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Natural Mortality of Diamondback Moth in Coastal South Carolina

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Abstract

Mortality of the diamondback moth, *Plutella xylostella* was assessed in field plots of collards using exclusion cages and a pyrethroid insecticide.Numbers of insects in untreated plots were kept below economically damaging levels by indigenous arthropod predators and the parasitoid *Diadegma insulare* (Cress.). Parasitism of DBM by *D. insulare* reached 95% in plots without the pyrethroid treatment. Predators accounted for up to 72% of larval mortality. The pyrethroid treatment caused diamondback moth resurgence due to reduction in natural enemy densities. Major predators were identified and laboratory studies showed that the spider *Pardosa milvina* (Hentz) consumed about one larva/day. This predator was the most active ground-dwelling species as determined by pitfall trapping, and its numbers were significantly reduced by pyrethroid insecticide applications. Simulated and natural rainfall did not cause significant diamondback moth larval mortality under our test conditions.

Introduction

The diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera:Yponomeutidae), remains the most serious insect problem on crucifers worldwide. In some areas of tropical Asia cocktail mixtures of insecticides are applied every other day for this pest without satisfactory control (M. Shepard, personal observations, Philippines). It is clear that the misuse of insecticides has exacerbated problems with DBM (Ooi and Sudderuddin 1978) and development of more ecologically-based management strategies has been slow in coming and difficult to implement on a large scale.Ullyett (1947) demonstrated that insecticides caused DBM populations to increase, and emphasized the negative effects of chemicals on natural biological control agents. In addition to chemical applications, many farmers now incorporate *Bacillus thuringiensis* Berliner into their control programs. Recent reports of DBM resistance to *B. thuringiensis* (Tabashnik et al. 1990) underlines the importance of developing management systems that employ a multifaceted approach with biological control as the core (Ooi 1990).

There are many examples of suppression of DBM populations using imported parasitoids (Goodwin 1979; Ooi 1990; Ooi and Lim 1989; Cock 1983; Sastrosiswojo and Sastrodihardjo 1986). Waterhouse and Norris (1987) selected DBM as one of several species as a likely candidate for successful classical biological control. Their major reason for suggesting this species was that biological control has already been achieved in several parts of the world with parasitoids. The major species used in these efforts in Asia include *Diadegma semiclausum* Horstmann, *Diadromus collaris* Gravenhorst, and *Cotesia plutellae* Kurdjumov.

Diadegma insulare (Cress.) is the most important parasitoid of DBM in North America (Latheef and Irwin 1983; Pimentel 1961; Oatman and Platner 1969; Harcourt 1960, 1963, 1986; Lasota and Kok 1986; Horn 1987). A few other parasitoid species (*Microplitis plutellae* Muesbeck, *Tetrastichus sokolowskii* Kurdjumov, *Cotesia plutellae* Kurdjumov, and *Spilochalcis albifrons*) have been reported to contribute to a lesser extent to DBM mortality (Parker 1971; Horn 1987; Ru and Workman 1979).

Surprisingly little attention has been given to assessing the role of predators in DBM management. Oatman and Platner (1969) listed syrphid larvae, coccinellids, *Geocoris*, *Orius*, nabids, and chrysopids as possible predators of DBM but quantitative assessments of their impact were not made. Likewise, a number of predatory arthropods were reported as important sources of DBM mortality in South Africa (Ullyett 1947). These included staphylinids, wasps of the genus *Polistes*, syrphids, chrysopids, hemerobiids, and anthocorids. Of these, syrphids and anthocorids were thought to be most important. Many of these predators were attracted initially to aphids and switched to DBM as aphid populations declined. Ullyett (1947) followed DBM populations through several periods and recorded total mortality between 83 and 92%. Of this, 23% was attributed to predation.

Suppression of DBM by field application of a granulosis virus has been reported (Wang and Rose 1978) and epizootics of the fungal pathogen *Zooptera radicans* (Brefeld) (= *Entomophthora sphaerosperma*) are considered important in some areas, e.g. South Africa (Ullyett 1947), Malaysia (Ooi 1979, 1981), New Zealand (Kelsey 1965), in North Carolina (K. Sorenson, North Carolina State University, personal communication) and Florida (G. Leibee, University of Florida, personal communication) but control by indigenous fungal pathogens has been sporadic and largely dependent upon rainfall (high humidity).Rainfall also has contributed directly to DBM mortality in the field by dislodging and drowning young DBM larvae (Hardy 1938; Harcourt 1963; Talekar et al. 1986).However, Ullyett (1947) did not consider the direct impact of rainfall as a significant mortality factor.

