are routinely applied by hand or by using a backpack sprayer without protective measures; evidence of chronic poisoning of growers in rural communities has been reported in

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International Journal of Pest Management
ISSN 0967-0874 print/ISSN 1366-5863 online © 2003 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/0967087021000043111

Southern Mexico and Nicaragua (McConnell and Hruska 1993, Tinoco and Halperin 1998). The need for sustainable techniques for pest management in maize is now becoming increasingly recognized (Andrews *et al*. 1992, Altieri and Masera 1993, Williams *et al*. 1999).

To investigate the effect of weeds on the impact of insect pests of maize and their associated natural enemies we carried out the present study on the Pacific coastal plain of Chiapas, next to the border between Mexico and Guatemala. In particular, we focused on food plant preferences by noctuid larvae, the prevalence of parasitism and the abundance of insect predators in maize plots with weeds compared with plots under a regime of rigorous weed control. The productivity of each regime was also compared by evaluation of grain yield in the presence or absence of competition from weeds.

2. Materials and methods

The field trial was performed 18 km south-east of Tapachula on the coastal plain of Chiapas and 1 km from the border with Guatemala, at an altitude of approximately 50 m above sea level. During the growing season, the typical daily temperature range is 23 – 35°C with a mean monthly rainfall of 300 mm and a relative humidity of $>$ 85%.

A local commercial variety of maize (Tacsa H-101) was planted in nine blocks in four different fields separated by a distance of between 50 and 500 m. Each block comprised a pair of subplots of 10 × 10 m with a 10-m gap between them and a 10-m zone around them (figure 1). Maize was planted at a standard density of 25 cm between plants and of 70 cm between rows (Andrews 1980). The trial was performed in August/September 1998 corresponding to the second planting cycle during the rainy season. Plots were treated with NPK (18 : 46 : 00) fertilizer (50 kg/ha) and urea (50 kg/ha) pre-emergence, and with urea at a rate of 100 and 150 kg/ha at 30 and 60 days post-planting, respectively. At no time were insecticidal applications made within a distance of 200 m of any experimental block.

The experiment involved manipulation of non-crop vegetation that developed naturally in experimental areas, hereafter referred to as weeds. Experimental blocks were randomly assigned to one of two treatments: strict weed control ($n = 5$) or minimal weed control (4). Strict weed control involved a regime of cutting weeds at 2 – 3-day intervals such that the height of weeds did not exceed 5 cm. Minimal weed control involved no control except at 37 days post-planting when weed height was reduced to a maximum of 30 cm and binding weeds were cut away from maize plants. In all cases mechanical control was employed using machetes; herbicides were only applied once when a towel soaked in a solution of glyphosate was dragged over the 10-m zone surrounding the experimental plots under the strict weed control regime 5 days before the start of the experiment.

An evaluation was made at 20 days post-planting and three times at 12-day intervals thereafter (32, 44 and 56 days) until plants were fully grown. These are subsequently referred as sample points 1 – 4. At each evaluation, the following data were collected. The density and diversity of weed species were determined by taking five quadrat samples (0.25 m^2) at random within each subplot of maize and five quadrat samples in the surrounding 10-m zone. The number of plants in each quadrat was counted and the plants were identified. Quadrats were searched by hand and the presence of lepidopteran larvae or any other insects recorded. Lepidopteran larvae were collected and reared in the laboratory on a semi-synthetic diet until death or pupation. Any parasitoids that emerged from these larvae were identified to species using published keys (Cave 1993, 1995).

