

Influence of Weather Conditions and Density of *Doru luteipes* (Dermaptera: Forficulidae) on *Diatraea saccharalis* (Lepidoptera: Crambidae) Egg Mortality

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ABSTRACT The influence of weather factors and the predator *Doru luteipes* Scudder density on *Diatraea saccharalis* (F.) egg predation was studied. Mortality of *D. saccharalis* eggs was determined by artificially infesting maize plots with egg masses at various times within each of two maize-growing seasons. Each egg cohort was monitored every 24–48 h to determine the fate of eggs, and predation rates were calculated. *Doru luteipes* were sampled every 7–10 d, and the mean air temperature, the minimum percentage of relative humidity, and rainfall accumulations were recorded during the egg exposure period. To test the effects of abiotic and biotic variables on egg predation, we used a generalized linear model (GLM). *Diatraea saccharalis* egg predation was negatively associated with rainfall, whereas *D. luteipes* density and mean temperature were positively correlated with mortality. The implications of these findings for the management of *D. saccharalis* are discussed.

KEY WORDS sugarcane borer, predation, earwigs, weather, maize

Diatraea saccharalis (F.) (Lepidoptera: Crambidae) is the key insect pest attacking sugarcane (*Saccharum* spp.) (Bessin et al. 1991) and is one of the most important pests of maize (*Zea mays* L.) in Argentina (Greco 1995, Moré et al. 2003). Temporal occurrence of this pest is characterized by the succession of three to four adult flights throughout the maize-growing season (Leiva and Iannone 1994). *Diatraea saccharalis* females lay their egg masses on the leaves, and soon after the eggs hatch, larvae bore into the stem (Ratkovich 1953, Greco 1995). Consequently, eggs and neonate larvae are the immature stages with highest mortality rates caused by abiotic factors and natural enemies. Third instars enter and feed within maize stalks, where further mortality is greatly reduced (Moulton et al. 1992, Rodriguez et al. 2001).

Previous studies on *D. saccharalis* have identified insect predators as important sources of egg and larval mortality (Negm and Hensley 1969, Hensley 1971, Cueva 1980, Meagher et al. 1998, Rossi and Fowler 2000). *Doru luteipes* Scudder (Dermaptera: Forficulidae) is reported as the dominant predator of immature stages of *D. saccharalis*, particularly eggs, in the central region of Argentina (Batallán et al. 2004, E.V.T., unpublished data). In Brazil, this generalist species has shown great potential as a biological control agent against two other maize pests: the fall armyworm, *Spodoptera frugiperda* Smith, and the corn earworm, *Helicoverpa zea* Boddie (Reis et al. 1988, Cruz and

Oliveira 1997). Different species of earwigs have also been reported as predators of eggs and larvae of *D. saccharalis* in sugarcane fields in the United States and Peru (Negm and Hensley 1969, Cueva 1980), as well as of the African stem borers *Busseola fusca* Fuller and *Chilo partellus* Swinhoe (Haile and Hofsvang 2001).

Generalist predators can significantly reduce pest numbers, and in some cases, reduce or prevent crop damage (Symondson et al. 2002). The design of an integrated pest management (IPM) strategy maximizing predator contribution requires the identification of factors affecting their activity (Gutierrez et al. 1990, Musser and Shelton 2003). The interaction of these factors is frequently not fully understood. Changes in environmental conditions may have a marked effect on the interaction between predator and prey and can result in a varying predation capacity (Negm and Hensley 1969, Mohaghegh et al. 2001). Several studies have shown that temperature has an effect on the response of generalist predators to prey (Grafius and Warner 1989, Kharboutli and Mack 1993, Giroux et al. 1995, Elliott et al. 2000, Mohaghegh et al. 2001). Also, detrimental effects of rain on insect survival have been observed (Beirne 1970, Moran et al. 1987, Norris et al. 2002), and humidity could influence feeding rates, considering earwigs prefer damp environments (Kharboutli and Mack 1993). However, no quantitative studies are available specifically addressing either the impact of earwig density on *D. saccharalis* population size or the influence of weather factors on egg predation.

