

# Interactions between Biological Control Efforts and Insecticide Applications in Tropical Rice Agroecosystems: The Potential Role of Intraguild Predation

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**Integrated pest management attempts to combine cultural, chemical, and biological approaches to bring about pest reductions and improve crop yields. In Asian wet rice agriculture, as in many crop systems, there is a real question as to how compatible chemical control methods are with other pest control approaches. Working in an irrigated rice paddy on Java, Indonesia, we crossed a natural enemy treatment (addition of wolf spiders, *Lycosa pseudoannulata* Boesenberg et Strand) with an insecticide treatment (monocrotophos) in a balanced, replicated, two-way factorial design to explicitly examine the potential interactions between chemical and biological control methods. Although adding either wolf spiders or insecticide to field plots significantly reduced abundance of pests (sucking homopterans), combining the two treatments together generated a significant, season-long interaction effect such that pest densities did not decrease. In other words, pest densities in plots receiving both spiders and insecticide were statistically comparable to those in plots receiving neither pest control method. Furthermore, we found additive effects of wolf spiders and insecticide on other generalist predators, and from those data we hypothesize that intraguild predation and ensuing indirect effects may be responsible for the interaction effect on pest density. Our results indicate that, far from being complementary and compatible approaches to pest reduction, combining treatments of natural enemy addition and insecticide application may be quite counterproductive.** © 1998 Academic Press

**Key Words:** Lycosidae; Mesoveliidae; Homoptera; rice agriculture; monocrotophos; intraguild predation; integrated pest management.

## INTRODUCTION

In tropical rice agroecosystems, integrated pest management (IPM) is a pest-reduction strategy that combines various techniques such as biological control efforts, farmer education programs, and insecticide applications to reduce pests. Crop-protection specialists promote IPM as a more environmentally friendly alternative to calendar-based applications of insecticides and herbicides. Given the diversity of management practices employed by IPM programs, it is worthwhile to understand the true level of compatibility of different pest control strategies used together in tropical rice agriculture (Way and Heong, 1994). In the experiment described here, our specific intent was to examine the potential complications that arise when such disparate tactics are combined. Many IPM workers would generally expect a certain level of incompatibility between chemical and biological control methods due to direct toxicity of pesticides to biocontrol agents (e.g., Settle *et al.*, 1996). But, are there other factors that might contribute to the incompatibility of insecticide-based and natural enemy-based control strategies in rice agriculture?

To address this question, we used a two-way factorial experimental design (insecticide [yes, no]) × natural enemy supplement [yes, no] that allowed us to test for any direct effects of as well as “interaction effects” between biological and chemical control strategies. In this two-way factorial design, the two treatments could have an additive effect where the effect of insecticide addition simply complements the supplementation of natural enemies. On the other hand, the two treatments could be incompatible resulting in an interaction effect where the effect of the natural enemy supplement depends sensitively on the presence or absence of the insecticide. Anticipating an absence of blanket compatibility between the two pest strategies (e.g., Settle *et al.*, 1996), we tested for such interaction effects in the

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population responses of the dominant herbivorous pest species and of important natural enemies known to be affected by chemical pesticides.

## METHODS

### *Generalists as Biological Control Agents*

Our research focused on the community impacts of a species of lycosid wolf spider (*Lycosa pseudoannulata* Boesenberg et Strand). While there are other important guilds of generalist predators (e.g., predaceous beetles, water surface-dwelling hemipterans), these wolf spiders are the most commonly found and are well known to and easily recognized by the indigenous farmers. Several features of these spiders make them attractive in the context of IPM (Riechert and Lockley, 1984; Nyffeler *et al.*, 1994). For instance, wolf spiders prey on a variety of important pest species in rice and often reach high densities (over 30 adults per m<sup>2</sup> [W.F. Fagan, pers. obs.]) in rice paddies early in the season when pest outbreaks would be starting and when more specialized natural enemies would typically still be at low density (Way and Heong, 1994; Settle *et al.*, 1996).

### *Field Site Description*

Our study site was a 1-ha rice paddy in the village of Tempuran, Karawang, West Java, Indonesia. We rented the paddy, one of several hundred in a contiguous irrigated basin devoted to rice agriculture, from a local farmer. Rice is grown synchronously over large areas in two seasons per year with a long dry-fallow period from July to October. This general region of Java (called the Jalur Pantura) is one of several "rice bowls" found in Indonesia. Rice grown here supports not only the local population, but it is also transported to other regions of Indonesia. Within the Tempuran area, farmers apply zero to seven insecticide applications per rice growing season (around 110 days) (Settle *et al.*, 1996). Our rented paddy had been a zero-spray IPM field for the past several seasons, but its immediate neighbors represented a general mix of management techniques. All paddies in the irrigation basin featured essentially synchronous planting/harvesting schedules.