The presence of insects on maize plants was determined by dissection of 20 plants per subplot (total of 40 plants per block). Plants were selected by reference to random number tables. The degree of damage of each plant was classified on a 1 – 5 scale, where 1 = 0 – 10%; 2 = 11 – 25%; 3 = 26 – 50%; 4 = 51 – 75%; and

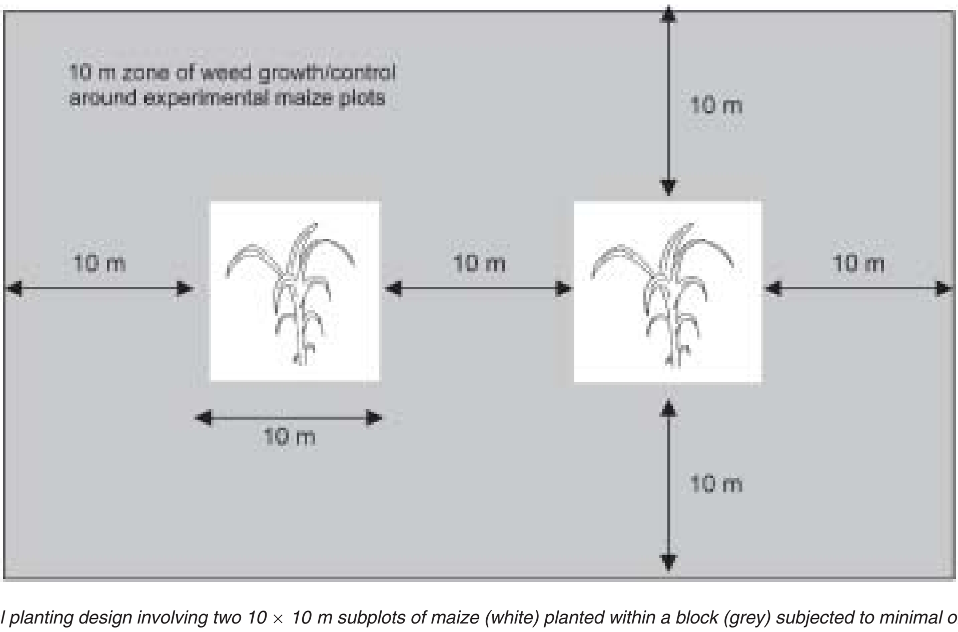

Figure 1. Experimental planting design involving two 10 × 10 m subplots of maize (white) planted within a block (grey) subjected to minimal or rigorous manual weed control practices.

5 = 76 – 100% defoliation (Kaya *et al.* 1995). Any lepidopteran larvae found were identified, transferred to the semi-synthetic diet and reared in the laboratory until pupation. The causes of death in these larvae were noted daily and any emerging parasitoids identified. Lepidopteran adults or egg masses were not abundant and were not included in the counts as they could not readily be identified to species or were easily disturbed during the evaluation procedure.

The presence of all other arthropods observed in the 20 plant per subplot sample was also recorded. In general, insects and spiders were classified into natural groups, e.g. *Solenopsis* spp., all types of spider, *Chrysoperla* spp. (all stages), predatory Coleoptera (coccinelids, carabids and staphylinids), other Coleoptera (mainly sap beetles of the genus *Colopterus* [Nitidulidae]), the presence of aphid infestations (comprising a minimum of 20 individuals, lesser infestations of aphids were ignored), other phytophagous insects (leafhoppers, etc.), earwigs (*Doru taeniatum* [Dohrn]), or other natural enemies (*Orius* spp., parasitoid cocoons, adult parasitoids, etc.). When the identity of an insect was uncertain, it was taken to the laboratory for identification.

The presence of ground active arthropods in experimental blocks was also monitored using five pitfall traps placed at random within each subplot of maize. Each trap comprised a smooth-sided plastic cup of 500 ml capacity with a small slit in the base to allow the escape of rainwater. A plastic dinner plate was placed 10 – 15 cm above each pitfall trap and was held in place with a pair of wooden supports. This acted as a protective roof to reduce flooding of the pitfall traps by the heavy rainfall of each afternoon. Pitfall traps were emptied every 3 – 6 days. Arthropods from these traps were killed by freezing, preserved in formalin and the most commonly captured insects were subsequently identified to family or to species.