The objective of our study was to identify major sources of mortality of DBM eggs and larvae in collards in coastal South Carolina.

Materials and Methods

Seasonal abundance of DBM and incidence of parasitism

A 0.73 ha collard field on the Coastal Research and Education Center farm, Charleston, South Carolina, was planted to 'Vates' variety collards on 27 February 1990, and thinned to 46 cm plant spacings on 17 April 1990. The field was divided into 12 plots, 0.025 ha each, and weekly sampling was carried out by inspecting 25 plants from each plot. DBM larvae, pupae and *D. insulare* pupae were counted. Plots were treated with either Javelin (*B. thuringiensis kurstaki*) at 0.56 kg/ha or the pyrethroid Asana-XL at 0.04 kg ai/ha. Control plots were left untreated. There were four replications. Treatments were applied on 25 April, 2 May, 23 May, 30 May, 6 June and 13 June 1990.

In addition to in-field counts, weekly collections of DBM larvae were made from five separate plants in each plot from 24 April to 18 June 1990.Larvae were placed on artificial diet and held in a rearing room at 26°C, 70±10% RH and a photoperiod of LD 12:12. Numbers of adult DBM and parasitoids that emerged were recorded.

Activity of ground-dwelling predators

Ground-dwelling predators were collected weekly using two pitfall traps in each plot from 11 May to 19 June 1990. Traps consisted of plastic DG8 Solo cups (11 cm diam x 4 cm depth) with tin covers (20 x 22 cm) suspended 2 cm above the cups to keep out rain. Ethylene glycol was placed in each trap to a depth of 1 cm to kill and preserve the arthropods.

Laboratory and field cage studies

Predation by *Pardosa milvina* in laboratory cages. Predation by *Pardosa milvina* (Hentz) on DBM larvae was determined in the laboratory using spiders collected from collard fields at the Coastal Research and Education Center farm, Charleston, South Carolina. Cage tests were carried out at Clemson University, Clemson, South Carolina.

Four-week-old collard plants were potted and caged individually using cylindrical plastic cages (9 cm diam × 19 cm high). First and second instar DBM were categorized as small and third and fourth instars were considered large. Small and large larvae were introduced into cages at density levels of 1, 2, 4 and 8 larvae/cage. Larvae were allowed to settle on the plants for about 2 hours before spiders were introduced. Spiders were starved for 5 days before the test began. Numbers of larvae consumed were recorded daily for 7 days. Larval density per cage was maintained by daily replacement. Also, larvae that molted to third instars in the small larvae treatments and those that pupated in the large larvae treatments were replaced. Partially consumed or dead larvae were counted as consumed. Each treatment was replicated six times except for controls (cages with no spiders) which were replicated three times. ANOVA followed by Duncan's multiple range test ($P<0.05$) was used to analyze data.

Predation on eggs. Egg predation studies were initiated by placing 4-6 colony-reared male and female DBM adults into small clip cages (DeBach and Huffaker 1971) on randomly selected pairs of plants in untreated control plots. These were left overnight and the clip cages were removed and eggs counted the next day. Clip cage location was marked on the plant in waterproof black ink to facilitate finding the eggs. Nylon mesh cages were then placed over one plant. The other plant was exposed to predators for 1 day and missing eggs were recorded. Two sets of tests were conducted: one using five pairs of cages (10-11 July) and the other using eleven pairs (20-21 July).

Larval predation. Field cage studies of predation on second to third instars were carried out in the untreated control plots on 40 randomly selected pairs of plants. Predators were removed from each plant and 10 or 15 DBM larvae were placed on both plants. A nylon mesh cage was then placed over one plant. Each cage was approximately 36 cm wide × 50 cm high supported by bent wires with ends pushed into the soil. The base of the nylon mesh cage cover was sealed on all sides with soil to prevent the entry of predators. Larvae were counted from all plants after 4 days.Two separate tests were carried out: one on 26-30 June 1990 and the other 6-10 July 1990.Control mortality (missing larvae) from the caged plants was accounted for using Abbott's formula (Abbott 1925).