### *Experimental Procedure*

Fifteen days after the rice had been transplanted (from the hand cultivated "seed beds" used in rice agriculture), we erected 40 open-top cages measuring 2m × 1m × 1m (length × width × height) constructed of plastic sheeting and bamboo supports (materials available locally). To prevent disruption by bad weather, we staked the cages and separated them from each other by at least 2m. Although the plastic sheeting substantially reduced arthropod dispersal across cage boundaries, we left the cages open at the top to mini-

mize cage effects like solarization. Thus, this cage design was a compromise between completely enclosed cages with their concomitant cage effects and barrier-free plots where high levels of arthropod dispersal might mask some effects of our treatments. Each cage enclosed 36 rice plants in a 9 × 4 array.

We arranged the cages in 10 blocks of 4 cages each to control for paddy edge effects and heterogeneity within the rented paddy. One cage in each block was assigned to each of four treatments: both insecticide and wolf spiders (*L. pseudoannulata*) added, only insecticide added, only wolf spiders added, or nothing added (i.e., double control). Our experiment was a two-way factorial with 10 replicates per cell in the design.

*Insecticide treatment.* One day following cage construction, we added the insecticide monocrotophos at a rate of 1.5 L/ha (the standard application rate, which equals 0.15cc monocrotophos per m<sup>2</sup>) to 20 cages. We hand sprayed the insecticide directly on each plant to localize the application and to minimize surface water contamination. Monocrotophos is a fast-acting, broad spectrum organophosphate with a short half-life (Heong *et al.*, 1994; Ali and Karim, 1995). Although officially banned for use on rice in Indonesia, monocrotophos is still one of the most widely used insecticides because it is relatively inexpensive and easily available (Settle *et al.*, 1996). To minimize subsurface mixing of the pesticide into the control cages, the plastic cage sheeting extended below the water surface into the mud while the monocrotophos was active.

*Spider treatment.* After waiting 4 days for the insecticide to take effect and subsequently degrade (Young and Bowman, 1967; Singh and Mukherjee, 1993; Ali and Karim, 1995), we added 80 adult or nearly adult wolf spiders (collected from nearby paddies the previous day) to each of 20 cages (10 having received insecticide earlier and 10 without insecticide). In anticipation of 10% mortality of the added spiders (due to the physical jostling associated with transplanting the spiders, based on prior experience), this treatment equals 2 added spiders per rice plant. Existing spider densities averaged about 3 spiders per plant (range 0 to 9). In the insecticide + spider treatment, the insecticide did not kill the added spiders because it had already degraded (see below). Total wolf spider densities resulting from these manipulations were well below the upper limit to wolf spider density in the Tempuran basin for that season (W.F. Fagan, pers. obs.).

Starting 1 week after adding the wolf spiders and continuing for six more weeks, we collected all the insects and other arthropods on each of three plants in each cage using handheld "FARMCOP" suction devices (modified portable car vacuums; Carino *et al.*, 1979; Perfect *et al.*, 1983) and netted metal canisters with a 400-cm<sup>2</sup> opening that enclosed individual rice plants and prevented the escape of arthropods during the

suction process. This sampling technique restricts the arthropods sampled to those from a single rice plant and has worked well for several years in rice agriculture. We staggered the individual plants from which we collected the arthropods in such a way that: 1) no plant was ever sampled twice, and 2) adjacent plants were not sampled during the same week or in any 2 consecutive weeks (to minimize disturbance effects associated with the prior sampling). All arthropod specimens collected during the sampling were identified to species or morphospecies whenever possible and were assigned to guilds and trophic groupings characteristic of rice agroecosystems (e.g., Settle *et al.*, 1996).

In our analyses, we concentrated on the responses of the major pest insects (a guild of sucking herbivores: chiefly cicadellids and delphacids) and mesoveliids, generalist predatory hemipterans important in rice agroecosystems. Mesoveliids, which hunt at the base of rice plants and on the water's surface, comprise a critical link in the natural suppression of herbivorous pest species (e.g., rice brown planthoppers: Kenmore *et al.*, 1984; Nakasuji and Dyck, 1984; Kuno and Dyck, 1985) but are also known to be especially sensitive to insecticide applications (Settle *et al.*, 1996). This pre-existing information, plus their small body size relative to wolf spiders, suggested that mesoveliid density would be a key response variable in this study.

