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Influence of weeding regimes and pearl millet genotypes on parasitism of the Oriental armyworm, *Mythimna separata*

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Abstract. We studied the effect of four weeding regimes (weed free, one manual weeding, one manual weeding + atrazine, and a weedy check) on larval density and leaf defoliation in four pear millet genotypes by the larvae of Oriental armyworm, *Mythimna separata*. Data were also recorded on the extent of larval parasitism under different weeding regimes, and the parasitoids involved. The leaf damage and larval densities were lower in weed free plots as compared to the weedy plots. This was also reflected in grain yield, as maximum grain yield was recorded in weed-free plots as compared to the weedy plots. Seven parasitoids (*Cotesia ruficrus*, *Metopius rufus*, *Sturmiopsis inferens*, *Palexorista solemnis*, *P. laxa*, *Carcelia* sp., and the entomopathogenic nematode *Neoplectana* sp. were recorded from *M. separata* larvae, of which *M. rufus*, *Carcelia* sp., and *Neoplectana* sp. were the most abundant. Parasitism by *M. rufus* was greater in plots with a weed cover and least in weed-free plots, while parasitsm by *Carcelia* sp. was lower in plots with one hand weeding than in weedy plots. Numerically, parasitism by *Neopletana* sp. was low in plots treated with atrazine, and maximum in plots weeded manually. Therefore, the minimum level of weeding, which does not affect the crop adversely should be undertaken to promote the biological control of *M. separata* in pearl millet.

Key words: agronomic practices, cultural control, *Mythimna separata*, Oriental armyworm, parasitism, pearl millet, *Pennisetum glaucum*, weeds

Introduction

The Oriental armyworm, *Mythimna separata* (Walker) (Lepidoptera: Noctuidae), is an important pest of cereals in Asia, Africa, and Australia (Sharma and Davies, 1983, 1988). The moths lay eggs on grasses and dried leaves of the host plants. A female lays nearly 900 eggs, and the egg incubation period is 3–5 days. The larvae mostly feed on the leaves inside the leaf whorls. In mature crops, the larvae at times damage the panicles, particularly in rice, and hence it is also called rice earcutting caterpillar. Feeding mostly occurs at night, while during the daytime, the larvae remain hidden in leaf whorls, in cracks and crevices, and under a weed cover. The larvae have a distinct solitary and a gregarious phase. In the solitary phase, the larvae feed singly, and are confined to the leaf whorls. At high population densities, the larvae congregate in large numbers and become gregarious. They move across the fields in a band, and feed as they encounter suitable host plants. Pupation mostly occurs in the soil, and the life cycle is completed in 26–38 days.

Prior to 1950s, the Oriental armyworm was a pest of minor importance. Since that time, serious damage has periodically been reported on millets, sugarcane, sorghum, rice, maize, and wheat. In recent years, outbreaks of *M. separata* have been recorded in India, China, and Japan (Sharma and Davies, 1983; Hirai et al., 1985; Singh et al., 1987; Thakur et al., 1987; Sharma et al., 2002). The occurrence of *M. separata* outbreaks has been attributed to drought following rain (which may restrict the activity and abundance of the natural enemies), floods resulting from heavy rainfall, immigration, heavy fertilizer use (leading to better crop growth for feeding and development), trash mulching (provides a better site for oviposition and hiding), and favorable temperature and humidity regimes during the outbreaks (Avasthy and Chaudhary, 1965; Koyama, 1970; Chin, 1979; Sharma et al., 2002). The moths are known to follow wind currents (Lin et al., 1964; Oku and Kobayashi, 1974), can fly 600–1400 km (Grist and Lever, 1969), and have been intercepted even over the sea (Hsia et al., 1963). Sudden increases in moth catches in the light traps have been recorded following cyclonic storms along the eastern coast of India (Sharma et al., 2002).

The need for ecologically sound and cost-effective pest management practices has prompted renewed interest in cultural methods of pest control (Machuca et al., 1990). Several agronomic practices, which help to reduce damage by insect pests, have become an integral component of traditional farming systems. Cultural practices to suppress pest populations are best suited for pearl millet-growing regions because they involve minimal additional costs to resource poor farmers, and do not disturb natural enemies of the crop pests (Sharma and Youm, 1999). However, species diversity in agro-ecosystems through the presence of weeds may help to minimize pest-associated losses. Crop diversity not only helps in regulating the abundance of herbivores, but also increases the efficacy of natural enemies. It is presumed that greater biological diversity of a community leads to greater stability of the community

(Pimentel, 1961), through its influence on the activity and abundance of the natural enemies of insect pests. In this article, we report the effects of four different weeding regimes on the extent of leaf damage by the Oriental armyworm, *M. separata*, and on the parasitism of Oriental armyworm larvae in four genotypes of pearl millet (*Pennisetum glaucum* L.) in different weeding regimes.

