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Interaction of Insect Pest Injury with other Stresses on Yield of Irrigated Rice

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We found that the combined attack of whorl maggot *Hydrellia philippina* Ferino and defoliators (mixed populations of green semilooper *Naranga aenescens* Moore and green hairy caterpillar *Rivula atimeta* [Swinhoe]) produced a synergistic yield loss on irrigated rice, while losses from stemborer *Scirpophaga incertulas* (Walker) and leaffolder *Cnaphalocrocis medinalis* (Guenée) were additive over both rice reproductive and ripening growth stages. Losses from insect pests became accentuated with each additional non-insect pest stress (weeds, low inorganic N, low solar radiation) added reaching a plateau with two or three such stresses. This result underscores the difficulty of predicting yield loss caused by a given insect pest complex in the field as it depends significantly not only on pests, but also on their interaction with the rice production environment. The combination of non-insect pest stress that produced the greatest yield loss was high solar radiation of the dry season, weed stress, and no added inorganic N. The null hypothesis was that the wet season with its low solar radiation would have caused the greatest stress and that the high solar radiation of the dry season would have allowed greater compensation to occur. The greatest non-insect stress for the most part turned out to be the combination of the dry season and weeds with N rate only contributing in some comparisons, and sometimes at 0 or 90 kg N/ha rates. We offer several explanations for this. The combination of the dry season and weeds was particularly stressful as the greater solar radiation benefitted weeds more than rice. Only rice suffered transplanting shock and in addition insect pests fed more on rice than weeds. At times the combination of dry season, no added N, and weed-free plots gave the lowest yield. In this case the rice crop suffered most from insect pest injury, transplanting shock, and N stress. That upredicable outcomes were probably due to the countervailing forces of compensation on the one hand and the effects of multiple stresses on the other.

Key Words: artificial pest infestation, damage compensation, multiple pest infestation, nitrogen stress, rice insect pests, solar radiation, weeds, yield loss

INTRODUCTION

Yield loss trials have underscored the difficulty in predicting rice crop loss solely on insect pest density (Litsinger 2009). Walker (1975) was one of the first to point out that yield loss from insect pests occurs in association with not only other kinds of insect pests, but other kinds of pests such as weeds, diseases, nematodes, etc., and concurrently from a multitude of abiotic factors such as nutrient deficiencies, moisture stress, low solar radiation, etc., where the contribution of each may or may not be additive. In other words, any factor that affects yield can also affect the degree of yield loss from insect pests (Bardner and Fletcher 1974; Willocquet et al. 2000).

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Poston et al. (1983) and Lamp et al. (1985) categorized the mode of interactions from multiple pest infestations as being: 1) additive (no interaction) where yield reductions caused by more than one pest attacking one plant are the sum of the reductions as if each species attacked separate plants, 2) synergistic where the response is significantly more than additive, and 3) antagonistic if the joint interaction is significantly less than additive. Higgins et al. (1983) concluded that if joint influence of two types of pests is synergistic rather than additive, then recommendations developed for single pests might fail. Also mentioned there have been limited studies that set about to quantify the crop's response to such interactions.

Plant responses to one stress factor may indirectly influence a subsequent impact with a second stress factor. Since the biotic and abiotic components of agro-ecosystems are variable and dynamic, it is essential that the combined role of plant pests be studied with respect to all other relevant components of the production system.

Litsinger et al. (2005) identified three chronic insect pest guilds that are prominent in the Philippines attacking irrigated wetland rice. The first guild attacks predominantly the rice vegetative stage and is composed of rice whorl maggot *Hydrellia philippina* Ferino and defoliating caterpillars we term 'defoliators' (green semilooper *Naranga aenescens* Moore and green hairy caterpillar *Rivula atimeta* [Swinhoe]). All three species often are found in the same field. Two other guilds are more abundant in the reproductive and ripening stages: stemborers and leaffolders. Species of stemborers and leaffolders can vary by location but the most common in Central Luzon is the yellow stemborer *Scirpophaga incertulas* (Walker) and several species of leaffolder: *Cnaphalocrocis medinalis* (Guenée) and *Marasmia* spp.

In the first guild, leaf damage caused by the three species is similar in appearance; thus farmers give the damage symptom a single name ('*aksip*' in Tagalog). The early instars of the two lepidopteran defoliators scrape the epidermis and the late instars remove portions of leaf blades. Hutchins et al. (1988) found that each of five defoliator species, comprising two insect orders that attacked the same stage of soybean, caused identical physiological responses they termed 'injury equivalents', as defoliation for each species was deemed similar in its effect on the plant. Based on this result, we feel confident that *Rivula* and *Naranga,* both noctuids, cause similar injury equivalents as they attack the same growth stage in the same manner. Whorl maggot, however, causes a different type of injury since the larva tunnels into the developing leaf buds. Leaves are deformed as they emerge. Our aim was to discover the contribution to yield loss caused by whorl maggot and defoliators separately and together. For stemborers and leaffolders our aim was to quantify the loss from infestation of the reproductive and ripening stages separately and together. The three insect pest guilds were tested in separate experiments.

Savary et al. (1994), had the same overall objective in mind of determining the interactions of an array of crop variables on yield. They measured over 30 crop production variables in C Luzon in an attempt to explain yield loss and found that different clusters of variables were associated with low or high yields. For example, the density of weeds was measured following the method of Savary et al. (1994) by estimating the amount of shade produced, which in conjunction with stemborer injury, contributed to low yields. Stemborers were the only insect group to be associated with significant yield loss in the study that also measured other chronic insect pests such as vegetative defoliators, whorl maggot, and leaffolders. It cannot be said that these insect pests do not cause yield loss in association with other crop variables, but because the study measured the effect of natural populations, their densities may have been too low.

An additional objective of our study was to examine how insect injury from each of the three guilds was affected by multiple interactions of three non-insect parameters: weediness, inorganic N level, and solar radiation (season). These variables when stressful (weed competition, low solar radiation, and N deficiency) can contribute to yield loss, but on the other hand removing weeds, adding inorganic N, and growing the crop in the high solar radiation of the dry season can promote crop compensation (Litsinger et al. 2011). Savary et al. (1994) relied on natural field infestations, which can vary greatly year to year. Therefore to ensure that yield losses would be significant, we artificially infested plants with insect pests. To ensure that the environmental variables were also stressful, we manipulated their presence in small plots on farmers' fields. Weeds were allowed to grow or were removed. Urea was applied at 90 kg N/ha or not applied. Solar radiation was manipulated by conducting the trials over two wet seasons and two dry seasons. The result of the manipulation of treatments was to obtain permutations of stresses for each pest guild so that we could advise farmers on which combinations resulted in the highest losses and which ones most contributed to crop compensation. We hypothesized that weedy plots without added inorganic N and grown in the wet season would result in the lowest yields when combined with insect injury in each of the three guilds.