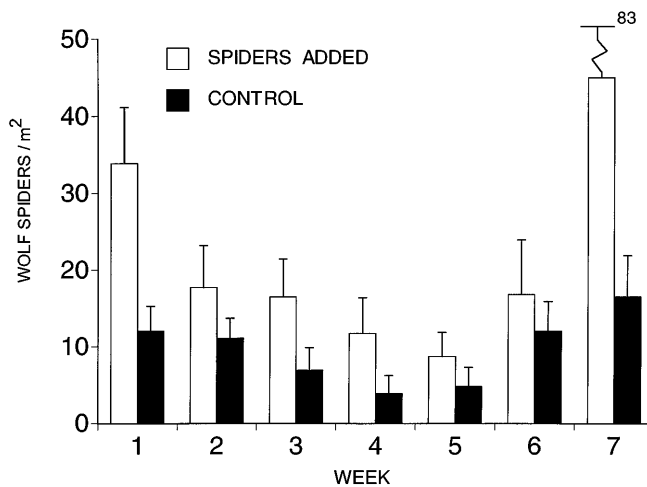
### Statistical Analysis

We analyzed our data as a balanced two-way ANOVA with spiders (Yes or No) and insecticide (Yes or No) as fixed design factors plus the spatial position blocking factor. For each functional group, we incorporated the suite of weekly samples as a repeated measure vector of length seven. For each week, arthropods from the three suction-sampled plants in each cage were summed to form the sample for each cage. For statistical analysis, we transformed all our data using the Freeman-Tukey method (Sokal and Rohlf, 1995) but rescaled the data to numbers per m<sup>2</sup> for presentation purposes.

## RESULTS

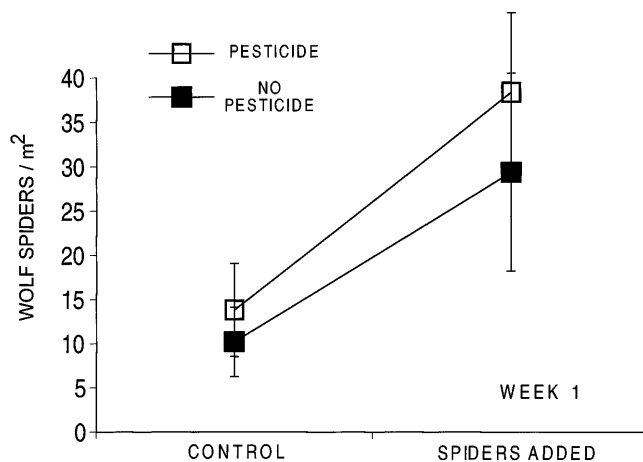
We sampled roughly 45 m<sup>2</sup> of paddy surface and captured nearly 13,000 specimens representing over 350 morphospecies from more than 100 families of arthropods. Most of these data are intended for other analyses; we concentrate here on the responses of pest species and the most abundant generalist predators (wolf spiders and mesoveliids).

On average, our wolf spider addition treatment successfully increased wolf spider densities by 225% relative to controls, averaged over the duration of the experiment (Fig. 1; repeated measures ANOVA:  $F_{1,27} = 26.611$ ,  $P < 0.001$ ). Because the insecticide had degraded by the time the spiders were added, the



**FIG. 1.** Mean ( $\pm 95\%$  C.I.) wolf spider (*Pardosa pseudoannulata*, Lycosidae) density with and without added spiders over the course of the rice growing season. Sample size for each bar is 20 cages.

insecticide treatment did not reduce wolf spider density overall relative to controls (repeated measures ANOVA:  $F_{1,27} = 0.912$ ,  $P < 0.348$ ) or even during week 1 alone when any effect of the insecticide residue should have been most evident (Fig. 2; ANOVA:  $F_{1,27} = 3.217$ ,  $P = 0.084$ ). Note that the nonsignificant trend toward an insecticide effect was toward increased wolf spider abundance in insecticide addition plots. Furthermore, over all sample dates, no significant interaction effect was associated with the density responses of wolf spiders to the experimental manipulations (repeated measures ANOVA:  $F_{1,27} = 0.450$ ,  $P = 0.508$ ). In general, wolf spider density was highest at the beginning and again at the end of the growing season (Fig. 1),