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The objective of this study was to empirically explore the effects of *D. luteipes* density, temperature, relative humidity, and rainfall on *D. saccharalis* egg mortality.

Materials and Methods

This study was carried out during two growing seasons (2001/2002 and 2002/2003) at the Manfredi Agricultural Experimental Station, National Institute of Agricultural Technology (INTA), located in Manfredi, Córdoba province, central Argentina. The experiments were conducted in maize fields (0.7 ha each) planted on different dates with the cultivar Dekalb 696 at a rate of eight plants per square meter and fertilized with 80 kg/ha of ammonium triphosphate. All the fields were managed using conventional agronomic practices, and no insecticides were applied in or near them. To measure *D. saccharalis* egg mortality, the method of predation of sentinel prey was used (Kidd and Jervis 1996). With this method, known densities of prey are placed out in the field for a set period of time, and the numbers of dead individuals were recorded (Kidd and Jervis 1996). Within each maize field, small plots were artificially infested with egg masses obtained in the laboratory at various times through the growing season. Seven egg infestations were conducted from January to mid-March 2002 and five from February to late March 2003.

We pursued some level of uniformity of maize phenological stages at the time of artificial infestations to avoid potential confounding effects. Different planting dates were established to have plants in the last third of the vegetative phenological stage available for infestations when enough egg masses were laid. Maize fields planted on 5 October, 12 November, and 28 December 2001 received one, four, and two infestations, respectively, whereas fields planted on 1 November and 13 December 2002 received two and three infestations, respectively. Each of these infestations, conducted in a single cage, was established in a different date. The approach we followed was trying to achieve as many infestation dates apart to each other as possible, to capture the variability of environmental conditions, aiming at a good strength in the lack of fit component of the data analysis.

For each infestation, a small experimental plot, each consisting of five rows of nine plants, was chosen and protected from natural egg lying with cages (6 m length, 3 m width, and 2.5 m height). Mesh size of the cages was 4 by 10 mm. The cages were knitted by a local textile factory with light polyethylene threads (thread diameter: 0.3 mm). Although the mesh size was large enough to allow for lateral movement of earwigs between inner and outer plants (Walsh et al. 2006), the bottom edges of the cages were lifted 5 cm above the ground to allow earwigs to crawl in and out the experimental units. Thus, the ability of earwigs to move freely through and below the cage walls permitted earwig density fluctuations to be comparable inside and outside the cages. This was corroborated in preliminary assessments by the authors and other

members of the research team (F. Fava, personal communication). The cages, each one supported internally by 10 bamboo poles buried 30 cm in the ground, were held on the plants during the whole period of each experiment (from plant emergence until egg hatching or egg predation). Light interception within the cages was not actually measured, but comparing the enclosure net we used with published technical features of commercial anti hail nets, we estimated a shading factor of 15–20%. The fact that the cages were relatively large, had large mesh holes, and were lifted above the ground allowed for good air circulation. Because of these factors, we assume that temperature differences between the air inside and outside the cages were negligible.

Female moths were captured with a light trap located near the maize plots, running from 0800 to 2000 hours. Moths were recovered from the light trap between 0800 and 0900 hours the following morning, taken to the laboratory, and held in cages. At 1800 hours, to get egg masses, groups of ≈ 20 individuals were placed into cardboard cylinders (30 cm diameter, 40 cm height) closed with a fine mesh to allow air circulation. Moths were held in the cylinders overnight at a temperature regimen fluctuating within the 20–26°C range, 60–80% RH, and a photoperiod of 16:8 (L:D) h. The next morning, at 0800 hours, the cylinders were open and cut into small sheets containing one egg mass each. With this procedure, we ensured that age of egg masses used as experimental cohorts differed at most by 14 h. Egg masses were selected so that the number of eggs per cohort did not differ by >10%.