Influence of rainfall on DBM mortality

Actual rainfall. Ten pairs of collard plants were selected from untreated control plots prior to expected thunderstorms and carefully cleaned of all arthropods. Second and third instar colony-reared larvae were placed on the plants and allowed to settle in before rainfall occurred. Just prior to the thunderstorm, a plastic bag was placed over one plant of the pair while the other plant was left exposed.The plastic cover was supported by wires described earlier for the larval predation study. At the end of the thunderstorm, covers were removed and larvae were counted. Rainfall was measured with a standard rain gauge. Student's t-test was used to compare means ($P<0.05$).

Simulated rainfall. 'Vates' variety collards were established in 1-l containers in the greenhouse with temperatures ranging from 18 to 27°C. Tanglefoot was applied to each container to exclude predators. Eight field-collected second to fourth instar DBM were placed on each plant for a minimum of 18 hours before simulated rainfall was applied. Most of the larvae moved to the undersides of the leaves and began feeding.

Simulated rainfall was achieved using a Spraying Systems Fulljet 1/4 HH 14.5 square cone spray nozzle at 0.55 kg/cm^2. The nozzle was placed 2.44 m above the top of the plants to allow water droplets to achieve terminal velocity (Shelton et al. 1985). The nozzle produced a drop size of 1140-4300 μ which is about the same size as that produced in a normal thunderstorm in South Carolina. Rainfall rate was 16.8 cm/hour and treatments consisted of simulated rainfall for 0, 20, 40, and 60 min.

Nine collard plants about 30 cm wide and 25 cm high were spaced at 30 cm intervals beneath the nozzle. Three replications were carried out and data were analyzed using ANOVA followed by Duncan's multiple range test ($P<0.05$).

Results

Seasonal abundance of DBM and incidence of parasitism

In general, natural enemies kept DBM populations below economically important levels throughout the growing season. Mean numbers of DBM larvae and pupae per plant are shown in Fig. 1 and 2, respectively. DBM population levels in *B. thuringiensis*-treated plots were approximately the same as those from untreated ones, but DBM numbers increased in pyrethroid-treated plots after 5 weeks and reached a peak of about 2 larvae/plant before declining. Parasitism by *D. insulare* reached a peak of over 90% in untreated plots. It is likely that resurgence in DBM numbers in the pyrethroid-treated plots was due to destruction of natural enemies by this chemical. Highest numbers of *D. insulare* pupae were found in the untreated plots (Fig. 3), and because of the upsurge in larval density in the pyrethroid-treated plots, the parasitoid moved into these plots and higher numbers of *D. insulare* pupae were subsequently found there during the last two sampling periods. It is likely that action by the parasitoid and not the chemical caused DBM populations to decline in these plots (Fig. 1 and 2, respectively).

Season-long collections of 1192 DBM larvae reared on artificial diet revealed that parasitoids emerged from 41%, DBM adults from 5%, and 54% died from unknown causes. More than 95% of all parasitoid species were *D. insulare*. High mortality of DBM in field collections was due to handling during collection and problems with rearing.