MATERIALS AND METHODS

Site Description and Crop Management

Field trials were carried out in Nueva Ecija province where a house in Zaragoza was rented as a local office and all trials conducted on nearby farmers' fields. A resident on-site research team from the International Rice Research Institute (IRRI) based in Los Baños performed the trials assisted by locally hired project-based field staff supplemented by daily paid workers. Zaragoza is located at the tail end of the gravity-fed Upper Pampanga River Integrated Irrigation System. The monsoon rainfall pattern consisted of a wet season followed by an essentially rain-free and cloudless dry season. Rice yields average 20% more in the dry season due to the greater solar radiation (Yoswhida 1981). Further site description can be found in (Litsinger et al. 2005).

Trials involved the early maturing IR64 (112 d), a modern rice variety that is resistant to brown planthopper *Nilaparvata lugens* Stål and green leafhopper *Nephotettix virescens* Distant and is moderately resistant to stemborers, but susceptible to whorl maggot, defoliators, and leaffolder. Six-8 seedlings per hill were transplanted from wet seedbeds 4 weeks after sowing. Spacing was 25 x 25 cm between hills. Inorganic N was applied as urea in amounts specified by treatments in two splits, half basal (soil incorporated during the last harrowing before transplanting) and half as a top dressing 7 days before panicle initiation. Also 30 kg P/ha was applied basally to all plots.

Field Trials

Four common rice insect pests were compared either as individual or combined species or as individual species with infestations in one or two rice growth stages. Three different experiments were replicated over four seasons, two in the wet (1988 and 1989) and two in the dry (1989 and 1990). Fields were sown early to minimize natural pest infestation. Insect pests were infested on 25 hills per replicate (1 m^2). Each experiment was replicated in six farmers' fields for a total of 150 hills per treatment per season. The first experiment involved both whorl maggot and *Naranga* and *Rivula* defoliators, each infested in separate treatments and combined as a third treatment. The second and third experiments were conducted with the yellow stemborer and leaffolder and followed the same infestation schedule. The first treatment involved infestation of the reproductive growth stage while the second involved the ripening stage. The third treatment was the combined infestation of both growth stages. A further variable for each experiment included sub-treatments of two levels of inorganic fertilizer (0 and 90 kg N/ha). And finally all treatments were divided into plots where weeds were controlled by hand removal (weed-free) and conversely where weeds were allowed to grow (weedy). The effect of season is mainly due to differences in the amount of solar radiation received by the crop. An actinograph set out in the agro-met station in Guimba, nearby Zaragoza, over the four crop seasons from 1988-89 recorded an average of 35% more solar radiation in the dry season (517 calories/cm^2/d) than wet season (383 calories/cm^2/d). Yoshida (1981) felt that in a monsoon climate, particularly in a northern latitude such as the Philippines with short days, the wet season rice crop would be stressed by lack of solar radiation.

Each replication of the set of three experiments per season comprised a different farmers' field planted over a 2-3 week period to spread the workload in the randomized complete block design. The fields were sown at the beginning of each season when the natural infestation was expected to be low so that there would not be significant densities of other pests present. Artificial infestation was employed in order to obtain the widest range of damage levels. There were two infestation phases per growth stage for each pest. The first phase for whorl maggot and defoliators occurred on 20 of the 25 hills per plot leaving five hills uninfested.

Field-collected whorl maggot eggs are rarely parasitized (Jahn et al. 2007), so mortality comes largely from predators. But predation is generally low at the beginning of each season. Leaf sections, each containing single eggs, were cut from plants in nearby fields. At 7 days after transplanting (DT) (first phase), 10 hills were each infested with two eggs and 10 each with four eggs. The leaf sections were affixed to rice leaves with household white glue. During the second phase at 10 DT, half of each set of previously infested hills was infested with four eggs so that sets of five hills had 0, 2, 4, 6, or 8 eggs. Maps were made of each replicate to keep track of which hills had been infested.

In treatment 2, 2^{nd}-3^{rd} instars of mixed *Naranga* and *Rivula* larvae were obtained from rearing colonies in the IRRI Entomology Department. The same infestation arrangement was followed as with whorl maggot. Five hills remained uninfested and on 7 DT 10 hills each received one or two larvae. On 10 DT, half of the hills infested at 7 DT with one or two larvae received an additional two larvae so that sets of five hills each had 0, 1, 2, 3, or 4 larvae. Care was taken to evenly mix the larvae of each species during infestation.

Stemborers and leaffolders were infested in each of two plant growth stages: 1) prior to panicle initiation (reproductive stage) 35 DT (first phase) and 42 DT (second phase) and 2) at panicle exsertion (ripening stage) 56 DT (first phase) and 63 DT (second phase). Leaffolder 2^{nd}-3^{rd}

instar larvae were obtained from IRRI headquarters from a rearing colony of *C. medinalis*. Four or eight larvae were placed on 10 hills, each with five hills left uninfested. In the second phase, 5 hills that had received four or eight larvae received an additional four, while five hills that received eight larvae received an additional eight so that each set of five hills bore 0, 4, 8, 12, or 16 larvae. The infestation rate was higher than for defoliators as the crop was older and hence each hill bore many more leaves.

Yellow stemborer moths, collected at outdoor lights, were caged on rice plants. Medium sized egg masses were selected for rearing in petri dishes and inspected at the blackhead stage following Bandong and Litsinger (2005). As *Scirpophaga* egg masses are laid in varying sizes, egg masses were cut with a razor to a size of a pre-described circle that would average about 50 eggs. Masses free of egg parasitoids were placed at three per 1 m^2 (25 hills), either 35 DT for the reproductive stage or 63 DT for the ripening stage. The dual stage infestation totaled six egg masses, three in each stage.

Insect damage was assessed on all 25 hills per 1-m^2 plot for all treatments. In the whorl maggot and defoliator experiment, the percentage of damaged leaves was determined 35 DT when all leaves were scored as either damaged or undamaged. Damage assessment from leaffolder reproductive stage infestation was carried out at 56 DT and the ripening stage infestation at the flag leaf stage 77 DT following the same manner. Reproductive stage stemborer infestation was assessed as percentage of deadhearts and whiteheads at panicle exsertion, while ripening-stage infestation was similarly assessed at 10 days before harvest. Hills were hand harvested with grains oven dried to 14% moisture and weighed on a top-loading electronic balance accurate to ± 0.1 g.