Materials and methods

Oriental armyworm larval population and the extent of leaf damage were recorded in four pearl millet genotypes under four weeding regimes at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India. The crop was sown on Alfisols (red laterite sandy soil) under rain-fed conditions. The main treatments were four weeding regimes: (i) weed-free (manual weeding when needed), (ii) one manual weeding + atrazine (@ 0.5 kg ha^{-1}), (iii) one manual weeding, and (iv) a weedy check. Four pearl millet genotypes (Ex-Bornu, G-73-K-77, BJ-104, and IVS-AX-75) were sown in each weeding regime as sub-plots, and there were three replications in a split plot design. The crop was grown on ridges 75 cm apart, and each plot had 12 rows, 9 m long (81 m^2). The plants were thinned to a spacing of 10 cm between plants within a row 15 days after seedling emergence. No insecticide was applied to the crop. Natural infestation of Oriental armyworm was very high, and the number of *M. separata* larvae were counted per square meter in the center of each plot at the milk stage of the crop, when the armyworm larvae were most abundant. Extent of leaf defoliation was evaluated on a 1–5 scale (1 = <10%; 2 = 11–25%, 3 = 26–40%; 4 = 41–60%, and 5 = >61% leaf area damaged).

Twenty larvae (third- and fourth-instars) were collected from each plot and reared individually on pearl millet leaves in 25 ml glass vials in the laboratory (27 ± 2 °C and 65 ± 5% RH) with food changed on alternate days. Data were recorded on pupation, adult emergence, number of larvae parasitized, and parasitoid species involved. Parasitoids were identified at the British Museum, London, UK. The crop was harvested at maturity, threshed, and grain yield recorded in each plot. Data were subjected to analysis of variance using GENSTAT Release 5.0. The data were analyzed by factorial analysis, with weeding regimes as the main treatments, and pearl millet genotypes as the sub-treatments. Data on larval density was converted to square root values before analysis of variance. Significance of differences between the treatments was judged by *F*-test, while the treatment means were compared by least significant difference (LSD) at $p < 0.05$. Larval density was correlated with leaf damage and grain yield under different weeding regimes.

Results

Oriental armyworm larvae were most abundant in the weedy check plots (194 larvae m^{-2}), than in plots weeded once manually (99 larvae m^{-2}). Differences in larval abundance were not statistically significant between weed free plots (57 larvae m^{-2}) and those treated with atrazine + one manual weeding (55 larvae m^{-2}) (Table 1). Averaged across weeding treatments, the differences in larval numbers between the cultivars were not significant. However, plots of G-73-K-77 had numerically more larvae (126 larvae m^{-2}) than those of Ex-Bornu, IVS-AX 75, and BJ-104 (87–98 larvae m^{-2}). Also, more larvae were recorded in weedy-plots of G-73-K-77, followed by Ex-Bornu, BJ 104, and IVS-AX-75. Leaf defoliation by *M. separata* larvae was significantly greater in weedy plots (DR 5.0) than in the weed-free plots, plots

Table 1. Oriental armyworm, *Mythimna separata* larval density (number of larvae m^{-2}) in pearl millet grown under four weeding regimes (ICRISAT, Patancheru, India)

Cultivar	No. of larvae (m^{-2})				
	Atrazine + one manual weeding	One manual weeding	Weed-free	Weedy check	Mean
Ex-Bornu	56	88	51	198	98
G-73-K-77	47	119	68	270	126
BJ-104	52	101	60	161	93
IVS-AX-75	64	87	47	146	87
Mean	55	99	57	194	101
				SE	LSD
SE and LSD for comparing mean larval density across weeding regimes				±21.50	43.9 (F_p = 0.001, df 3)
SE and LSD for comparing mean larval density across cultivars				±21.52	NS (F_p = 0.29, df 3)
SE and LSD for comparing larval density for cultivars × weeding regimes				±43.04	NS (F_p = 0.62, df 9)

NS = non-significant, F_p = *F*-test probability, df = degrees of freedom.