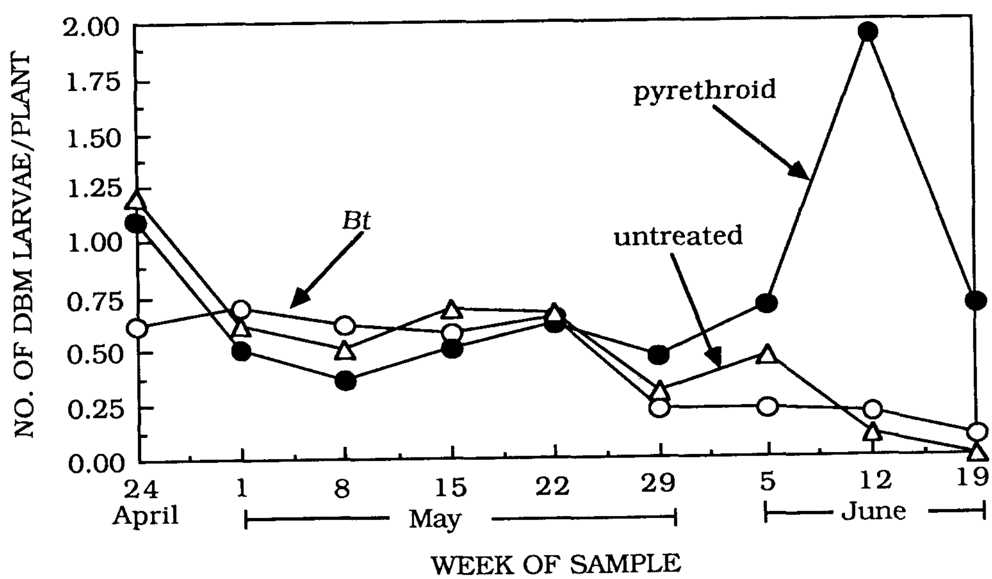

Fig. 1. Seasonal abundance of DBM larvae from untreated collard plots and those treated with a pyrethroid and *Bacillus thuringiensis*. Charleston, South Carolina, 1990.

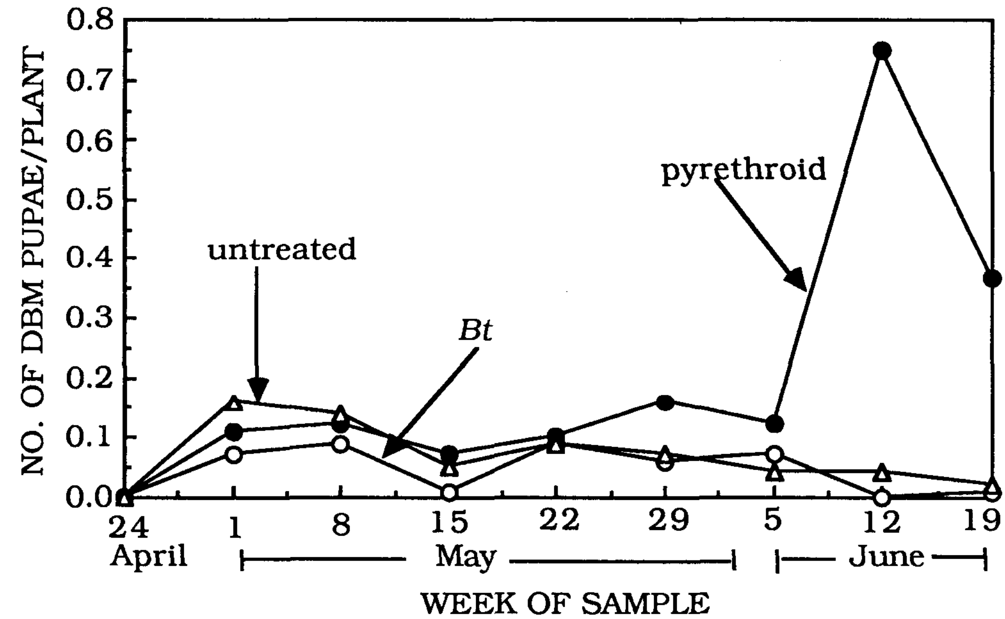

Fig. 2. Seasonal abundance of DBM pupae from untreated collard plots and those treated with a pyrethroid and *Bacillus thuringiensis*. Charleston, South Carolina, 1990.