Weed infestation was measured by making a visual assessment of the percentage ground area covered above and below the rice canopy in each plot following the method utilized by Savary et al. (1994). Weeds above the canopy compete more with rice and thus are more important in terms of yield. No herbicide or hand-weeding was used thus tillage and water management were the only weed control methods employed. Therefore weeds usually attained moderate densities.

Statistical Analysis

The data were subjected to one-way ANOVA analyses for each experiment using SAS software. To normalize the data, an arcsine transformation was used before analysis. The factorial experiment was a randomized complete block design and means were separated by the LSD test. When comparing two variables the t-test was used. The level of significance was $p < 0.05$.

RESULTS

The main weeds encountered below the canopy in the trials were *Monochoria vaginalis* (Burm.f.) Presl., *Cyperus diformis* L., *Eleusine indica* (L.) Gaertn., *Paspalum distichum* L., and *Scirpus supinus* L. Species above the canopy were dominated by *Echinochloa* spp., followed by *Scirpus maritimus* L., and *Ischaemum rugosum* Salisb. The average area covered below the canopy in younger rice was 43%, while 27% of the canopy was shaded in the older crop over the four seasons. The weed infestation was typical of local farmers as the trials were conducted on a farmer's field. There was no significant disease pressure during the trials due to the resistance in IR64.

Whorl Maggot and Defoliators

The artificial augmentation of rice whorl maggot and *Naranga* and *Rivula* defoliators achieved a range of densities that was higher than normally occurs in the field for both pests in order to ensure yield losses. For whorl maggot, the average was 38% damaged leaves that rose up to 64%. A damaged leaf is one that shows any feeding injury from the concerned pests. A similar result occurred with defoliators: 31% damaged leaves that ranged to 59%. When combined, the damage averaged 51% damaged leaves with a high that rose to 84%. These levels are about twice that of their action thresholds (Litsinger et al. 2006a).

Within the whorl maggot and defoliator guild, means averaged over the eight treatment combinations each revealed a yield loss for whorl maggot (20.0%) that was not significantly different from that of defoliators alone (23.2%) (Table 1). But the combined infestation (32.6%) was significantly different from whorl maggot but not defoliators.

Of the eight treatments where only whorl maggot was infested, the associated stresses that gave the highest percentage loss were weedy plots in the dry season at both 0 (40.5%) and 90 (39.7%) kg N/ha rates. These same two treatments in the wet season had lower losses (20.9 and 26.9%, respectively) that were statistically intermediate. Contrarywise, greatest compensation (lowest losses) from whorl maggot damage came without weed pressure in both the dry (4.2%) and wet (3.3%) seasons with 90 kg N/ha. The losses for the same treatments, but at 0 kg N/ha, were significantly intermediate for the dry (10.7%) and wet (14.1%) seasons. Therefore highest losses were the weedy treatments in the dry season followed by weedy treatments in the wet season regardless of N level. The higher solar radiation of the dry season, even in the presence of high N, did not allow for crop compensation when under weed stress.

Table 1. Effect of combinations of Nitrogen (N) levels, weediness, and season on the yield of IR64 rice with hills artificially infected with common chronic rice insect pests, Zaragoza, Nueve Ecija, Philippines, over four consecutive crops: 1988 & 1989 wet and 1989 & 1990 dry seasons.

					Yield Loss (%)[1]/				
	Whorl Maggot (WM) [2]/ and defoliators (DEF) [3]/			Stem Borer (infested in indicated plant stage)			Leaffolder (infested in indicated plant stage)		
Treatment	WM	DEF	Both Pests	Reproductive [4]/	Ripening [5]/	Both Stages	Reproductive [6]/	Ripening [7]/	Both Stages
Dry Season *No Weeds*									
ON	10.7 ± 3.0 b	28.5 ± 12.3 bc	58.2 ± 22.7 c	6.8 ± 3.0 ab	30.0 ± 12.4 c	31.2 ± 6.6 c	9.4 ± 4.2 b	13.9 ± 2.9 b	13.4 ± 4.2 b
9ON	4.2 ± 1.3 a	3.7 ± 3.5 a	34.8 ± 14.5 bc	0.9 ± 1.5 a	7.7 ± 2.0 ab	16.7 ± 5.4 b	2.9 ± 1.8 a	0.4 ± 1.1 a	3.8 ± 1.7 a
Weeds									
ON	4.5 ± 13.6 c	44.7 ± 19.7 c	37.8 ± 12.1 c	11.7 ± 1.8 b	18.5 ± 4.5 bc	33.6 ± 10.9 c	21.6 ± 7.9 c	23.7 ± 6.3 c	25.0 ± 7.1 c
9ON	39.7 ± 12.8 c	33.8 ± 11.8 bc	40.0 ± 21.6 c	11.6 ± 2.7 b	32.2 ± 7.2 c	25.9 ± 5.3 c	27.1 ± 8.7 c	8.3 ± 2.6 ab	29.4 ± 8.8 c
Wet Season *No Weeds*									
ON	14.1 ± 3.1 b	14.3 ± 2.7 b	19.3 ± 3.7 bc	5.5 ± 2.0 ab	8.9 ± 3.6 ab	15.2 ± 5.6 b	4.3 ± 1.3 a	7.8 ± 2.5 ab	14.5 ± 3.2 b
9ON	3.3 ± 1.4 a	7.2 ± 4.2 a	21.0 ± 3.2 bc	6.0 ± 2.2 ab	9.5 ± 2.6 ab	13.5 ± 2.0 b	3.5 ± 1.7 a	4.5 ± 2.3 a	9.6 ± 3.4 ab
Weeds									
ON	20.9 ± 12.3 bc	38.7 ± 12.8 c	32.3 ± 12.9 bc	12.3 ± 1.8 b	17.0 ± 5.5 b	20.3 ± 6.7 bc	17.3 ± 3.2 bc	17.2 ± 4.5 bc	18.9 ± 3.4 bc
9ON	26.9 ± 11.8 bc	14.7 ± 4.5 b	23.2 ± 2.8 bc	8.8 ± 3.1 ab	21.9 ± 6.8 bc	20.1 ± 5.9 bc	14.8 ± 2.2 b	13.9 ± 4.2 b	22.4 ± 5.1 bc
P		<0.0001			<0.0001			<0.0001	
df		575			575			143	
F		9.19			11.89			10.06	
Mean [8]/	20.0 ± 5.6 a	23.2 ± 6.1 ab	32.6 ± 8.9 b	8.0 ± 3.1 a	18.2 ± 4.7 ab	22.1 ± 4.8 b	12.6 ± 4.4 a	11.2 ± 3.5 a	17.1 ± 4.0 a
P		0.04			0.004			ns	
df		71			71			71	
		3.68			7.43			2.07	