To assess the activity of adult egg parasitoids in the presence or absence of weeds, individual *S. frugiperda* egg masses (approximately 50 – 80 eggs each) were attached to the underside of equilateral triangles of transparent plastic (about 8 cm each side) using office staples. Each plastic triangle was stapled to the top of a wooden support 40 cm in length. The egg masses were less than 2 days old and were obtained from a laboratory culture held in ECOSUR. At 23 days post-planting, in each experimental block five egg masses were placed in the 10-m zone around the maize subplots to detect parasitism by the egg – larval parasitoid, *Chelonus insularis* Cresson (Hymenoptera: Braconidae), one of the most abundant parasitoids observed attacking *S. frugiperda* in the study area. Egg masses were collected after 24 h in the field. Larvae that emerged from these eggs were reared on semi-synthetic diet in the laboratory until pupation or the emergence of parasitoids. The incidence of parasitism in the larvae from each egg mass was registered.

2.1. *Data analysis*

Weed diversity was calculated using the Berger – Parker dominance index; a simple equation that expresses the proportion (d) of the total catch (N_{tot}) due to the dominant species (N_{dom}): $d = N_{dom}/N_{tot}$ (May 1975, Southwood 1978). Diversity index values were subjected to Student's *t*-test at each sample point separately. Mean per cent weed cover and associated standard errors were calculated using a GLIM procedure with a binomial error structure (Crawley 1993).

Arthropod data were analysed by a repeated measures multivariate ANOVA in which changes in the abundance of each arthropod group was analysed comparing the number of each type of arthropod in each experimental block (as the sum of the two sub-blocks) with the value calculated for the preceding time point. Overall changes in response variables with time were calculated as was the effect of treatment and the interaction Time*Treatment. In all cases, the validity of the analysis was assessed by checking each variable independently for normality and the dispersion matrices were examined to determine that the variances and covariances were independent from the means and were the same within groups (Marriott 1974, Chatfield and Collins 1980). The significance of effects detected by repeated measures analysis was determined using the SAS program by calculating the *F* value given by Pillai's Trace. The limited power of the analysis arising from the lack of restrictions on the variance – covariance matrix made it necessary to adopt a critical α value of 0.075 rather than the conventional 0.05. Such a measure is recommended for situations when undertaking repeated measures MANOVA to avoid an excess of type II errors (acceptance of a false null hypothesis) (Stevens 1992, von Ende 1993).

Where appropriate, treatment means at a particular sample point were subjected to a *t*-test in which the assumption of equal variances was examined; in all cases the assumption was rejected and a test with unequal variances was performed.

Catches of arthropods recovered from pitfall traps in each treatment were summed over all sample points and compared by χ^2-test, whereas changes in the catch size over the course of the study were subjected to repeated-measures analysis as described above. Parasitism of larvae reared from *S. frugiperda* egg masses exposed to *Chelonus insularis* was analysed by the Mann – Whitney *U*-test.

3. Results

3.1. *Weed cover*

The sample time-points covered all growth stages of the maize plants, from 16.3 ± 1.1 cm (mean ± SE) plant height to fully developed plants showing tasselling and the formation of cobs at 159 ± 8.6 cm. The presence of weeds did not affect maize plant height at any stage ($F_{3,5} = 2.29$, $p = 0.20$). In the weed-controlled plots, only the grass-like purple nutsedge, *Cyperus rotundus* L. (Cyperaceae) was present and did not grow to more than 5 cm in height. In the weedy plots, nine plant species were routinely observed (in order of abundance): *C. rotundus*, *Phillanthus niruri* L. (Euphorbiaceae), *Eleusine indica* (L.) (Gramineae), *Euphorbia hirta* L. (Euphorbiaceae), *Ipomoeae* sp. (Convolvulaceae), *Digitaria sanguinalis* Scop. (Poaceae), *Portulaca oleracea* L. (Portulaceae), *Echinochloa colonum* Link (Poaceae) and *Cucumis* sp. (Cucurbitaceae). Mean weed cover in weedy plots ranged from 34 to 47%, whereas diversity index values ranged from 0.63 to 0.74. Neither parameter differed significantly within the zone planted with maize compared with the surrounding maize-free zone at any time-point (figure 2). The reduction in within-plot weed cover between sample points 2 and