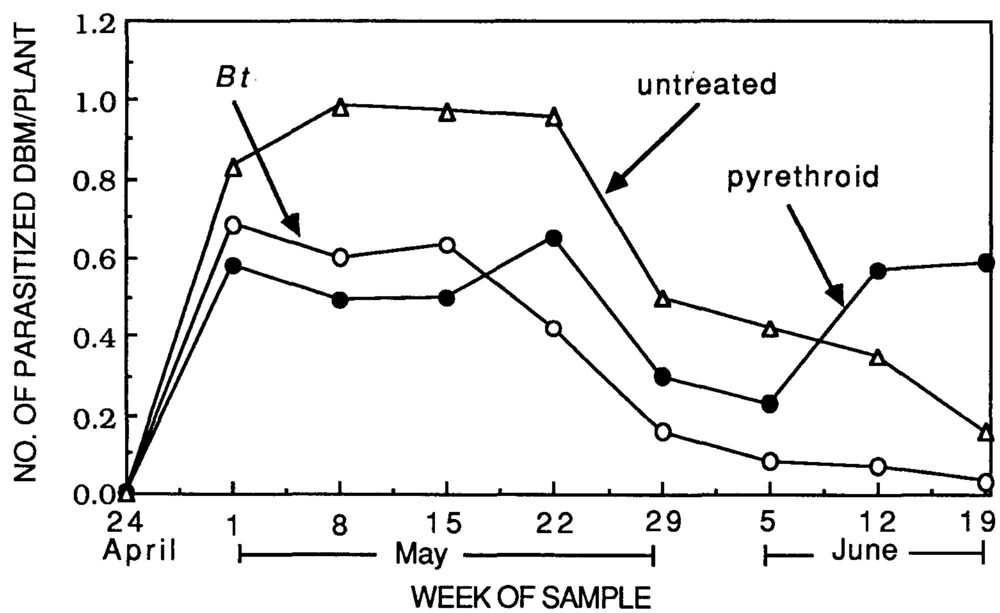

Fig. 3. Seasonal abundance of *Diadegma insulare* pupae per plant in untreated collard plots and those treated with a pyrethroid and *Bacillus thuringiensis*. Charleston, South Carolina, 1990.

Activity of ground-dwelling predators

By far the most numerous ground-dwelling predator determined by pitfall trap collections was the lycosid *Pardosa milvina*. The seasonal activity of this spider is shown in Fig. 4. Mean numbers of *P. milvina* from the *B. thuringiensis*-treated, untreated and pyrethroid-treated plots were 8, 7, and 3 spiders/trap, respectively. Numbers of spiders were significantly ($P<0.05$) lower in the pyrethroid-treated plots. The *P. milvina* population peaked on 21 May 1990 and gradually declined throughout the remainder of the season although there was a gradual increase during the last 2 weeks in the untreated plots. Other major predators that were commonly encountered in the collard plots are listed in Table 1.

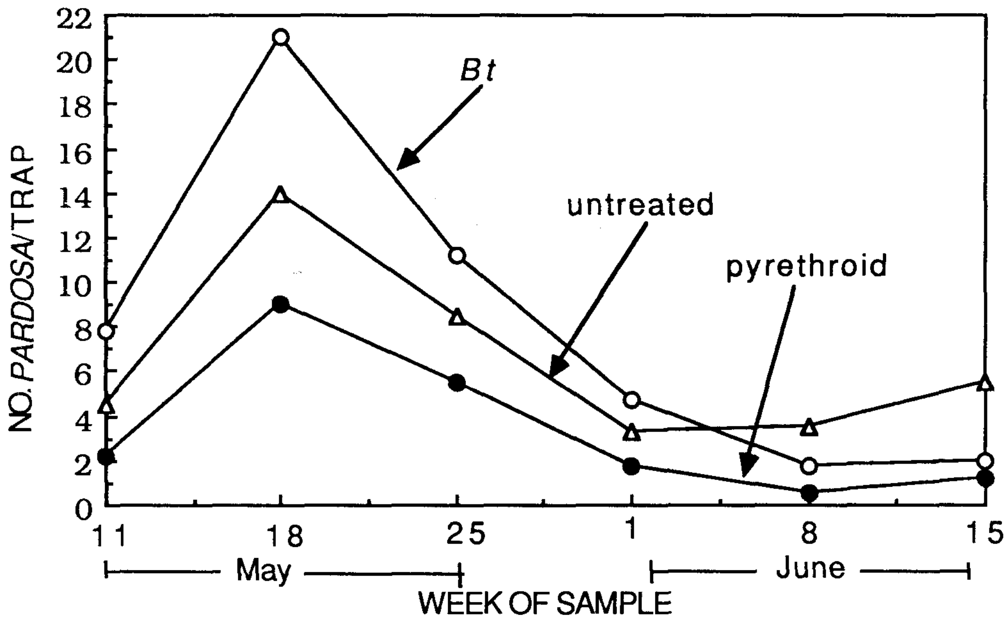

Fig. 4. Numbers of *Pardosa milvina* per trap in untreated collard plots and those treated with a pyrethroid and *Bacillus thuringiensis*. Charleston, South Carolina, 1990.

Table 1. Common predators in South Carolina collard fields.