Each artificial infestation was carried out in 15 plants in the three central rows of the experimental plot, whose phenological stages were V13–V19 (vegetative stages), according to the scale proposed by Ritchie et al. (1986). Two egg masses (<24 h old) were pinned on the upper side of maize leaves at mid-plant level of the target plant. Thus, each infestation had 30 egg masses. Each egg cohort was monitored approximately every 48 h using a $\times 10$ field magnifying lens to determine egg mass condition (predated or not predated). At the end of the egg period (ranging from 7 to 10 d), the final number of predated egg masses was recorded. Following Phoofolo et al. (2001), predation was assumed to be the cause of mortality when $\geq 50\%$ of the eggs within an egg mass had their chorions damaged or the whole egg mass disappeared. Egg predation rate was calculated as the number of egg masses predated out of the total number of egg masses placed in each plot.

Weather conditions were recorded daily by an INTA official weather station located 1,200 m away from our experimental maize plots. Rainfall (mm), mean temperature (°C), and minimum relative humidity (%) were recorded during each day of the egg development time (egg period). We used mean temperature because the daily amplitude is quite narrow ($\sim 10^\circ\text{C}$) for the study location (INTA Weather Page 2006). For relative humidity, we used the minimum values based on the assumption that this factor could

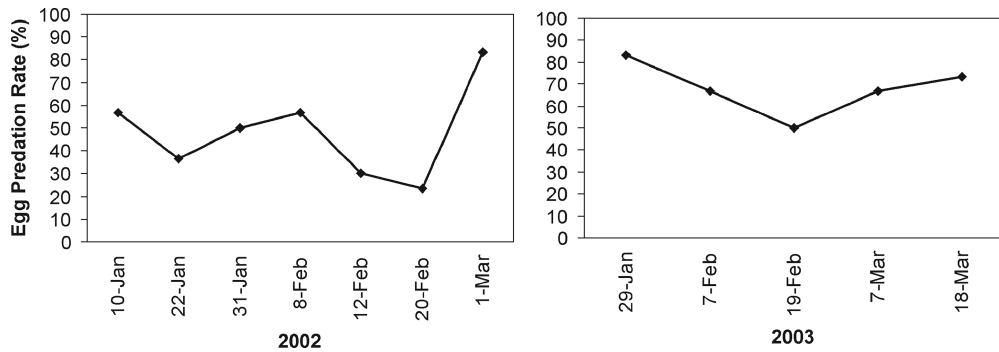


Fig. 1. Temporal variation of *D. saccharalis* percentage of egg predation during maize-growing seasons 2002 and 2003. Each date corresponds to the day of artificial infestations with newly laid egg masses.

influence egg predation through detrimental effects of low humidity on earwigs' behavior. In statistical analyses, independent variables were set as follows: for each egg period, the average of the daily mean air temperature records was used, whereas for the minimum relative humidity we used the lowest value. For rainfall, we used the millimeters accumulated throughout the egg period.

In both growing seasons, from January to March, earwig sampling was carried out in each maize field, for as long as the combined artificial infestations with *D. saccharalis* eggs lasted in each of them. Ten consecutive maize plants from each of nine sampling units were picked to count earwigs by visual examination every 7–10 d. Plants within cages were not considered for earwig sampling, based on the assumption of free movement of *D. luteipes*, as explained above. Sampling units were selected using a double entry, pseudorandom table, with entries representing crop rows and steps within rows. Adults and third- and fourth-instar nymphs of *D. luteipes* were sampled. The first and second instars were not sampled because of their negligible predation rate (Reis et al. 1988). *D. luteipes* density was calculated as the total number of individuals recorded on 10 plants.