[1]/ The table shows data from three separate experiments conducted for each pest guild on farmers' field. There were 6 replications (farmers) in each of 4 consecutive seasons. Each treatment represents an individual insect pest or combination thereof as well as a specific growing season, level of weediness, and level of inorganic N. Each plot comprised 25 hills (1 m^2).
Weeds were allowed to grow in the weedy treatments and were totally removed by hand in the weeded treatments. N was applied 30 kg/ha basal and 60 kg/ha at panicle initiation in the 90 kg N/ha while no N was applied in the 0 kg N/ha treatment.
Analysis was undertaken within of each of the three pest guilds separately to compare yield losses among all of the imposed stresses. Yield loss was determined by everaging the yield from the uninfested hills and subtracting the yield from the mean of the infested hills for each pest guild. Within Means ± SEM in a column each pest guild followed by a different letter are significantly different (P ≤ 0.05) by LSD.
[2]/ To provide a range of damage levels among the 25 hills, at 7 days after transplanting (DT) (1st phase), 10 hills were each infested by 2 eggs and 10 with 4 eggs. Leaf sections were affixed with white glue. During the 2nd phase at 10 DT, half of each set of previously infested hills was infested with 4 eggs so that sets of 5 hills had 0, 2, 4, 6, or 8 eggs.
[3]/ On 7 DT 2nd - 3rd instars of mixed *Rivula* and *Naranga* larvae were infested: 10 hills each received 1 larva while 10 hills received 2 larvae. On 10 DT half of the hills infested at 7 DT with 1 or 2 larvae received an additional 2 larvae so that sets of 5 hills each had 0, 1, 2, 3, or 4 larvae.
[4]/ 3 medium-sized stemborer egg masses were infested per 25-hill plot at 35 DT and separated at 42 DT.
[5]/ ibid at 56 DT and at 63 DT.
[6]/ 2nd-3rd instar leaffolder larvae/hill infested at 35 DT (1st phase) and repeated at 42 DT (2nd phase): 4 larvae were placed on 10 hills and 8 larvae were placed on 10 other hills with 5 hills uninfested. In the 2nd phase, 5 hills that had received 4 or 8 larvae received an additional 4, while 5 hills that received an additional 8 so that each set of 5 hills bore 0, 4, 8, 12, 04 16 larvae.
[7]/ ibid at 56 DT and 63 DT
[8]/ Analysis undertaken within of each of the pest guilds to compare mean yields of each of the three treatments (two treatments infested individuallly and the third was the combination) per guild by LST test. Means ± SEM in a row within each pest guild followed by a different letter are significantly different (P ≤ 0.05) by LSD.

With defoliators, greatest crop stress occurred from the combination of weedy fields and 0 kg N/ha in both the dry (44.7% loss) and wet (38.7% loss) seasons. Intermediate losses came in the dry season, either without N but weeded or with applied N but weedy. Lowest loss from defoliator injury came in treatments of the mirror image, i.e., weeded fields and 90 kg N/ha in both the dry (3.7% loss) and wet (7.4% loss) seasons.

Greatest loss came for both pests combined in the dry season in weedy plots at both N levels (37.8 and 40.0% loss). There was a synergistic yield loss for whorl maggot + defoliators in both the wet and dry seasons in weed-free and high N conditions (Table 1). In the dry season, the effect was more noticeable where yield loss in whorl maggot alone (4.2%) and defoliators alone (3.7%) was significantly less than that of the combined infestation (34.8%). The sum of individual pest losses was only 7.7%, some 4.4 times less. In the wet season, loss from whorl maggot alone (3.3%) and defoliator alone (7.2%) summed to 10.5%, which was significantly less than the 21.0% in the combination. No treatment of the combined infestation, however, attained high levels of compensation equal to those of the single pest infestation, underscoring significant negative effects from the increased stress posed by both insect injuries acting in concert.

Greatest compensation occurred in the wet season at the high N rate regardless of season for the single pest infestations. In the combined infestation, no environmental combination showed high levels of compensation. Further analysis was undertaken in the data set where the abiotic and weed stresses were compared for each pest treatment (Table 2):

Season

The overall effect of season was measured as the comparison between wet and dry seasons on yield loss for each of the three vegetative pest comparisons. There was no observed effect of season with whorl maggot infested alone (16.3 versus 23.7% loss), but for defoliators (27.7% versus 18.8 loss) and for the combined infestation (42.7% versus 22.5), dry season yield losses were significantly higher than in the wet season.

Nitrogen

For whorl maggot infested alone, there was no significant effect of applying N on crop loss (18.5 versus 21.5% loss), although the data leaned toward higher yield loss when not applied. Urea treated plots produced lower yield loss and thus greater compensation in the defoliator (14.9 versus 31.6% loss) and combined (28.3 versus 36.9%) treatments.

Weediness

There were significantly higher yield losses for the three pest comparisons when weeds were uncontrolled versus controlled: whorl maggot (32.0 versus 8.0 % loss), defoliators (32.9 versus 13.5% loss), and the combination (33.3 versus 24.3% loss). The differences in loss from weediness were the greatest among the three factors tested showing the great suppressive effect of weeds in limiting compensation.

Stemborer

Artificial infestation from placing egg masses in the field achieved a mean of 31% deadhearts/whiteheads from either growth stage alone with a range up to 48%, while infestation in the ripening stage averaged 36% that rose to 57%. The figures for the combined growth stage infestation were 45% deadhearts/whiteheads for single stages and reached a high of 77%. Action thresholds are 25% deadhearts in the reproductive and 10% deadhearts in the ripening stages (Litsinger et al. 2006c), and damage was just above the action threshold level for the

Table 2. Effect of insect pest combinations from three guilds as separate experiments each under the influence of two levels of three environment variables (season, N level, and weediness), Zaragoza, Nueva Ecija, Philippines, over four consecutive seasons: 1989 & 1990 wet and 1989 & 1990 dry seasons.