ARACHNIDA	
Lycosidae	Erigonidae
Pardosa milvina (Hentz)	*Eperigone fradeorum* (Berland)
Pardosa pauxilla Montgomery	Linyphiidae
Pardosa delicatula Gertsch & Wallace (New Record)	*Florinda coccinea* (Hentz)
INSECTA	
Formicidae	Lygaeidae
Solenopsis invicta	*Geocoris punctipes* (Say)
Unidentified spp.	*Geocoris uliginosus* (Say)
	Pentatomidae
Coccinellidae	*Podisus maculiventris* (Say)
Coccinella septempunctata L.	Nabidae
Hippodamia convergens Guerin-Meneville	*Nabis americoferus* Carayon
Coleomegilla maculata (DeGeer)	Vespidae
Scymnus spp.	*Polistes* spp.
Syrphidae	Hemerobiidae
Unidentified spp.	Chrysopidae
Carabidae	Labiduridae
Calosoma sayi	Reduviidae
	Anthocoridae

Laboratory and field cage studies

Predation by *P. milvina* in laboratory cages. Numbers of small and large DBM larvae consumed by *P. milvina* in laboratory cages are shown in Fig. 5A and 5B, respectively. At all density levels, consumption increased with time and prey density. There was no significant difference between consumption of small and large larvae. In general, each *P. milvina* consumed about 0.5-1 larva/day at the highest host density (eight).

It is not possible to extrapolate these results to the field. However, high activity levels of *P. milvina* in the collard plots as detected by pitfall traps and results from the field cage studies which showed up to 72% mortality of DBM larvae by indigenous predators, provide strong evidence that this spider species may be an important source of DBM mortality.

Predation on eggs. Numbers of eggs removed by predators were highly variable. This may be due to the artificially clumped food source. None of the eggs were missing after 1 day from the tests using five pairs of clip cages. On the other hand, percent missing eggs ranged from 0 to 100% ($\bar{x}$ = 42%) in the second test (n = 11). The implications here are unclear and further testing is necessary using the appropriate egg distribution pattern.

Predation on larvae in the field. Average percent DBM larvae missing from uncaged plants (n = 40) in test one was 60% after correcting for missing larvae in cages. In test two (n = 40), 72% of the larvae were missing from the uncaged plants due to the action of indigenous predators.

Larval mortality due to actual rainfall

Influence of rainfall on DBM mortality. Second and third instar DBM larvae were exposed to normal afternoon thunderstorm activity producing 0.89 cm of rain in test one and 3.13 cm of rain in test two. However, there was no evidence to suggest that rainfall washed small DBM larvae from plants (e.g., counts of larvae on covered plants were not significantly different from those on exposed plants).

Field observations by the authors during heavy rainfall revealed that larvae were not affected by natural rainfall under conditions of our test.

Simulated rainfall. There was no significant difference in numbers of larvae from control plants and those subjected to simulated rainfall.These results are inconsistent with reports of loss or mortality of DBM larvae due to rainfall (Hardy 1938; Harcourt 1963; Talekar et al. 1986). However, these experiments were conducted on collard plants under controlled conditions with no wind and at optimum temperature. This does not rule out the possibility of reduction of DBM populations due to a combination of environmental factors or the disruption of adult flight, mating, or ovipositing (Talekar et al. 1986). In addition, collard plant hosts may have provided more protection from being dislodged by rainfall than would cabbage or some other cruciferous crop.

Discussion

The population density of DBM rarely reached levels that would be considered economically important except in plots treated with the pyrethroid insecticide.Our preliminary evidence shows the parasitoid *D. insulare* and indigenous communities of arthropod predators are the major mortality factors impacting mainly on DBM larvae. Indigenous pathogens were not important. Data from laboratory studies of predation by *P. milvina* suggest that this spider is an important member of the predator complex, and its populations were most active according to pitfall trap sampling. Nemoto (1986) used a precipitin test to show that lycosid spiders were an important