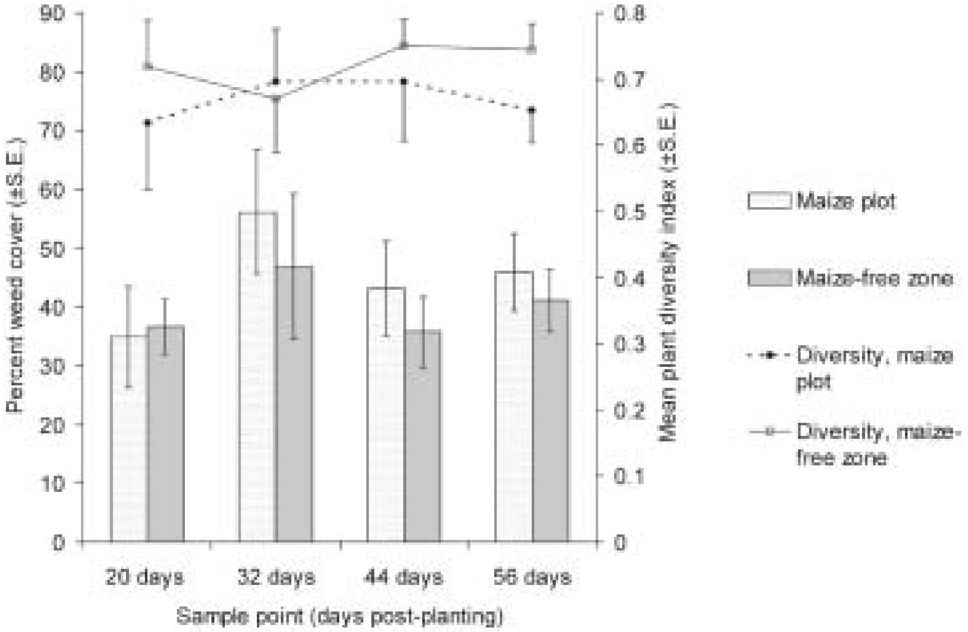

Figure 2. Per cent ground cover in weedy plots among maize plants (maize plot) and in a 10-m zone surrounding each plot (maize-free zone). Lines indicate weed species' diversity calculated by the Berger–Parker dominance index for the area planted with maize (maize plot) and in the surrounding maize-free zone. Error bars are SEM.

3 (32 and 44 days post-planting) was a consequence of weed cutting that occurred after the second sample point to avoid choking of maize plants by creeping weeds. Weed diversity changed little during the course of the study, the grass *C. rotundus* being consistently dominant.

3.2. Arthropods on maize

The total number of arthropods changed significantly over the course of the study ($F_{3,5} = 17.56$, $p = 0.004$), a phenomenon that was not affected by the presence of weeds ($F_{3,5} = 0.39$, $p = 0.77$). Considering each group of arthropods separately, infestation by the principal maize pest *S. frugiperda* was significantly affected by the presence of weeds during the course of the study ($F_{3,5} = 4.91$, $p = 0.059$) (table 1). Initially, densities of *S. frugiperda* larvae were high, particularly in maize in non-weedy plots where the mean levels of infestation were more than double those observed in weedy maize plots. Densities of *S. frugiperda* larvae fell significantly between sample points 2 (32 days) and 3 (44 days) ($F_{1,7} = 46.4$, $p < 0.001$), and by samples 3 and 4 (56 days) very few *S. frugiperda* larvae were recovered probably due to the disappearance of the developing leaf whorl in fully grown maize that is the preferred feeding site for this insect. The density of *S. frugiperda* larvae found by quadrat sampling of weeds in weedy plots was initially 12.4 ± 6.8 larvae/m^2 but it declined to 3.0 ± 1.9 larvae/m^2 at 32 days post-planting and remained very low (< 1 larva/m^2) thereafter. The number of larvae of other lepidopteran species on maize, mainly consisting of *Diatraea lineolata*, *S. exigua* (Hübner) and *Mocis latipes* (Guenée) was consistently very low and was not significantly affected by the presence of weeds ($F_{3,5} = 1.15$, $p = 0.41$).