		Yield Loss (%)[1]/								
		Whorl Maggot (WM) [2]/ and defoliators (DEF) [3]/			Stem Borer (infested in indicated plant stage)			Leaffolder (infested in indicated plant stage)		
Main Variable	Sub-variable	WM	DEF	Both Pests	Reproductive [4]/	Ripening [5]/	Both Stages	Reproductive [6]/	Ripening [7]/	Both Stages
Season	Dry	23.7 ± 6.3 a	27.7 ± 4.5 a	42.7 ± 15.3 a	7.8 ± 3.8 a	22.1 ± 5.9 a	26.9 ± 7.3 a	15.3 ± 5.2 a	11.6 ± 4.3 a	17.9 ± 4.2 a
	Wet	16.3 ± 3.9 a	18.8 ± 4.3 b	22.5 ± 7.0 b	8.2 ± 2.7 a	14.3 ± 3.8 a	17.3 ± 5.7 a	9.9 ± 5.3 a	10.9 ± 4.3 a	16.4 ± 6.2 a
	P	ns	0.03	0.01	ns	ns	ns	ns	ns	ns
	F	2.67	5.34	6.89	2.01	1.99	2.54	1.93	1.56	2.41
	df	47	47	47	47	47	47	47	47	47
Nitrogen	0 kg/ha	21.5 ± 4.0 a	31.6 ± 7.8 a	36.9 ± 14.4 a	9.1 ± 3.3 a	18.6 ± 3.5 a	25.1 ± 9.0 a	13.2 ± 5.1 a	15.7 ± 3.0 a	18.0 ± 6.3 a
	90 kg/ha	18.5 ± 5.5 a	14.9 ± 6.1 b	28.3 ± 8.9 b	6.8 ± 2.9 b	17.8 ± 4.4 a	19.1 ± 5.1 a	12.1 ± 5.8 a	6.8 ± 2.3 b	16.3 ± 5.2 a
	P	ns	0.01	0.03	0.04	ns	ns	ns	0.04	ns
	F	2.13	5.67	4.55	4.37	1.03	1.34	1.47	2.35	3.28
	df	47	47	47	47	47	47	47	47	47
Weediness	Weedy	8.0 ± 1.7 a	13.5 ± 5.7 a	24.3 ± 8.4 a	4.8 ± 2.7 a	14.0 ± 5.0 a	19.2 ± 4.7 a	5.0 ± 2.3 a	6.7 ± 3.7 a	10.3 ± 2.9 a
	No Weeds	32.0 ± 6.3 b	32.9 ± 7.7 b	33.3 ± 11.2 b	11.1 ± 3.3 b	22.4 ± 5.6 b	25.0 ± 5.6 b	20.2 ± 6.8 b	15.3 ± 6.4 b	23.9 ± 6.2 b
	P	0.01	0.01	0.005	0.01	0.03	0.003	0.01	0.004	0.006
	F	7.78	6.03	6.32	5.46	4.66	7.26	6.54	7.34	6.03
	df	47	47	47	47	47	47	47	47	47

[1]/ For each of the nine insect pests or combinations and within each environmental variable, means ± SEM in a column followed by a different letter are significantly different ($P \leq 0.05$) by t-test. ns=not significant. See footnotes in Table 1 for description on artificial infestation methods and environmental variables.

reproductive stage infestation but over twice that for the ripening stage for single stage infestations. The combined stage infestation was 1.8 times that of that of the action threshold for the reproductive stage and 4.5 times that of the ripening stage.

Comparing the overall results among the three stemborer treatments, the combined infestation resulted in the highest yield loss (22.1%), significantly more compared to the reproductive stage infestation (8.0%). The ripening stage infestation was intermediate (18.2%) in terms of significance (Table 1).

Focusing on reproductive stage infestation, highest losses came from weedy plots in the dry season at either 0 kg N/ha (11.7%) or 90 kg N/ha (11.6%), but also in the wet season with weeds and 0 kg N/ha (12.3%). These losses, however, were not as high as in the ripening stage or combined infestation. Greatest compensation (0.9% loss) came in the dry season with 90 kg N/ha without weed pressure.

Ripening stage infestation produced highest losses in two treatments, both in the dry season: in the weedy plot with 90 N (32.2%), but surprisingly also in the weed-free treatment without applied N (30.0%). There was no treatment that gave significant compensation, but relatively low losses were registered in three weed-free treatments: two in the wet season with (8.9%) and without (9.5 %) applied N, and the third in the dry season with 90 kg N/ha (7.7%).

When both growth stages were infested, highest loss occurred in three dry season treatments: two treatments under weed stress with (25.9%) and without (33.6%) applied N, while the third was in a weed-free plot without applied N (31.2%). Again there was no treatment that attained a very low yield loss, but the closest came from three treatments, all in weed-free conditions: two in the wet season with and without applied N (13.5 and 16.7%) and one in the dry season with 90 kg N/ha (15.2%). Following are the data from the dataset analyzed for the three non-insect pest stresses (**Table 2**):

Season
There was no significant difference in yield loss between the dry and wet seasons for any of the three treatments: reproductive stage infestation (7.8 versus 8.2% loss), ripening stage (14.3 versus 22.1%), or both stages combined (17.3 versus 26.9%).

Nitrogen
Only in the reproductive stage infestation was there significant compensation from applied N: 6.8% at 0 versus 9.1% at 90 kg N/ha. The reproductive stage represented the least stress from stemborer allowing applied N to exert its beneficial effect. Neither ripening (17.8 versus 18.6%) nor combined stage (19.1 versus 25.1%) infestation showed a compensatory response to applied N.

Weediness
Again the greatest yield depressing effect came from weed pressure, as there were highly significant differences in all three pest treatments comparing weeded with weedy plots: the reproductive stage infestation (4.8 versus 11.1% loss), ripening stage (14.0 versus 22.4%), and combined stage infestation (19.2 versus 25.0%).

Leaffolder
Artificial infestation of larvae resulted in an average of 36% damaged leaves in the reproductive stage which reached 61% damaged leaves. This was twice that of the action threshold level of 15% damaged leaves (Litsinger et al. 2006b). For the ripening stage, the average infestation was 34% up to 68% damaged leaves. The action threshold is 15%. These were over twice the level of the action thresholds. The combined infestation averaged 55% damaged leaves which reached 82% damaged leaves. This was 3.7 times the action threshold.

There were no significant differences in loss between the mean of the three leaffolder treatments when averaged over all other stresses (11.2-17.1%) (Table 1). In the presence of imposed stresses, reproductive stage infestation resulted in highest yield loss in the dry season under weed pressure with (27.1%) or without (21.6 %) applied N. Intermediate loss occurred in the wet season under weed pressure without applied N (17.3%). Lowest yield loss, and thus greatest compensation, occurred in both seasons in three treatments all without weed pressure: in the wet season with (3.5%) and without (4.3%) applied N, and in the dry season with applied N (2.9%).

Highest loss in the ripening stage infestation occurred in one treatment: again in the dry season under weed pressure but only without applied N (23.7%). Intermediate loss again came in the wet season in association with weeds and no applied N (17.3%). Lowest losses came in two treatments: one in each season, but otherwise both under the same conditions of being weed-free and with applied N: 0.4% in the dry and 4.5% in the wet season.