To test the effects of abiotic and biotic variables on egg predation, we used a generalized linear model (GLM) (McCullagh and Nelder 1989) pooling data sets of both growing seasons. The analysis was carried out using the R statistical software, version 2.0.1 (R Development Core Team 2004). The response variable was mortality rate expressed as the proportion of

egg masses predated with a binomial error distribution and the logit link function. The group of explanatory variables consisted of the meteorological factors described above and the logarithm of *D. luteipes* density. The statistical significance of each variable was tested in turn in the model (forward stepwise procedure), and those that contributed to the largest significant change in deviance from the null model were retained. The change in the deviance was tested by the likelihood ratio test, considering a χ^2 distribution with a significance level of 0.05. This step was repeated until all variables remaining in the model were significant at $P < 0.05$. The relationship between mortality and each predictor variable was evaluated by visual examination of partial residual plots.

Results

Mortality of *D. saccharalis* egg masses fluctuated considerably within each growing season. However, the percentage of predated egg masses was more variable in the 2001/2002 growing season (24–84%) than in the 2002/2003 season (50–82%; Fig. 1). Rainfall was the more variable factor during both growing seasons, and *D. luteipes* density was more variable in the first period, oscillating between 1.3 and 4.6 individuals per maize plant (Table 1). During the whole study, the percentage of nonviable eggs was <1%.

The construction of the GLM model for *D. saccharalis* egg predation is shown step by step in Table 2. The set of variables that together best explained egg predation in the GLM model indicated that mortality

Table 1. Mean \pm SE, coefficient of variation, and range of weather variables and *D. luteipes* density (no. earwigs in 10 plants) recorded during *D. saccharalis* egg development time in two growing seasons: 2001–2002 ($n = 7$) and 2002–2003 ($n = 5$)

Variables	Growing season	Parameters across the season			
		Mean \pm SE	CV	Lowest	Highest
Mean temperature ($^{\circ}$ C)	2001–2002	21.30 \pm 0.42	5.27	19.63	22.96
	2002–2003	21.50 \pm 1.06	11.06	19.74	25.65
Minimum relative humidity (%)	2001–2002	37.32 \pm 2.84	20.11	21.23	43.00
	2002–2003	37.80 \pm 5.19	30.70	27.00	55.00
Rainfall (mm)	2001–2002	50.37 \pm 16.05	84.30	5.60	130.60
	2002–2003	14.90 \pm 5.53	82.93	5.00	35.00
<i>D. luteipes</i> density	2001–2002	21.29 \pm 4.51	56.05	12.89	46.38
	2002–2003	22.73 \pm 1.69	16.62	20.00	28.93

Table 2. Summary of the stepwise procedure used to build a multiple regression model for *D. saccharalis* egg predation

Model	Coefficient	SE	Residual deviance	df	Change in deviance	Pr (χ^2)
No terms added (null model)			53.965	11		
Intercept	-10.077	2.121				
+ <i>D. luteipes</i> density (log)	5.194	1.018	38.171	10	34.207	<0.0001
+ Mean temperature	0.192	0.079	33.155	9	5.016	0.025
+ Rainfall	-0.015	0.004	19.758	8	13.397	0.0002

The model assumes a binomial distribution of errors and uses the logit link function. The change in deviance after inclusion of a term in the model was tested through a likelihood ratio test ($P < 0.05$).

was negatively associated with rainfall (Fig. 2A; Table 2), whereas *D. luteipes* density and mean temperature were positively correlated with mortality (Fig. 2, B and C; Table 2). The model explained $\approx 97\%$ (total deviance change was 52.62 out of 53.96) of the variation in *D. saccharalis* egg predation (Table 2).