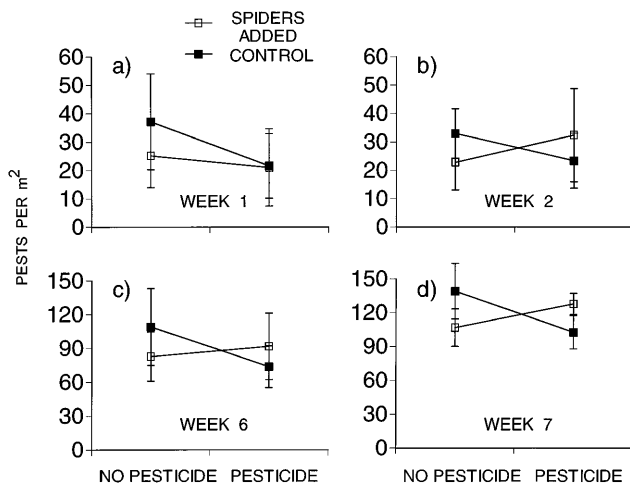
**FIG. 2.** Mean ( $\pm 95\%$  C.I.) wolf spider (*Pardosa pseudoannulata*, Lycosidae) density after 1 week. Sample size for each plotted point is 10 cages. Note that the nonsignificant trend toward an insecticide effect was toward increased wolf spider abundance in insecticide addition plots.

corresponding to the generation cycle of *L. pseudoannulata*.

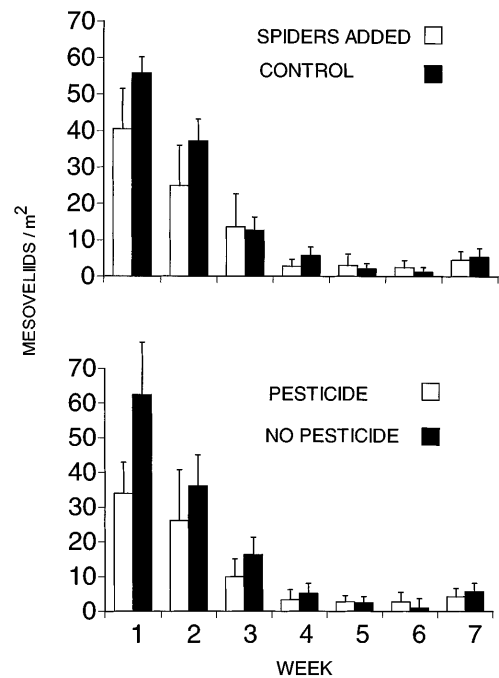
Spider and insecticide treatments had a significant interactive effect on the densities of pest species (sucking herbivores: delphacids and cicadellids; repeated measures ANOVA:  $F_{1,27} = 5.746$ ,  $P = 0.024$ ). Specifically, whereas the spider addition and insecticide addition treatments both reduced pest densities when used alone, the two techniques in combination produced no net change in pest densities (i.e., pest densities comparable to those in the absence of either pest strategy [Fig. 3]). This interaction effect required a 1-week lag to take effect (Fig. 3a) but remained true thereafter (Figs. 3b–d). The interaction effect was most pronounced during the later samples (weeks 5 to 7) when pest densities were highest (Figs. 3c–d). During week 5, for example, cages that had received both spiders and insecticide featured pest densities 72% higher than did the double control treatment (i.e., no insecticide, no added spiders).

Insecticide application alone reduced pest densities by an average of 16% over the full season, and had its greatest effect during week 1 (immediately after the application) when pest densities were suppressed by 44% (Fig. 3a). Spider addition alone had similar effects, reducing pest densities by an average of 14% over the full season and 42% during the first week.

Spider addition significantly reduced the densities of mesoveliids (an important group of generalist predators) throughout the experiment (Fig. 4a; repeated measures ANOVA:  $F_{1,27} = 5.699$ ,  $P = 0.024$ ). This mesoveliid effect was most pronounced during the first part of the season (weeks 1 to 4), when mesoveliids were at their peak densities. Insecticide addition also reduced mesoveliid densities for the duration of the experiment and during the first 4 weeks (Fig. 4b;



**FIG. 3.** Mean ( $\pm 95\%$  C.I.) pest (delphacids and cicadellids) densities early and late in the rice growing season. Sample size for each plotted point is 10 cages.