When both growth stages were infested in the same plants, highest losses occurred in two treatments in the dry season and in the presence of weeds, with (25.0%) and without (29.4%) applied N. High losses also were recorded in the wet season under weed pressure without regard to N level: 18.9% at 0 and 22.4% at 90 kg/ha. Lowest yield loss occurred only in one treatment in the dry season in weed-free conditions with applied N (3.8%). Next lowest losses (9.6%) came in the wet season in weed free plots with 90 kg N/ha. Following are the data from the dataset analyzed for the three non-insect pest stresses (Table 2):

Season
No significant differences between seasons occurred for any of the three leaffolder-infestation treatments: reproductive stage (9.9 versus 15.3% loss) for wet and dry seasons respectively, ripening stage (10.9 versus 11.6%), and combined stages (16.4 versus 17.9%).

Nitrogen
There was a significant benefit from applied N in the ripening stage infestation (15.7 versus 6.8%), but not in the reproductive stage (13.2 versus 12.1%) or combined stages (18.0 versus 16.3%). Low N levels therefore did not exert high plant stress

Weediness
Once more, there were significant effects of weed pressure in lowering yields for each infestation treatment: reproductive stage (5.0 versus 20.2% loss), ripening stage (6.7 versus 15.8%), and combined stages (10.3 versus 23.9%) underscoring the intense stress weeds produce.

DISCUSSION

Insect Pests
The set of environmental factors that should produce the lowest yields in association with insect injury would be the wet season (i.e., low solar radiation), weed stress, and 0 kg N/ha. Except for weed stress, these conditions seldom were associated with the highest losses, but were associated more commonly with intermediate losses.

Whorl maggot and defoliators
Highest losses occurred in conjunction with whorl maggot injury when combined with defoliators in the dry season under stress from weeds, regardless of N level. With defoliator injury, highest losses came under the combination of dry season, weed stress, and 0 kg N/ha as well as the predicted wet season, weed stress, and 0 kg N/ha. The environmental factors most affecting loss under the infestation of both whorl maggot and defoliators were the dry season under weed stress or dry season under 0 kg N/ha and the implausible combination of dry season, 0 kg N/ha, but weed-free.

Let us first discuss possible reasons for the contribution of dry season and weed stress to highest loss. It is known that, if uncontrolled, weeds grow faster than rice, especially in the early growth stages (DeDatta 1981). Despite the fact that weed infestation was considered to be moderate and the crop was transplanted (a method that gives rice the edge in growth over weeds), competition turned solidly in favor of weeds. In the case of our trials, we followed the farmers' transplanting practices which utilized 30-day-old seedlings which suffered transplanting shock due to root injury. Transplanting shock refers to slow seedling recovery after transplanting and results from the loss of rootlets when seedlings are pulled from dry nursery beds (Matsushima 1980). Farmers have problems obtaining irrigation water for their seedlings in the dry season which probably led to drier seedbed soils than in the wet season. Farmers do not incorporate organic matter into their seedbeds during land preparation and the heavy clay soils of Central Luzon cling tightly to root systems when dry. The farmers therefore could not follow the recommended practice of transplanting 20-day-old seedlings, as pulling seedlings at this young age results in the plants being ripped in half. Therefore the farmers waited until the seedlings grew larger and thus will withstand the strain. It is known that 20-day-old seedlings tiller more and thus would compete better with weeds (DeDatta 1981), even more so if injury to rootlets is mitigated by farmers applying compost to the seedbed. Seedlings take two weeks to recover from transplanting shock as they need to regenerate new rootlets. Weeds therefore get a significant head start over rice. Also, possibly leaf loss from the defoliator damage to rice opened up the canopy to allow more sunlight resulting in more weed growth in the non-weeded plots.

An additional possible reason is that insect damage may have weakened the rice plants which reduced their competitive ability with weeds. Field trials have shown that weed biomass increases significantly in insecticide treated rice fields (Litsinger 1993). This means that insects also feed on weeds, but due to the pests' preference for rice, weeds have a further growth advantage. All pests except yellow stemborer have a number of alternative hosts closely related to rice. Two groups of weeds that are alternate hosts for these vegetative stage pests are *Echinochloa* spp. and *Eleusine indica* as noted for whorl maggot (Ferino 1968), *Naranga* (Pantua and Litsinger 1984), and *Rivula* (Reissig et al. 1986). Perhaps due to double rice cropping, where rice became more prevalent in the landscape in both temporal and spatial dimensions, these pests developed a greater preference for rice (Strong 1979). In the wet season, weed growth was less prolific than in the dry season, most likely due to the lower solar radiation, therefore weeds were less competitive with rice, irrespective of whether N was added or not. Thus both rice and weeds were negatively affected by the lower solar radiation of the wet season so that even applied N could not compensate from the resulting stress.Whereas in the dry season, weeds took more advantage of the solar radiation than did rice.

The environmental combination of dry season, 0 kg N/ha, and no weeds led to highest losses when both whorl maggot and defoliators infested the crop. In this case, rice was under multiple stress from not only injury from two insect groups but also from transplanting shock and N deficiency. N deficiency was high, as a wet season crop had just been harvested further depleting N reserves. The turnaround time between crops is less between wet and dry seasons. Possibly, the high levels of solar radiation were present as well as standing water in the fields, the crop may have suffered moisture stress due to the root injury from transplanting shock and possibly from nematodes. Prot et al. (1991) found high densities of nematodes in rice roots and soil in fields near the study site. The combination of dry season, no applied N, and no weeds led to highest losses only under the joint injury from both whorl maggot and defoliator perhaps because they accentuated plant moisture stress.

We noted synergistic losses for the combined whorl maggot and defoliator infestation in both the wet and dry seasons under the most favorable weed-free and high N growing conditions (Table 1). Synergism may result between whorl maggot and defoliators as their injury occurs in the same crop growth stage. Injury from leaffolder and stemborer was additive but each pest occurred in different growth stages and therefore was less stressful to the plant. Three other studies, however, concluded that whorl maggot is not a pest. Valencia & Mochida (1985), Viajante & Heinrichs (1986), and Shepard et al. (1990), all performed yield loss trials on the IRRI Farm and found that even crops suffering > 60% damaged leaves did not produce significant loss. Ferino (1968), however, presented data that showed whorl maggot caused significant loss. Litsinger et al. (2011) pointed out that in the IRRI Farm trials, defoliators were not present, whereas in Ferino's trials, most likely stemborers were associated pests contributing to loss. Indeed in Table 1**,** the data show that for whorl maggot, when acting alone in either the dry or wet season, loss was not significant. For that matter neither did defoliators when acting alone in either season. But when their infestations were combined, losses were significantly more than additive in both the dry and wet seasons, respectively. Reasons for synergistic losses pointed out by Litsinger et al. (2011) were believed to be due to the added stress of transplanting shock and use of older seedlings that tiller less. Losses from both pests became much higher, particularly when combined with weeds (with or without added N), and synergism was no longer evident.