The degree of infestation by aphids, *Rhopalosiphum maidis* (Fitch), changed significantly between all sample points ($F_{3,5} = 313$, $p < 0.001$) and was significantly greater in the absence of weeds in all but the first sample point ($F_{3,5} = 3.51$, $p = 0.03$) (table 1). The abundance of phytophagous Coleoptera, mostly represented by a sap beetle, *Colopterus* sp. (Nitidulidae), increased significantly over the experimental period ($F_{3,5} = 30.8$, $p = 0.001$) and was consistently lower in weedy plots ($F_{3,5} = 7.30$, $p = 0.03$). The density of other potential pests (leafhoppers, thrips, phytophagous bugs, etc.) was not affected by the presence of weeds at any sample point ($F_{3,5} = 0.20$, $p = 0.89$).

The abundance of insect natural enemies in experimental plots was not greatly affected by the weed control regime. The density of earwigs, *Doru taeniatum* (Dohrn), *Chrysoperla* spp., all types of spiders, and ants of the genus *Solenopsis* increased markedly during the experimental period in both treatments (table 1). In contrast, the abundance of other natural enemies (syrphid larvae, predatory bugs, etc.) ($F_{3,5} = 3.38$, $p = 0.11$) and predatory Coleoptera ($F_{3,5} = 2.21$, $p = 0.21$) on maize plants did not change significantly over the course of the study in plots of either treatment.

3.3. Arthropods in pitfall traps

Overall, more than double the number of arthropods were captured in pitfall traps placed in weedy ($n = 570$) compared with weed-controlled plots (278) ($\chi^2 = 100.5$, d.f. = 1, $p < 0.001$) (table 2). The most abundant insect captured was the carabid *Calosoma calidum* F. (Coleoptera: Carabidae), which comprised 66% of the total capture of arthropods in clean plots and 78% of the total capture in weedy plots. Males of *C. calidum* were very clearly attracted to traps containing a female and the results were perceptibly affected by this characteristic. The capture of *C. calidum* did not change significantly over the study ($F_{7,1} = 18.7$, $p = 0.18$). A significantly greater number of *C. calidum* were trapped in weedy than in clean blocks ($\chi^2 = 107.6$, d.f. = 1,

Table 1. *on maize plants grown in plots with weeds (weedy) or under a strict weed control regime (clean). Data are means ± SE of the sum of both subplots (total 40 plants/block).*