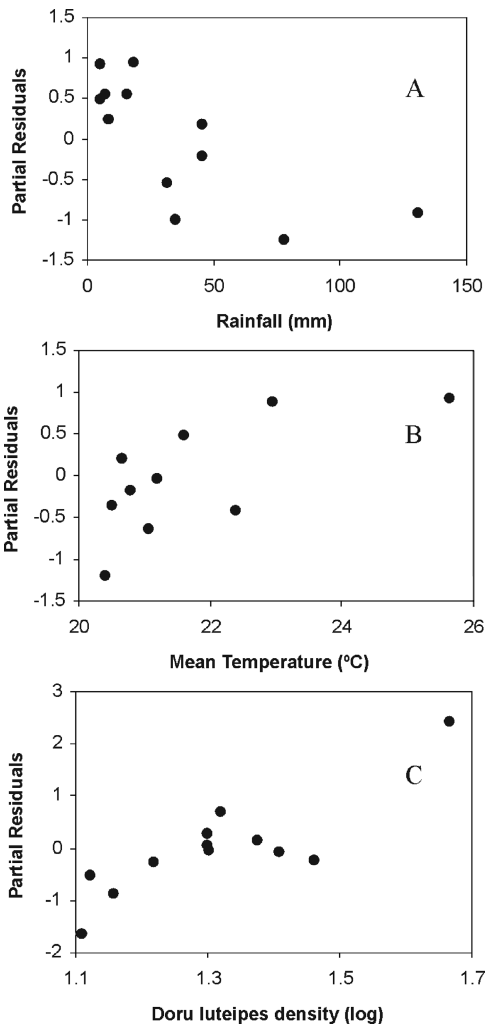


Fig. 2. Partial residuals for the relationship between *D. saccharalis* egg predation and (A) rainfall, (B) mean temperature, and (C) *D. luteipes* density.

The partial residual analysis shows an apparent outlier (Fig. 2). To test its influence, the statistical analysis was repeated excluding that single data point. This procedure is the extreme of a weighted regression because it is equivalent to assigning zero weight to the outlier (Faraway 2006). Because the new analysis did not change the model selection described in Table 2, we decided to keep that extreme data point.

Discussion

Our results reveal that *D. saccharalis* egg survival was affected by predator density and weather factors. In general, *D. saccharalis* eggs suffered similar predation rates as those reported for other borer insects (Negm and Hensley 1969, Frye 1972, Phoofolo et al. 2001). We assumed that predation was caused only by *D. luteipes*. Our concentration on this one particular species proved justified because this was by far the most abundant arthropod predator in the maize plots and the only one present throughout the period of study. Other predators like ladybeetles and lacewings were present only occasionally. In a study dealing with the impact of the insecticide deltamethrin on arthropods in maize under conventional practices, the same earwig species was also found to be the most abundant predator when no insecticide was applied (Badji et al. 2004).

The positive relationship we found between predation of *D. saccharalis* eggs and density of *D. luteipes* (Fig. 2C; Table 2) is consistent with a similar association between mortality of the same stem borer and a predator complex, reported by Negm and Hensley (1969). It is also in agreement with Reid (1991), who found that the density of the insect predator *Orius insidiosus* (Say) correlated with egg mortality of *Ostrinia nubilalis* Hübner, the European corn borer, and *H. zea*, the corn earworm. Ferguson and Joly (2002) had to statistically account for changes in prey abundance to identify effects of predator abundance. In our study, the fact that the number of egg masses were kept at a constant level during all the experiments shows that increases in numbers of predated eggs were attributable to change in *D. luteipes* abundance and possibly activity and not just a result of an increase in prey density (Reid 1991).

Generalist predators, such as *D. luteipes*, are known to consume not only a broad range of arthropod prey but also exploit plant materials (Jervis and Kidd 1996).

Musser and Shelton (2003) observed less biological control of *O. nubilalis* when alternative foods (aphids and pollen) were available. In our study, predation was measured only during maize vegetative stages. Possibly, the availability of pollen during the R1 maize phenological stage (Ritchie et al. 1986) would have diminished earwig predation on *D. saccharalis* eggs. Although, in our experiments, *D. luteipes* showed high level of egg consumption in the absence of pollen, it is necessary to consider that the potential of this species as natural enemy of *D. saccharalis* eggs could be affected by the availability of alternative foods.

Unlike our approach, other studies addressed the effects of predators on prey populations using a statistical correlation approach. For example, Hardman et al. (2005) studied the empirical relationship between prey and predatory mite densities through linear regression, and Ferguson and Joly (2002) explored the influence of predaceous mites (generalist predators) on the growth rate of a springtail population through time series analysis. In these studies, predation was not dealt with directly, but through the assumption of a predation pressure proportional to the predator density or integrated implicitly within the prey growth rate. In our study, we specifically addressed predation of one particular life stage (eggs). From a population dynamic viewpoint, concentrating on just one life stage could be regarded as a limited analysis. However, in the context of a management model for *D. saccharalis*, prediction of egg mortality is critical.