The conditions that produced the least yield loss were the same in both single pest infestations: weed-free and 90 kg N/ha, while season was not important. This is the reason nitrogen and weediness were important.

Stemborers

Research has shown that rice is more susceptible to stemborer damage in the ripening stage (Bandong and Litsinger 2005) and the results from this trial tend to support this outcome (Table 1). Looking at each stage of stemborer infestation, loss in the combined stage infestation was higher than in the reproductive stage alone with the ripening stage alone being statistically intermediate.

The high loss in the reproductive stage in the wet season combined with weeds and no added N was as predicted, but the majority of the environmental combinations that led to highest losses occurred in the dry season under weed pressure irrespective of N level. The explanation given for the high losses due to differential feeding of insect pests on rice rather than weeds would not be true for yellow stemborer as it is monophagous to *Oryza* spp. (Banerjee and Pramanik 1967). Thus in that combination, weeds would be left undamaged by the stemborer. But in the trials, older seedlings were used and the transplanting shock would have occurred, which combined with weed stress, could explain the high losses in the dry season favoring the growth of weeds relative to rice.

But with ripening stage or the combined growth stage infestation, equally high losses occurred in the dry season, without added N, but under weed-free conditions. How can these losses be explained? Evidently under the combination of no added N and high solar radiation, the crop became particularly stressed when combined with stemborer injury. One possibility is that, due to the head start weeds got in the early growth stages, which along with the greater solar radiation of the dry season, caused weeds to shade the crop particularly in the ripening stage. This stress combined with that of stemborer led to high losses.

The environmental conditions that favored lowest yield losses were, as would be predicted, to be the dry season, 90 kg N/ha, and weeded conditions. This was clear in all three modes of stemborer infestation where highest yields occurred under these conditions. However, losses were higher under the combined growth stage infestation (16.7%) than in any single stage infestation: 0.9% for the reproductive stage but 7.7% for ripening stage. The difference between ripening stage and combined stages was not significant, however, showing there is no evidence of synergistic loss with stemborers attacking at different growth stages.

Leaffolders

As with the other pest guilds, the environmental factors most associated with high yield losses occurred in the dry season under weed stress with N level important only with ripening stage infestation. Rice leaffolder has a larger number of alternative weed hosts than whorl maggot and defoliators (Barrion et al. 1991); and it was found that leaffolder most preferred rice. Thus in the presence of leaffolder, rice would be damaged relatively more than the weed hosts. Conditions in the dry season would also favor weed growth as was discussed earlier.

Leaffolder loss in the reproductive and ripening stages did show additivity as was also found in Litsinger et al. (2011). In the dry season adding single stage losses (2.9% + 0.4% = 3.3%) was almost equal to the loss in the combined infestation (3.8%). The same result occurred in the wet season where adding single stage losses (3.5% + 4.5% = 8.0%) was almost equal to that of the combined infestation (9.6%) (Table 1).

The trial results of the means of the nine treatments in Table 1 showed no difference in yield loss from reproductive (12.6%) and ripening (11.2%). Losses are close to being additive, however: 12.6% + 11.2% = 23.8% versus 17.1% in the trial for the combined attack. Heong (1990) reported, however, that losses from leaffolder were greater in the ripening stage crop from the same level of damage than in the reproductive stage. Our results, however, do not support this outcome.

Stemborers or leaffolders, each sequentially attacking two crop stages, caused yield loss no different than the sum of each stage attacked individually. Thus the combined damage was additive for each pest. This result implied that a crop weakened by damage in the reproductive stage did not predispose the ripening stage to greater injury. This occurred despite a study from Schoeneweiss (1975) who reported repeated bouts of defoliation over the life of different plant species resulted in synergistic loss. But for rice and leaffolder this does not appear to be the case.

Those environmental conditions that led to lowest yield losses were mixed. The obvious mixture of dry season, added N, and no weeds did lead to lowest losses for each infestation but other conditions also led to similar results. The wet season and weed-free condition with 90 kg N/ha was also associated with low losses in the ripening stage infestation as well as wet season and weed free regardless of N level for the reproductive stage infestation.

Insect Pest Infestations Combined with Stresses

N and solar radiation are key inputs of photosynthesis and rice growth, thus high losses can be expected when any of these factors is deficient. Weeds likewise are effective competitors of rice for these same resources. The results of this study show that in the presence of insect pest injury when one or more of these three factors is combined, even higher losses tended to occur.

Weeds

The combination of insect injury and weed stress has been noted in other studies as being particularly aggravating. Higgins et al. (1983) found that compensatory plant re-growth from defoliation injury may be compromised if the plant is also under stress from weeds. Savary et al. (1994) noted that lowest yields were associated with stress from weed species such as *Echinochloa* that reach above the canopy, particularly in association with stemborer injury. *Echinochloa*, which is given the local name 'antenna' by farmers, is difficult for hand-weeders to distinguish from rice thus often goes uncontrolled. In a companion study in India where a number of biotic and abiotic factors were also considered, Savary et al. (1997) showed that, in the presence of weeds, increasing insect pest abundance was more likely to counteract plant compensation.

Of the three non-insect stresses in the current study, weeds exerted the greatest yield depressing influence. This is best illustrated in Table 2 where all nine comparisons showed the significant influence of weeds in yield loss. Even though weed competition had a greater effect than the two abiotic stresses, weed incidence was considered to be average. Most farmers practiced good water control during early crop growth, but as irrigation comes from the main canal fields do become dry periodically allowing weeds to germinate and thus weeds were more common in the DS. Higher weed infestations no doubt would have overwhelmed the rice crop probably to the extent that the contribution of other stresses could not have been measured. Weeds compete with rice for water, nutrients, solar radiation, and space that collectively compromise numerous plant physiological processes (DeDatta 1981). In this study we noted that weeds significantly interacted with the two abiotic variables. Their roots remove N and other vital nutrients, thus in combination with treatments without added N, the combination should have been greater yield depression. Also by providing shade, they limit solar radiation, which should have accentuated the negative effect particularly in the wet season. The combination of weeds in the dry season produced the most suppressing effect with N level associated with little effect.

We have already stated that the probable reason for greater impact of weeds in the dry season was due to transplanting shock and use of low-tillering, 30-day-old seedlings by the farmers. The majority of weeds germinated from the weed seed bank in the soil. The natural advantage transplanting gave the rice plants a month's head start but was compromised by the two-week recovery period from the extensive root injury. This problem is more common in the dry season when irrigation water flows less regularly and rainfall does not supplement.