	Interval post-planting								Analysis[1]	
	20 days		32 days		44 days		56 days		Time	Interaction
	Clean	Weedy	Clean	Weedy	Clean	Weedy	Clean	Weedy		
Spodoptera frugiperda larvae	97.5 ± 45.2	35.5 ± 16.0	11.0 ± 3.1	18.0 ± 1.2	0.3 ± 0.2	2.3 ± 1.6	0.0 ± 0.0	26.3 ± 1.2	***	*
Other lepidopteran larvae	6.0 ± 0.4	0.8 ± 0.4	2.1 ± 0.2	0.5 ± 0.2	0.8 ± 0.3	1.0 ± 0.4	0.6 ± 0.4	3.2 ± 1.2	NS	NS
Aphid colonies	3.6 ± 1.9	6.2 ± 2.7	4.2 ± 1.2	1.8 ± 0.4	5.6 ± 2.8	2.5 ± 0.1	0.4 ± 0.2	0.0 ± 0.0	***	*
Phytophagous Coleoptera	7.4 ± 3.2	6.3 ± 3.2	22.2 ± 2.4	8.5 ± 1.6	35.1 ± 6.0	22.0 ± 6.4	54.6 ± 1.6	25.1 ± 2.4	***	*
Other phytophagous insects	6.6 ± 2.5	3.0 ± 0.4	19.9 ± 4.2	15.6 ± 5.1	16.4 ± 8.6	13.1 ± 6.0	30.6 ± 15.2	21.3 ± 9.5	***	NS
Earwigs	2.4 ± 1.2	2.8 ± 2.4	6.6 ± 4.8	3.3 ± 2.7	26.4 ± 6.7	16.5 ± 1.6	65.2 ± 12.4	63.5 ± 20.8	***	NS
Chrysoperla spp.	0.2 ± 0.2	0.8 ± 0.4	7.8 ± 1.6	13.5 ± 6.4	32.2 ± 10.8	22.7 ± 13.6	136.7 ± 40.1	117.3 ± 58.3	***	NS
Spiders	8.8 ± 1.5	2.5 ± 0.4	9.8 ± 0.7	5.5 ± 1.1	20.2 ± 0.8	19.5 ± 0.8	24.6 ± 4.7	25.5 ± 3.2	**	NS
Solenopsis spp.	0.2 ± 0.2	0.5 ± 0.3	13.8 ± 5.9	12.7 ± 9.2	72.1 ± 27.2	135.5 ± 97.2	25.4 ± 4.8	21.7 ± 10.7	*	NS
Predatory Coleoptera	4.8 ± 1.9	1.9 ± 0.4	3.0 ± 1.1	5.5 ± 1.6	23.1 ± 10.7	15.0 ± 1.6	15.6 ± 4.8	15.5 ± 5.5	NS	NS
Other natural enemies	6.4 ± 2.1	6.8 ± 2.3	8.0 ± 1.6	14.3 ± 2.9	10.2 ± 3.6	10.3 ± 3.5	8.4 ± 3.0	6.0 ± 3.1	NS	NS

[1] Repeated measures analysis of variance of the number of arthropods observed at each sample point and the interaction time*treatment. $^*p < 0.075$, $^{**}p < 0.01$, $^{***}p < 0.001$, NS = Not significant $p > 0.075$.

Table 2. Overall mean (± SE) pitfall captures in experimental plots during experimental period

	Clean plots	Weedy plots
Calosoma calidum	36.8 ± 15.9	111.5 ± 34.6
Other Carabidae	3.0 ± 0.8	11.5 ± 3.4
Cinindelidae	4.2 ± 1.1	6.5 ± 1.6
Elateridae	1.2 ± 0.4	3.5 ± 1.8
Scarabeidae	0.8 ± 0.3	1.5 ± 0.6
Other Coleoptera	2.6 ± 0.7	2.0 ± 0.8
Aranae	1.6 ± 0.6	2.0 ± 0.9
Other arthropods	5.6 ± 1.4	2.9 ± 0.5

$p < 0.001$). The total capture of arthropods remained significantly greater in weedy than in clean plots when *C. calidum* captures were excluded ($\chi^2 = 4.65$, d.f. = 1, $p = 0.03$).

Other carabid species were also regularly found in pitfall traps and comprised 37 and 16% of the total capture of arthropods in weedy plots and clean plots, respectively (when *C. calidum* captures were excluded). The capture of these carabids was significantly higher in weedy than in clean plots ($\chi^2 = 15.75$, d.f. = 1, $p < 0.001$). Cicindelids were also regularly found in pitfall traps and comprised 22 and 21% of the total arthropod capture (when *C. calidum* captures were excluded) in clean and weedy plots, respectively ($\chi^2 = 0.53$, d.f. = 1, $p = 0.47$). Beetles of the families Scarabaeidae, Elateridae, Trogidae, Curculionidae and Melolonthidae together represented 22% of the captures in clean plots and 23% of the captures in weedy plots (when *C. calidum* captures were excluded). Spiders, crickets, bugs, earwigs and millipedes were captured sporadically and in low numbers during the study and together. Captures of ants were ignored as the *Solenopsis* spp. present in maize plots were prone to build nests under the pitfall traps that may have resulted in erroneous capture rates.