Table 2. Oriental armyworm, *Mythimna separata* leaf feeding on four pearl millet cultivars in four weed treatments (ICRISAT, Patancheru, India)

Cultivar	Damage rating[a]				
	Atrazine + one manual weeding	Onemanual weeding	Weed-free	Weedy check	Mean
Ex-Bornu	2.3	2.7	2.3	5.0	3.1
G-73-K-77	3.0	3.3	3.0	5.0	3.6
BJ-104	3.3	3.3	2.3	5.0	3.5
IVS-AX-75	2.3	2.3	2.3	5.0	3.0
Mean	3.0	2.9	2.5	5.0	3.3
				SE	LSD
SE and LSD for comparing mean damage rating across weeding regimes				±0.26	0.54 (F_p = 0.01, df 3)
SE and LSD for comparing mean damage rating across cultivars				±0.25	0.53 (F_p = 0.07, df 3)
SE and LSD for comparing damage rating for cultivars × weeding regimes				±0.52	NS (F_p = 0.75, df 9)

NS = non-significant, F_p = F-test probability, df = degrees of freedom.

[a] Damage rating ($1 < 10\%$ leaf area consumed, and $5 > 61\%$ leaf area consumed).

weeded once manually, and the plots treated with atrazine + one manual weeding (DR 2.5, 2.9 and 3.0, respectively) (Table 2). Across weeding regimes, the differences in leaf feeding among the genotypes tested were significant only at p 0.07. IVS-AX-75 suffered less damage (DR 3.0) than G-73-K-77 (DR 3.6). Variability in genotypic resistance to *M. separata* observed earlier (Sharma and Sullivan, 2001), was evident under weed-free conditions in the present study. However, under weedy conditions, there were no differences in leaf defoliation among the genotypes tested because of heavy insect density.

There were significant differences in grain yield under different weeding regimes. Grain yield was greatest in weed-free plots (3,065 kg ha^{-1}), followed by plots treated with atrazine + one manual weeding (2,266 kg ha^{-1}), and plots with one manual weeding (1,098 kg ha^{-1}). Grain yield in weedy check plots was very low (168 kg ha^{-1}). Differences in grain yield in the four genotypes tested across weeding regimes were not significant. Maximum grain yield was recorded under weed-free conditions in IVS-AX-75 (3,202 kg ha^{-1}), followed by BJ-104 (3135 kg ha^{-1}). Lowest grain yield was recorded in G-73-K-77 (98 kg ha^{-1}) under weedy conditions. Grain yield was significantly and negatively correlated with the larval density

Table 3. Effect of different weeding treatments on grain yield (kg ha^{-1}) of four cultivars of pearl millet (ICRISAT Center, Patancheru, India)

Cultivar	Atrazine + one manual weeding	Onemanual weeding	Weed-free	Weedy check	Mean
Ex-Bornu	2355	1110	2959	251	1669
GK-77-3	2225	1043	2962	98	1582
BJ 104	2320	1152	3135	172	1695
IVS AX 75	2164	1085	3202	152	1651
Mean	2266	1098	3065	168	1649
				SE	LSD
SE and LSD for comparing mean grain yield across weeding regimes				± 39.5	109 (F_p = 0.01, df 3)
SE and LSD for comparing mean grain yield across cultivars				± 73.9	NS (F_p = 0.51, df 3)
SE and LSD for comparing grain yield for cultivars × weeding regimes				± 155.1	428 (F_p = 0.05, df 9)

NS = non-significant, F_p = F-test probability, df = degrees of freedom.

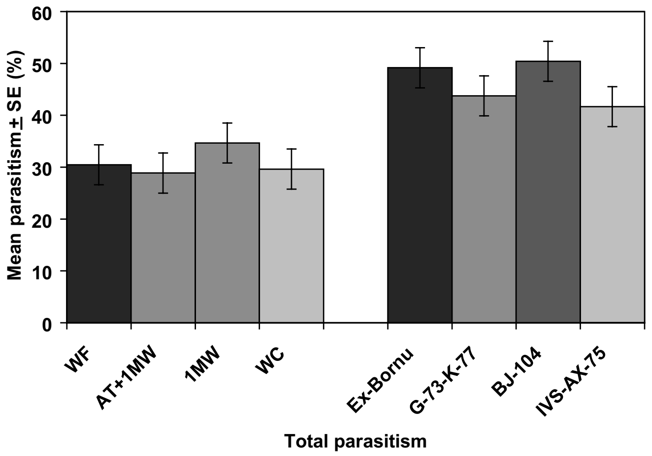

Figure 1. Parasitism of Oriental armyworm larvae (n = 60), *Mythimna separata*, under four weeding regimes in four pearl millet genotypes (ICRISAT Center, Patancheru, India). WF = weed free; MW = manual weeding; WC = weedy check; and AT = atrazine.