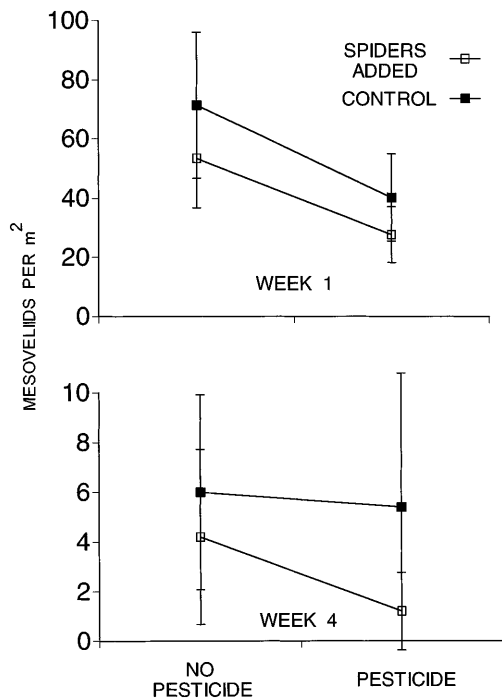


**FIG. 4.** Mean ( $\pm 95\%$  C.I.) densities of mesoveliids throughout the rice growing season, as functions of the two pest control manipulations. Sample size for each bar is 20 cages. The seasonal time course of these mesoveliids is typical of many generalist predators in rice agroecosystems, reaching peak densities in the first few weeks of the season.

repeated measures ANOVA:  $F_{1,27} = 7.930$ ,  $P = 0.009$ ). Combining spider and insecticide additions together produced an additive effect on mesoveliid densities (i.e., no interaction significant effect existed;  $F_{1,27} = 0.687$ ,  $P = 0.414$ ). Together the treatments reduced mesoveliid densities more than either manipulation alone, and suppressed the densities of these generalist predators to approximately 50% of the double controls (Fig. 5).

## DISCUSSION

Acting alone, the spider addition and insecticide addition treatments reduced pest densities to similar levels both initially and for the duration of the experiment (Fig. 3). However, the two strategies in concert did not further reduce prey densities, but rather they effectively canceled each other out. Prey densities in the combined treatment were statistically indistinguishable from those in the double control plots that received neither treatment. Note that these results reflect a true interaction between the chemical and biological control strategies and not some experimental mishap wherein the insecticide killed the added spiders in the combination treatment (Fig. 2). Our results are intriguing ecologically because they suggest that powerful indirect effects are at work in this complex rice arthropod community (see below). Furthermore, these results



**FIG. 5.** Interaction plots for mean ( $\pm 95\%$  C.I.) densities of mesoveliids during the early part of the rice growing season, showing the additive effects of spider and insecticide addition on mesoveliid densities.

have profound implications for pest management strategies that advocate combining insecticide applications with biological control using existing natural enemies.

Based on the additive impacts of spider and insecticide treatments on mesoveliid densities (Fig. 5), we suggest that the primary ecological mechanism responsible for the nonadditivity of the chemical and biological control strategies may be "intraguild predation," a form of omnivory involving the consumption of one predator species by another, where both species share a common prey resource (Polis *et al.*, 1989; Rosenheim *et al.*, 1993). Often a size-dependent factor is involved in intraguild predation (Diehl, 1992, 1993; Rosenheim *et al.*, 1993), wherein the larger-bodied predators prey extensively on smaller-bodied species but not vice versa. In rice agroecosystems, wolf spiders and mesoveliids are both major components of a guild of generalist arthropod predators that appear to exert considerable top-down control on arthropod abundance (Kenmore, 1980; Nakasuji and Dyck, 1984; Way and Heong, 1994; Settle *et al.*, 1996). Within this guild of generalist predators, wolf spiders are typically among the largest-bodied species, while mesoveliids are generally smaller-bodied.

Although adding either wolf spiders or the pesticide monocrotophos did reduce mesoveliid densities (as in Fig. 4), the remaining mesoveliid densities apparently were still sufficient to prevent resurgence of the pest

species. We speculate that only when we increased wolf spider densities and chemically eliminated some mesoveliids (as incidental casualties of our broad spectrum insecticide) did our manipulations push the densities of smaller-bodied consumers below a critical threshold for pest control, leading to the increased pest densities we witnessed in the spider + insecticide treatment. In this scenario, the increased densities of wolf spiders could not compensate for the dramatic two-pronged decrease in density of the smaller-bodied mesoveliids, leading to lower overall predation intensities, and consequently, increased pest densities (Fig. 3). Adding mesoveliids to insecticide addition plots (after the insecticide had degraded) would be one way of experimentally testing the intraguild-predation hypothesis we propose here.

Wolf spiders and mesoveliids have both been touted as potential biocontrol agents of phytophagous pests in rice (e.g., Heinrichs *et al.*, 1982; Fabellar and Heinrichs, 1984; Way and Heong, 1994). Although this experiment was not designed to assess the relative efficacy of different biocontrol agents, it does demonstrate how careful researchers must be when selecting biocontrol agents. As has been reported for interspecific interactions within multispecies assemblages of biological control agents (e.g., Spiller, 1986; Ehler, 1992; but see Chang, 1996), interactions between chemical and biological control agents may be detrimental to pest control efforts.

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