3.4. *Parasitoid abundance*

By far the most common parasitoid was the egg–larval parasitoid *Chelonus insularis* Cresson (Hymenoptera: Braconidae), which represented 92–94% of all observed parasitism in *S. frugiperda* larvae collected in all plots. The overall prevalence of parasitism by *C. insularis* during the study period was 27% ($n = 504$) in clean blocks and 29% (233) in weedy blocks ($\chi^2 = 0.54$, d.f. = 1, $p = 0.38$). Other parasitoid species that emerged from *S. frugiperda* larvae were *Eiphosoma vitticolle* Cresson (Ichneumonidae), *Meteorus* sp. (Braconidae), *Pristomerus spinator* (F.) (Ichneumonidae) and *Lespesia archippivora* (Riley) (Diptera: Tachinidae), but numbers were too low for statistical analysis. Of the *S. frugiperda* larvae found feeding on weeds in weedy plots at the first sample point, 15% ($n = 62$) were parasitized by *Chelonus insularis*. No parasitized larvae were found on weeds thereafter. Parasitism of *S. frugiperda* egg masses from the laboratory culture placed out in experimental plots to evaluate the activity of *C. insularis* at 23 days post-planting was significantly higher in egg masses placed in clean plots (42.0%) compared with those placed in weedy plots (3.75%) (Mann–Whitney *U*-test, $p = 0.014$).

3.5. Maize yield

The mean plant damage score fell from 1.38 ± 0.17 in clean plots and 1.21 ± 0.03 in weedy plots at 20 days post-planting to 1.0 ($<$ 10% defoliation) in both treatments at 56 days post-planting ($F_{3,5} = 9.09$, $p = 0.018$), reflecting the initial heavy attack of *S. frugiperda* observed in young plants and the subsequent reduction in the density of this pest. The presence of weeds did not affect the levels of plant damage ($F_{3,5} = 0.85$, $p = 0.52$). The yield of maize grain (mean dry weight ± SE) was not significantly affected by the presence of weeds being 3.64 ± 0.41 t/ha in weedy plots and 3.81 ± 0.19 t/ha in clean plots after correction for moisture content ($t = 0.241$, d.f. $= 7$, $p = 0.82$).

4. Discussion

A pilot study on the effect of weeds on the abundance of insect pests and natural enemies in maize grown in Southern Mexico indicated that weeds may reduce the prevalence of certain pests with little overall effect in crop yield. Overall, weed diversity did not change markedly over the study period. This is probably a reflection of the relative abundance of species in the existing seed bank and the high competitive ability of *Cyperus rotundus* (Cyperaceae), which remained the numerically dominant species at all sample points. Competition between maize and *C. rotundus* may be more severe at the root rather than the shoot level with *C. rotundus* being the more aggressive species, although the outcome of the interaction may be mediated by the availability of nitrogen (Tuor and Froud-Williams 2002a, b).

The density of many insect and other arthropod groups increased during the course of the study, reflecting the process of colonization of the growing maize plants and to some extent the reproduction of these invertebrates in the experimental plots. This may be particularly true for the fast-reproducing species such as aphids, thrips, parasitoid wasps, syrphid flies, etc. In contrast, the prevalence of other species, like larvae of the maize pest *S. frugiperda*, fell markedly during the study both on maize plants and on weeds; possibly as a result of mortality factors such as the heavy rainfall that occurred during the study period and the action of natural enemies such as parasitoids and generalist predators of which the earwig *Doru taeniatum*, *Chrysoperla* spp., and predatory Coleoptera were the most common.

Overall, maize plants in weedy plots had significantly fewer *S. frugiperda*, aphid colonies and sap beetles (Nitidulidae), all important pests. Pitfall trapping revealed far higher densities of beneficial predatory carabids in weedy plots, which may explain the lower incidence of pests. The only undesirable effect of weeds detected was that parasitism of experimental *S. frugiperda* egg masses was lower in weedy plots. The egg masses were placed at a height of approximately 30 cm above the soil surface, at a similar level to the non-crop vegetation and may have been less apparent to searching parasitoids. In contrast, egg masses in clean plots were highly apparent to females of this parasitoid and individuals were observed to arrive and commence parasitism of eggs while the egg masses were still being distributed. This observation was counter to our initial hypothesis that a greater number of parasitoids would be present foraging for pollen, nectar and hosts among weeds than in open areas that were under strict weed control and not in close proximity to maize plants.