($r = -0.69^{**}$; *, ** correlation coefficient significant at $p = 0.05$ and 0.01, respectively), leaf damage rating ($r = -0.71^{**}$), and weed dry weight ($r = -0.94^{**}$). Larval abundance was correlated positively with

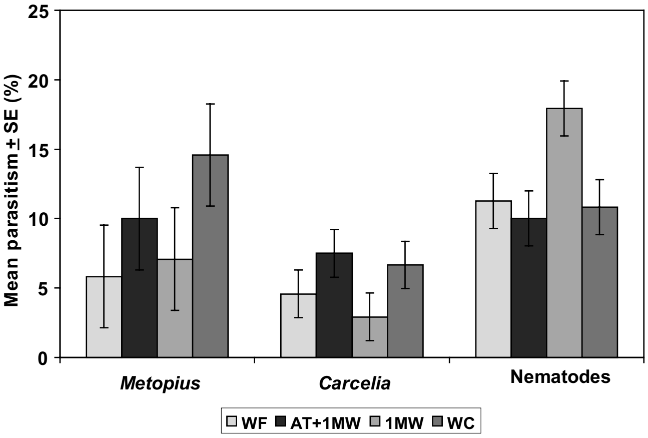

Figure 2. Effect of four weeding regimes on parasitism of Oriental armyworm larvae, *Mythimna separata*, by *Metopius rufus*, *Cercelia* sp. and mermithid nematode (ICRISAT Center, Patancheru, India). WF = weed free; MW = manual weeding; AT = atrazine; and WC = weedy check.

weed dry weight ($r = 0.67^{**}$) and leaf damage rating ($r = 0.63^{*}$) (Table 3).

From the field-collected *M. separata* larvae, two hymenopteran parasitoids [*Cotesia* (*Apanteles*) *ruficrus* Hal. and *Metopius rufus* Cam.] were recovered, of which *M. rufus* was more abundant (6–14% parasitism) than *C. ruficrus* (<1%). Four dipteran parasitoids parasitized the armyworm larvae [*Carcelia* sp., *Sturmiopsis inferens* Thn., *Palexorista*

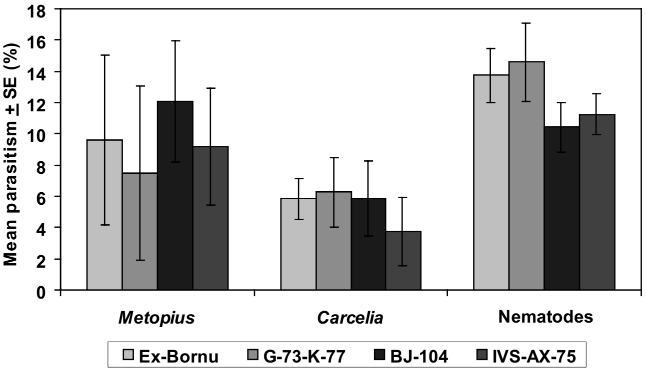

Figure 3. Parasitism of Oriental armyworm larvae, *Mythimna separata*, on four pearl millet genotypes by *Metopius rufus*, *Cercelia* sp. and the mermithid nematode (ICRISAT Center, Patancheru, India).

solemnis Wlk., and *P. laxa* (Curran)], of which *Carcelia* sp. was most abundant. The entomogenous mermithid nematode, *Neoplectana* sp. also parasitized the *M. separata* larvae. There were no statistically significant differences in total parasitization of the larvae collected from plots with different weeding regimes or from plots of different pearl millet genotypes (Figure 1). Parasitism by *M. rufus* was greatest in plots with a weed cover (14%) and least in weed-free plots (6%) (Figure 2). Although the differences were not significant statistically, parasitism by *Carcelia* sp. was lower in the plots weeded once manually as compared to the weedy check plots (7%), while the parasitism by the entomopathogenic nematodes was greatest in plots weeded once, and relatively less in weed-free plots, and the plots sprayed with atrazine. Differences in parasitism levels by *M. rufus*, *Carcelia* sp., and entomopathogenic nematodes in the four pearl millet genotypes tested were not statistically significant. However, parasitism by *M. rufus* (14%) was numerically greatest in plots of BJ-104 (13%) and least in plots of G-73K-77 (7%) (Figure 3). Parasitism by *Carcelia* sp. was lower in plots of IVS-AX-75 as compared to G-73-K-77. Nematode activity was greater in plots of G-73-K-77 than in BJ-104.