Our data also showed the significant role of weather conditions on *D. saccharalis* egg predation, with rainfall negatively influencing egg predation (Fig. 2A). Rain can kill small or immobile insects, and this is often associated with declines in insect population size (Moran et al. 1987, Norris et al. 2002). There are many examples of pests that increase their population levels after flooding, and this could be caused by the destruction of their natural enemies by drowning (Beirne 1970). Although this study was not aimed at determining the causes of *D. luteipes* mortality, we believe that this is not a plausible explanation for this species, because it is frequently found hidden in the leaf axes or in the ears of maize plants when it rains. Physical factors affect searching efficiency of natural enemies (Kidd and Jarvis 1996). For example, rain and wind were found to have strong effects on the foraging activity of the aphid parasitoid *Aphidius rosae* Haliday (Weisser et al. 1997). Therefore, rainfall may reduce *D. luteipes* activity by affecting its foraging behavior, and this could be one of the reasons for lower mortality of *D. saccharalis* eggs during rainy periods. In extreme situations such as floods, *Labidura riparia* (Pallas) (Dermaptera: Labiduridae), one of the predators of the yellow stem borer, *Scirpophaga incertulas* (Walker) (Lepidoptera: Pyralidae), was found to have no activity in flooded deepwater rice (Catling and Islam 1995).

Our results also showed that mean temperature had a positive effect on *D. saccharalis* egg predation (Fig. 2B), whereas no association with minimum relative

humidity was identified. Higher mean temperatures would act on the activity of the predators, possibly increasing their searching efficiency and thereby generating greater rates of mortality (Giroux et al. 1995, Elliott et al. 2000, Mohaghegh et al. 2001). Similar results were obtained by Kharboutli and Mack (1993). In a laboratory study, these authors examined the effects of temperature, humidity, and prey density on feeding rate of the *L. riparia* and showed that prey consumption increased with temperature and prey density but not with humidity.

The issue of how weather factors affect natural enemies has been addressed by several researchers through laboratory experiments with various controlled conditions (Hansen and Jensen 2002, Parajulee et al. 2006) to identify ranges of temperature, humidity, etc., within which parasitoids and predators should be expected to perform best. However, extrapolation of results to field conditions may be misleading. We believe that our empirical approach, though providing indirect evidence, is more representative of the fluctuating conditions of the field.

With endophytic pests like *D. saccharalis* larvae, estimating egg mortality rate and the factors that cause its variation could play an important role in the calculation of economic thresholds. Indeed, Tollefson and Calvin (1994) developed an economic threshold (ET) model to calculate the optimum timing of insecticide sprays for *O. nubilalis* management. The economic injury level (EIL) is calculated with a loss function based on third-instar larvae numbers per plant. Third instars are considered the stage when larvae are established in the stems and begin stalk tunneling. Because a control decision cannot be made when the third or older larvae are already present in the plant, the ET must be derived. The ET is expressed as the number of egg masses per plant yielding the EIL. Once the EIL is defined, the ET depends on the survival rate of the eggs and first and second larval instars.

In such ET models, the quantification of egg mortality and its variation is a key component. Our data suggest that, in central Argentina, *D. saccharalis* egg predation is associated with *D. luteipes* density during the vegetative phenological stages of maize, whereas among weather factors, mean temperature and rainfall were the most influential.

Our study is the first contribution to an equivalent ET model for *D. saccharalis* (E.V.T., unpublished data). A preliminary ET model proposed by Trumper (2006) for *D. saccharalis* management shows that mortality rates in the range of those found in this study make the ET, expressed in terms of percentage of maize plants infested with egg masses, vary up to three-fold. This shows the relevance of the effects on egg mortality found in our work.

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