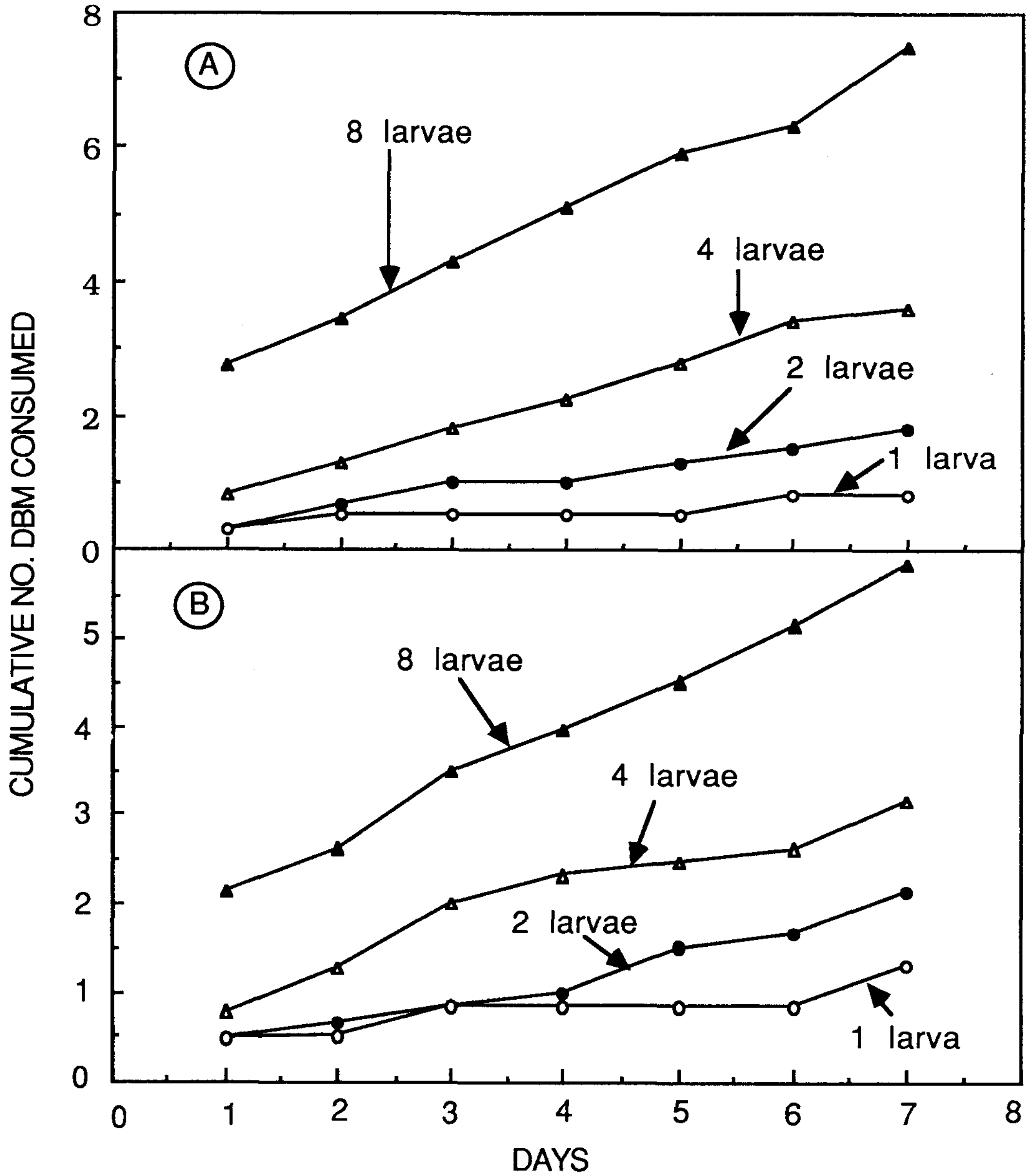

Fig. 5. Cumulative numbers of 'small' (A) and 'large' (B) DBM larvae consumed by *Pardosa milvina* in laboratory cages over collard plants. Clemson, South Carolina, 1990.

source of mortality for third and fourth instar DBM. Under conditions of our tests, neither natural nor simulated rainfall caused significant DBM mortality.

It is clear that in some areas of the world, the rich complex of natural enemies (either introduced or indigenous) keep DBM populations in check unless chemical insecticides are applied. We believe that this is the case for coastal South Carolina.

Further research is needed to quantify the impact of arthropod natural enemies more clearly and to develop a management program for DBM that incorporates this information into IPM decisions.

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