A number of studies have reported that habitats with increased plant diversity tend to lead to greater densities of beneficial arthropods compared with habitats with a low plant diversity (Sotherton 1984, 1985, Wallin 1986, Thomas *et al.* 1991). The periodic destruction of planted crops, the disruption of the soil by ploughing and regular weeding hamper the development of natural enemy – pest interactions in ephemeral habitats such as maize crops. Pest insects usually colonize newly planted crops shortly after emergence. Such habitats are conducive to the growth of pest populations given an abundant food supply, ample oviposition sites and the relative paucity of natural enemies.

Indeed, Wiedenmann and Smith (1997) have argued that in ephemeral habitats, the action of biological control measures can have the greatest impact early in the growing season before pest populations have fully colonized the crop and begun an exponential phase of reproduction. This idea appears to be in agreement with the effect of weeds on early *S. frugiperda* infestation (at 20 days post-planting) observed in our study. The integration of habitat management techniques and classical biological control initiatives has recently been outlined in a proposal for integrated biological control programmes. This proposal explicitly examines ways in which habitat improvement can cater to the physical and nutritional needs of biocontrol agents released in inundative and inoculative programmes of biological pest control (Gurr and Wratten 1999).

The majority of studies have focused on crops grown in temperate rather than subtropical or tropical regions (e.g. Speight and Lawton 1976, Thomas *et al.* 1991). The degree of infestation of maize by *S. frugiperda* in the Southern USA was consistently higher in weed-free plots compared with maize grown in plots containing natural or a selected mixture of weed species in which insect predator populations were enhanced. In contrast, the incidence of another important polyphagous pest noctuid, *Helicoverpa zea*, appeared to be unaffected by the presence of weeds (Altieri and Letourneau 1982). In Honduras, the degree of infestation of maize by *S. frugiperda* and *M. latipes* was higher in plots without weeds whereas *S. latifascia* (Walker) and *Metaponpneumata rogenhoferi* (Moschler) populations did not appear to be affected by the presence of weeds (Portillo *et al.* 1991). Laboratory feeding studies indicated a clear preference by neonate *S. frugiperda* for non-crop vegetation, *Amaranthus* sp. and the grass, *Ixophorus unisetus* (Presl.), over maize or sorghum (Portillo *et al.* 1996). Neither of these species was present in the present study. Instead, the preferred non-crop host plant for *S. frugiperda* was *C. rotundus*, an abundant and aggressive weed in the region.

Although the benefits of weedy habitats both inside and around crop habitats for the development of natural enemy populations and/or the dilution of host plant stimuli is becoming increasingly recognized (Risch 1981, Altieri 1995), farmers may be reluctant to adopt such techniques believing competition from weeds to be detrimental to crop yields. In the present study, the weedy cropped maize yielded just 4.4% less than the maize maintained under a rigorous regime of weed control, a non-significant difference, suggesting that weed interference with maize production can be trivial when minimal weed control practices are employed.

Clearly the findings of this preliminary study require support from additional trials focussing on other types of maize production systems, including irrigated maize planted during the dry season (November – April), and studies performed in other parts of the Mesoamerican region. The benefits of concepts such as conservation of non-crop vegetation may be best disseminated among growers by way of programmes of farmer participatory research, which have met with considerable success among resource-poor agricultural producers in other parts of Mesoamerica (Haverkort 1991, Andrews *et al*. 1992).

Acknowledgements

The authors thank Velitchka Nikolaeva and Nehemias Narvaez (CIICA) for preparing and managing experimental plots, and Vasty Castillejos, Luis García, Olivia Hernández, Roxbel Armenta, B. Gómez, Alvaro García and Agustín González (CIICA) for field and laboratory assistance. This work was funded by a European Commission Project No. IC18-CT96-0097, by a SIBEJ project to J. C. (01-022-97) and by an internal ECOSUR scholarship to D. I. P.

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