Discussion

The Oriental armyworm larvae were most abundant in the weedy plots, followed by the plots weeded once manually, and the weed-free plots. Leaf defoliation by *M. separata* larvae was also greatest in the weedy plots, followed by plots weeded once, plots treated with atrazine + one manual weeding, and the weed-free plots. Variability in genotypic resistance to *M. separata* observed earlier (Sharma and Sullivan, 2001) was evident under weed-free conditions. However, under weedy conditions, there were no differences in leaf defoliation among the genotypes tested because of heavy insect density. In earlier studies, spotted pod borer, *Maruca vitrata* (Geyer) damage has been found to be lower in plots weeded 3–4 times than in non-weeded plots (Ofuya, 1989). However, effects of weeding frequency on pod damage by *M. vitrata* were not consistent (Ezueh and Amusan, 1988). Damage by the pod borer, *Helicoverpa armigera* (Hub.) is lower under low planting densities (3 plants m^{-2}) than at high planting densities (33 plants m^{-2}) (Lal et al., 1986). However, Sithanantham and Reed (1979) reported that planting densities did not affect the extent of losses due to *H. armigera* in chickpea. Therefore, effects of weed cover and planting density on insect damage vary with crop, nature of damage, and the insect species involved.

The hymenopteran parasitoid, *C. ruficrus*, is the most important parasitoid of *M. separata* (Patel and Patel, 1991; Charyulu et al., 1994; Mallapur, 1997; Sharma et al., 2002), although tachinids have also been found to be important (Pati et al., 1996). Complete biological control of *M. separata* has been achieved in New Zealand by using a strain of *C. ruficrus* imported from Pakistan (Simmonds, 1976; Mohyuddin and Shah, 1977). However, very low levels of parasitism by *C. ruficrus* were observed in the present studies. This may be because of the effect of microclimate; as *C. ruficrus* has been found to be more abundant on sorghum in black soils than on pearl millet in light red soils (Sharma et al., 2002).

There were no statistically significant differences in total parasitization of the larvae collected from plots with different weeding regimes or from plots of different pearl millet genotypes. However, parasitism by *M. rufus* was greatest in plots with a weed cover (14%) and least in weed free plots (6%). Although the differences were not significant statistically, parasitism by *Carcelia* sp. was also lower in the plots weeded once manually as compared to the weedy check plots. Parasitism by the entomopathogenic nematodes was greatest in plots weeded once, and relatively less in weed-free plots, and the plots sprayed with atrazine. Thus, there was considerable influence of weeding regimes on the activity and abundance of natural enemies of *M. separata*. Maintaining non-crop weed hosts, which serve as a source of alternate prey, nectar, and pollen for the natural enemies can be used to conserve natural enemies and reduce crop damage. A threshold level of weed hosts can be maintained either along the field borders or within the crop such that the presence of weeds does not affect the crop yields adversely, e.g., allowing weeds to grow with collards considerably decreased flea beetle densities on the collards and minimized the leaf damage (Altieri et al., 1977). Weed diversity has also been found to reduce the incidence of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) in maize (Altieri and Whitcomb, 1980). However, maintaining weeds in and around the crop does not always lead to a reduction in pest damage. Weed diversity does not reduce the density of earworm, *Helicoverpa zea* (Boddie) in maize (Altieri and Whitcomb, 1980).

Leaf damage and larval densities of the Oriental armyworm were lower in weed-free plots as compared to the weedy plots. Clean cultivation reduced *M. separata* damage as the weed-free crop most likely deprived the larvae of their hiding places, and thus, resulted in low leaf defoliation. This was also reflected on grain yield, as maximum grain yield was recorded in weed-free plots as compared to the weedy plots. However, parasitism by some natural enemies was greater in weedy plots as compared to the weed free plots. Therefore, the minimum amount of weeding, which is essential to maintain crop yield should be undertaken to promote the biological control of the Oriental armyworm, *M. separata* in pearl millet.

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