Nitrogen

Applied N increases tiller, leaf, and spikelet densities that lead to increased rice yield (DeDatta 1981). Litsinger (1993) and Boling et al. (2004) demonstrated that increasing N rates promoted compensation from insect pest damage. In the current trial, when N was isolated as the sole factor, its application stimulated compensation in four of the nine pest combinations (Table 2). In looking at the interactions (Table 1), N in particular helped compensate for defoliator injury, both when infested singly and when combined with whorl maggot as well as leaffolder infestation of the ripening stage. The role of N probably stimulated more leaf growth to increase the leaf area index. N would also have increased tillering, bolstering the crop's tolerance to stemborer injury.

The turn-around period between crops in this double rice cropping system is shorter between the wet and dry season crops which means that the natural soil fertility is relative lower in the dry season than the wet season crop (DeDatta 1981). This could be another reason why the dry season crop produced greater yield depressing stress. When N application was withheld, lowest yields resulted when: 1) defoliators were infested in combination with weed stress in the dry season, 2) ripening stage leaffolder infestation occurred in combination with weed stress in the dry season, 3) reproductive stage stemborer infestation under weed stress in the wet season, 4) stemborer infestation in the ripening stage, and when 5) both stages were combined where in both instances this occurred without weed stress in the dry season. There was only one instance where 90 kg N/ha was associated with lowest yields and that was with the ripening stage stemborer infestation in the dry season under weed stress. We mentioned before that the third example mentioned above would have been predicted as the combination most associated with lowest yields when in fact this was an exception. Of the twelve combinations that led to lowest yields, 0 N level was important in only half. More commonly, lowest yields were associated with the dry season and weed stress.

Solar radiation

The analysis of the data in the current study included the interactions of insect pest injury from three chronic guilds in combination with other stresses found that lowest yields were associated with weed stress particularly in the dry season and mostly independent of N level (Table 1). This result was surprising, as one would have expected lower yields to be in the wet season in weedy crops without applied N. Solar radiation is cited as being one of the most important abiotic factors affecting rice yield (Yoshida 1981). In the Philippines, dry season yields are typically 20% higher than those of the wet season mainly due to greater solar radiation (Litsinger et al. 2005). In the currently study, the average tiller density per hill at the maximum tillering stage in the 90 kg N/ha weed-free treatments was 24% higher in the dry season (31.3 tillers/hill) than the wet season (21.8 tillers/hill) ($P < 0.0001$, $F = 200.5$, $n = 324$). The comparison of number of leaves per hill was 124.5 versus 100.2 ($P < 0.0001$, $F = 51.45$, $n = 324$), a difference of 44%. Better growth in the dry season was due to a fuller rice canopy to capture incident radiation, resulting in greater panicle densities per hill and a higher percentage of filled grains (DeDatta 1981). Low solar radiation is due to a combination of cloudy weather and short day-lengths as the wet season crop is typically in the ripening stage from Sep-Nov. Kenmore et al. (1984) felt that the wet season crop in Nueva Ecija led to perennial borderline physiological crop stress due to chronic low solar radiation.

In Table 2 only two of the nine comparisons found season significant, therefore it seemed the least important of the three non-insect stresses. However, in 12 of the combinations of non-insect stresses that resulted in lowest yields, 11 were significant for dry season and one in the wet season. Thus by itself season was not as important as when combined with weed stress, notably the dry season.

CONCLUSIONS AND RECOMMENDATIONS

Implications for Pest Management

This study points out the need to test the hypothesis that the reason the dry season and weeds were significantly associated with highest yield loss was due to the added stress of transplanting shock and use of older seedlings. One should also test the benefit of applying compost to the seedbed to ameliorate transplanting shock and to see if 20-day-old seedlings can tolerate vegetative stage insect pest injury as is the case on the IRRI Farm. A corollary study would be to test the role of transplanting shock on the ability of 20-day-old seedlings to compete with weeds, particularly in the dry season.

Furthermore trials should be conducted to validate the hypothesis that synergistic yield loss occurs from the combination of whorl maggot and defoliator injury that is exacerbated by transplanting shock and use of older seedlings. If it turns out that there is synergistic loss without transplanting shock being involved, then farmers should target defoliators with insecticide, as whorl maggot is very difficult to control with foliar sprays, the favored method of applying insecticides for Filipino farmers (Litsinger et al. 2009). In earlier trials, where insecticide sprays were applied in response to action thresholds (Litsinger et al. 2005), we registered 50% control of damage from defoliators, but only 28% control of whorl maggot. These results show first that insecticide sprays were not a highly effective insect pest control method on rice and secondly that defoliators are more readily controlled than whorl maggot. If there is a synergistic effect, then removing defoliators should be all that is necessary to protect yield.

Farmers can mitigate the suppressive effect of low solar radiation on yield by planting earlier in the wet season (Loevinsohn et al. 1993). This has several advantages: 1) escape seasonal insect pest buildup, 2) reduces risk of the most damaging typhoons which normally occur from Oct 15-Nov 15, and 3) the ripening stage occurs during longer daylight hours which will increase yield potential.

A further result would support a recommendation for farmers to invest more efforts in controlling weeds in their field rather than spend resources on insecticides as a first line of enhancing the crop's ability to compensate for insect pest damage. Applied research trials conducted by farmers could demonstrate the benefit of this tactic by setting out small weed-free plots of 25-50 m^2 to be compared with similar plots under the farmer's management. Such trials can convince farmers who thought their level of weeding was adequate (IRRI 1987).

Our trials have demonstrated that the extent of yield loss depends significantly on the pest composition as well as the rice production environment. Combinations of insect pest infestations, whether between different species or the same species infesting different rice growth stages, exacerbate yield loss. Such losses are further aggravated by the level of weeds, solar radiation, and N which can affect the degree of yield loss from chronic rice insect pests. But due to the dynamic nature of the yield loss relationship, the results were not always predictable. This is due to countervailing forces that act on the crop between stresses that reduce yield and compensatory factors that enhance it.

We suggest that farmers adopt preventative crop management practices to promote crop compensation. The more measures that farmers can put into practice, the higher he can raise his action threshold decision level that would trigger a corrective insecticide application. Our research supports the work of Savary et al. (2006) who concluded that undertaking a management strategy based on rice injury and crop environment profiles is more relevant than that of focusing on individual insect pest injuries. Knowledge of such broad-based causes of crop loss provides entry points for management. In order to implement such a new strategy, the farmer needs to be able to recognize the major stresses affecting his field. When there are combinations of stresses that are known to elicit great yield loss, the farmer does not have to eliminate all of them but can correct those more easily to manage stresses such as weeding, particularly in the dry season (Litsinger 2009).

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